

# Motivating city-commuters to carpool

Exploring the stimulus of various factors and policies

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# PREFACE

Proudly I present the reader this report, which is the result of a six month graduation project carried out in collaboration with Eindhoven University of Technology and Goudappel Coffeng BV, advisors in mobility. This report fulfills the last requirement for the Master's degree of the curriculum Construction Management and Engineering. This implies that the report in front of you will signal the end of the five and half years that I have been a student at the TU/e.

The purpose of this thesis is to aid local and higher governments in The Netherlands in their decision making process concerning congestion issues. The importance of different carpool stimulating policies in motivating commuters to carpool can be predicted. It is also possible to estimate the reduction in the total number of vehicles on the road as a means to reduce the level and effects of congestion.

Due to increased urbanization, concentration of working and living in urban centers, free space will become scarce and the level of urban congestion will continue to rise. Two action plans exist that are mostly used to reduce the magnitude of congestion issues at urban main roads, i.e.: reducing the supply of vehicles and thus the demand for infrastructure, or expanding the size of the network's capacity by constructing new roads. The little amount of available space in the urban center needs to be divided over different purposes: infrastructure and parking lots, residential buildings, offices, public green, commercial buildings, sport accommodations, educational buildings, etc. Therefore, utilizing existing infrastructure and capacity is the right way forward. One way to do this is to increase the average vehicle occupancy of private vehicles, which are currently responsible for traffic bottlenecks on urban main infrastructure during rush hours. Carpooling can yield a promising solution for this problem, since its main characteristic is increasing the average vehicle occupancy of commuting vehicles.

This study will explore how commuters traveling to the center of a large city by car can be motivated to switch to carpooling. Can a separate lane, reserved for carpoolers, on which the allowed vehicles are given priority, result in a reduction in travel time? Can this facility turn out to be a special motivator for carpooling? By studying how carpooling can be stimulated, I became very enthusiastic about the important role carpooling can play in reducing the number of vehicles on the road, while it serves as an intermediate or hybrid form between driving solo and using public transport. I hope you will get enthusiastic about carpooling as well. Please enjoy reading this thesis!

# Acknowledgements

During the execution of this study and the writing of this thesis I faced many different challenges. The process started with finding the right topic. A topic that was interesting for me and a potential supervising company. When writing the research proposal, focusing on a new approach to reach more sustainable transportation, I became more and more enthusiastic. When I first met Peter Baas from Goudappel Coffeng BV at the company's office in Eindhoven, I got even more inspired and enthusiastic about the topic my proposal was describing (mainly due to his interested attitude). I would like to thank Peter Baas, not only for his intellectual and professional help for which I respect him, but for his support and belief in the research and in me as well. Thank you for providing me the opportunity to receive valuable help and advice from Goudappel Coffeng and for emphasizing the importance of maintaining a clear planning and keeping a close eye on the available time for the project.

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# Nomenclature

<i>AVO</i>	<i>Average vehicle occupancy</i>
<i>DCM</i>	<i>Discrete choice modeling</i>
<i>HOV</i>	<i>High occupancy vehicle</i>
<i>MNL</i>	<i>Multinomial logit</i>
<i>SP/SC/SA</i>	<i>Stated preference/choice/adaptation</i>
<i>VKT</i>	<i>Vehicle kilometers traveled</i>

## Chapter 1

# Research introduction

This study aims to identify the most important factors that influence the decision making process of choosing carpooling as the mode of travel for a commute trip into the city center. In this chapter, the research design is explained in detail. First, some background information and a motivation for this study will be sketched by trends that have recently happened in the Dutch mobility sector. As can be seen, growing freedom of mobility by the general population and the increased consciousness about negative effects of congestion (loss of time, increase in emissions, etc.) are important causes for this study. In subsequent paragraphs, research questions are formulated and some hypotheses derived. These questions correspond to the problem(s) stated in the problem definition. Sub-research questions will be derived from the main question, aimed at answering the main question step by step. Research boundaries and limitations that create a framework for this study are written down and methodologies that will be used to find an answer to the raised questions will be described.

## 1.1. Recent trends in the Dutch mobility sector

### Increased ownership and use of private motor vehicles

The number of motor vehicles on the road in The Netherlands has increased rapidly between 1990 and 2011, from 5 million to almost 8 million, see table 1. The mobility level of people has also increased, and the number of kilometers travelled by the Dutch population increased from 93 billion kilometers in 1985 to 143 billion kilometers in 2005 (increase of 35%). In the same year 75% of these kilometers were travelled by a private motor vehicle and only 11% by public or shared transport (Wijlhuizen, et al., 2012; C.B.S. Statline, 2013). This small coverage of public transport is mainly due to a lack of capacity, since the increase of 50 billion kilometers alone is equal to 2.5 times the current public transport capacity. This means when all trips at that time were to be made by public transport, its capacity should have been multiplied by 7.5 times.

Recent figures show that a private motor vehicle is chosen in 75% of all journeys that people undertake (Statline C.B.S., 2013). The number of passenger cars on the road is also steadily increasing, as can be seen in table 1. Combining these facts with the increasing space shortage for infrastructural facilities in urban areas, the level of congestion that travelers experience continues to rise. As a result of the increased amount of cars on the road, the total amount of lost travel time in the Netherlands due to congestion increased rapidly between 2000 and 2008; with almost 55% in total during this time span (equating 68.5 million hours in 2008). However, after 2008 it started to decrease slowly each year, and it almost reached the same level in 2012 as it was in 2000 (46,1 million hours) (Kennisinstituut voor Mobiliteitsbeleid, 2012). Main reasons include local changes in travel patterns (people living closer near their work location), construction of new infrastructure (investments in capacity) and the international economic crisis (a lower desired level of mobility). Recent research shows this decline will stop in the coming years because the economy will start to recover slightly and energy and fuel prices will be low.

Congestion problems are not only imposing an adverse effect on the national economy, but also on people’s quality of life due to delays, accidents, and environmental pollution. Total costs for the Dutch economy due to traffic jams, traffic (un)safety and environmental damage equaled between 18 and 24 billion euros in 2007 (Kennisinstituut voor mobiliteitsbeleid, 2008).

	2007	2008	2009	2010	2011	2012	2013
Number of passenger cars	7.230.178	7.391.903	7.542.331	7.622.353	7.735547	7.858712	7.915613
Privately owned	6.407.804	6.518.812	6.633.454	6.749.169	6.876.304	6.988.589	7.042.937
Company owned	822.374	873.091	908.877	873.184	859.243	870.123	872.676

**Table 1 - Number of private cars in The Netherlands (Statline C.B.S., 2013)**

Urban areas face increasing concentration of people and buildings, the use of existing infrastructure is growing, resulting in congested roads. Infrastructural capacity should therefore be increased. However, urban planning policy makers in Dutch cities are experiencing many difficulties in deciding upon land-use for new residential, commercial, industrial, institutional areas and infrastructure. A trade-off must be made to allocate scarce land to different types of land-use. The Dutch national database Statline shows that the total Dutch road network consists of 138.199 kilometers of paved road (Statline C.B.S., 2013). Almost 91% of these roads are managed by local authorities (mainly municipalities). In general, local roads are smaller and a lower speed limit is often allowed. Since many congestion studies (both national and international) focus on freeways, this study makes an attempt to explain and reduce (the effects of) congestion on urban infrastructure.

Policy makers try to develop and promote public transport systems instead of the private car as a means to reduce congestion and environmental problems. Large amounts of money are being invested in public transport systems worldwide (e.g. light rail). Efforts in this direction are not successfully to date. In the United States many cases of massive overforecasting the positive impacts of public transport systems have emerged, mainly due to ignoring the latent demand for car use. This study therefore tries to incorporate the efforts of public transportation planners with known preferences (e.g. freedom, flexibility and time savings) that commuters have regarding their private car.

## **Increased attention for sustainable transportation alternatives**

After electricity and heat generation, the transportation sector is the largest source of global carbon dioxide emissions (22% of total) (International Energy Agency, 2012). Transport related emissions have grown rapidly, increasing by 45% in the last 2 decades. In 2012, road transport accounts for 74% of this sector's emissions, equaling 16% of total global CO<sub>2</sub> emissions. As a means to decrease the negative environmental effects caused by road vehicles, many cities are planning and constructing new types of public transport systems (Mackett & Edwards, 1998; White, 2009). These systems should fit in the low-carbon spatial planning strategy cities worldwide are employing (Pan, et al., 2008; Banister & Givoni, 2013).

Between 1990 and 2006, emission gasses from the mobility sector in The Netherlands have increased with 35%. This is more than the European average (Hanschke, et al., 2010). The gasses consisted mainly of small particulates (PM), nitrogen oxides (NO<sub>x</sub>) and carbon oxides. On average, a Dutch resident is yearly responsible for a total emission level of 1,100 kg CO<sub>2</sub> as a result of its transportation activities. Between the years 2009 and 2012, the entire Dutch mobility sector was responsible for about 20% of national CO<sub>2</sub> emissions, 60% of national NO<sub>x</sub> emissions and 30% of the national emission level of small particulates (Goudappel Coffeng, 2009; Compendium voor de leefomgeving, 2012). As sustainable mobility is an important objective of the transition to a more energy neutral climate in the Netherlands, many studies are currently carried out on how to reduce the level of emissions. Effective policies aimed at creating a more sustainable mobility environment are focused mainly around the following aspects, called the '4V approach' (Goudappel Coffeng, 2009; Bos & Temme, 2012). To achieve more sustainable transport, future trips have to be prevented (voorkomen), shortened (verkorten), the travel mode has to be changed (veranderen), and modes of transportation should be cleaner (verschoenen).

More and more papers are recognizing the behavioral changes of individual car users to reach sustainable transportation (Stradling, et al., 2000; Steg, 2007). A combination of policies is necessary to target the wide variety of factors that support car usage and hinder the use of more sustainable modes of public transport. When anticipating on future trends, carpooling can prove to be a useful alternative to fluctuating and increasing fuel prices as the costs of a trip will be shared among multiple people. Furthermore, advances in technology can aid group formation in carpool, and also public acceptance for carpooling instead of public transport can turn out to be higher when trying to sell the concept as being sustainable and naming carpooling a form of smart mobility (due to smart IT usage).

The European Union has developed the Sustainable Urban Mobility Plan (SUMP) as a method to tackle transport-related problems in urban areas more efficiently. It aims at involving citizens and other stakeholders throughout the decision making process to obtain an achievable, integrated and balanced approach to future transport planning (European Sustainable Urban Mobility Platform, 2013). As carpooling is expected to be more useful over larger distances, it can in this light turn out to be a helpful supplement for public transport in urban areas.

### **Active carpool policy (1992-2000)**

From 1992 until the year of 2000; the Dutch government employed an active carpool policy to promote carpooling as a way of transportation (Ministerie van verkeer en

waterstaat Adviesdienst Verkeer en Vervoer, 2000). Its main objectives were to reduce congestion and to increase the livability, accessibility and free (green) space of both rural and urban areas. The focus was mainly on increasing the awareness and image of carpooling. It is difficult to express the effectiveness of this policy in concrete figures. Based upon a research of 'Research voor Beleid' in The Netherlands, the conclusion was drawn that in 1995, 90% of the Dutch population believes in the importance of carpooling to reduce traffic issues (Research voor beleid, 1995). Different policy elements were implemented as discussed below. As can be seen, not all policies were equally effective:

- ◇ National mass-media campaigns: not effective, only when used regionally to communicate and support implementation of a new carpool project or physical measure;
- ◇ Carpool-partner matching programs: despite they were free, they were not used to large extent. Commuters in most cases consider only family and colleagues at work to drive together with;
- ◇ Implementation of carpool meet locations/parkings: only communicative function, not used to large extent (3% of carpoolers);
- ◇ Fiscal regulations: required administrative effort and flexibility of employers is too large, were not used in practice.

The report of Research voor Beleid further concludes that the only carpool lane implemented in 1993 in The Netherlands (described in more detail in appendix C), proved to be highly effective. However, because of negative media attention and a provoked law-suit, the carpool lane was fast considered as a bust and closed because of safety issues. According to the report, the lane was not only effective in increasing the number of carpoolers, but also in breaking through the current behavioral pattern (Ministerie van verkeer en waterstaat Adviesdienst Verkeer en Vervoer, 2000). Carpool lanes can have a positive influence on the image of carpooling, at least when they are established correctly.

While in the Netherlands the HOV-lane test flopped because of political fencing, the United Kingdom for example increasingly discovered its advantages. Multiple lanes are created on urban main roads in among others the cities Leeds (3 lanes), Bristol (2), Bradford (1) and Birmingham (1). The results of the HOV-lane on the A647 in Leeds consist of an increased regional accessibility, increase of the occupancy rate from 1.3 to 1.43 and a raise of people travelling by bus from 1% to 20% in four years (Metz, 2012). After a 36 months trial period, the HOV-lane in Birmingham was made permanent since the capacity of the road increased and almost no people gave negative feedback. Based on similar project in Madrid, Trondheim and the United States, carpool lanes prove to be efficient in using the infrastructure capacity more efficient. The British Department of Transport (Department for Transport, 2008) notes that 2+ lanes (for cars carrying 2 or more persons) increase the local level of car sharing, but that the lanes have a bigger impact on how many people take the bus. More specific examples of HOV lane successes and failures will be displayed in the literature review chapter and the appendix.

### **Reduction in number of carpools**

Despite the active carpool promoting policy, figures from the Dutch 'Centraal Bureau voor de Statistiek' show a decline in the number of carpools in the past. Since the most clear data is available until the year 2002, this data is displayed in table 2 (C.B.S. Statline, 2003; C.B.S. Statline, 2004; Molnár, 2004).

	1995	2002
Total number of commuting cars	2.250.000	2.800.000
Carpooling commuting cars	314.000	218.000
Number of people commuting	2.800.000	3.125.000
Number of People carpooling	680.000	500.000
Percentage of cars carpooling	14%	8%
Percentage of people carpooling	24%	16%
People carpooling as passenger	400.000	320.000

**Table 2 – Number of commuters and carpools (Molnár & Konen, 2003)**

From table 2, some general trends can be noticed. First of all the number of commuting cars and the number of commuting people has increased over the timespan 1995-2002. In this table, only people working at a location outside their hometown are included. Opposed to the increasing number of people commuting solo, the number of people carpooling decreased by 26%. Furthermore, the number of people reaching their work destination as a carpool passenger has dropped by 20%. The number of carpoolers decreased by another 12% between 2005 and 2012 (Kennisinstituut voor mobiliteitsbeleid, 2013).

## 1.2. Problem identification

For a clear definition of the problem identification, it is a good idea to identify all relevant main causes of the problem. This can be done by using a cause and effect diagram, like the fishbone diagram that is displayed in appendix A. Five main groups of causes are identified: people, resources, processes, economic and environment factors.

**People:** over the recent years, people have bought more and more cars. This is mainly as cars are being considered the primary way of transport for longer distances and people increasingly desire a freedom of movement. However, just now this trend is coming to an end as young people living in cities do not require owning a private vehicle since they are mostly only traveling short distances. As a result of the wish to be free and mobile, people (commuters) prefer to drive alone instead of carpool with other colleagues upon which they then are dependent.

**Resources:** as the current public transport facilities in the Netherlands are not attractive enough to replace car driving or to reduce congestion to a large extent, they do not sufficiently attract commuters. Furthermore, the current level of infrastructure is not enough to reduce congestion. As free space is becoming scarce due to increased concentration of activities, not much room exists for developing new infrastructure.

**Processes:** carpooling entails a certain dependency upon other people who are travelling in the same car. In most cases this results in an aversion for carpooling. At the same time, an active carpool policy employed by the Dutch government did not result in more carpoolers, but it can be argued this had the opposite effect.

**Economic:** carpooling has the potential to save travel costs (fuel, parking, depreciation, maintenance). Also, when more people are carpooling and/or share-cars, less private vehicles have to be bought, resulting in other cost savings (purchase, insurance, maintenance, etc.).

**Environment:** over the last years, a growing consciousness for sustainable modes of transportation has been developed. More cars on the road, or more congestion, means more emissions. As carpooling reduced the total number of cars on the road, the cumulative effect of all cars will therefore be substantially less. Furthermore, more and more green spaces are being damaged and used for infrastructure development.

As can be derived from these causes and the fishbone diagram (see appendix A), the main problem definition can be described as follows:

**‘A low average vehicle occupancy causing congestion on urban main roads’**

However, congestion does not necessarily have to be a bad thing. Therefore, some sub-effects of congestion have been described. When congestion on urban main roads increases, the accessibility of the area reduces, vehicle emissions and nuisance increase, and the environmental quality and green space will be damaged over a larger time span, as new infrastructure will be constructed. Travel times and uncertainty will also increase due to slow moving traffic in congestion zones.

### 1.3. Research objective and relevance

The main research objective is to study which factors can stimulate city-commuters to switch to carpooling to an extent large enough to significantly *increase the average occupancy rate of vehicles by stimulating commuters to share vehicles and combining trips, so the amount of vehicles per piece of infrastructure (intensity/capacity) is reduced as a result*. A central question in this study is the role of a special lane reserved for carpoolers, a HOV lane, as an extra stimulus or complementary factor combined with other facilities or factors. An achieved increase in the average occupancy rate of vehicles will result in three main effects: 1) less energy usage, fewer emissions, and cleaner air, 2) a reduced requirement for parking places and a smaller amount of necessary infrastructure resulting in more space for green spaces, 3) an increased traffic flow and thus accessibility of the urban area.

Most current studies in the field of construction management and urban development are focused on reducing the level of congestion by implementing new public transport systems and by devising technological solutions for transportation and environmental issues (Beirão & Sarsfield Cabral, 2007; Moriarty & Honnery, 2008; Gemeente Eindhoven, 2009). Another option to increase the average vehicle occupancy is by stimulating people to carpool. Relieving the city center will indirectly affect the usage of public transport, since the city center (intersection of public transport modes) is more easily accessible. Carpooling can thus aid the public transport system by serving as a complement for public transport. But, how can commuters be motivated to carpool (i.e. to share free vehicle capacity)? Carpooling can become a win-win situation for both commuters and the public, since carpoolers can directly achieve cost and environmental savings and at the same time the growing requirement for new infrastructure can be reduced.

This question is of particular interest to municipalities of larger, because of different trends and issues that are currently occurring in those cities (think of smog, congestion, and reduced accessibility). Cities are increasingly facing emission problems and are experiencing negative side-effects like a higher chance of (deadly) collisions and accidents. Those negative

effects of congestion problems can therefore be even larger than expected, and even a small reduction in the level of congestion or the number of cars on the road can bring satisfactory results. This is one of the main reasons why the topics of congestion management and smart mobility are currently vastly studied and actual topics worldwide.

One way is motivate commuters to share cars and capacity is to combine carpooling with special lanes, called high-occupancy vehicle lanes, reserved for cars with occupancy rates higher than a certain value (e.g. carpoolers). These lanes can turn out to be a good motivator for people to stop driving alone to work. It is argued that the construction of new general purpose lanes perform better in reducing congestion in the city center and therewith reducing travel times (Shewmake, 2012) than do HOV lanes. However, when the right initial conditions exists, the right policy is in place and high occupancy lanes will be well utilized, their performance in terms of congestion and travel time reduction is almost equal to general purpose lanes (see figure 1). However, since more people are making their trips in fewer vehicles, environmental effects are often significantly better when using HOV lanes. Also in terms of accessibility, carpooling will result in fewer cars on the road, less required parking places in the busy urban center and less waiting time at junctions or roundabouts. So when the holistic picture is considered instead measuring the success of the different lane time solely in terms of the delay on one road, stimulating carpooling by using HOV lanes seems a better alternative.

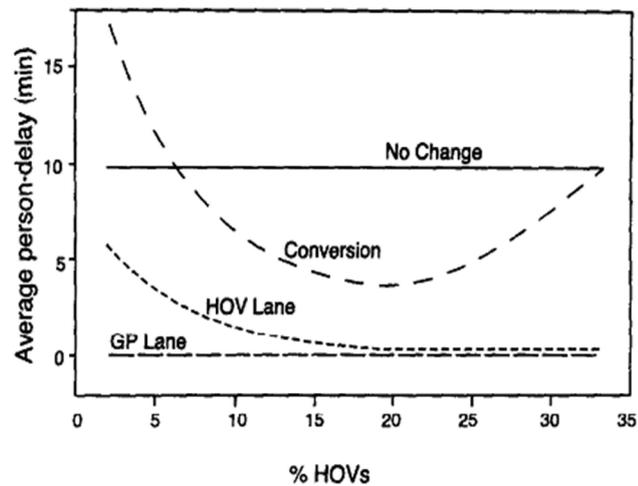


Figure 1 - Delay as a function of the initial percentage of HOVs (Dahlgren, 1998)

Understanding the behavioral responses of individuals to the actions of business and government will always be of interest to a wide spectrum of society (Louviere, et al., 2000). This is also true for infrastructural policies, especially when a change in behavior and/or acceptance by the general purpose is required. The government's interests in this case are the effect and evaluation of new policies (e.g. monetary value of reduction in travel time due to HOV lanes). Companies are more interested in the demand and commercial value of the new service or product. For example, large logistics and transportation companies will benefit to a great extent of achieved congestion reductions and travel time savings, which in turn will prove to be beneficiary to the Dutch economy. Increasing urban air quality is important for the general health level of city residents. Besides this, improving the accessibility and travel time to the city center is important for businesses and thus the economy of the city. The increased speed of movement and traffic flow is seen more as a benefit for the users. A reduction of nuisance for local residents is also an important benefit to keep in mind.

## 1.4. Research questions and hypotheses

### Main research question

To be able to reach the study objectives as stated in this chapter, research questions are defined. In this paragraph, one main research question is composed and a set of sub questions are derived. As stated above, the main question is which factors can stimulate carpooling for commuters traveling to a large city (>75.000 residents). The main research question is composed as follows:

**‘What are the most important factors influencing the travel mode choice made by city-commuters, between solo driving and carpooling?’**

### Sub-research questions

To answer this research question, a set of sub research questions is composed. Some of these sub-research questions will be answered based upon information gained from the literature review, others based on the survey outcomes and by using the created tool. However, a combination of both literature and survey results will be used for the majority of the sub-research questions, where the written information from other studies will serve as a framework to link the data obtained from the questionnaires to expert’s information. Some research questions relate to the application/modeling of the study results to a case-study (predictive value). The following sub research questions can be defined to obtain an answer for the original research question:

#### *Literature related*

1. **What is carpooling, why is it a promising alternative to reduce congestion on urban main entry roads; what are important factors, facilities or policies that stimulate carpooling?**
2. **What is a high-occupancy-vehicle (HOV) lane; how can its benefits stimulate carpooling; and how can the success of a HOV lane be measured?**
3. **What facilities should be in place to trigger city-commuters to carpool; how can public policies support or facilitate carpooling and HOV lanes?**

#### *Model related*

4. **How can the proportion of carpoolers for a specific case-study be predicted; what is the effect on traffic flow, environment and accessibility of the urban center; how application or translation of this prediction tool to larger scale?**

### Hypotheses

Some hypotheses are formulated at this point, based on several studies on carpooling. In the literature review, the data analysis and model estimation chapter, and the case-study application chapter these hypotheses will be tested.

- I. Travel time uncertainty is perceived as being more important (negative utility) than actual travel time (mainly issues like waiting for other passengers, requirement to make a deviation) (Beirão & Sarsfield Cabral, 2007; Li, et al., 2007; Crockett, et al., 2010);

- II. Safety and ambience during the trip in the carpool vehicle are considered more important than travel costs (Huyer, 2004; Crockett, et al., 2010);
- III. City-commuters perceive (direct) costs of their commute trip more important than the effects of the trip on the environment (Buliung, et al., 2009). This will be captured in the attitude questions. The type of car commuters are currently driving gives no direct information about this expectation since more consuming vehicles (having a negative influence on the environment) are in general also more expensive to drive;
- IV. Designated parking places for carpoolers and travel time savings in the carpool alternative can increase the probability a commuter chooses to carpool.

### 1.5. Limitations of the research

Since a (pre)defined time is scheduled for this study, not all aspects affecting the switch to carpooling can and will be studied in this thesis. A framework for this study will shortly be described, including its limitations. The first is that in this study only preferences of commuters (i.e. travelers between home and work locations) in switching to carpooling will be considered. It is chosen to do so, since in rush hours congestion problems are at their highest level, and commuters are mainly responsible for this. Furthermore, commuters in general have the lowest average vehicle occupancy. A second limitation is that only drivers of a private vehicle are considered and not current users of public transport. This is because carpooling is presented as a more sustainable form of transportation compared to private cars and public transport is normally seen as an even greener and thus more desired alternative, as more trips can be combined in this way. Therefore, it would not be wise to motivate users of public transport to switch to modes of sharing private cars, since this will result in an increase of the number of cars on the road, instead of a decrease. Third, only commuters that work in a large(r) village or city where urban bottlenecks occur are surveyed. This is because of the objective to study if HOV lanes (and carpooling) can reduce urban bottlenecks. This bottleneck only exists when the number of movements is sufficient, which is generally only the case at freeway bottlenecks or main city entry roads. When no bottleneck exists, no travel time differential can be achieved on the HOV lane. Fourth, because of time and budget restrictions, the sample size of the questionnaire will be limited. However, a necessary minimum number of respondents will be questioned to be able to make semi-strong statistical conclusions.

### 1.6. Thesis outline

Some general trends in the recent past and for the short-term future in The Netherlands have been sketched to this point. The importance of reducing congestion issues and 'sustainabilizing' today's mobility and transport sector is emphasized. The research design is explained including the research question, hypotheses, the research objective, used methodologies and limitations of the research.

Chapter two presents the literature review, which focuses on the definitions and characteristics of urban bottlenecks. Furthermore, a typology of carpooling and its main characteristics (including the juridical, economical and international context) are described. Important factors are identified which are expected to play a significant role in motivating

city-commuters to carpool, including the reserved lanes for carpoolers (called HOV lanes). The HOV concept is defined and its benefits and challenges are explained.

The third chapter explains the discrete choice modeling methodology and applies it in the context of this study, resulting in a stated adaptation based questionnaire. Chapter three also describes the expected results of this methodology and the process of collecting the necessary data. Chapter four is about the data analysis (of information obtained from the constructed questionnaire). A multinomial logit model (MNL model) is estimated reflecting the importance of the identified variables from answers given by respondents in the questionnaire. Results are compared to the literature study and expert interviews. From the MNL estimates, a tool is created that predicts the proportion of commuters that can be motivated by a certain policy or physical change. Together with information from traffic information models, the effect of different policies and facilities/configurations on the number of carpoolers can be predicted. The model can be applied or translated to any given route in the Netherlands, since commuter-preferences are estimated on a national scale. In chapter 5, this model is applied to a case-study: the Noord-Brabantlaan in Eindhoven, The Netherlands.

Chapter six states the most important conclusions and summarizes the answers on the research questions. A short discussion about the findings is started. Chapter seven states the limitations of this study and brings forward recommendations for future research on the topic.

## Chapter 2

# Urban congestion and carpooling

The literature study will continue on from the problem background that was sketched in the introduction. The literature chapter is divided into two main parts, the first part focuses on urban congestion issues and bottlenecks. Questions are answered like: what are the characteristics of urban bottlenecks, what is the typology to order different types of congestion causes, what current remedies exist and which of these are often used to overcome congestion problems? Extensive literature is reviewed to identify the main physical causes and characteristics of structural bottlenecks. The second part describes carpooling in more detail. The focus will be on the economic, juridical and international context of carpooling and HOV lanes in particular. Policies and factors motivating people to switch to carpooling as their commuting mode, current figures and statistics of carpooling in The Netherlands are researched and future perspectives on the expected carpool level belonging to certain policies and facilities are researched. The benefits, challenges, success and failure factors, and examples abroad of HOV lanes are also discussed. Scenarios and factors are derived that determine when and where HOV lanes can be successfully implemented. Potential triggers and user's preferences in The Netherlands to switch to carpooling are identified so these factors can be used in the stated adaptation questionnaire that will be created in the next chapter.

## 2.1. Congestion and bottlenecks

### Definition and typology

Congestion can be defined as: *'an excess of vehicles on a roadway at a particular time resulting in speeds that are slower - sometimes much slower - than normal or free flow speeds'* (Cambridge Systematics, Inc. & Texas Transportation Institute, 2005). Congestion basically entails: a) loss of time in general and b) uncertainty of travel time, also known as queuing time and scheduled delay (Arnott, et al., 1990). In most cases, congestion leads either to stopped or stop-and-go traffic. Congestion can be caused by traffic influencing events, variations in traffic demand or physical features of the infrastructure. More

comprehensively, a total of seven causes of traffic congestion can be identified within the three defined groups stated below (Cambridge Systematics, Inc. & Texas Transportation Institute, 2005; Central Massachusetts Regional Planning Commission, 2011):

- 1) Traffic-influencing events:
  - 1) Traffic incidents;
  - 2) Work Zones;
  - 3) Bad weather.
- 2) Variations in traffic demand:
  - 4) Fluctuations in normal traffic;
  - 5) Special events.
- 3) **Physical infrastructural features (structural bottlenecks)**
  - 6) Insufficient physical capacity of the infrastructure;
  - 7) Poor signal timing/traffic control devices.

This first category involved incidental events which are for a large part out of the control of the policy maker and are therefore not receiving attention in this paper. The second category corresponds more to the behavioral aspect of travel. When commuters for example can be influenced not to travel during peak hours, congestion caused by these temporary fluctuations in traffic amounts can be overcome. Both categories mentioned so far are external or special events (i.e. not influenced by the infrastructure itself) that can have a major effect on the traffic flow. The last category, structural bottlenecks, involves all causes where the number of vehicles trying to pass a certain infrastructural point is higher than the physical capacity of this passage. The capacity at this point is also limited compared with downstream sections. This type of congestion can be compared with fluids trying to run through pipelines. Examples include smaller road segments, interchanges, traffic signals and toll booths (Beckmann, 2013). A main difference between both categories is that structural bottlenecks, because of its recurring nature, can cause permanent changes in demand. People can alter their trip out of everyday frustration. External events in most cases however are only a source of temporary changes in demand (e.g. people avoiding a certain point only for a short time period because of an accident) (Sullivan, et al., 2013; European Conference of Ministers of Transport, 2007). The true level of congestion on a specific passage is determined by the interaction of both categories. The consequences of a traffic accident also depend on the physical capacity available at that point (Cambridge Systematics, Inc. & Texas Transportation Institute, 2004).

Furthermore, three different types of bottlenecks are distinguished, i.e. moving, phantom and stationary. Moving bottlenecks are formed by slow-moving obstructions prevailing on traffic streams. A moving bottleneck is created when a vehicle is travelling at a slower speed than the free-flow speed. When this occurs, vehicles are forced to slow down, decreasing the capacity of the infrastructure. Because of the reduced capacity, a queue will build behind the vehicle driving at low speed (Cassidy & Bertini, 1999; Munoz & Carlos, 2004). Moving bottlenecks can be transformed into phantom bottlenecks when people slow down to reach the point of a suspected obstruction and find out no such obstruction exists. As a result, suddenly the flow of traffic is free and more rapid (Gazis & Herman, 1992; Gazis, 2002). Stationary bottlenecks always arise at the same, fixed location and are caused by infrastructural characteristics where capacity is short. This last category of bottlenecks is targeted by the measure of implementing a HOV lane to stimulate carpooling.

## **Structural bottlenecks on city entry infrastructure**

In The Netherlands, structural bottlenecks are responsible for 71% of the national congestion level, compared to only 29% due to traffic-influencing events and variations in traffic demand (Faber, et al., 2011). Therefore, the research in this paper will be limited to the first category. As stated before, structural bottlenecks occur because a specific point of infrastructure has limited capacity compared to the supply of vehicles per instant of time. The flow (and thus the speed) of the vehicles depends on the capacity of and density at this specific point. Reasons for structural bottlenecks to occur can be special objects like bridges, tunnels, traffic lights, toll booths and interchanges. However, very often structural bottlenecks arise when different routes converge at a particular point (both in space and time). This is for example the case near the edges of a city road network, near main city entry roads. Since these structural bottlenecks typically have a more or less fixed location and predictable recurring cause(s), they can easily be identified and remedies or policies devised to reduce the impact of those bottlenecks. Typical elements of these bottlenecks include (Central Massachusetts Regional Planning Commission, 2011):

- ◇ A predictable recurring cause.
- ◇ A flow of traffic or vehicles;
- ◇ A disruption or delay;
- ◇ A traffic queue upstream of the bottleneck;
- ◇ A beginning point for the traffic queue;
- ◇ Free flow traffic conditions downstream of the bottleneck.

## **Potential solutions for overcoming congestion**

The most obvious solution for overcoming congestion problems at specific infrastructural places is to increase the capacity by adding lanes (Kimathi & Illner, 2012). In many cases however this option is hampered by a lack of resources, space and/or because of environmental and political issues. Also, because of the belief that public transport will not be able to cope with the (expected) growing congestion issues, other solutions have been proposed in literature (adapted from Downs, 2004):

- ◇ charge peak-time tolls: when tolls are set high enough, the number of vehicles could be reduced to the point that everybody could move at high speed. However, this solution can be seen by the general population as discriminating, since wealthier people are free to drive whenever they want to, and poorer people will simply be bound to off-peak times. This alternative closely resembles a recent proposal in Dutch politics called 'rekening rijden', where people have to pay for using the road. This proposal was rejected in politics since a lot of open questions existed around the concept (NRC Handelsblad, 1999). In the United Kingdom, currently a study is carried out to estimate the effects of road pricing where tolls are dependent on the time and location of driving, based on the success of a similar approach in London;
- ◇ greatly expand the road capacity: this is not a smart solution since the giant concrete slab of huge roads constructed for peak-hour transportation will be totally underutilized in non-commuting hours (Downs, 2004);

- ◇ Use intelligent transportation devices to control speed of traffic flows: by using electronic, variable signs and signal lights speeds can easily be adjusted, as is already possible on most Dutch highways, limiting the effects of congestion;
- ◇ **Carpool or transit oriented parking programs:** increasing the average vehicle occupancy by firms or governments making it appealing to carpool, for example by allowing them to park their carpool vehicle or transit vans more easily or by financial schemes (Crockett, et al., 2010);
- ◇ **Creation of HOV lanes:** as a means to not only reduce cars on the road and congestion, but minimizing the requirement for private cars, parking places and reducing total vehicle kilometers driven and emissions. However, a debate exists whether total capacity should be increased or if capacity can be deducted from current general purpose lanes (Dahlgren, 1998);
- ◇ Restrict outwards movement of new developments: for example by limiting urban growth and setting spatial boundaries. This will reduce total driving at the edges of a region. However, *'shorter driving distances may not reduce congestion because higher densities concentrate more vehicles in smaller areas'* (Downs, 2004).

Since resources and space will be limited in many cases in the Netherlands, the option to increase utilization of existing infrastructure is one of the few options that remains and therefore is a necessity to be studied. Sharing current free capacity is one of the most important ways to achieve this. Carpooling can be the most promising alternative in this light based upon similar cases in other countries.

### **Stakeholders of congestion issues**

Important stakeholders in the study will include:

- ◇ Users of the infrastructure, mainly commuters are of focus (travel time savings);
- ◇ (higher and local) Governments and planning departments (congestion relief, cleaner air, accessible and attractive city center);
- ◇ Residents living in the vicinity of the bottleneck (noise and air pollution).

Since it will prove extremely difficult to enforce the idea that only people driving to work are allowed to drive on the lane, users will include all kinds of travelers (commuters, businesses, shoppers, tourists, etc.). As is assumed that users follow the concept of maximization of utility, this means they make choices based on maximizing their total utility by weighing the individual importance of many different factors (departure time, travel time reliability, travel mode, etc.) at the same time. Of course trade-offs within choices have to be made. By having said this, users will not only focus on travel time minimization, but will keep in mind other factors that they perceive as important. Utility levels are measured on an ordinal scale; this means only the relative values matter between alternatives (Bliemer & Rose, 2009). Higher government consists mainly of the ministry of infrastructure and local governments include provinces and municipalities. People living near the congestion area (local residents) can be seen both as users willing to utilize the infrastructure, and as receivers being hindered by (noise, visual and emission) pollution.

## 2.2. Carpooling

### Definition and typology

The Oxford English Dictionary defines carpool as: ‘an arrangement between people to make a regular journey in a single vehicle’. In the Netherlands, a person formally is considered a carpooler when he or she i) drives with others in one vehicle; ii) to work; iii) at least two times a week; iv) while the other occupants are also on their way to work. Carpooling is also known as ride-sharing, lift-sharing, co-voiturage and, in Dutch, as auto-pooling. Carpooling became popular during the oil crisis in 1973 and the energy crisis in 1979, when the first vanpools were organized by companies as Chrysler and 3M (Oliphant & Amey, 2010). During these crises, for the first time in history supportive measures other than advertising were applied to encourage carpooling. By having more people travelling in one vehicle, carpooling reduces travel costs for each individual, such as fuel costs, tolls, and the stress of driving. It is a more environmental friendly and sustainable way of travel as shared modes of transport reduce traffic congestion on the roads, carbon emissions, and the need for parking areas.

The European consortium behind the ICARO (increase of car occupancy) project defines carpooling as follows (Sammer, et al., 1999):

*‘Car-pooling is at least two people riding in a car, usually belonging to one of the occupants, (...) where each member would have made the trip independently if the carpool had not been there’.*

In the above more general definition, the focus is not only on home-work trips. However, as congestion problems mostly occur during rush hours, i.e. when commuters are on their way to work, this group is seen as mainly responsible. Commuting vehicles on average have a low occupancy compared to social-recreational traffic (Ministerie van verkeer en waterstaat Adviesdienst Verkeer en Vervoer, 2000). This study assumes that all carpoolers had made the trip anyway, if no carpool alternative existed should hold. Because all forms of people traveling together are considered as carpooling, one of the most occurring forms of carpooling in which family members are traveling together also falls in this category. There is no restriction or minimum age for carpool passengers to mark a vehicle as a high-occupancy vehicle. In the Netherlands, if the average vehicle occupancy (nationally) can be increased from 1.2 to 1.6 persons, traffic jams will no longer exist (Minister van Verkeer en Waterstaat, 1995). Therefore, if this level can be attained by stimulating carpooling, no other infrastructure investments have to be made.



Figure 2 – Benefits and effects of carpooling (Hoffman, 2014)

Carpooling is not always arranged for the whole length of a journey: passengers are able to join only for a part of the trip. Extra flexibility is the result and this enables more people to share journeys and save money. Currently, more and more online matching programs are emerging to find a travel partner. In most cases, a community-based trust mechanism is used to create a trustable platform for users. Carpool arrangements can be made by public web-based platforms or marketplaces, closed (company) websites for employees, carpooling smartphone applications, manned carpooling agencies and fixed pick-up points.

Carpooling can be divided into internal carpooling or fam-pooling (where household and/or family members are allowed as passengers) and external carpooling (which excludes household members and persons with accompanying purposes). The latter can be further divided as follows (Li, et al., 2007; Oliphant & Amey, 2010):

- ◇ Hitchhiking: a completely random form of carpooling where all elements of the ride (destination, costs, etc.) is arranged on the road where the driver and passengers meet. Passengers can't predict the waiting time and if they will be picked-up at all. The ride is usually free;
- ◇ Slugging: drivers and passengers meet at predefined location where the routes are set and passengers can be expected to be picked up relatively soon. No money exchanges hands, but a mutual benefit exists, like using designated lanes for the driver;
- ◇ Traditional carpooling: all details like place, time, costs, route, etc. are set in advance through a medium;
- ◇ Flexible carpooling: a form of ad-hoc carpooling where formal carpool locations are designated for travelers to join carpools;
- ◇ Real-time ridesharing: state-of-the-art form of carpooling where organizing the trip can take place as little as a few minutes in advance of the meeting through e.g. smartphone applications. The passengers are picked up at his/her current location.

Another distinction in carpool forms is by looking at the gathering location of the carpool passengers. Three different forms can be distinguished (Kennisplatform voor Verkeer en Vervoer, 2013): i) the gathering location is the house of the driver; ii) the driver picks up all passengers on his way to work or makes a detour; iii) the driver and other passengers gather at a certain central location to continue their journey driving together. The first and last options are also considered in the case study application in chapter five. The different policies result in a different estimated number of solo drivers and carpoolers. Furthermore, gathering closer to the origin/home location of commuters will yield the largest vehicle-kilometers-traveled savings.

### **General characteristics of carpoolers based upon literature**

Most people are highly dependent on car travel as their main mode of transportation. But, for the majority, the car is far more than just a means of transport. Other motives than its instrumental function of carrying people from point A to B seem to play important roles. These include feelings of sensation, power, freedom, status and superiority (Beirão & Sarsfield Cabral, 2007). The specific benefits of car usage depend on the social-spatial relations and lifestyles of its users. Commuting by making use of carpooling

is more popular for people who work in places with a high job density, and who live in places with higher residential densities. Carpooling is highly correlated with transport operating costs, commute length, and is less likely among older workers, and homeowners (DeLoach & Tiemann, 2010). This finding is strengthened by a study carried out in Lisbon, where most promising carpool candidates were identified as young persons with a lower income (Correia & Viegas, 2010). Based on American, Belgium and Dutch sources, some clear distinguishing characteristics of the average Dutch carpooler can be described:

- ◇ carpoolers on average have a workweek of 30 hours or more (Molnár & Konen, 2003);
- ◇ carpoolers are mostly people living further away from their work location than solo drivers: the average distance travelled by a carpool vehicle is 31 kilometers per day, compared to 21 kilometers by solo drivers (Molnár & Konen, 2003; Traject, 2008);
- ◇ carpoolers are responsible for almost 12% of total commuting kilometers (Kennisplatform voor Verkeer en Vervoer, 2013);
- ◇ a designated central carpool gathering place is available and used in only 3% of all carpool trips in The Netherlands (KPVV, 2006);
- ◇ carpool is more popular by industrial, production or recreational workers, higher educated office workers use carpooling to a smaller extent (KPVV, 2006; Traject, 2008);
- ◇ at work locations where public transport connections are bad, carpooling is increasingly utilized (KPVV, 2006);
- ◇ the tendency to carpool decreases with one's education level and income being higher (Dowling, et al., 1996);
- ◇ carpoolers on average drive a less expensive and less luxurious car than people that do not carpool (Correia & Viegas, 2010);
- ◇ people who have a hard time finding a parking place for their vehicle at the work location carpool to a large extent (Beirão & Sarsfield Cabral, 2007; Crockett, et al., 2010; Correia & Viegas, 2010);
- ◇ areas with dense populations and concentrated employment patterns show a higher percentage of carpooling among car users (Dowling, et al., 1996);
- ◇ Vehicle ownership of households is negatively correlated with the tendency to carpool, as can be seen from table 3 below (Dowling, et al., 1996):

Incidence of carpooling as a function of household vehicles						
Number of household vehicles	0	1	2	3	4+	All households
Percent carpooling to work	26.5%	23.4%	14.9%	13.8%	13.5%	16.3%

Table 3 – Carpooling as a function of household vehicles

### Challenges of carpooling (success/failure factors)

For carpooling to be successful and for motivating many commuters to switch to carpoolers, the following prerequisites have to be met. Carpooling should be **secure**; sharing a vehicle with strangers turned out to be an obstacle because of safety reasons. Setting up carpools by making use of the internet can overcome this problem by using feedback systems. Carpools with colleagues are normally considered to be secure. Furthermore, carpooling should be **flexible**; changes to work times or patterns can be important reasons for commuters without a fixed work schedule to not engage in carpooling. One survey

identified this as the most common reason for not carpooling (Li, et al., 2007). Some others value stops on the way home from work (e.g. a supermarket). Some fixed carpool programs guarantee a ride home to increase one’s flexibility. A recent study by the Kenniscentrum InfoMil also highlights the importance of a guaranteed ride home. Carpooling should also be **reliable**; if only a small proportion of the population or workforce carpools, it may be difficult to find a solution for certain trips. Sometimes, when rides are internet-created, some people may not show up or last-minute cancel the ride; Carpooling should be **effective** and potential users should be aware of this; combining cost advantages with appropriate incentives motivates more commuters to join carpools (HOV, subsidies, free parking, etc.); Finally, carpools should be **endogenous**. This means no ad hoc assumptions about the behavioral responses required to achieve the predicted potential should be made. This study aims to fill this gap by analyzing the stated behavior of commuters and not just looking at the theoretical and technical potential.

Factor	Rank	Mean score
Access to HOV lanes	1	3.77
Relaxation while traveling	2	3.60
Enjoy travel with other	3	3.26
Help environment and society	4	3.23
Travel time saving	5	3.16
Other	6	3.16
Sharing vehicle expenses	7	3.15
Reliability of arrival time	8	2.93
Splitting tolls on toll roads	9	2.38
Get work done while traveling	10	2.24
Drop off kids at school/day care	11	2.23
Carpool partner matching program	12	2.07
Encouraged by program at work	13	2.00
Preferred parking at work	14	1.94

**Table 4 – Reasons for carpooling, based on Li, et al. (2007)**

### Economic aspects of carpooling

As already stated in the introduction, certain trends have led to the demand of new approaches and types of sustainable transportation. Carpooling can serve as an alternative between public transport and solo driving since it comes with more flexibility than public transport, and it is generally cheaper than driving a motor vehicle alone. Furthermore, looking from the environmental perspective, carpooling is a more sustainable alternative, since when more trips can be combined fewer cars will be on the road. As a result, the level of emissions will be lower and also the required amount of infrastructure will be lower. This allows more land to be used for other purposes, like green areas. Applied to the Dutch context, people in today’s society get more individually-oriented and, as a result, desire a higher level of privacy, freedom, and flexibility. This is exactly what carpool tries to accomplish, as being a balanced approach between public transport and solo driving.

Congestion costs are seen as a form of external costs caused by external effects. These are effects that are connected to the use of products or services, but are not included in the intended market mechanism (Kennisinstituut voor mobiliteitsbeleid, 2009). Other examples in transportation include climate change and safety risks. For calculating the external costs due to congestion, it has to be kept in mind that infrastructure users normally do not consider the delay they cause to other road users. A part of the congestion costs caused by infrastructure users (mainly travel time loss) is taken into account and paid for by potential new users planning a trip. These people will for example choose to depart later, take another route or another mode of transport. Therefore, the resulting congestion costs will be self-adapting and slightly lower than just the grand summation. Another paper quantifying congestion costs states that extra travel time is the most important category of transport costs and time savings are the greatest benefit of transport projects improvements (Victoria Transport Policy Institute, 2013). Other factors such as travel reliability and comfort can be quantified by adjusting the value of travel time cost. Different time valuation perspectives are presented like clock time (objectively measured), perceived time (as experienced by users), paid travel time, and personal travel time. In this thesis, and in the stated preference survey, the travel time is equal to the perceived time as experienced by respondents. Finally, the (financial) value of time people attach to time travelling can be presented. From data obtained by the Kennisinstituut voor Mobiliteitsbeleid (2013), it can be derived that one hour stuck in congestion is valued at €26.75 during work time when he is travelling by car. When travelling by train this is equal to €19.75 (price level 2010).

Carpooling can yield large direct economic savings. When fuel and parking costs are shared between (a group of) carpoolers, savings between €1250 and €1900 a year are reported for a 4 day carpool week and a distance between home and work location of 50 kilometers (Milieu Centraal, 2005). Sometimes, when the carpool is arranged by the employer, taxes have to be paid over compensations gained by employees. For example, when the employer provides its employees access and use of a car or bus registered to the company to enable its workers to carpool to work, they are not allowed to receive any travel cost compensation in addition. However, when employees are carpooling with their own privately owned car, two possibilities exist in current Dutch legislation (Staatssecretaris van Financiën, 2010). The first is when the employer asks an employee to pick-up other employees on his way to work. In this setting, the driver will receive a tax-free compensation of 19 eurocents per kilometer, including the diversion kilometers to be made for picking up his colleagues. However, when employees make carpool arrangements without their employer organizing it, all passengers can receive the 19 eurocents per kilometer compensation, calculated from their home to work location. Of course, the driver is worse off compared to the trip mentioned before when he also received compensation for the kilometers he had to divert to pick-up his colleagues. In the latter scenario, he is dependent upon the willingness of his colleagues (who have no costs at all as passengers) to give him some extra compensation, or to switch turns.

### **Environmental aspects of carpooling**

The environmental benefit of carpooling seems obvious: because it combines journeys, more persons can be transported by using fewer vehicles and thus using less fuel. Cars that are carrying more persons use almost using the same amount of fuel. However, the expectation of using less fuel in total is not true when no reduction in total vehicle

kilometers travelled (VKT) by all occupants is achieved. Carpooling should be coupled with a VKT reduction of a different vehicle; because otherwise greenhouse gas emissions are not reduced. For example, when commuters are carpooling who were previously using public transport; the level of emissions will remain the same or will increase as a result, provided that the service level of public transport remains the same. Even if the level of public transport decreases, the total emissions still can increase since public transportation uses less fuel than all cars together necessary to carry the same number of people (Metz, 2009). This possibility of people switching from public transport to carpooling is often not taken into account by researchers when estimating the effects of carpooling on emissions. Another factor that can significantly reduce carpool fuel savings is the transportation of passengers to their individual locations. This effect can be countered by studying commuters working or living closely to each other and thus by making this extra distance relatively small compared to the overall distance travelled. 17.6% of fuel that is currently consumed in the OECD countries can be saved if one additional person is added in each urban commuting trip (International Energy Agency, 2005).

In the Netherlands, for the year 2012 road traffic was responsible for 30% of national NO<sub>2</sub> emissions, 40% of NO<sub>x</sub> and 25% of PM<sub>10</sub> emissions, as can be seen from figure 3 on the right (de Haan, 2013; C.B.S. Statline, 2014). Of these percentages, private vehicles are responsible for 29% of NO<sub>x</sub>, 48% of PM<sub>10</sub>, 80.5% of CO and 62% of CO<sub>2</sub> emissions. Because of this large contribution of road traffic on national emissions, a small reduction in the number of cars of 10% (1 out of every 10 person starts to carpool) therefore can yield important results. In the application of the created tool in chapter five, a calculation will be made estimating the potential savings in CO<sub>2</sub> emissions for the selected case-study.

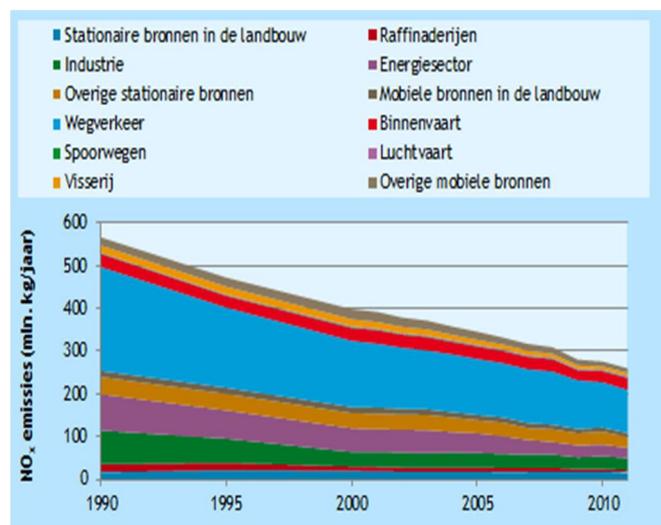


Figure 3 – Environmental effects of road traffic in the Netherlands (de Haan, 2013)

### Ways to stimulate carpooling

For commuters to change their behavior, a broad package of measures should be incorporated. These include: well-designed and easy to access carpool meet location, reserved lanes with priority, availability of special parking facilities for carpoolers, fiscal or economic measures, or educating the public about carpool advantages, the conversion of current general purpose lanes to special carpool lanes (HOV lanes), or the construction of additional lanes.. Different institutional and cultural frameworks exist in various European countries. Based on the European ICARO project report, existing projects and measures aimed at increasing car occupancy and stimulating carpooling in a wide range of European cities have been evaluated and will now summarized in table 5 (Sammer, et al., 1999):

CITY	COUNTRY	MEASURE
Leeds	United Kingdom	Combined bus, cycle and HOV lane
Leeds	United Kingdom	Assessment of various scenarios: sensitivity tests, possible 3+ occupancy level scenario
Brussels	Belgium	Carpool center with matching service
Salzburg	Austria	Decentralized small carpooling parking areas near freeway interchanges
Salzburg	Austria	Assessment of possible effects of an HOV lane on motorways around the city of Salzburg
Pilsen	Czech Republic	Large-scale information campaign and carpooling coordination center
Bern, Lyss, Oberglatt and Yverdon	Switzerland	Preferential parking
Graz	Austria	Carpooling scheme in area with bad public transport provision
Rotterdam	The Netherlands	Guaranteed ride home scheme
Madrid	Spain	Effect of raising minimum car occupancy on HOV lane from two to three people was modelled
Thessaloniki	Greece	Assessment of possible effects of an HOV lane into city center

**Table 5 – Carpooling stimulating measures in various European cities**

Main findings of the study can be summarized as follows: in general people have positive attitudes towards carpooling as an environmentally friendly mode of transport. Responsibilities and inconvenience for driver are mentioned as negative aspects of carpooling. Close partnerships between carpooling organizations and companies is most effective in promoting carpooling. The study concludes with the fact that one of the most effective ways of increasing car occupancy is through infrastructural measures, like HOV lanes (Sammer, et al., 1999).

### **Physical possibilities to stimulate carpooling**

#### *Carpool meet locations/P+R*

One way of promoting carpooling is by facilitating parking places where commuters can meet after which they drive together in one car towards their work location. Another possibility is where commuters park their car and continue their journey with public transport (P+R). Travelling by making use of a transfer point yields certain benefits (Fujii, et al., 2001; Anwar, 2009). In general, parking places at those areas are easy to find and the parking fee is cheap compared to the inner city or totally free. Sometimes the parking fee includes the ticket for a return public transport trip. Travelling by public transport or sharing a car, on average is cheaper than driving your own car (Kennisplatform voor Infrastructuur, verkeer, vervoer en openbare ruimte, 2003).

In the city of Nijmegen, a study was carried out that measured customer evaluations of the attributes of P&R facilities and the features of connecting transport (Bos, et al., 2003). Results indicated that social safety, quality of the connecting public transport mode and relative travel times of the different transport modes are key attributes to the success of P&R facilities and contextual variables only have a minor impact. Another study identifies

that a secure parking of passenger's car, clear information, and comfort, speed and frequency of the public transport connection as being the most important characteristics of a successful P+R facility (Kennisplatform voor Infrastructuur, verkeer, vervoer en openbare ruimte, 2003). Based on these and other findings, the belief is raised that public transport will not be able to cope with congestion problems efficiently, since always people will exist that demand a higher level of comfort and privacy. A compromise has to be found that balances the use of private vehicles and public transport. A smaller social system, more targeted towards the private sphere is desired. This is exactly what carpooling and carpool transfer places try to accomplish.

The Netherlands offers a total of 795 transfer locations (January 2013), of which 443 are park and ride (P+R) facilities, 342 are carpool meet locations and 10 locations offer both P+R and carpool facilities (Kennisplatform voor Verkeer en Vervoer, 2013). P+R facilities on average are larger than carpool location (154 parking places against 29). 42% of all P+R capacity are located in an urban area and 354 P+R facilities have direct connection with a train station. Noord-Brabant is the province with the most carpool meet locations (51). Despite P&R areas exist to promote a higher occupancy per vehicle at these places; they are underused (Maes & Ververs, 2014).

### *High occupancy-vehicle lanes*

Despite the fact that our highways and urban roads are congested to a large extend in peak hours, still thousands more people can be easily transported by just increasing the number of passengers in each vehicle. Since most people currently drive alone, an easy solution is to encourage more car drivers to join or start a carpool and use a form of transit for their commuting trip. Rewarding carpoolers by giving them priority at traffic lights and by avoiding congestion can be achieved by implementing HOV lanes. According to Dahlgren (1996), constructing an HOV lane reduces person-delay by:

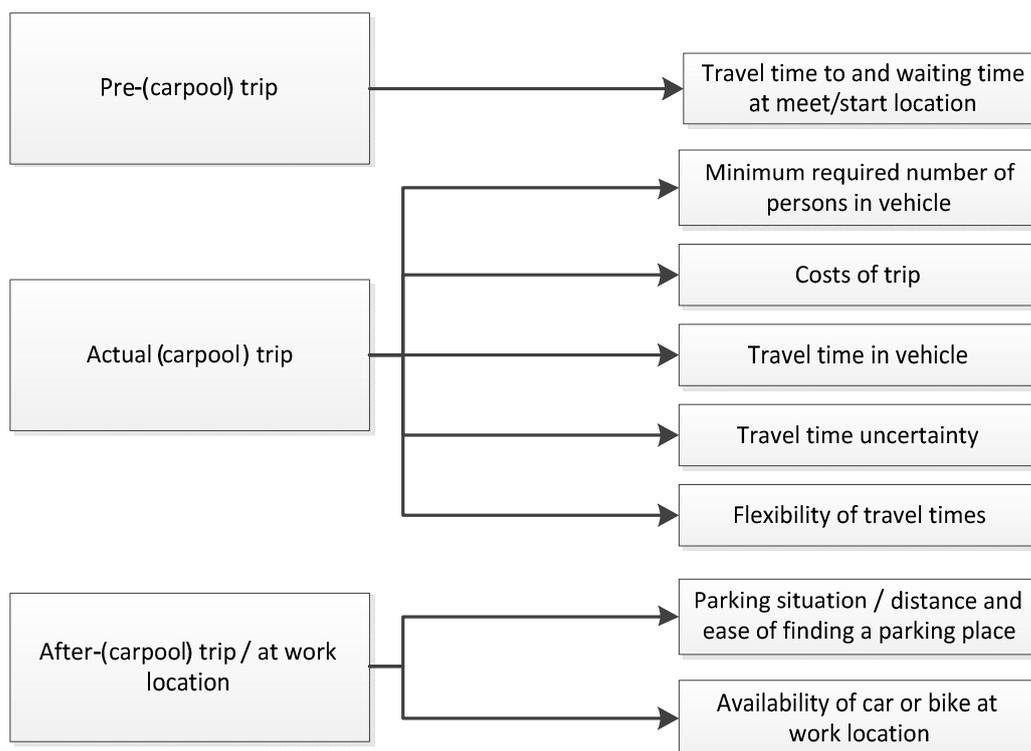
- ◇ Motivating people travelling in LOVs to switch to HOVs, thus reducing the number of vehicle trips;
- ◇ As HOVs will have priority, more people in less vehicles can pass the bottleneck ahead of other vehicles;
- ◇ Increasing capacity due to extra lane (not measured in vehicles, but in persons).

A more detailed background on HOV lanes that is relevant for this study is described in appendix C. The definition, characteristics and juridical implications of HOV lanes are presented in this appendix. Also, challenges that occur when implementing HOV lanes (success and failure factors), its benefits on the level of congestion and the environment, equations that describe the expected shift to HOV lanes relative to a reached travel time differential are explained in appendix C. Examples of HOV lane implementations abroad and the results achieved are also described case-specific.

## **2.3. Carpool stimulating factors**

Some understanding of user's preferences and attitudes towards carpooling is already obtained at this point to construct the experimental design. From these literature sources together with expert interviews, a comprehensive list of relevant attributes was

formed as the basis for the SP designs, as is displayed in appendix D. This first set of important factors influencing the choice of respondents to carpool can be reduced by grouping factors in larger constructs. By carefully weighting and analyzing the interpretation of the factors and completeness of the set in capturing the choice to switch to carpooling, a final set of three groups containing total of eight attributes resulted. Two factors can be linked to the starting location (pre-transport), four factors can be linked to the (carpool) trip itself (actual journey), and the last two factors are linked to the work location (after-transport). This gives a total of 8 attributes, which are displayed in figure 44. Since stated adaptation is used, these eight attributes change only for the carpool alternative in the nine choice profiles. The reference alternative (driving solo) can change between respondents; however some values are fixed for this alternative, like no travel time to the carpool meet location. The value of number of persons in the vehicle will also be equal in the solo alternative, i.e. equal to one. Flexibility of trip times is always high and there is always the availability of a car at the work location in the solo alternative. The remaining four attributes are based upon the answers of the respondent in the first part of the questionnaire. The number of attributes and their levels have an effect on the experimental design and the number of choice situations that will be required. This will be explained below in the experimental design paragraph.



**Figure 4 - Identified important variables in stimulating commuters to carpool**

## 2.4. Chapter conclusions

In this chapter an overview of congestion types and causes, along forms of bottlenecks are presented. Potential solutions aiming at reducing the level of congestion are described. Stakeholders that suffer from congestion issues are identified: ranging from users of infrastructure (commuters, companies and all other travelers), to local residents living in the vicinity of a bottleneck, and to local and higher governments and planning agencies that are responsible for the infrastructure and the functioning of the traffic network for the national economy.

In the second part carpooling is researched in detail, characteristics of carpoolers are described. Success, failure and stimulation factors for promoting carpooling are presented. Main findings of the literature review focus on factors that are expected to be most important in motivating commuters to switch from driving solo to carpooling. Eight factors are identified that are used in the questionnaire that will be created in the next chapter to study their importance in how carpooling can be stimulated. A couple of these factors are linked to the HOV lane benefits (travel time (uncertainty) reduction, and the minimum occupant requirement). The first implementation (and closure) of such an HOV lane in the Netherlands is described in the appendix belonging to this chapter, together with the current juridical framework. Success and failure factors of a HOV lane are described and formulas given for calculating the switch to carpooling due to a HOV lane's time differential compared to general purpose lanes.

## Chapter 3

# Capturing commuters' preferences

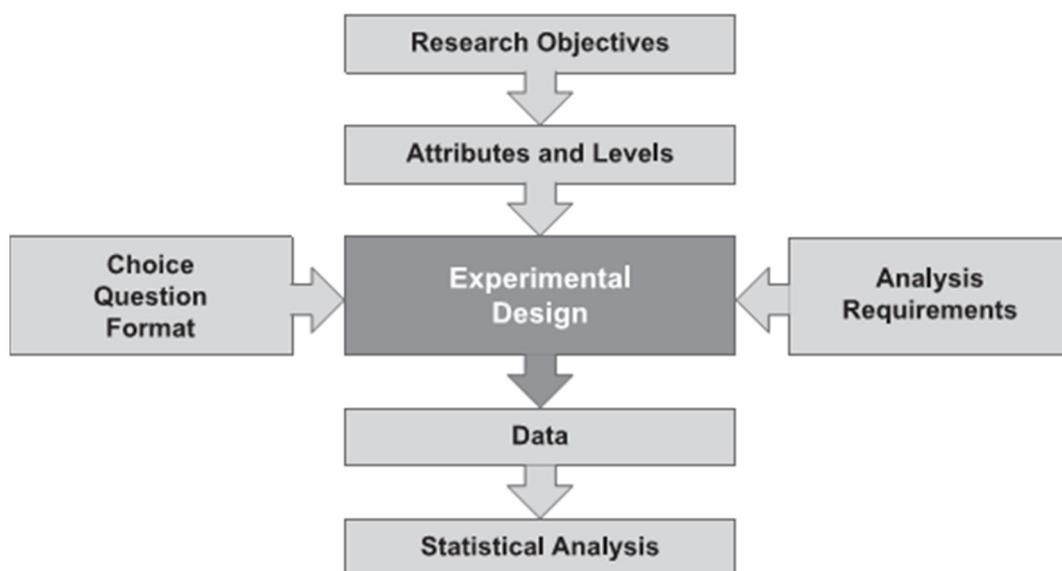
Discrete choice modeling is used as the main research technique to identify significant attributes in the choice of commuters to carpool. A web-based self-completion survey is created in this thesis in which respondents are asked to choose an alternative for their home-work trip. The survey's design will be generic so that responses can be gathered from respondents on a national scale. In this way, valuations of the different factors by respondents can be transferred between different contexts and projects later. The underlying principle for deriving the questionnaire will be based upon stated adaptation. This is a discrete choice modeling technique where respondents have to choose between one alternative representing the current, reference scenario and another alternative representing the carpool alternative. Completed questionnaires will be analyzed so that commuters' preferences and desires regarding carpooling can be identified and their importance estimated.

A literature study has been carried out to define some relevant concepts related to carpooling and to gain some basic understanding of which factors influence the decision making process of commuters in selecting their mode of travel. This resulted in a clear definition and understandings of concepts like: urban bottlenecks/congestion, carpooling and the potential stimulus of different factors and policies, like a HOV lane. Interviews with experts in the fields of mode choice behavior, carpooling, public transport, P&R, choice modeling and psychology, discrete choice models, traffic congestion analysis and traffic forecasting/modeling have been held. At this point some research questions have already been answered by literature (the specific answer will be reflected upon in the conclusion chapter). The question that remains at this point and will be answered in the following chapters is questions 4:

- 4. How can the proportion of carpoolers for a specific case-study be predicted; what is the effect on traffic flow, environment and accessibility of the urban center; how translation to larger scale?**

### 3.1. Stated adaptation

The main difference between discrete choice modeling (DCM) techniques and general market surveys is that in the former experimental designs are used. These designs are to be calculated in advance and the data is to be analyzed with a specific model form. Respondents value multiple choice profiles with different alternatives, from which their preferences are obtained. For a series of hypothetical multi-attribute alternatives, each formed by a series of levels that constitute the practical definition of the attributes, respondents indicate their preferences (Wang, et al., 2000; Hurtado & Manuel, 2010). The most important strengths of discrete choice modeling include i) it forces respondents to make a trade-off between attributes, ii) it enables implicit coefficients to be estimated for attributes, iii) can be used to estimate the level of customer demand for alternative ‘service products’ in non-monetary terms, and iv) it can reduce the possibility of a respondent to behave strategically (Train, 2009). Outputs of discrete choice models are: i) a model equation, ii) set of estimates of the marginal utilities for each of the attributes of interest, and iii) variance statistics for each of the utilities estimated (Train, 2009). In figure 5, the key process for developing a discrete-choice based questionnaire is displayed.



**Figure 5 – Key stages for developing a discrete-choice experiment (Reed Johnson, et al., 2013)**

Two mainstream discrete choice based research types can be identified to carry out effective behavioral research on the potential effects of their choices, i.e. revealed preferences (RP) and stated preferences (SP). When using the RP method, factual information is asked or actual behavior is observed on what the respondent actually did. RP looks at the current market equilibrium, only existing alternatives are observed (Sanko, 2001). In the SP survey the respondent is asked what he or she would do in a specific situation that the researcher designed. SP is widely used in travel behavior research to identify behavioral responses to choice situations that are not or cannot be revealed (yet) in the market. These alternatives however should be imaginable and rational (Hensher, 1994; Louviere, et al., 2000). Summarized the main advantages and disadvantages of SP compared to RP are (adapted from Sanko, 2001):

### Advantages of stated preferences

- ◇ SP can get ranking, rating and choice information, RP can only get choice results;
- ◇ SP can capture hypothetical behavior and non-existing alternatives, RP can only capture existing alternatives and observable behavior;
- ◇ no measurement error exists in SP data;
- ◇ the range of attributes' levels can easily be extended; the range of attributes in RP situations is limited;
- ◇ the ability to control multicollinearity among attributes exists in SP;
- ◇ the choice set can be defined in a brief and clear way, and more responses can be gathered per respondent.

### Disadvantages of stated preferences

- ◇ behavior in reality can be inconsistent with SP choices made, no real commitments with answers exists. Contrastingly, RP is derived from observed behavior, so this is always consistent;
- ◇ biases can occur because respondents try to justify their actual behavior or try to control policies.
- ◇ SP data must be collected in a highly specific fashion in order to avoid temporal, learning and segment biases.

In this study it is chosen to use stated preferences instead of revealed preferences due to a combination of different reasons. Since the target audience of the study is already quite selective (respondents have to be commuters that are traveling by car to a city center which is not their hometown), it would be very difficult to find sufficient people that are currently already carpooling to the work with the same restrictions. Secondly, one of the identified factors that is influencing the decision making process, i.e. the HOV lane, requires a large investment to implement. Therefore, the respondent's behavior in real life in using this lane cannot be captured easily, as a result revealed preference is unable to capture the behavior resulting from this measure. Thirdly, when using stated preferences, multicollinearity can be controlled and it can be made sure choice tasks are more equally divided over all respondents and choice sets and therefore the frequency in which they occur is more equally distributed.

Stated preferences theory is mainly based on foundations from three behavioral study fields. In chronologic order the first is Lancasterian consumer theory (1966), which proposes that utilities for goods can be decomposed into separable utilities for their characteristics or attributes (Adamowicz, et al., 1998). The second building block is information processing in judgment, and decision making in psychology. The third cornerstone, being random utility theory, forms the basis of several models and theories of consumer judgment and decision making economics and psychology. Discrete choice models are usually derived under the premise of a utility-maximizing respondent and therefore random utility theory is often used. In random utility theory, the respondent (and thus commuter) will choose the alternative that maximizes his or her own utility. Translating this to stated adaptation choice profiles, the respondent will choose the alternative where he or she derives the most utility from. Some (mathematical) background of random utility theory is sketched in appendix E.

Based upon the information gained in the first two techniques, a questionnaire is created in which commuters driving at least one time per week to their work are surveyed. The survey includes a reference situation resembling the current commute trip of the respondent and a hypothetical situation based on the carpooling concept in combination with an HOV lane. In this way, it is easier for the respondent to recognize his current work trip and compare the alternative with his/her current trip. This technique, where questions are first asked to a respondent to report his or her current commuting behavior, and subsequently hypothetical situations are presented the respondents has to choose between, is called **stated adaptation (SA)** (Khademi, et al., 2012). The stated adaptation methodology will prove to be particularly useful for determining the potential of HOV lanes as a new mode of transport before the system is implemented in practice (MVA Consultancy, 2008). This is because the concept of HOV lanes (one of the main factors studied in this research) is rather new, and no actual choices (like in revealed preferences) can be observed. A large number of factors make up the mode choice decision of commuters; stated adaptation is able to reduce this large set to a finite set of attributes to be considered in the choice situation. This is done by constructing choice experiments based on the information provided at the first stage of the questionnaire. Since the alternative resembling the respondents' current trip will not change, the respondent will not have to read through this information every choice situation, which saves time. As a result, more choice situations can be asked to a single respondent. The questionnaire is not based on a certain period of time, but on habitual behavior. SA experiments deal with individual's adaptation behavior under policies that are exogenous (Nijland, et al., 2006; Van Bladel, et al., 2008). This means the respondents' task is not to express a preference or choose between possible alternatives, but to indicate changes in their behavior (Khademi, et al., 2012). The (stated) preferences of these commuters are captured by making respondents choose combinations of factors that trigger them to switch to carpooling, or on the contrary, make them stick with the solo alternative. The central question in the presented stated adaptation based survey is (Arentze, et al., 2003):

**“Would you, as a consequence of the presented scenarios with corresponding parameters, choose [adaptation option] instead of your current mode of travel, for conducting your home-work trip? How would you rate [adaptation option]?”**

Also, respondents' attitudes towards for example the environment or traveling with unknown persons are surveyed. From this information, statistical models are created in which estimates reflecting the importance of certain attributes are calculated and the probability of respondents that are willing to switch to carpooling can be estimated.

### 3.2. Questionnaire development

As stated in the previous paragraphs, users are first asked about characteristics of their current home-work trip. Subsequently they are asked to choose between this situation (reference) and the carpool situation (alternative). The ordered steps that need to be undertaken for deriving a well-based stated adaptation questionnaire, can be summarized as follows (adapted from Hensher, 1994; Rose & Bliemer, 2008):

**1. Model specification**

- a. Determine the **model type** (MNL, NL, ML);
- b. Choose the **response dimension** (ranking, rating or choice based questions);
- c. Determine the **number of alternatives/utility functions** and decide if alternatives should be **labeled or unlabeled**;
- d. Define related **attributes** (generic versus alternative-specific) and their corresponding **levels**;
- e. Specify the **utility function**;
- f. Find out if **interaction/non-linear effects** exist (including their parameter estimates)

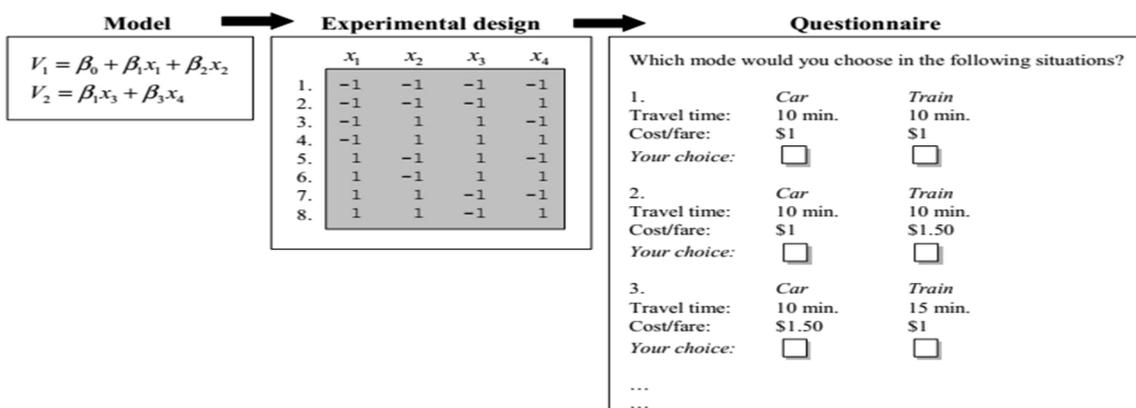
**2. Experimental design generation**

- a. Choose **coding scheme**: design, orthogonal coding versus actual values;
- b. Decide upon **type of design**: optimal orthogonal choice, efficient choice designs, choice percentage designs;
- c. Determine the **number of choice situations** (larger or equal to number of parameters to be estimated (degrees of freedom));
- d. Determine the required **sample size** and if and how the choice situations should be split over the respondents.

**3. Questionnaire construction**

- a. **Selecting respondents**;
- b. **Replace the coding** of levels with actual values;
- c. Randomize **order of choice situations** to exclude ordering effects;
- d. Decide upon **medium** to be used: responsiveness/tailor-made.

In figure 6, the above mentioned steps are displayed graphically for an example with two alternatives: car and train; two attributes: travel time and cost (each with two levels); and three choice situations.



**Figure 6 – Steps in designing a stated choice experiment (Rose & Bliemer, 2008)**

The identified steps will now be discussed in more detail for creating the questionnaire about preferences for the HOV lane. All these discrete choice models have the following requirements or features:

- ◇ The set of alternatives must be *exhaustive*;
- ◇ Alternatives must be *mutually exclusive*;
- ◇ The set must contain a *finite number* of alternatives.

The first condition, being exhaustiveness, ensures the choice set includes all possible alternatives. By using this requirement, the respondent is forced to choose an alternative from the set. Often, the alternative class 'other' or 'none' is used to make sure the set of alternatives is exhaustive. In this case, the choice is made to not include the alternative 'other', since commuters in the current situation are already choosing for the reference trip instead of 'other' modes. This is ensured by the selection procedure for respondents. Also, the option that both alternatives are equally scored (no choice) by the respondent is not included, since this is also not possible in real-life. Mutually exclusiveness is achieved by only enabling the respondent to choose one alternative from the set. Choosing one alternative automatically implies not choosing any other alternatives. The third alternative, being the number of alternatives is finite, is restrictive. It is the defining characteristic of discrete choice models. It distinguishes DCM from regression models, where the dependent variable is continuous, i.e. an infinite number of possible outcomes or alternatives (Train, 2009).

### 3.2.1. Model specification

#### 1a. Model type

The development and selection of a model is not straightforward. The conceptual model which will be created later can be seen as a combination of behavioral theories, statistical methods and subjective judgments of the researcher (Hoyos, 2010). The statistical method that will be used is the multinomial logit model (MNL). This technique is most used for analyzing stated preference data. Using the multinomial logit (MNL) model the utility functions for the solo and carpool alternative are estimated, indicating overall preferences. Logit models are used to determine the choice probability for each choice alternative based on the determined utility functions.

#### 1b. Choice dimension

In stated preference behavior research, generally two categories of response dimensions exist. An individual is either asked to indicate his/her preferences among alternatives or to actually choose one of the alternatives. The former, being a judgmental task, usually receives a response on one of two metric scales: a rank ordering or rating scale. The other (choice dimension) does not request information on the ordering or relative value of each alternative and is often called a first-preference choice task (Hensher, 1994). Making the respondents choose overcomes problems as rating all attributes as attractive, attributes having the same rank and the question of relative importance. To overcome these questions, the choice scale, where the respondents make a trade-off is selected in this study. After the choice task is completed, respondents are asked to assign a score to the carpool alternative. This is to gain some information on the value of each carpool alternative when the respondent chooses to stick to the current trip (reference) alternative.

#### 1c. Alternatives

*'An important stage in any SP design is to identify the range of alternatives and attributes to be tested'* (MVA Consultancy, 2008). The two selected alternatives (modes of transportation) in this study are: *driving solo* and *carpooling (by using the HOV lane)*. The alternative *'carpooling without using an HOV lane'* is not included in the study, since it is assumed that rational people will choose for the carpool option in combination with a

special carpool lane delivering them a positive time differential (dominance of HOV lane combination). Public transport is also not included since the aim of this study is not to motivate commuters that are using public transport to switch to carpooling. The two alternatives that are used are labeled to increase the chance of the generally perceived negative image of carpooling as well. As the alternatives have now been identified, attributes and their levels can be defined. Because every combination of attributes can be defined as an alternative, they should be inherent for each alternative (Louviere, et al., 2007). Users will choose the alternative with the highest total utility from a set of alternatives, all with different scores for attributes (Carrion & Levinson, 2012).



Figure 7 – Graphical representation of the carpool alternative, as used in the questionnaire

#### 1d. Attributes

The purpose of conducting the SP experiment is to determine the influence of design attributes upon the choices that are made by sampled respondents (Rose & Bliemer, 2009). Attributes could either be generic (for all alternatives the same attributes) or alternative-specific. In this study, the goal is to identify important attributes or preferences that influence carpooling behavior. Some of the identified attributes in the previous chapter that will be used in the questionnaire do not exist when driving solo, e.g. driving to a pick-up location or waiting for other passengers. Therefore, alternative specific attributes will be defined for both alternatives. When defining the levels of attributes, the following points should be considered: (Sanko, 2001; Rose, 2011):

- ◇ a wide range of attribute levels is preferred over a narrow range;
- ◇ levels should be realistic and appear plausible;
- ◇ levels need to relate to the respondents' experience of each attribute;
- ◇ levels should ensure that competitive trade-off decisions are presented;
- ◇ levels should present trade-offs that cover the range of valuations of each respondent.

The first point means some values have to be used near the boundaries of the realistic and imaginable field of respondents to be able to detect differences in preferences between respondents. The levels in combination with the experimental design will make sure competitive trade-off decisions are created. In this study the number of levels for each attribute is three. This is the result of a trade-off between the number of attributes, the expected number of respondents and the desired explanatory power of the results. For each attribute identified in the previous chapter, three levels are created that cover a wide range of valuations held by respondents, but are realistic at the same time. These levels are based upon literature research. Besides the identified variables in the figure, a choice has to be made if a constant will be included in the model. Since the alternatives are labeled, it is helpful to include an 'alternative-specific-constant' (ASC) in the model that captures the

initial perceived preference or aversion towards a specific alternative (Bliemer & Rose, 2005). As will be shown in later chapters, carpooling will have an initial negative utility (aversion). When an ASC would have been excluded from the model, the remainder of the model parameters would attempt to capture this effect, which will result in biased attribute parameter estimates.

**1e. Specification of the utility function**

The conceptual MNL model for determining the utility of the carpool alternative will be based on a summation of all involved attributes multiplied by a specific coefficient for each attribute. It is also possible that interaction effects exist between attributes. The standard model (utility function) looks as follows:

$$U_{carpool} = \beta_1 * x_1 + \beta_2 * x_2 + \beta_3 * x_3 + \beta_{45} * (x_4 * x_5) + \dots$$

Where  $x_i$  is equal to a certain value of attribute  $i$  that the respondent chooses, and  $\beta_i$  shows the relative importance of the same attribute  $i$ . The most common specification of the utility function in DCEs is linear. However, it can be argued that utility functions are not likely to be linear due to the existence of diminishing marginal utilities or gain-loss asymmetries. The exact utility function are given later since they specification differ slightly for the two presented models. It is assumed no interaction effects exist in both models, since the selection of the variables and the design that was used did not lead to an incentive for checking this. Therefore, a linear model containing only main effects is used in this study.

**3.2.2. Experimental design**

**2a. Coding scheme**

The more traditional approach, as generally proposed by literature is to code ordinal attributes when creating a multinomial logit model. When no direct linear relationship exists between the levels and the marginal utility differences between level pairs are not equal, a coding scheme should be used (Kuhfeld, et al., 1994). Different coding methods exists, including dummy coding, effect coding, orthogonal and non-orthogonal comparisons, post hoc test, and polynomial contrasts. In this thesis, effect or contrast coding is used, since effect coding compares each level to the grand mean, as opposed to reference (or dummy) coding which compares each level to one coded reference level. Effect coding requires to create codes for all attribute’s levels. For three levels the coding scheme can be used as presented in table 6 below (the effects must sum to zero for each attribute):

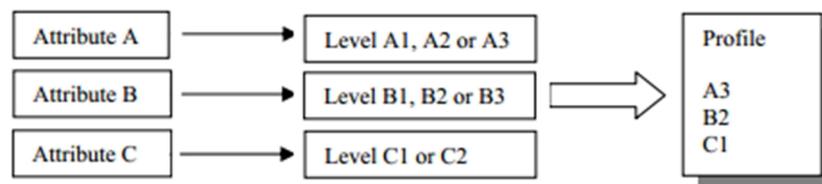
Attribute level	Attribute 1.1	Attribute 1.2
Level 1	1	0
Level 2	0	1
Level 3	-1	-1
Sum	0	0

**Table 6 – Used effect coding scheme for attributes with three levels**

**2b. Type of design**

Experimental designs are at the basis of all stated choice studies. The objective of using experimental designs is to maximize the information collected in SP surveys, while at

the same time reducing the number of choice profiles that are required to be asked to respondents. It is a strict scheme for controlling and presenting hypothetical scenarios. Based on experimental design theory, it could be determined when certain attributes or combinations should be shown in the questionnaire (Rose & Bliemer, 2009). In the experiment, respondents are given a number of choice tasks in which they are asked to choose one out of two alternatives (reference situation and carpooling alternative). Both alternatives are defined on a number of attribute dimensions, each of which further described by pre-specified levels drawn from an underlying experimental design (Train, 2009). As can be seen from figure 8, a choice task (profile) is created by choosing and combining a level from each attribute. In this case, an orthogonal fractional design is employed. This design ensures the data has little or no collinearity. When collinearity was to be present, this would imply that the number of choice situations asked is not optimal and information exists captured by collinear factors that are redundant and add no new information (Train, 2009). However, the design may still have too much questions for a single respondent. Also, it may contain useless choice situations (dominance). In this study, test were carried out to ensure no such effects exists.



**Figure 8 - Example of a choice situation creation, adapted from Hurtado & Manuel (2010)**

### 2c. Number of choice situations

Since the total number of attributes in the stated adaptation design is equal to eight, with each having three levels, the full factorial design is equal to  $3^8 = 6561$  choice situations (see table 7). Using SPSS, a fractional, orthogonal design with a minimum of 27 of these choice situations can be derived as displayed in appendix F. When the number of choice tasks is determined, a decision has to be made if this number of questions is too large for one respondent to answer. As a result, the design possibly has to be split amongst different respondents (Adamowicz, et al., 1998). Since nine scenarios is the typical upper bound at which respondent fatigue begins to become manifest in SP experiments, the choice sets are divided into three different sets each (a, b and c) containing nine choice sets (MVA Consultancy, 2008). The decision if a questionnaire's task is too large for a single respondent also depends on the response dimension chosen (Louviere, et al., 2000). Since in this case only two alternatives are compared in each situation of which one is the reference or current situations, it is not expected that choice situations will require too much time or effort. As shown in appendix F, every level of each attribute is equally divided over each choice set. The final experimental design has to be translated into a set of scenarios in the data collection phase. This is also shown in appendix F, where both level codes and their original levels are given. The question group column refers to the choice set, defined by a, b, and c. The number refers to the question number in the choice set. For example, '6b' refers to choice set b, question 6.

Number of attributes	Number of levels			
	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
<u>4</u>	16	81	256	625
<u>5</u>	32	243	1,024	3,125
<u>6</u>	64	729	4,096	15,625
<u>7</u>	128	2,187	16,384	78,125
<u>8</u>	256	6,561	65,536	390,625

**Table 7 – Number of choice situations in a full factorial design with given attributes and levels**

## 2d. Required sample size

For a reliable analysis, sufficient respondents are required. The link between the underlying experimental design used and the sample size required to obtain statistical significant results is vastly studied in literature (Rose & Bliemer, 2008; Bliemer & Rose, 2009). A reduction in the sample size or questions asked should not come at the expense of reliability of the obtained results. Literature sources recommend a minimum sample size of between 10 and 50 cases per independent variable (Schwab, 2002; Bliemer & Rose, 2005). Our questionnaire exists of 8 independent variables, which means a minimum sample size somewhere between 80 and 400 respondents is sufficient for the multinomial logit model.

### 3.2.3. Finishing the questionnaire

#### 3a. Pilot questionnaire

Before the final version of the questionnaire is sent to respondents, a pilot version of the survey was sent to a population resembling the desired final population. This pilot version serves different goals. First of all: mistakes, inconsistencies and vague questions open for misinterpretation can be identified and improved. Furthermore, the complexity and required time for filling in the questionnaire can be measured. A third important goal of the pilot is to use its results to get an impression of the signs and values of the coefficients of all attributes. Also, some first feelings of redundant questions or dominant answers were found in this way.

#### 3b. Respondent selection

For making sure sufficient respondents were obtained, contact was made with different parties that have the availability over a panel or are somehow interested or linked to the research subject. A second important source for reaching potential respondents is the network of and people working for Goudappel Coffeng, the graduation supervising company. Furthermore, the author's personal contacts (social media, family/friends) and any forwarded contacts of Goudappel Coffeng's employees were contacted. Since this study have a very specific research objective and a select group of the population is belonging to the target audience, obtaining a large enough sample size proved somewhat difficult. Only respondents were selected that:

- ◇ drive at least one time per week to work with in a private vehicle;
- ◇ are working in a relatively large city (more than 75.000 residents);
- ◇ do not live in the city they work in.

### 3c. Survey design

The questionnaire consists of four, clearly distinguishable, main parts. The first part asks respondents about their current home-work trip. Variables include costs, travel time, current uncertainty in travel time, current carpool activities, etc. The respondents has the choice to give an estimate of their commute trip costs themselves or let the system calculate this figure depending on the distance and type of car. In the second part, the current trip as described in the first part is compared to a carpool alternative (the stated adaptation part). The respondent has to choose between one of the two options. No option exists to select neither alternative, since the trip to work has to be made. Additionally, the respondent has to rate the carpool alternative on a five point scale. In the third part, respondents are asked to rate aspects related to organizing the carpool, the carpool trip itself, the HOV lane, and psychological and economic aspects. These questions are called attitude questions and can be used to group the data in different segments, so multiple independent models can be created for these different groups in later research. The fourth part asks respondents to entail some personal information, like their postal code, age and car ownership (see the questionnaire in appendix G). The questionnaire entails about 70 questions and the estimated time required to complete the questionnaire is timed at 15 minutes.

### 3d. Data collection

The data is collected by using the Berg Enquête System<sup>1</sup>. Within the Berg Enquête System, data of completed questionnaires can easily be exported afterwards to Excel, SPSS, NLOGIT or BioGeme<sup>2</sup> (Bierliere, 2003). The Berg Enquête System has the opportunity to make the questionnaire responsive, to skip pages and/or questions (depending on earlier answers given) and to calculate in-between values, enabling the system to recall these

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<sup>1</sup> <http://vragen1.ddss.nl>

<sup>2</sup> <http://biogeme.epfl.ch/>

values later on in the questionnaire. For the comparison of current trip information (the reference) versus the carpool alternative in the stated adaptation part of the questionnaire, this is extremely important. The next chapter will describe the data analysis of the obtained answers.

### 3.3. Chapter conclusions

In this chapter, the different methodologies that are used for developing the stated adaptation questionnaire were presented. The basics of discrete choice modeling and related theories were explained. Random utility theory states that the respondent will only choose a certain alternative, if the utility he or she derives from this alternative is greater than all other alternatives in the choice set. Furthermore, the revealed preferences, stated preferences and stated adaptation techniques are compared so a well-founded selection is made for the most appropriate methodology in this study. Stated adaptation captures the current trip characteristics and creates alternatives based upon this current, recognizable trip.

In the second part of this chapter, the more detailed process steps to be followed in developing the questionnaire are described. This process starts with a specification of the model, like the model type (MNL model), response dimension (a combination of choice plus ranking), and the decision to use two labeled alternatives. Eight attributes were identified based upon literature and expert interviews, together with their three corresponding levels. The utility function is written down and the model is checked for interaction effects. From model specification the process goes to the generation of an orthogonal, effect coded experimental design. The total number of choice situations is reduced because of the orthogonal fractional design to 27, which is divided over three choice sets with nine profiles each.

On the basis of these steps the questionnaire is now constructed, first on paper and later by using the online questionnaire system. The questionnaire is attached entirely to this paper (appendix G). Respondents were selected and contacted by using different channels. The effect coding that was used in the orthogonal design was replaced by the original values of levels to present the choice situations to respondents. The questionnaire was sent out by using the Berg Enquête System and analyzed later by making use of computer software called BioGeme.

# Estimating the importance of various carpool stimulating factors

Before the model describing the behavior and motivation of commuters to carpool is expressed, some general observations about the questionnaire and its results can be made. Tables and graphs describing frequencies and distributions of the basic data are displayed in appendices I and J. Some graphs are displayed to improve the explanatory power of the text. The choices respondents made in selecting the reference alternative or carpool alternative are analyzed by estimating a multinomial logit model. Apart from the created MNL model, the statistical package SPSS is used to calculate and describe the basic analyses. For the MNL model, BioGeme is used.

The average duration for completing the questionnaire is equal to 16 minutes and 39 seconds (as can be seen from appendix H). The smallest time a respondent required to finish the questionnaire was 3 minutes and 33 seconds. The median time spent was just under 10 minutes and a total time of 98 hours has been spent on completing the questionnaire by all respondents.

## 4.1. Response rate

It is not exactly clear how many people the questionnaire was sent to and who received it, as it was sent by group mails and to larger (social) networks where people shared it over and over. From the survey that was sent out to the personal network about 1/6<sup>th</sup> of all respondents did either not meet the selection criteria or quit the survey system when they reached the information page explaining the stated adaptation section. For the respondents of the paid panel, 58.7% met the selection criteria. Of this group less than 1% closed the questionnaire when they reached the information pages of the stated adaptation part. Therefore, when the strict selection criteria are not taken into account, the proportion of respondents that completed the questionnaire of all people that started with the questionnaire is quite high.

## 4.2. Dataset cleaning

One respondent answered he travelled 15.000 kilometer every day to his work (single trip). Corresponding costs for this trip would be €2,116. Of course, this does not make sense and biases all data. It is possible the respondent misunderstood the question or answered in yearly kilometers. This case and similar cases therefore are (manually) excluded from the data set. Some tests are done for this cleaning of the data. Fuel costs for example can to a large extent be linked to travel distance and time. A 30 minute single commute trip with fuel costs estimated at €250 doesn't make sense. In this case it could be that the respondent did not read or understand the question well enough and answered the fuel costs per month. Other errors identified in the data set include (among others):

- ◇ fuel costs of €500 and completion time for the questionnaire of only 3.7 minutes;
- ◇ €70 for a single day toll and parking expenses;
- ◇ fuel costs of €50 or more in combination with a travel time of 50 minutes or less;
- ◇ a completion time of the questionnaire of less than 3 minutes.

In total, 11 cases have been excluded when cleaning the data. This was mainly done by looking at the fuel costs, travel time, and parking and toll costs, since minimum and maximum values for these variables can more easily be set. A total of 346 cases result that will be used in the analysis of the dataset.

## 4.3. Sample description

Main findings relating to the demographical, behavioral and psychological parameters, perceptions of the current trip of respondents and other demographical information are displayed in the tables and figures of appendix I and J. A summary is also included in appendix H with the most important findings from the data analysis. Some figures can be biased a bit, since in the introduction, the objective of the questionnaire is explained. Respondents can be inclined to select carpooling as their current way of travel to make sure they belong to the targeted sample. About 12% of all respondents did not continue with the questionnaire after arriving at the stated preferences introduction page. Respondents that only completed the first part (where they had to fill in their current commute trip) are not be used in any part of this analysis, since this information cannot be linked to any other information and therefore is not useful for this study.

### Current trip characteristics

Over halve of the respondents require between 20 and 40 minutes of travel time from door to door. Seventy percent of all respondents schedule between 5 and 15 minutes extra travel time to avoid uncertainties due to congestion, accidents or other exogenous factors. On average, commuters currently schedule 36.4% of their original travel time as safety time. For eleven respondents, the scheduled safety time is higher than their original travel time. A relatively large travel time in general means a large route or a high level of congestion. Since these both factors can be causes of travel time uncertainty, it is expected that travel time and uncertainty in travel time are (strongly) correlated. Therefore, the Pearson correlation coefficient is calculated by using SPSS, and the result is displayed in appendix L. The variable indicating the parking situations is also included since this can also

have a strong effect on both travel time and uncertainty. The Pearson correlation coefficient can be used in this case, since all three variables are fairly normal distributed. From the table the conclusion can be drawn that indeed travel time and scheduled safety time are correlated with a Pearson correlation coefficient of 0.444 (significant at the 2-tailed 0.01 level). This means a moderately strong correlation. The second finding is that the parking situation is absolutely not correlated with travel time. However, parking availability is only weakly correlated with travel time uncertainty. This is explained since a large time requirement searching for a parking place results in more travel time uncertainty.

### **Conclusions based on the attitudinal questions**

Based upon the attitude questions, it could be stated that respondents value the safety of the trip itself (in the vehicle) as the most important aspect when choosing for carpooling (85% rate this as important or at least as neutral). The ambience during the trip is almost equally important as safety as perceived by respondents. As corresponds with what was expected when drawing up the hypotheses in paragraph 1.4. The opportunities and easability of organizing the carpool trip is valued at third place. Furthermore, a very strong preference (score 72%) exists to carpool with a known person (acquaintance, colleague, family friend). Subsequently, a fair distribution of the costs made during the trip among all passengers is important, followed by the desire of respondents to be flexible and have the freedom to go wherever they want to go. The comfort of the vehicle and the safety at the meeting location are also important. Facilities at the meeting location, the opportunity to work during the (carpool) trip and the private vehicle as an expression of personal success or status are not rated as very important in the decision to carpool or not. Also, the effect of taxes to be paid when SOVs want to drive on the HOV lane and a strict level of enforcement are not important in the shift to carpooling. This may be because these measures impose additional (indirect) costs when implemented. The role during the carpool trip (driver or passenger) shows a remarkable indifferent/neutral scoring. This means for commuters in general in would not make a difference if they have to drive to carpool vehicle or have to act as a passenger.

### **Carpool advocates versus opponents**

In this part of the analysis, it is calculated how often the carpool alternative was chosen by each respondent. This figure, which should be an integer between 0 and 9, can then be used to form two groups. Respondents choosing the carpool alternative 5 times or more are called carpool-advocates, the rest are called opponents. For these two separate groups, now the differences in means for all other variables with an independent T-test sample can be compared. Looking at the Levene's Test for Equality of Variances significance levels in appendix M, it can be noticed that respondents that are currently already (occasionally) carpooling are more inclined to choose the carpooling alternative. Contrastingly, respondents having a better current parking situation, respondents driving a company or lease car, and women can be labeled as carpool opponents. Advocates of carpooling are strongly favoring a fair distribution of travel costs.

Choice set number	Total number of responses	Did not select carpooling	Proportion did not select carpooling
Choice set 1	113	36	32%
Choice set 2	111	46	41%
Choice set 3	122	50	41%
<b>Total</b>	<b>346</b>	<b>132</b>	<b>38%</b>

**Table 8 – Division of respondents over three choice sets**

### Socio-economic aspects

Next to presented attributes and constants, socio-demographic variables can be included in the model, e.g. income, age, gender. These attributes do not vary over alternatives, but do vary between decision-makers. These variables can only enter the model if they are defined in ways that create differences in utility between alternatives (Train, 2002). Therefore, the effects of these variables on each utility function can differ, and thus coefficients of these variables can differ between alternatives. However, in this thesis those decision-maker specific factors are not incorporated in the created model, since the focus is on the larger picture, i.e. the proportion of the total number of trips for a specific route in terms of carpoolers compared to solo drivers. Of course, to motivate people segments to switch to carpooling, a strategy should be followed at group level. A second reason is the time constraint for this study. Testing which covariate should be added to a model, would result in extra time necessary for the modeling part. Multiple models are to be created for different segments. It is chosen to use this available time for developing a prediction tool for applying the MNL model estimates. As a result, adding personal characteristics (as covariates to the model) to make the model more specifically applicable will be considered a recommendation for further research.

Therefore, some general remarks about which person traits could be important are sketched only shortly. By checking the correlations between other factors, strong relationships can be found between various numbers of factors. For example, a strong link exists between the income and level of education of a respondent, which is very straightforward. Analysis shows that commuters that are driving a company or lease car in general are males, have a higher education level and do not get any travel cost reimbursement. Men significantly show more full-time employment compared to women. The two financially related factors (fiscal advantages and fair distribution of costs) are also correlated. A factor analysis can prove to be helpful to reduce these variables into one component constituting both variables.

When households with a relatively high income level are selected (more than €60.000 gross income per year), it can be noticed that this group schedules significantly more safety time than the average value for all respondents. Furthermore, men on average have a slightly higher income than women. Flexibility and freedom of movement is rated as more important in the higher income segment. The expectation that fiscal advantages are important for high income classes is not confirmed. In the situation with a small average travel time (less than 20 minutes), the amount of safety time respondents schedule is

relatively small. This confirms the finding that travel time and uncertainty are correlated. In the opposite case, a travel time larger than 60 minutes, 65% of the respondents schedule a safety time of more than 15 minutes (the highest option). Commuters having a large travel time work more full-time on average.

#### 4.4. Multinomial logit (MNL) model estimation

When constructing a multinomial logit model which includes ordinal attributes, effect coding as mentioned before should be used to code those attributes (parking situation, availability of bike/bicycle, and flexibility of travel times). This is the more traditional approach and is substantiated in theory. However, to make it possible to also use original travel times as filled in by the respondents and to facilitate the application of the model to a case, a second model is created which uses original values (for travel time to and waiting time at the meet location, actual travel time and travel time uncertainty, costs, and the number of persons in the carpool alternative). Both models will be shortly discussed in this paragraph.

##### Model 1. Effect coded model with reference trip fixed at zero

In this case the reference alternative (driving solo) is fixed at zero (coded zero) for all attributes and all levels. This makes the carpool's utility function and thus its coefficient estimates for all attributes totally relative to the solo alternative. The utility functions of this model is as follows:

$$U_{solo} = 0$$

$$U_{carpool} = ASC_{CP} + MEET_{1\_CARPOOL} * waitcarp1 + MEET_{2\_CARPOOL} * waitcarp2 \\ + TTIME_{1\_CARPOOL} * ttcarp1 + TTIME_{2\_CARPOOL} * ttcarp2 \\ + TUNC_{1\_CARPOOL} * unccarp1 + TUNC_{2\_CARPOOL} * unccarp2 \\ + COST_{1\_CARPOOL} * costcarp1 + COST_{2\_CARPOOL} * costcarp2 \\ + PERS_{1\_CARPOOL} * perscarp1 + PERS_{2\_CARPOOL} * perscarp2 \\ + PARK_{1\_CARPOOL} * parkcarp1 + PARK_{2\_CARPOOL} * parkcarp2 \\ + CARB_{1\_CARPOOL} * carbcarp1 + CARB_{2\_CARPOOL} * carbcarp2 \\ + FLEX_{1\_CARPOOL} * flexcarp1 + FLEX_{2\_CARPOOL} * flexcarp2$$

\* where all 1's and 2's stand for the first and second effect coded level of attributes

The estimates of the effect coded model can be found in table 9. Leaving out some of the insignificant variables does not statistically significant improve the model's performance expressed in the likelihood ratio test. This model has a log-likelihood of -1670.489 compared to the null model which has a log-likelihood of -2158.460. In the null model, the change that a person chooses to carpool or will drive to his/her work alone is 50%/50%. To test if the effect coded model performs significantly better than the null model at 99% significance, the following calculation is made (where  $LL_A$  = log-likelihood value of alternative model,  $LL_0$  = log-likelihood value of null model):

$$Difference\ test\ statistic = 2(-LL_A - LL_0) = 2(-1670.489 + 2158.460) \approx 975.942$$

$$\chi^2_{0.99}(11) = 23.21$$

It is shown that the calculated test statistic is larger than the value belonging to a 99% confidence level chi-square distribution with 11 degrees of freedom. Therefore, it can

be concluded that the estimated MNL model performs significantly better than the null model with equal probabilities for each alternative. This means the model is valid and can be used.

Variable name		SOLO	CARPOOL
<b>Alternative specific constant</b>		0	-1.15
<b>Travel and waiting time start location</b>	0%	Fixed (0)	0.440
	20%		0
	40%		-0.440
<b>Travel time in (carpool) vehicle, main route</b>	100%	Fixed (0)	-0.405
	85%		0
	70%		0.405
<b>Uncertainty in travel time*</b>	100%	Fixed (0)	-0.0783*
	80%		0*
	60%		0.0783*
<b>Costs of trip</b>	100%	Fixed (0)	-0.387
	70%		0
	40%		0.387
<b>Number of persons in vehicle*</b>	2	Fixed (0)	0.0178*
	3		0*
	4		-0.0178*
<b>Parking situation at work location</b>	Good	Fixed (0)	0.217
	Average		0
	Bad		-0.217
<b>Car/bike availability at work location*</b>	Car or bike	Fixed (0)	0.0679*
	Bike only		0*
	None		-0.0679*
<b>Flexibility of travel times</b>	High	Fixed (0)	0.114
	Average		0
	Low		-0.114
<b>Null log-likelihood: -2158.460</b>			
<b>Final log-likelihood: -1667.023</b>			
<i>* means insignificant effect level at 95% confidence level</i>			

**Table 9 – MNL model estimation with effect coded inputs (solo alternative is coded as 0)**

From this model in which all attributes are estimated, it can be noticed that the second level of all effect coded attributes is not significant for all three variables. This does not mean the prediction is not valid, but the difference between the first and second, and the second and third level does not change (i.e. both are equal and linear). Because of this insignificance, the intermediate level of the variable is fixed at zero and the positive difference to one side is equal to the negative difference on the other side. This adaptation can be seen in table 10 below for the flexibility of travel times as an example.

Flexibility of travel times			
<b>Original levels</b>	High	Average	Low
<b>Effect coding</b>	1,0	0,1	-1,-1
<b>Model coefficient estimation</b>	0.138	-0.0481*	-0.0899*
<b>Adjusted coefficients because of insignificance</b>	0.138	0	-0.138

**Table 10 – Coding and translation with second level insignificance**

**Model 2. Original values model for both reference and carpool alternative**

The utility function of the second model, in which the original values as presented to the respondents are used, is as follows:

$$U_{solo} = ASC_{SL} + MEET_{SOLO} * solomeet + TTIME_{SOLO} * solott + TUNC_{SOLO} * solounc + COST_{SOLO} * solocost + PERS_{SOLO} * solopers + PARK_{1\_SOLO} * soloparkeff1 + PARK_{2\_SOLO} * soloparkeff2 + CARB_{1\_SOLO} * solocarbeff1 + CARB_{2\_SOLO} * solocarbeff2 + FLEX_{1\_SOLO} * soloflexeff1 + FLEX_{2\_SOLO} * soloflexeff2$$

$$U_{carpool} = ASC_{CP} + MEET_{CARPOOL} * carpoolmeet + TTIME_{CARPOOL} * carpooltt + TUNC_{CARPOOL} * carpoolunc + COST_{CARPOOL} * carpoolcost + PERS_{CARPOOL} * carpoolpers + PARK_{1\_CARPOOL} * carpparkeff1 + PARK_{2\_CARPOOL} * carpparkeff2 + CARB_{1\_CARPOOL} * carpcarbeff1 + CARB_{2\_CARPOOL} * carpcarbeff2 + FLEX_{1\_CARPOOL} * carpflexeff1 + FLEX_{2\_CARPOOL} * carpflexeff2$$

\* where all 1's and 2's stand for the first and second effect coded level of attributes

Variable name		SOLO	CARPOOL
<b>Alternative specific constant</b>		Fixed (0)	-0.953
<b>Travel and waiting time start location</b>		Fixed (0 min)	-0.0760
<b>Travel time in (carpool) vehicle, main route</b>		-0.0626	-0.0737
<b>Uncertainty in travel time</b>		-0.0562	-0.0446*
<b>Costs of trip</b>		-0.0923	-0.104
<b>Number of persons in vehicle</b>		Fixed (1)	-0.0209*
<b>Parking situation at work location</b>	Good	0.392	0.130
	Average	-0.194	0
	Bad	-0.198	-0.130
<b>Car/bike availability at work location</b>	Car or bike	Fixed (car)	0.0855*
	Bike only		0
	None		-0.0855*
<b>Flexibility of travel times</b>	High	Fixed (high)	0.138
	Average		0
	Low		-0.138
<b>Null log-likelihood: -2158.460</b>			
<b>Final log-likelihood: -1638.512</b>			
<i>* means insignificant effect level at 95% confidence level</i>			

**Table 11 - MNL model estimation with original values inputs from questionnaire**

Using the original values (in Euros, minutes) makes it easier to apply the estimated coefficients from the model to a physical case study, as will be shown in the application chapter. In general, coefficients in this model have a lower coefficient, since the values that will later be inserted have a broader range, instead of effect codes of -1, 0 and 1. For example, the travel time of a certain respondent can be as low as 5 minutes or as high as 30 minutes. Furthermore, coefficients belonging to the carpool alternative are more negative

compared to the solo alternative, except the value of travel time uncertainty. A reasonable explanation for this is that commuters already expect increased uncertainty when carpooling, due to the dependency on other people. Therefore, a further uncertainty in travel time may not be perceived as being that bad as in the case of the solo alternative. An explanation for the higher negative values for the other variables is that the domain or scale of those variables is also smaller (e.g. it is assumed that the travel time and costs on the HOV lane can only be reduced in the carpool alternative). The latter model, with the original (non-coded) variables, performs significantly better than the model in which effect coding was used. This is proved in the following equations, where the difference test statistic is significantly higher than the corresponding  $\chi^2$  value at the 99% confidence level:

$$\text{Degrees of freedom test statistic} = df(\text{model B}) - df(\text{model A}) = 17 - 11 = 6$$

$$\text{Difference test statistic} = 2(LL_B - LL_A) = 2(-1638.512 + 1670.489) = 63.954$$

$$\chi^2_{0.99}(6) = 16.81$$

Another test for the goodness of fit of estimated models is the pseudo-rho squared. When the estimated model is no better than the null model, this figure takes the value of zero. On the contrary, a perfectly predicted model would deliver a pseudo rho-squared of 1. 'As a rule of thumb, well fitted models occur with  $R^2$  greater than 0.2, with it being rare to find an  $R^2$  greater than 0.4' (Hoyos, 2010). Since the adjusted rho-squared in the last estimated model is equal to 0.233, it is concluded that the model performs sufficiently well.

#### 4.4.1. From utility to probability

To translate the derived utility functions by the MNL model into choice probabilities, a choice probability function should be derived. In calculating the probabilities, the absolute level of the calculated utilities do not matter, only the differences between the utility levels between the alternatives do. The choice probability that a certain commuter chooses one of the two alternatives is equal to (Train, 2002):

$$P_i = \text{Prob}(U_i > U_j) \quad \forall i \neq j$$

$$P_i = \text{Prob}(U_i - U_j > 0) \quad \forall i \neq j$$

$$P_i = \frac{e^{U_i}}{e^{U_i} + e^{U_j}}$$

In both the identified models above a standard preference for driving solo exists. In the first model (effect coded) the alternative specific constant (ASC) for carpooling is -1.15 and in the other model the ASC for carpooling is -0.953. These constants are interpreted as the average impact of all non-included factors on the utility of carpooling relative to driving solo. When a model is created in which no attributes are used, but only the alternative specific constants, the ASC for carpooling equals -1.06 when the ASC for driving solo is fixed at zero. This translated in a standard willingness to carpool of:

$$P_{solo} = \frac{e^0}{e^0 + e^{-1.06}} \approx \frac{1}{1 + 0.346} \approx 0.74$$

$$P_{carpool} = 1 - P_{solo} \approx 1 - 0.74 = 0.26$$

Looking at those two models, it could be expected that  $1/4^{\text{th}}$  of all commuters travelling to work by car will carpool. These values are true if no other attributes are assigned a value and the HOV lane speed differential does not exist. In reality however, since a carpool is only formed when two or multiple carpool-minded commuters meet, the real proportion of carpoolers will be lower. Also, since carpool often means a deviation from the shortest route, an increase in uncertainty, loss of privacy, etc., the real level is lower. The percentage above (26%) gives only the perceived disadvantage associated with carpooling.

In the case study application in the next chapter, the same function to calculate a probability is used but the utility level is based upon the characteristics of and answers given by commuters making use of the road section of interest. Secondly, it should be noticed that the above equations calculate the proportion of persons that carpool, where the number of trips should be divided by two, three or even four, dependent on the policy that is in place. An average vehicle occupancy of 2.2 (of carpool vehicles) for example results in a proportion of  $\frac{0.26}{2.2} = 0.118$  (11.8%) carpooling trips.

#### 4.4.2. Correlation and interaction effects

Looking at correlations between variables in the above mentioned models, it can be noticed that most correlations are between -0.1 and 0.1, which is close to zero (this is good since this means no correlation exist between those two variables). However, by default effect coded variables are correlated and should have a value around -0.5 or 0.5, which is true for most of the coded variables. Besides this, a correlation exists between some of the insignificant variables as described before. This implies that those variables should not be used in the model but that its effect is already estimated by the correlated variable. Since the estimated values of these insignificant variables are very small relative to the significant variables, this will not oppose a large problem. Also, some correlation exists between the same variable but from each alternative (solo and carpool). This correlation is around 0.8 and holds for the scalar attributes. This effect is explained since percentages were used to describe the carpool alternative based upon information in the solo alternative, for example 60%, 80% or 100%, averaging around 80%, so a 0.8 correlation level.

Testing if an interactive effect is present between two variables (e.g. trip costs and the minimum required number of persons in the carpool vehicle) is done by estimating a new model in which the interaction effect is included the multiplication: trip cost\*minimum required number of occupants as a separate coefficient. The estimated model shows the multiplicative term is insignificant for the carpool alternative. This was expected since no relation between the two variables (costs and persons) was created or described in the questionnaire. Also, the orthogonal design that was created earlier assumes only linear effects.

### 4.5. Description of most optimal variables and most optimal combination

Of course, for some people driving their own car bring feelings of luxury, freedom, flexibility and privacy. Therefore, some upper limit exists that prescribes the maximum potential number of commuters willing to switch to carpooling. As 38% of all respondents never chooses the carpool alternative in the questionnaire, it is assumed that 100%-

38%=62% of all commuters are potential people that can be motivated to carpool. To reach this upper limit, the most optimal, but realistic values should be selected for each attribute. In this way, the highest possible utility for carpooling is obtained. Some steps that can be taken to derive this most optimal scenario are now discussed:

- ◇ From the effect coded model (with standardized coefficients) can be derived that the travel and waiting time to or at the carpool meet location has the highest coefficient and therefore is the most important variable to change the utility of carpooling. Keeping this time as small as possible yields the highest utility. The most obvious optimal solution is to locate the carpool location at the home address of commuters. However, since this is not always possible as carpooling consists of multiple users most often not living at the same address, a small variation can be to locate this carpool location on the route to the work destination. When looking at the second model, the coefficient for the meet travel time is just slightly more negative than the normal travel time. However, to keep the solution close to optimal, a carpool location closer to home increases the final utility. The most optimal value is 0 minutes.
- ◇ The secondly important variable is the travel time in the carpool vehicle. In general, the longer the travel time is the more negative the utility for an alternative becomes. When carpooling, a direct route should be chosen just like one would do in the solo driving situation. As travel time can be reduced by the HOV lane, this outcome of travel time being of great influence in determining the utility of carpooling is promising in this light. Corresponding to the maximum possible reduction in travel time as derived from examples abroad and maintained in the questionnaire, it is assumed that a maximum reduction of 30% is possible.
- ◇ Costs of the trip are thirdly important. The higher the costs, the lower the utility of any travel mode. Therefore, to decrease the costs, either a direct route should be chosen, a large part of this route should be driven in a carpool setting (having the possibility to share costs between passengers), a smaller or less-consuming car should be chosen, or a carpool stimulating policy should be facilitated by the government to reduce the costs of carpooling. The questionnaire displayed a maximum cost reduction of 60% is realizable. This level is for example attained when traveling with 3 or 4 people in the carpool vehicle, with respective cost reduction of (67% and 75%). However in most cases the carpoolers first have to drive to a central meeting location, increasing the costs a bit.
- ◇ Parking policy can be focused on carpooling, facilitating carpool vehicles to park (e.g. closer to destination, cheaper, more spaces) while at the same time making it more difficult for commuters that drive solo to the city center or work location to park. Since this variable is effect coded, this translates into a 'very good' parking situation in the carpool alternative and a 'bad' parking situation for the solo driving alternative.
- ◇ The level of flexibility in travel times that is offered by employers or co-travelers is not that easy to influence by public policy making or infrastructure adjustments. However, this could also relate to the employment density in the direct surroundings, enabling passengers to select another carpool trip (non-fixed carpool formations). A higher density implies a high level of flexibility, which increases the utility of carpooling. Since flexibility in travel times is also effect coded, a 'high flexibility' level is the most optimal.

Less important are the variables of number of persons in the carpool vehicle, uncertainty in travel time, and car or bike availability at the work location. For these variables therefore optimal values are chosen without much debate. The less possible

number of persons in the carpool vehicle (i.e. two), the availability of a car, and the smallest possible travel time uncertainty for carpooling (60% from solo driving uncertainty as used in the questionnaire) result in the highest utility. The uncertainty level in the solo alternative is 36% of actual travel time. The results of this most optimal configuration applied to the case study in terms of number of trips divided by each alternative, amount of kilometers traveled in this configuration and potential savings will be displayed in the next chapter.

	Small MNL model estimates	Original MNL model estimates	Differences in utility between models
Constant	-1.09	-0.953	-0.137
Meet time	-0.0727	-0.0760	0.0033
Travel time	-0.0723	-0.0737	0.0014
Uncertainty time	-0.0399*	-0.0446	0.0047
Costs	-0.107	-0.104	-0.003
Sum of difference			-0.1306

**Table 12 - Comparison of full original values model with small model (i.e. without insignificant variables)**

*\* is significant when a confidence level of 90% is used instead of 95%*

It is also possible to exclude those attributes that are insignificant in the model. Especially, since in the application section as described in the next chapter only time, distance and cost related variables will be used, it is a good practice to shortly compare the model estimates with the insignificant values present, and a model in which they are not present. In table 12 above, a ‘small’ model is estimated for the attributes time to/at meet location, in vehicle travel time, travel time uncertainty and costs of the trip only. It can be noted that the difference between the two models is small. Time related variables are estimated with a less negative utility in the smaller model. An explanation is that in the more complete model those estimates correct the biased estimates from less significant variables.

#### 4.6. Chapter conclusions

This chapter described the data analysis process that was carried out and the results that this analysis came up with. First some information about the response rate in combination with the effects of the strict selection criteria was given. Main findings were that some people quit the questionnaire halfway, where a lot of new information was presented. However in general the response rate was certainly sufficient. The data was cleaned by checking outliers in daily travel distance and costs and way to short completion times. After this, some general information of the sample descriptions was given, like division of respondents on age/gender/commute distance/frequent carpoolers/current parking situation/etc. These figures are displayed in appendix K. Information on groups, distinguished by socio-economic factors or current commute trip characteristics, were analyzed and summarized.

In the second part of the chapter, two multinomial logit models were created. Effect coding was used for one model and all attributes belonging to the reference trip (driving alone to work) were fixed to zero. From this model, it is possible to draw conclusions about the relative importance of attributes in the carpool alternative. The translation from utility functions to probabilities is described and the standard initial aversion in the perception of

commuters is presented, equaling 74% of all commuters that prefer solo driving and require more stimulating effort. The second model, where original values (like actual travel times and costs) are used, makes it possible to create a tool or model that predicts the proportion of commuters that can be stimulated to carpool for a specific case-study. In this second estimated MNL model, the reference alternative is not fixed to zero. The relative effect on the resulting utility and thus the probability that a respondent chooses a certain alternative depending on the specific context can be estimated with the latter model. This model will be applied in the next chapter to the case-study Noord-Brabantlaan, Eindhoven.

The last part of the chapter tests for interaction and correlation effects. Also, the most important variables in motivating a commuter to carpool are described in order of importance. These findings are based mainly on the effect coded model. Since it is now known which factors are most important, and the most positive level of each attribute can also be identified, it is possible to describe a most optimal scenario. The potential of this scenario in the amount of carpoolers that can be motivated for the case-study will be estimated in the next chapter as well.

## Chapter 5

# Eindhoven Noord-Brabantlaan

In this chapter, the estimated MNL model is used together with traffic information model data and general literature to predict the number of commuters that will carpool for any given route to a selected city center. Commuters and a city center are selected since this was also the contexts of the created questionnaire, and estimates are only valid for these trips. The traffic modeling software package Omnitrans is used to identify origin-destination pairs and to prepare the input data to be used in the tool's predictions in terms of carpooling. The number of movements, distances and travel times are derived from the traffic model. In the first paragraph, a universal tool is constructed that can be used for every to be selected case-study in The Netherlands. In following paragraphs, this tool is applied to a specific project/route in The Netherlands.

## 5.1. Creation of universal carpool prediction tool

A tool is developed in Microsoft Excel based on the estimated coefficients of the discrete choice model where the original values were used (in minutes, euros, etc.). Different configurations of factors and policies can be tested by assigning different values to each parameter. For each configuration, the utility functions for both the solo and carpool alternatives can be calculated. From these utilities, probabilities and the expected proportions of solo drivers and carpoolers can be predicted. As it is assumed that for all possible case-studies, origin-destination pairs are known from traffic models. From this, the route both travel mode users are travelling can be predicted, the amount of vehicle kilometers traveled (VKT) can be calculated and therefore the potential savings in VKT and emissions as a result of carpooling. Extreme values can be inserted to test the sensitivity of the model. This is done in the next paragraphs, where a case study is selected on which the tool is applied. A scenario analysis is carried out which delivers a good idea of this study's and in particular the created model's predictive ability.

The tool that is developed is static. This means for a fixed number of origin-destination pairs and other parameters, the model estimates how many commuters will travel to their work by each transportation mode. For increased prediction power however,

the results from the multinomial logit model should be inserted into a dynamic simulation model (like Omnitrans). In this way the effects of induced demand (from other routes, other times, additional trips and other growth sources) and the carpool lane becoming more congested can also be taken into account. To calculate the exact effects of implementing of a HOV lane on delay, congestion, emissions and accessibility, many of those interrelated effects should be considered.

## 5.2. Case study selection

The idea behind this study is to identify factors that stimulate solo car drivers to carpool. It is assumed that the target group benefitting the most from carpooling are people working in an area with a high employment density (typically large cities), but who are living in smaller 'satellite' villages around this city. Eindhoven knows a strong commute originating from the direct surroundings of the city (Gemeente Eindhoven, 2009). Since it is difficult to facilitate high quality public transport for all these commuters from the scattered areas, most of these commuters travel to the inner city by car. Therefore, an individually organized measure is assumed to prove a more useful approach in reducing the number of private vehicles and improving the accessibility, livability and air quality of the city. Since only a few city entry roads normally exist to facilitate the supply of cars heading towards the city center, congestion often occurs at the edges of the city where multiple routes converge. The functioning of bottlenecks is important for realizing objectives like urban accessibility, regional development, economic growth and local living conditions (Wortelboer-van Donselaar, et al., 2012).

Eindhoven is selected as case-study, since it has the mindset to become an energy neutral city by 2040. This is also reflected in the municipality's traffic and transportation research activities (Gemeente Eindhoven, 2009). In its urban and land-use planning activities it therefore tries to promote ways of transportation that save the environment (i.e. cleaner cars and more conscious drivers, more use of bicycles, comfortable and safer pavements for pedestrians and promoting the use of HOV and public transport) (Kerkdijk & Hal, 2013). By 2009, plans were created for a second 'high quality public transport' connection going from the North of Eindhoven (starting at Nuenen in the north, going past the station and the TU/e, continuing to the south of the city, i.e. High Tech Campus). A budget of 125 million euro is available for this project which should be realized in the timespan 2001-2014. In March 2014, first road works started at the south part of the connection (Aalsterweg) (SRE, Gemeente Eindhoven & Gemeente Nuenen, 2014). The whole high quality public transport connection is expected to be finished at the end of 2016. The aim this plan is to reduce the number of cars in the inner ring with 30%. This will mainly be reached by efficient usage of current infrastructure, dynamic traffic management, and an optimal utilization of transport chains (P+R, carpool meet locations, bicycle parkings, etc.). Carpool lanes can be associated with all these types of measures; however they are not part of the high quality public transport plans at this point (yet). However, the belief that public transport alone will not be able to cope with increasing amounts of vehicles and land-use discrepancies is raised. The lanes that will be constructed will therefore be underutilized. As a result, the presented alternative of car sharing should be integrated since it is researched in multiple studies as being very suitable as a supplement for public transport (Katzev, 2003; Huwer, 2004). Furthermore, almost no extra investments need to be made. This current development

therefore is the ultimate case-study to test the potential of promoting carpooling by using reserved HOV lanes.

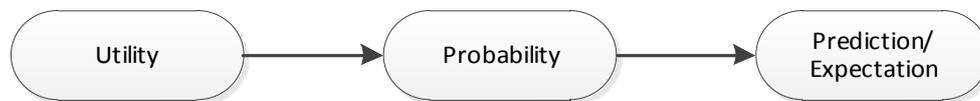
The Noord-Brabantlaan in the west of Eindhoven is selected as the center of focus. This route is selected due to the current special bus lane that exists on this route; testing solutions of high occupancy lanes to increase the average occupancy per vehicle (e.g. opening these lanes to other high occupancy vehicles) will require small investments but can turn out to be of great benefit. The exact selected case study area covers all zones to the west median of Eindhoven which would normally make use of the Noord-Brabantlaan. The carpool square is located at the west end of the Noord-Brabantlaan and in the current situation the travel time from this location to the station is about 15 minutes. It is assumed that nobody will drive longer from their origin (home location) to the carpool square compared to the maximum travel time on the carpool lane. As a result, only origins are selected with a maximum total travel time of  $15+15 = 30$  minutes of current travel time to the city station. The station, as being the center of the city, is chosen as the destination area because of different reasons. First of all, a station in general is situated somewhere in the central of a city. At this place, the mean distance to all work locations of the city is (almost) the shortest. Secondly, a station is the connecting node where many different additional modes of transport converge (train, bus, metro). A third reasons to select the station as the ending (or starting) point as where a HOV lane should stretch is the current generally high level of parking problems at this location. Because carpooling entails more commuters travelling together in one car, fewer cars will eventually reach the destination and thus will require a parking spot.

### 5.3. Traffic model data

By making use of the computer package Omnitrans, data is obtained about possible origin-destination pairs that most likely will make use of the selected case-study lane. The selected zones of interest are split into three sets. The first set contains all origins of people traveling to the city center (for the morning peak period these are the homes of commuters). The second set contains the carpool meet location, and the third contains the city center or station area. Since the carpool square is located at the west-end of the Noord-Brabantlaan, all origins are selected north, south and west of this point. Between all the 1953 selected geographical points the distance, travel times and number of movements in the morning rush period are calculated and stored in a dataset. A test is carried out to ensure only centroids are selected for which the case-study route (the HOV lane) is a plausible alternative to make the trip from these origins towards the city center. The zones to the west of Eindhoven that lie within a 30 minutes travel time radius are selected and displayed in appendix N (in red). The carpool area is displayed in appendix N in light green. After the test is carried out, a total of 1583 zones remain, with a total of 967 movements/person trips during the 2 hour morning rush period.

By combining this traffic information data (i.e. the actual levels of variables) into the utility functions as estimated by the MNL model before, the resulting utility for each transportation mode for a specific person originating from a originating zone can be calculated. These utility levels can be translated to probabilities and predicted volumes by using the formulas as described in paragraph 4.4.1. In figure 9 below this process is displayed

graphically. As the model coefficient's estimates are calculated by surveying the national population, the constructed model will be usable for any desired route or trajectory.



**Figure 9 – Application model's process of predicting the number of carpoolers from utility functions**

## 5.4. Scenario analysis

All zones displayed in appendix N are within a 30 minute travel time of the city center of Eindhoven. As the end location of the trip the city center is chosen (station and reachable zones within a 5 minute walk). 1583 origins zones are selected, 40 destination zones, and 1 zone is chosen where the carpool meet location is to be constructed (at the end of the selected case-study trajectory). Different scenarios are tested to study which policy or facilities should be in place that has the largest positive effect on the number of carpoolers. Combinations are studied as well. All results are displayed in tables 14 and 15.

The presented scenarios are divided into two parts. The first uses the model in which the carpool meet location is fixed. Since zones/centroids were collected in a rather fast and manual way, an extra test is carried out to ensure the carpool meet location and constructed HOV lane is indeed a potential route for commuters from certain origins. This test is as follows:

**Travel time HOV lane trajectory  $\leq 1.5 * \text{normal travel time to city center}$**

This results in 1386 originating zones and 820 person trips. This figure will be used for the base model, for the HOV lane time reduction scenario, for the improved parking scenario and the person change to a minimum of 4 required people scenario.

### 5.4.1. Base model

In the base model, the carpool location is fixed at the end of the Noord-Brabantlaan (as identified in green in appendix N) and a carpool (HOV) lane is constructed to the city center. To ensure only trips are selected for which the carpool location is a good alternative, an extra check is carried out to not take into account trip in the carpool alternative having to travel a distance larger than 1.5 times the normal direct distance (without first driving to the carpool location).

For this base model, around 176 people will carpool ( $\pm 22\%$ ), equaling 88 trips ( $\pm 11\%$ ). 644 persons will travel alone to their work location. Of course, not all carpooling vehicles will exactly carry 2 persons; the average occupancy will therefore be a bit higher. However, for illustration purposes, in this study it is assumed exactly the minimum required number of persons is occupying the carpool vehicle. For a thorough sensitivity analysis of adjusting parameters in the created model, certain assumptions are made listed as follows:

- ◇ costs per km are estimated at €0.42, based upon respondent's car distribution<sup>3</sup>;
- ◇ an average cost reduction of 50% in the carpool alternative (based on 2 persons);
- ◇ the travel time uncertainty for both alternatives is equal in the base model. This is since carpooling on the separate lane and with priority measures in place reduces the dependency of the trip on traffic lights, congestion, etc. However, since more people are in one vehicle, some extra uncertainty has to be allowed in every carpool setting due to waiting time for passengers, and congestion on the way to the carpool location. Therefore, the travel time uncertainty for both alternatives is fixed at 36% of the final travel time in the initial model;
- ◇ 20.3% of all respondents state flexibility in travel times is not important (those are assigned a low utility level of -0.138); 10.6% state a neutral importance (neural utility of 0); and 69.1% state flexibility and freedom is important (positive utility of 0.138). These values are assigned to zones by using the probability distribution of the percentages presented above and by generating random numbers between 0 and 1;
- ◇ the parking situation, the work location and the availability of a (company) car or bike are fixed to the null level in the base model (utility of 0).

#### 5.4.2. HOV lane time reduction

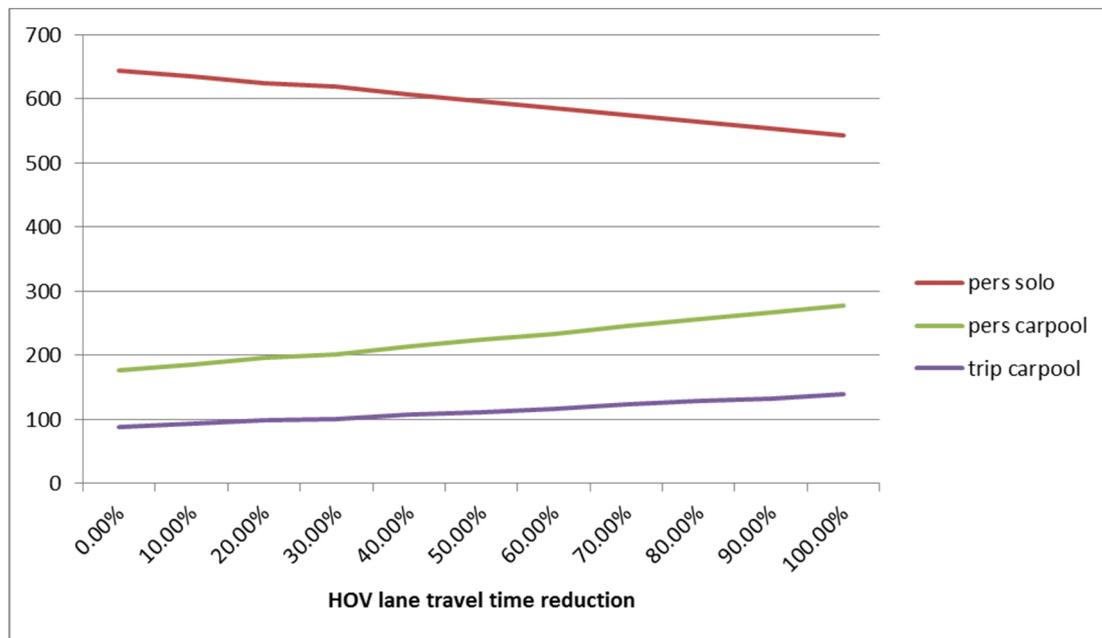
Since travel time in the carpool vehicle is the second most important variable (looking at the standardized coefficient from the effect coded MNL model), changing the value of this variable should have a significant effect on the carpool utility function. As can be seen, decreasing the travel time on the HOV lane by 50% yields an increase in carpoolers of 50 persons and a decrease of 25 vehicle movements. As the estimated coefficient (and thus the effect of changing the travel time on the gained utility) is linear. From table 13 below it can be seen that the estimated number of carpoolers is also linearly dependent on the travel time reduction.

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<sup>3</sup> 109 respondents answered they own a compact class car, 137 own a mid-class car, and 22 own a luxurious car. Based upon estimates by Dutch companies ANWB and Nibud, costs per kilometer are estimated at €0.33 for compact class cars; €0.47 for mid-class cars and €0.55 for luxurious cars. *average cost/km* =  $\frac{109 * \text{€}0.33 + 137 * \text{€}0.47 + 22 * \text{€}0.55}{268} = \text{€}0.42$  (Nibud, 2013).

Travel time reduction	# pers solo	# pers carpool	# trips carpool
0.00%	644	176	88
10.00%	634	186	93
20.00%	624	196	98
30.00%	618	202	101
40.00%	606	214	107
50.00%	596	224	112
60.00%	586	234	117
70.00%	574	246	123
80.00%	564	256	128
90.00%	554	266	133
100.00%	542	278	139

**Table 13 – Prediction of carpoolers by changes in travel time reduction due to the HOV lane**



**Figure 10 – Graphical display of different travel time reduction levels on the expected number of carpoolers**

### 5.4.3. Improved parking scenario

It is possible to improve the parking situation at the work location. For example, parking places can be reserved for carpoolers and/or these places can be located more closely to the final work location. This increase from a normal to a very good parking location results in 9 extra carpoolers (this is an increase of 10%), see table 14.

#### 5.4.4. Minimum person requirement

Raising the minimum person requirement to be labeled a HOV and to be allowed on the HOV lane from two to four persons, decreases the total number of carpoolers by 51% compared to the base model. However, since some HOVs are optimally occupied, the amount of vehicle-kilometers-travelled saved is highest in this option, see table 14.

#### 5.4.5. No fixed carpool gather location (home)

For the next four scenarios, the location of the carpool meet location is not fixed. However, all vehicles will still make use of the same HOV lane trajectory. This means, the test as mentioned before, about the minimum length of the trip that have to take place over the HOV lane will no longer have to be used. The upper limit of the distance to the carpool location is either the distance to the city center or to the HOV lane start point. In the next four scenarios, 1583 origins zones are selected and 967 person trips each morning rush period. This scenario has the largest positive effect on the environment since when a small distance to the meet location is chosen, the largest part of the route will be traveled in carpool formation. This means trips that would otherwise have taken part separately can now almost entirely be combined. Results are displayed in table 15. From this table it can be seen that when the carpool location is at home for all passengers, this would yield 155 carpool trips and a savings in vehicle-kilometers-travelled of 5,157 every morning peak period.

#### 5.4.6. No fixed carpool gather location (variable 0-5 km)

The model is able to set a fixed distance or a random distance between two values for each origin (e.g. 0 and 5 kilometers) to the meet location. When altering the distance of the meet location locating it further from respondents' homes, the number of carpoolers and the VKT savings decrease, as can be seen in table 15.

#### 5.4.7. No fixed carpool gather location (fixed at 5 km)

Again, the further the meet location is from the homes or commute origins of respondents, the smaller the proportion of carpoolers is and the less VKT savings, explanations and results in table 15 correspond to the previous paragraph.

#### 5.4.8. Most optimal configuration

Another scenario is the one where different 'best' policies are combined. This scenario is already described in paragraph 4.5. Therefore, only the results on the expected number of solo drivers and carpoolers in the most optimal configuration will be given in table 15.

### 5.5. Comparison of the results

The results in terms of the estimated number of solo drivers and carpoolers in the base model and each scenario that will be presented below are displayed in tables 14 and 15. The first figure (without brackets) gives the total expected number including the current number of carpoolers. The figure within parentheses is the adjusted value that takes into

account people that are currently already carpooling. This number is estimated at 10% (96 persons), since the average vehicle occupancy for commuting motives is estimated between 1.04 and 1.25 in different sources (Mobiel Vlaanderen, 2013; Statline, 2013). The following observations can be made from analyzing the figures in the tables below:

Four scenarios with a fixed carpool meet location	Persons solo	Persons carpooling	Trips carpooling	VKT all solo	VKT with carpool	VKT savings	CO <sub>2</sub> reduction (kg)	AVO
Base model with carpool meet location	644	176 (80)	88 (40)	17140	17099	41 (19)	5 (2)	1.12
HOV time reduction 50%	596	224 (128)	112 (64)	17140	17099	42 (24)	5 (3)	1.16
Parking improved	626	194 (98)	97 (49)	17140	17099	42 (21)	5 (3)	1.13
Person change (4)	648	172 (76)	43 (38)	17140	16868	272 (120)	33 (14)	1.19

**Table 14 - Four scenarios with a fixed carpool meet location**

Four scenarios with no fixed carpool meet location	Persons solo	Persons carpooling	Trips carpooling	VKT all solo	VKT with carpool	VKT savings	CO <sub>2</sub> reduction (kg)	AVO
No fixed carpool location (home)	658	310 (214)	155 (107)	18735	13578	5157 (3560)	619 (427)	1.19
No fixed carpool location (between 0-5 km)	692	276 (180)	138 (90)	18735	14787	3948 (2575)	474 (309)	1.17
No fixed carpool location (fixed at 5 km)	725	242 (146)	121 (73)	18735	15943	2792 (1684)	335 (202)	1.14
Most optimal configuration	403	564 (468)	282 (234)	18735	7886	10849 (9002)	1302 (1080)	1.41

**Table 15 - Four scenarios with no fixed carpool meet location**

- changing the minimum required number of persons to drive on the carpool lane from 2 to 4 affects the utility function of the carpool alternative, and thus the estimated number of carpoolers, only to a small extent. The cause for this is the insignificance of the minimum required number of occupants parameter in the MNL model;
- comparing the improved parking measure with the reduced time on the HOV lane measure, the latter has a larger effect (128 extra carpoolers versus 98 in the improved parking alternative).

## Estimated effect on the environment

As can be seen from tables 14 and 15, it depends mainly on the chosen (combination) of policies to determine the saved vehicle kilometers traveled, and thus the CO<sub>2</sub> emissions. The CO<sub>2</sub> reduction is calculated in the tables by using a 120gram/km average emission in 2011 by private motor vehicles in the EU (European Environment Agency, 2011). However, a reduction in the amount of kilometers driven is not the only way to decrease the effects of carpooling on the environment. If an electric powered carpool vehicle is used or a very clean petrol vehicle, this would just like normal cars save extra. An increase in the number of persons in each carpool vehicle from 2 to 4 only yields a small decrease in vehicle kilometers traveled and emissions. This is mainly because the attractiveness to carpool is lowered to a too large extent. As a result only few people will be motivated to carpool in this scenario. Besides the most optimal configuration, locating the carpooling meeting point at the home of commuters scores second in reducing the negative side-effect of commuting trips on the environment. The reduction in delay further reduces emissions of hydrocarbons and carbon monoxide, which are roughly proportional to vehicle-hours (Dahlgren, 1998).

### 5.6. Validation of the model

Since no HOV lanes exist (anymore) in the Netherlands, and it would be expensive to construct those for validation purposes, other methods of validating the model should be used. Three options that exist to validate the model:

- ◇ Studies and implementation of HOV lanes abroad can be used to check the prediction. Especially in the United States a vast amount of literature exists on the effectiveness of HOV lanes. However, one large disadvantage exists. As the identified importance of carpooling factors in this study is based on the (stated) preferences of Dutch people, and habitants from other nationalities generally have a different culture and therefore different preferences, the question is to what extent their behavior corresponds to that of Dutch people;
- ◇ Except the HOV lane part of the model, the importance of other factors can be validated by referencing the results with outcomes of other studies that are carried out in The Netherlands;
- ◇ A third possibility is to enter the data in traffic simulation models, which in turn can run quick simulations of different areas. This is particularly helpful when applied to HOV trajectories abroad (point i). If results correspond with realized carpool traffic, the model can be considered valid.

Since no traffic information data from trajectories abroad where HOV lanes have been implemented is readily available, validating the model by applying the model to this route is too time consuming and therefore not possible in the timespan of this study. However, this is stated as a recommendation for further research since it is important the model is validated before further research is carried out on this topic.

## 5.7. Chapter conclusions

In this chapter, a tool was created that combined the estimated MNL model estimations with traffic model data. Since the data that was used for the MNL model estimations was collected on a national scale, these results can be applied to any case-study in The Netherlands that is thinking of motivating commuters working in a larger city to carpool. The created tool was applied to the case-study of the Noord-Brabantlaan in the city of Eindhoven, The Netherlands. The two main reasons for this selection, was the current existence of a reserved lane for busses (cheaper to implement and test the carpool lane), and the plans of the municipality of Eindhoven to reduce the number of cars in the city center and to become energy neutral by 2040. From the traffic models, information about the number of movements, from each destination zone to the city center, and the distance and travel time of each such trip was obtained.

Different scenarios were tested, including the base model with the HOV lane, but without travel time differentials, a travel time reduction of 50%, improved parking at the work location, a minimum person requirements change, and different locations of the carpool meet location. Finally, the most optimal situation was described. For each scenario, the proportion of people solo driving and carpooling were calculated, together with the amount of vehicle-kilometers-traveled and potential travel vehicle emission savings. In the last paragraphs, some suggestions to validate the model are discussed.

# Conclusion and discussion

In this chapter, conclusions from all individual chapters are summarized. This is done by first recapping the methodologies that were used and the results that were obtained by each. Secondly, the sub-research questions are handled, and a short, clear answer on each of them is given, which is derived from the foregoing analyses. The main research question is subsequently answered. In paragraph five, a résumé presents in short the most important findings of this study. The chapter concludes with a discussion of the results.

## 6.1. Methodology review

This summary of the methodologies that were used and their results is divided in three parts: a review of the literature study, a review of the multinomial logit model and a review of the case study application. The literature review that was carried out resulted in a long list of potentially important variables to motivate commuters to carpool in The Netherlands. However, as the literal sources were originating from many different countries, and no clear consensus on which variables are most important was reached; relevant sources were selected that more closely resemble the Dutch society. The literature review, together with expert interviews finally resulted in eight attributes that were assumed to be important in affecting the commute travel mode choice. The link with the reserved lane for carpoolers, the HOV lane, was also captured in four of these variables.

The second methodology that was used is discrete choice modeling. This consisted of a questionnaire development and a multinomial logit model that was estimated upon results obtained by the questionnaire. The model showed a standard aversion for carpooling, when all other attributes are equal to zero. This means carpooling is considered as a worse mode to commute to work with than driving solo. Important factors were in order of importance from most to least important: travel and waiting time at the meet location, actual travel time in the carpool vehicle, costs of the trip, parking at the work location, and flexibility in travel times. Insignificant were: the level of uncertainty in travel time, availability of a car or bike at the work location, and the minimum required number of persons in the vehicle to be allowed to drive on the special carpool lane.

The third methodology, that of the case study application (Noord-Brabantlaan, Eindhoven, Netherlands) resulted in a translation of the estimated model with corresponding utility functions in predictions of expected volume in terms of carpoolers and solo drivers when certain facilities are in place. The model is nationally applicable, since it captured preferences of commuters working in cities all over The Netherlands. Different scenarios were analyzed in which among others travel time savings, improved parking situation, and a fixed and variable meet location were tested. The output figures of the model give a good insight in which policy or physical facility results in a desired increase in the level of carpoolers. However, results of the model should be interpreted qualitatively and relative compared to the base model or current situation, instead of quantitatively. The model is meant to illustrate the scale of effects when altering a certain value or policy, figures are only estimates.

## 6.2. Hypotheses

### I. **Travel time uncertainty is perceived as being worse (having a more negative utility) than actual travel time**

The first hypothesis is false, as showed by the multinomial logit model estimation results. Based upon answers of 346 respondents, an increase in travel time uncertainty with one minute results in an extra utility of -0.0446 (which is marked insignificant at a 95% confidence level), while an increase in actual travel time by one minute results in an extra negative utility of -0.0737, which is more negative and significant at 95% confidence (see table 11). Therefore, the first hypothesis is proved to be false in this study.

### II. **Safety and ambience during the trip in the carpool vehicle are considered more important than travel costs**

From the scores on the attitudinal questions that were asked to the respondents, it can be derived that 85% of all respondents value trip safety as being (very) important, 86% value the ambience as being (very) important, and 84% value costs of the trip as important. The differences between those characteristics of the trip are only small. In this study the hypotheses seems to be right, however the difference is not significant large enough to really prove the hypotheses.

### III. **City-commuters perceive (direct) costs of their commute trip more important than the effects of the trip on the environment (environmental costs)**

A possibility to share costs fairly among carpoolers is valued by 62% of all respondents as being important, fiscal advantages are valued by 47% of all respondents as important, as compared to 36% of the respondents that value the effect of their trip on the environment as important. Due to the large differences in these percentages, this hypothesis is therefore proven to be right within the power of the sample size that was used.

### IV. **Designated parking places for carpoolers and travel time savings in the carpool alternative can increase the probability a commuter chooses to carpool.**

From the multinomial logit model and the application of the created tool in the case-study, it can be derived that improved parking facilities (like a designated parking place for carpoolers) and travel time savings can indeed increase the utility of the carpool alternative.

An improvement in the parking situation and distance from the parking place to work location from 'average' to 'good', yields an increase in utility of 0.217, whereas a reduction in travel time of 10% increases utility by 0.220. Both attributes indeed increase the utility a respondent derives from carpooling, and thus increases the probability he or she will choose to carpool.

### 6.3. Sub-research questions

#### 1. What is carpooling, why is it a promising alternative to reduce congestion on city-entry bottlenecks; what are important factors or facilities that stimulate carpooling?

Carpooling is one of the many solutions that exist to battle congestion issues. Since to date many measures were focused upon increasing the capacity, and not so much on reducing the supply of vehicles = demand of infrastructure. Policies aimed at stimulating public transport are also not achieving their desired objects. Therefore, a new approach that lies somewhere in between the current modes of transport (solo driving and public transport) could be promising, since commuters are attached to the comfort of their private vehicle, but at the same time are also experiencing the negative effects that occur when everyone is driving to work in their car as a single occupant. Carpooling reduces the amount of vehicles on the road (by combining trips), which will result in a lower demand for infrastructure. Direct effects are fewer movements (trips), less parking space requirements (e.g. in the city center), while long-term effects can even turn out to be that less cars will be bought by the general public (due to car-sharing). Eight important factors that stimulate carpooling are used in the questionnaire, however three of those turned out to be less or not important. Important factors that stimulate carpooling therefore are: travel time and waiting time at the meet location, actual travel time in the vehicle, costs of the trip, the parking policy that is in place, and the level of flexibility in carpool travel times.

#### 2. What is a high-occupancy-vehicle (HOV) lane; how can its benefits stimulate carpooling; and how can the success of a HOV lane be measured?

As stated before, a high-occupancy-vehicle lane is a reserved lane for the exclusive use of vehicles with a driver and one or more passengers. Its main benefits for occupants of HOVs is that a HOV lane can reduce travel time due to less congestion on the lane, or by receiving priority at crossings. As a result, more commuters will be motivated to carpool and thus HOVs, and the total supply of vehicles on the road will therefore decrease. This again will reduce total congestion on all roads. Total benefits of the HOV lane will be travel time savings, uncertainty time reduction, and environmental benefits. The success of a HOV lane in each context can be measured by using a wide variety of factors presented in literature, including: the total reduction in travel time (person-delay, lost vehicle hours, vehicle throughput, level of congestion that remains, level of emissions, or a combination of factors. It depends on the objectives of the local or higher government and the reason why a HOV lane is implemented in a specific case-study.

#### 3. What facilities should be in place to trigger city-commuters to carpool; how can public policies support or facilitate carpooling and HOV lanes?

In this study different facilities have been researched that can be implemented by public policy making. Governments for example have the power and ability to construct new

roads, extend capacity, make sure the proper regulation is in place and also has the financial means to both implement and promote these facilities. As the HOV lane that was implemented in the years 1993-1994 failed mainly because the right legislation did not exist, this is important in facilitating the correct operation of the HOV lanes. Most important policy-determined factors in this study are the implementation of the HOV lane, improved parkings at the city center for carpoolers, and a potential fiscal or economic (subsidies) scheme offered by the government. Also, offering carpool meet locations at the right locations can prove to be an important stimulus that the government can facilitate.

#### **4. How can the proportion of carpoolers for a specific case-study be predicted; what is the effect on traffic flow, environment and accessibility of the urban center; how translation to larger scale?**

By using traffic models, the movements for a specific area during for example the morning peak rush period can be obtained in large databases. When testing the implementation of a HOV lane from the city center to one side of the city ring, the study-area can further be reduced by selecting only zones to this direction of the city center. The created model requires three different inputs/zones: all origins from where commuters travel to their work (their homes), the carpool meet location (if it exists), and the destination zones, which is often the city center (however other destination are also equally possible). The model predicts the proportion of carpoolers and the remaining solo drivers; it also estimates the amounts of vehicle-kilometers-travelled that are saved, which gives an idea of the reduction of vehicle emissions. Furthermore, the number of vehicles on each lane can be calculated by reserving one lane for carpoolers and remaining lanes for solo drivers. If congestion on the general purpose lane significantly increases due to conversion of the lane, constructing a new lane can turn out to be a better option. Furthermore, the number of parking places that are saved in the city center zone can be calculated by summing the number of solo trips and carpool trips. The model is nationally applicable, so translation to a larger scale will only require the input of more zone numbers in the model inputs.

### **6.4. Main research question**

#### **‘What are the most important factors influencing the travel mode choice made by city-commuters, between solo driving and carpooling?’**

This question has been answered already for a large part in paragraph 4.5. The travel and waiting time at the meeting location is most important, a small value gives the highest probability that a commuter will carpool, with a most optimal value of 0 minutes (meet at home). Secondly, the actual travel time in the (carpool) vehicle is of great influence in determining the utility and therefore the probability of someone choosing to carpool. A maximum reduction in travel time due to the HOV lane is the optimal value. Thirdly important are the costs of the trip, the higher the cost the less likely someone will carpool. However, when costs are high in the solo alternative, and the carpool consists of a large number of occupants, the travel cost savings (per person) are largest. Fourth, a good, easy to find, and reserved parking location for carpoolers close to the work location is important in increasing the likelihood someone carpools. Lastly, the level of flexibility in carpool travel times is important in affecting the carpool utility.

## 6.5. Résumé

- A standard aversion for carpooling exists in the perception of city-commuters, this negative utility for carpool equals -1.06, which can be translated into a standard willingness for carpooling of 0.26 or 26%, in practice the number of commuters that carpool is lower since many other factors are also affecting the choice to carpool.
- For 38% of all commuters it is not possible to carpool or they will never be motivated or willing to carpool, this corresponds to about the same percentage as found in literature;
- The most important variables that have been identified in this study that influence the decision to carpool are (in order of most to least important): travel and waiting time at/to carpool meet location, actual travel time in (carpool) vehicle, costs of the trip, the parking availability and distance at work location, and the level of flexibility in travel times. Not significantly important are: the number of required persons in the vehicle (minimum occupancy level), the availability of a car or bike at the work location, and (reduction of) uncertainty in travel time;
- In the stimulated base scenario, the average vehicle occupancy is 1.12, in the most optimal scenario this level can be increased up to 1.41 people per private vehicle;
- The stimulating effect of separate policies (HOV lane with travel time savings, parking policy, number of persons) on the achieved number of additional carpoolers relative small (AVOs between 1.14 and 1.19 compared to the original 1.12) however combined with other facilities this effect (and the proportion of carpoolers) can be increased;
- VKT savings of 20% to 50% can be achieved by motivating sufficient commuters to carpool and when meeting close to home (i.e. traveling largest proportion of commute trip in carpool formation). This VKT savings can be directly translated into estimated for CO<sub>2</sub> and NO<sub>x</sub> emissions caused by road traffic.

## 6.6. Discussion

As various recent studies pointed out a standard aversion for carpooling exists as perceived by commuters, carpooling needs a certain stimulus for people to get motivated to do it. This finding is confirmed in this thesis by the standard negative utility associated with carpooling of -1.06, when the utility function of driving solo to work is fixed at zero. Motivating people to carpool therefore can be achieved in two different ways: the carpool utility has to be increased by encouraging carpooling or the utility one derives from driving solo has to be reduced by discouraging driving alone. However, as the luxury of cars keeps improving due to technological advances, the latter is not expected to happen anytime soon.

Different factors and policies have been studied in this paper to encourage commuters to carpool. One of these physical means is a reserved lane for carpoolers (high occupant vehicles). The required investment for this lane is assumed to be small in the case that existing bus lanes will be used (e.g. in Eindhoven). However, the current two bus lanes (one in each direction) at the Eindhoven Noord-Brabantlaan seem not to be sufficient to combine with carpooling private vehicles, since busses have to stop at frequent intervals. At these points overtake possibilities have to exist. Furthermore, currently priority is given to the bus lane at traffic junctions. 112 carpool vehicles will drive on this bus lane in the two

hours peak period (as derived from table 14 when travel time is reduced by 50%), equaling 56 per hour. Combined with the current bus intensity at some points on the Noord-Brabantlaan, equaling about 20 per hour, this will result in a total number of about 75 vehicles per hour. Since these figures are relatively small compared to a normal vehicle capacity of 2,200 vehicles per lane, no large problems or congestion issues are expected to arise on this lane. However, when this lane needs to be given priority about every 48 seconds, the functioning of the normal junctions will be severely hampered. However, over the long term it may be possible to construct tunnels or bridges for HOV lanes to ensure a free flow travel speed.

(Investment) costs of a HOV lane implementation are not limited to construction costs. Other costs involve enforcement costs, lost income due to urban space reservation/use, and an increase in traffic congestion costs if a current general purpose lane is converted. Per context, many different characteristics of a HOV lane need to be defined, like converting a current general purpose lane or building an additional lane, separating the lane by a ramp or just markings, the number of entrances and exit ramps, the minimum required number of occupants in a car, the type of enforcement, etc. Since the higher government and cities as well are stimulating cleaner ways of transportation, the lane can also be opened to electric cars, to taxis, busses, emergency vehicles, motorcyclists, etc. These questions need to be answered per context. However, this study gives an idea of the extent of solo drivers that can be motivated to switch to carpooling in different scenarios. How these scenarios can be realized exactly, is not captured in the scope of this study. For example, a travel time reduction of 40% is expected to be achievable based upon literature sources. However, if this is to be realized by giving the HOV lane priority or by a strict allowance scheme for vehicles to drive upon the lane is not of the concern of this study. These questions have to be answered in a later stadium.

The expected main prerequisite for carpooling to actually increase the average vehicle occupancy, is to adequately use information technology next to the physical advantages that can be implemented (like HOV lane travel time savings). Since the advance in information technology (internet everywhere, the occurrence of carpooling apps on the market enabling instant carpooling) makes it possible to more easily organize a carpool trip, this trend can increase the effects of other policies and/or factors. A HOV lane can only be utilized well if the trajectory is sufficient in length, the intensity on the current route is high, the final destination of the lane is densely populated or sufficient people are working in the close surroundings, and IT support is in place to make it easy for commuters to form carpools. Carpool groups should be flexible and commuters should not be dependent on his fellow travelers. Furthermore, governmental policies like legal or fiscal regulations aid significantly in motivating commuters to carpool.

However, will carpooling be able to increase the average vehicle occupancy to a level that is sufficiently high to cancel out current congestion or avoid future bottlenecks? Will the necessary costs incurred to reach desired levels of factors as identified by the MNL model offset the benefits of the extra carpoolers and the reduction in the total amount of vehicles on the (urban) roads? Promoting carpooling only by advertisements and campaigns did not work, as showed by the study. Therefore, other measures are necessary to be implemented. This is especially true when cities want to achieve their targeted environmental sustainability goals and public transport is not expected to attract sufficient commuters. Promoting

carpooling by using HOV lanes in other countries is reporting positive results (both direct for commuters as indirect for the municipality or region). The specific contexts of these applications should more closely be studied and compared to potential sites in The Netherlands before implementation of a HOV lane. When using the created tool for predicting the proportion of car poolers from this study induced demand has to be taken into account, as generally, expansions in capacity cause demand to increase, which may result in a worsening of traffic. This increase in demand may come from people who were using other models (transit, off-peak, or non-motorized transportation), people taking more trips because congestion has cleared up, and long-run changes (e.g., people building houses farther away from city centers).

The objective of this study is not to come up with a clear-cut answer or prediction on how congestion can be solved by stimulating carpooling and implementing HOV lanes, however it serves as a means to make policy-makers start thinking about the direct and indirect effects that carpooling can achieve for the accessibility of the urban center and quality of urban life.



## Chapter 7

# Recommendations and limitations

## 7.1. Recommendations

The tool that is created for predicting the proportion of carpoolers can be used by different agencies to describe the tendency and effect of different measures and policies to stimulate carpooling.

More and more cities are extremely busy with inventing and testing means to decrease the negative effects of the large number of vehicles in the urban centers. Eindhoven for example, since 2005 is implementing high quality bus lanes receiving priority at traffic junctions. Plans exist for new high quality bus lines and for a new railway station. Since it is planned that the city of Eindhoven will have constructed reserved bus lanes to three of the four wind directions (North, South and West) by the end of 2016, the city would be a good testing ground for the HOV facilities in combination with a HOV/carpool lane (see figure 11). Municipalities can use the estimates from the estimated MNL model to analyze the effects of a policy in terms of cars reduction in the city center, congestion nuisance or emissions before implementation. Since all the current separated bus lines will cross at the station/city center, carpoolers that are allowed to drive on these lanes coming from one direction will be able to switch to another HOV/bus lane at this point. It is also a smart idea to facilitate sufficient parking places at good location for carpoolers at the city center.

Traffic consultants are able to use the created tool and insights gained in this study to base carpool related advice on. The importance of various factors influencing carpooling behavior is sketched. The tool can be used for the same possibilities as described above for the municipalities. Elaborated research can be carried out based on this report, for example, what would be the implication if HOV lanes on freeways can be coupled with carpool lanes to the city center? As the distance increases, and possible the reduced travel time due to avoiding congestion, the motivation for commuters to carpool also expands. Should HOV lanes be applied to a national scale, obtaining the same size as the current railway network? Further research is recommended to answer the questions above. Educational institutions and traffic consultants should together execute research in this field to deliver the answers.

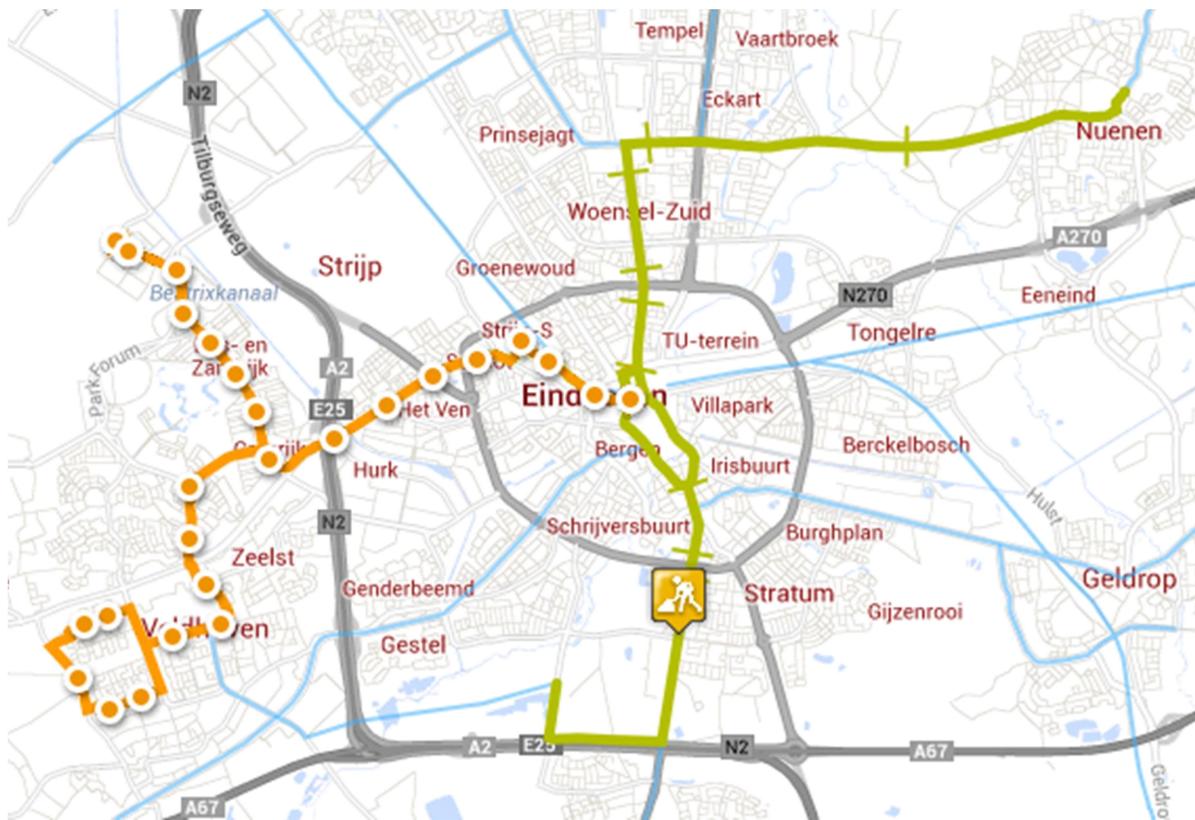


Figure 11 - Planned high quality public transport network with separated bus lanes

## 7.2. Limitations

The limitations paragraph describes the framework within which the results of this study were obtained and may be used. The most important remark is that, as the estimates of the multinomial logit model are derived from preferences and perceptions in the mind of Dutch commuters it is not possible to use these estimates in similar studies in other countries, since perceptions may change between cultures and countries. Estimates should be compared and validated by local or national studies in other countries first. The sample size that is used for estimating the MNL model is limited, but considerable higher than the minimum required sample size. As the power of statistical experiments increases with the sample size, obtaining more respondents is a good practice when the results are used for further research.

This study focuses on the preferences and behavior of commuters working in cities with a population higher than 75,000 residents. They are the target audience in the questionnaire, and later in the case-study application. Their preferences are capturing for the home-work trip during the morning rush hours. Since in most traffic/mobility studies and analyses, peak rush periods are usually leading, the estimates of the MNL model can be used for all commuting trips towards the city center. Especially since the accessibility of the city center is of main interest, most movements into the city will be office workers and therefore will be captured in the peak rush time span. Furthermore, the results are expected to also be

useable for the commute trip from the work location to the home in the afternoon, since almost the same factors play a role, only in the opposite direction. An easy to access and close by parking situation at work in the morning, can be translated into a parking location that is quickly reached after work and from which the commuter can easily reach the HOV lane.

Next to the limitations of commuters, only private cars are considered in the study. To calculate the total number of vehicles on the road, the proportion of private cars could be used in combination with a correction factor for other modes. However, as private cars are responsible for 75% of all road kilometers traveled in the Netherlands (C.B.S. Statline, 2013), the bias of this limitation will also not be very significant. Furthermore, the focus lies on motivating solo car drivers to carpool, and not public transport users or (motor) cyclists.

The results of the attitude questions were only shortly discussed and used as a reference for group segmentation. However, multiple multinomial logit models can be created for each group separately. In this way, the effect on the utility function of a certain variable can be differentiated between the identified segments or groups. The importance of socio-demographic variables (covariates) in the multinomial logit model was checked. As turned out they would not have a significant effect on the model estimates, it would however be helpful to include the most important covariates as still will remove some bias from the estimated attributes of the current model. Also, attention should be paid to the panel data effect. This occurs when a respondent answers multiple choice profiles. However, again research shows the model's accuracy when taking this effect into account does not improve to a large extent. Especially for describing the larger tendencies in terms of an increase or decrease of carpoolers by using large figures will factor out small deviations, and thus the resulting effect is partly balanced.

The tool that was created for the case-study application is static (e.g. a fixed travel time differential is considered). For a careful and precise traffic flow analysis, congestion factors and induced demand should also be considered, since it is fairly straightforward that over time an increase in the amount of vehicles on the road and thus in the level of congestion will occur; resulting in turn in a lower travel time differential. Therefore, a dynamic model should be constructed in elaboration steps following this research which takes into account all the factors in appendix O, including lane capacity of carpool lanes and general purpose lanes (thus the effect of lane conversion). Induced demand can occur on both types of lanes, since when a HOV lane is constructed as an additional lane reduces the number of vehicles on the original general purpose lane. Induced demand can result from other routes, times or growth/additional trips. This possibility exists by integrating the MNL estimation results into algorithms behind the dynamic computer models. However, due to the restricted time available for this study, integrating the results in the algorithms of the computer software packages is not possible during the allowed time for this work.

No comparison of the obtained results (in terms of the achievable benefits according to the application of the tool in the case study) to studies abroad has been carried out. Also, the estimates for the case study in terms of the proportion of carpoolers, the travel time savings, and achieved emission reduction could be validated more extensively by using studies from abroad. However, it is expected preferences of commuters in choosing to carpool will differ significantly between countries and cultures, therefore it could be argued

that a separate model describing choice behaviors for each country should be constructed and used.

The last restriction is of course, that not all factors affecting the choice to carpool to the work location are used in the study. A comprehensive list was created based upon literature research from which the most important variables were chosen (based upon literature and expert interviews). The fact that not all factors affecting the travel mode choice can be incorporated in the questionnaire and later in the MNL model is a general characteristic of discrete choice studies. It would simply be impossible to identify and analyze all effect influencing the travel mode choice behavior of commuters.

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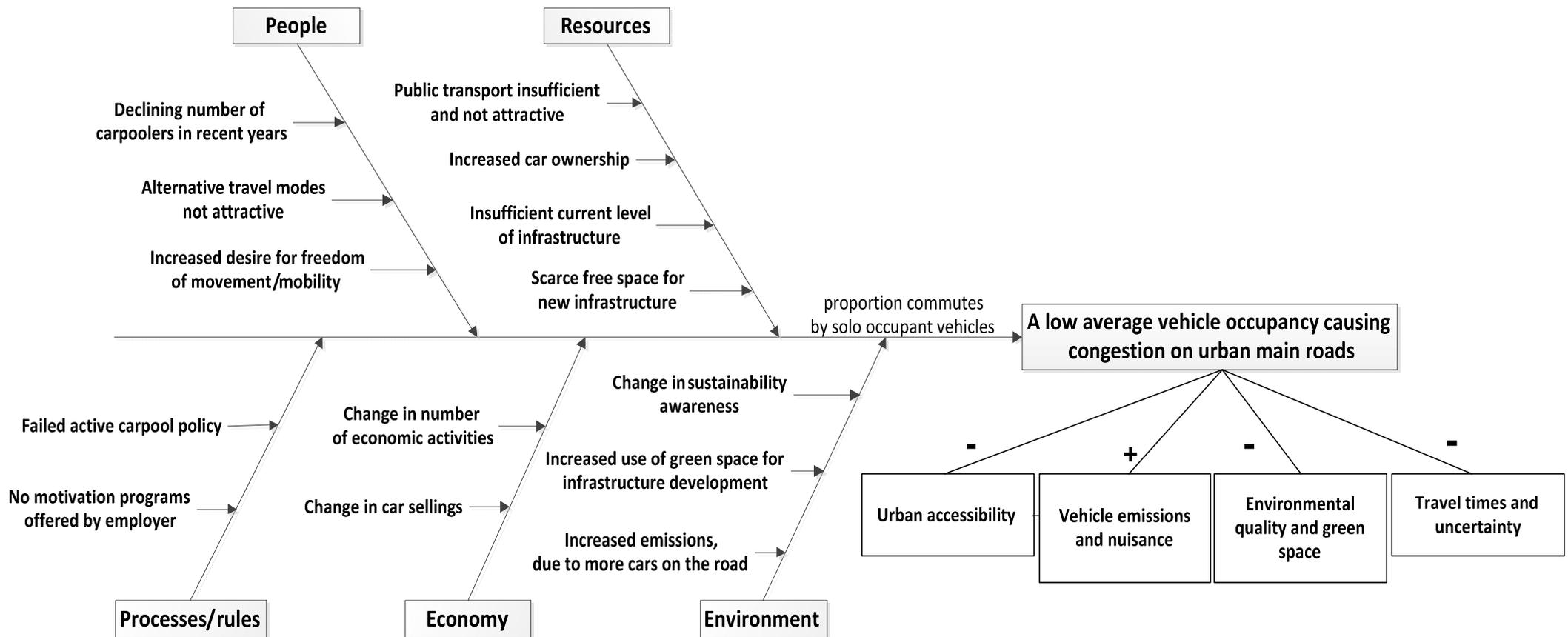
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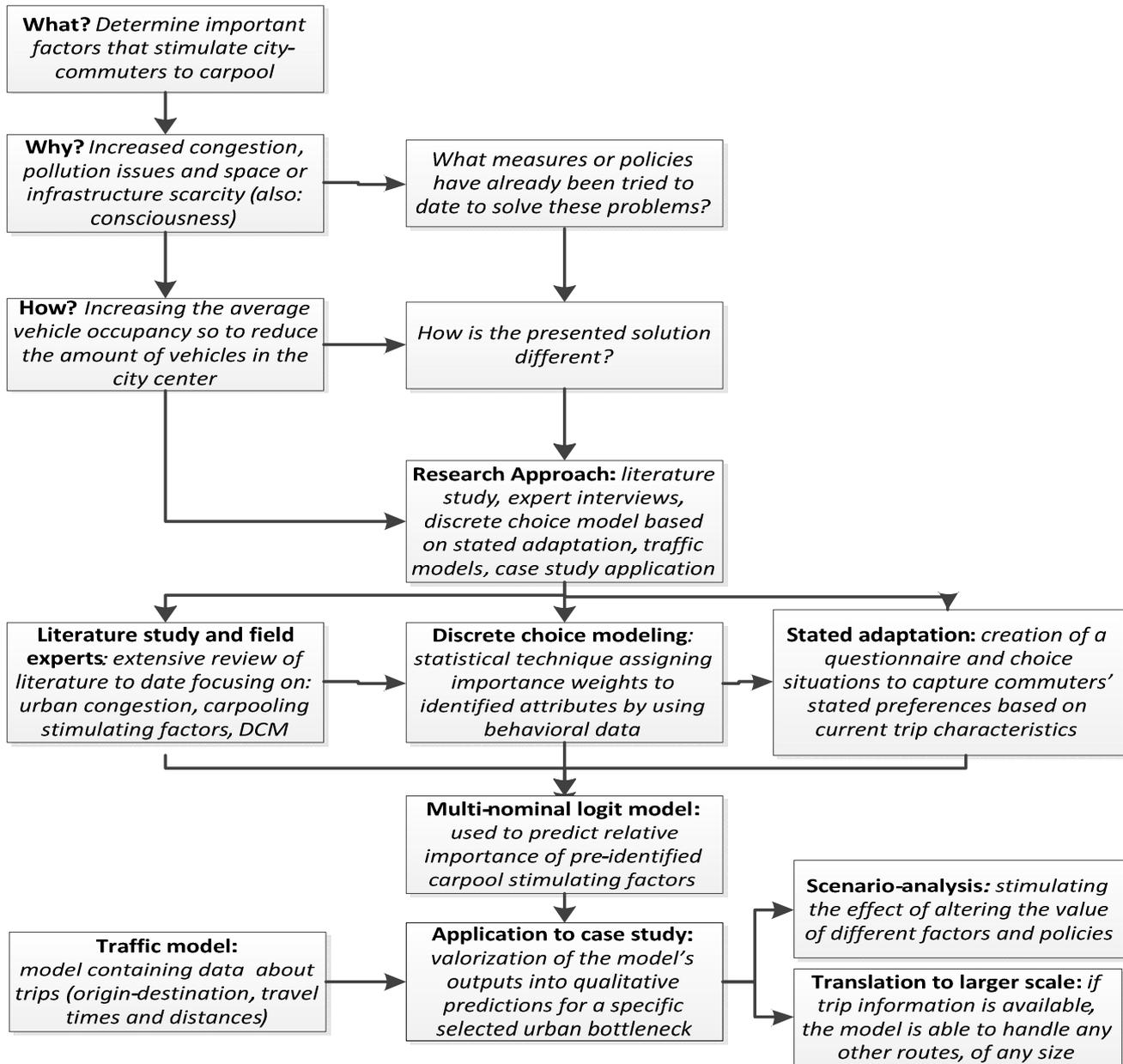
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# Appendices

## Appendix A – Cause-and-effect diagram for problem identification



Appendix B - Outline of the study report process and thesis outline



## Appendix C – Background information about HOV lanes

The definition of a HOV lane is ‘a highway or street lane for high-occupancy vehicles, usually marked with large diamond shapes on the pavement’. It is a reserved traffic lane for the exclusive use of vehicles with a driver and one or more passengers (e.g. carpools, vanpools, and transit buses). High-occupancy-vehicle lanes (also known as diamond lanes, commuter lanes, transit lanes and carpool lanes) are encouraging people towards transit use and ridesharing. The belief is raised that those lanes will be more effective in reducing congestion and emissions compared to general purpose lanes (Giuliano, et al., 1990). However, for HOV lanes to be a success, a travel time differential between the HOV and general purpose lane has to be maintained. This means a delay on the general purpose lanes should continue to exist.



**HOV lane sign (Federal Highway Administration, 2008)**

Furthermore, emissions are reduced because of both a reduction in amount of vehicle trips and by reducing vehicle and person delays. This thesis researches an innovative approach to manage congestion issues, based upon the concept of vehicle sharing, called ‘high-occupancy-vehicle’ (HOV) lanes. The idea is not new however, since HOV lanes are used to a quite large extent in the United States, the United Kingdom, and some other European countries. However, implementing them successfully in The Netherlands will be a unique and therefore quite innovative approach. In the HOV concept, vehicles are allowed to drive on the HOV lane only when they seat a certain minimum amount of passengers. Initially, when relatively few high occupancy vehicles will exist, this lane will have a smaller travel time (uncertainty) compared to the general purpose lanes and thus will motivate people to switch to modes of carpool, enabling them to use the special lane (i.e. change their behavior). When carpooling, people are free to choose with whom and when they want to drive to their destination. In this way, the traditional (generally negative) image of an P+R location where users transfer to a connecting mode of public transport is changed to a more private form of carpooling. Travelers do not longer depend on fixed forms of public transport but are free to decide upon the composition of people with whom they want to share a vehicle. In this way, levels of comfort and social safety are increased.

In the Netherlands, carpooling on a separate lane is seen as a controversial measure, because the principle of non-discrimination is affected by it. In 1993, the first carpool lane in Europe was opened on the A1 motorway in the Netherlands. The 28 million euro lane was only available for vehicles seating a driver and 2 or more passengers, so a total of three occupants (called a HOV 3+ lane). The objective of this special lane was to increase the average vehicle occupancy from 1.2 to 1.34. This would have the same effect of doubling the public transport capacity. Both these options would be just enough to make sure all congestion on this route would disappear. In the first weeks of operation, results were satisfactory and the number of vehicles on the HOV lane (carrying 3 or more persons) increased with 20% from around 300 to 360 per hour

(Minister van verkeer en waterstaat, 1994). The average occupancy rate was 3 persons in a car and 40 occupants in busses. This strong increase validated the expectation that during the busy morning rush hours, the usage of the HOV lane will double during a two year timespan.

During the pilot of this carpool lane on the A1 motorway, questions were raised about the efficiency of allowing vehicles seating 2 people on the lane (HOV 2+) instead of a minimum of 3 occupants. Of course, such a policy change can more easily result in congestion on the HOV lane and a smaller resulting time differential. After the first test results of the pilot study were collected, new studies were started aimed to investigate the feasibility of HOV lanes in other projects, e.g. Eindhoven-Valkenswaard and the connection Rosmalen-A2 motorway (Minister van verkeer en waterstaat, 1994). The second evaluation report of the minister of traffic and transportation states that the HOV lanes turned out to be extremely safe, and that it reached the expected travel time savings: 17 minutes in the direction of 't Gooi and 23-28 minutes in the direction of Flevoland (Kamerstukken I 1993/94, 23 400, nr. 62, p. 4, n.d.). However, the total increase in the number of 3+ vehicles was limited to this point. At its peak, capacity of the HOV lane was used only for around 25%. Therefore, again the question was raised of changing the lane to a HOV 2+ lane.



**Example of a HOV lane with congestion on general purpose lanes in the US**

Just after the opening of the lane, a former Dutch politician by the name of Tjerk Westerterp, provoked a law suit because of the unfair and discriminating nature of the HOV lane. At this time, the Dutch law had not defined what carpoolers are and the sign that was placed at the entrance was not legally approved. Therefore, the judge ruled in the favor of the politician (Trouw, 1994). Due to this ruling, the expectation was raised that people driving alone will now massively start using the HOV lane. Therefore the lane was quickly closed, mainly because of safety issues (Aanhangsel Handelingen II 1993/94, nr. 739, n.d.). The opposed study of a HOV 2+ lane where vehicles are allowed to drive on the lane if they carry 2 or more persons could therefore not be evaluated because of this

preliminary closure of the lane. However, policy makers and public prosecutor were convinced that the lane was closed prematurely and that the ruling was based on a misinterpretation of road traffic legislation. The lawsuit should not have led to the closure of the carpool lane in such an early stage. Sufficient legal basis existed for the carpool lane as well as positive test results. However, reasons of clarity, discrimination and safety issues led to the rash closure of the lane. According to documents from the Dutch parliament, vigorous efforts were to be made after the lane was closed to incorporate carpool definitions in the Dutch traffic regulations book. In April 1996, a newspaper article appeared in which the idea was presented to re-open the flexible lane on the A1 motorway for carpoolers again (Gollin, 1996). A spokeswoman of the Dutch Ministry of Traffic could not tell if there would be an adaptation of regulations in the near future. However, she stated that creating special lanes for a specific target group still is an important part of the governmental strategy to battle congestion issues.

However, none of the required changes for carpool lanes to have a legal basis in Dutch law books have yet been made. For a HOV lane to be successfully implemented in The Netherlands, first adaptations to the Dutch 'Wegenverkeerswet' have to be made. This study therefore tries to motivate the government to start legalizing carpool and other special target audience lanes. Belgium made some advances in its law book regarding carpooling. For example, drivers are insured by their work accident insurance when they make a diversion to pick-up some passengers, i.e. when they carpool to their work. The Belgium government politically and fiscally identifies carpoolers as a group with an individual identity (see the figure on the right).



**Traffic road signs for carpool lanes (Belgium)**

The exact effects of HOV lanes on the environment have not really been quantified to date. Politicians build HOV lanes because it makes them pro-environmental. The purpose of HOV lanes is to reduce congestion on highways and urban areas. However, since our current way of life and economy is dependent on automobiles and cannot be sustained without these vehicles, a reduction of the congestion level will in turn (and over time) attract other persons and thus vehicles to a certain road or bottleneck (Fontaine, 2009). Therefore, some opponents of HOV lanes claim, the objective desired by HOV implementers is in close contrast to real reductions of environmental damage. The latter is only attained when car usage is made less pleasant and dependency on automobiles is reduced. Fontaine (2009) argues walkable cities are one of the best opportunities that exist to reduce our overall carbon emissions and eco-footprint.

**Challenges of HOV lanes (success/failure factors)**

As stated before, a HOV lane reduces person-delay by: reducing the number of vehicle trips, giving priority to HOVs and thus maintaining free flow, and by increasing total road capacity. However, when an HOV lane is converted from a general purpose

lane, only the first two effects will exist. Dahlgren (1996) presented a model to estimate the shift to HOVs and the effects of this change of modality on the amount of vehicle delay hours. The model was focusing on freeway bottlenecks; however urban bottlenecks are expected to closely resemble this situation. The travel time differential between the general purpose lanes and the newly to be constructed HOV lane is the main predictor of the predicted number of travelers to switch travel mode.

According to Sammer et al (1999), flexible working hours, which are increasingly occurring, oppose a serious obstacle to carpooling as not all workers will be going home at the same time. However, the latter can also be used as an advantage to fine-tune travel times between occupants since workers in this case have a large degree of freedom to anticipate on work times of colleagues. The probability of commuters switching from driving alone to carpooling on HOV lanes is a function of (Dahlgren, 2002):

- ◇ the HOV trip (travel and waiting time, ambience, costs, inconvenience);
- ◇ the current (SOV) trip (travel time, costs, ambience, parking and driving situation);
- ◇ the person or individual making the trip (working hours, live and work location, income, childcare requirements, availability of automobile).

When a HOV lane is studied for implementation, its effectiveness is to be tested and compared with other alternatives to increase the average car occupancy, both in effectiveness and commercial value or potential. Summarized, important aspects that should receive attention are that the (stated) behavior and irritations of current users of the studied structural bottleneck location(s) should be concretized and it should be clear what facilities are necessary for increasing the potential of car sharing measures, and the policy making process should be aided with this information. The more restrictive an implemented measure is (e.g. a minimum required number of 4 persons to drive on the HOV lane), the more influence it will have on the car occupancy rate, but the less accepted it is amongst the population' (Sammer, et al., 1999). HOV lanes can best be implemented when certain conditions are met. The following conditions hold in cases where the HOV lane will be an additional lane, so the current road system for solo drivers will stay in place (Minister van verkeer en waterstaat, 1994; Dahlgren, 1996; Dahlgren, 1998; Sammer, et al., 1999):

Success factors:

- ◇ The initial proportion of HOVs is in the order of 15-20% of total volume;
- ◇ The initial delay is 25-30 minutes or more;
- ◇ Public transport should be able to benefit from the HOV lane;
- ◇ Promoting campaigns and/or park-and-pool facilities should be in place;
- ◇ (urban) Congestion should exist at the place where the carpool lane is implemented; making sure a time difference will exist;
- ◇ A potential growth in carpoolers/car sharers should exist at the location;
- ◇ The HOV lane should be safe and proper enforcement should be in place;
- ◇ A strong cooperation between local municipalities, police and justice has to exist;
- ◇ Successes should be measurable.

Failure factors:

- ◇ A high number of traffic accidents on or near the HOV lane;
- ◇ No cooperation from police, justice and local authorities, bad enforcement;
- ◇ Low traffic intensity on the lane, disappointing usage.

### 7.2.1. Estimating the shift to HOV lanes

The probability that one individual chooses to use a HOV lane can be represented with the following logit model, where H stands for HOV lane characteristics and L for single-occupancy vehicle (SOV) or low-occupancy vehicle (LOV) characteristics, i.e. persons driving alone (Dahlgren, 1998).

$$P_{HOV} = \frac{e^{\sum \beta_i H_i}}{e^{\sum \beta_i H_i} + e^{\sum \beta_i L_i}} = \frac{1}{1 + e^{\sum \beta_i L_i - \beta_i H_i}} = \frac{1}{1 + \gamma e^{\sum \beta_t (T_L - T_H)}}$$

This equation is however just taking one parameter into account, that of the HOV lane. Of course, many more factors are influencing the resulting shift from solo drivers to carpooling. The most important factors that will be selected are summarized in figure 4. Their importance will be surveyed and a model created which keeps the most important factors in determining the stimulating value in mind.

The effectiveness of a HOV lane can be measured in many different ways. Among others, the shift to HOV lanes is based upon figures relating to vehicle volume, person volume, travel time savings, congestion reduction, average vehicle occupancy, vehicle speed, trip (travel time) reliability. No clear answer exists on what measurement to use in a specific context. HOV lanes for example often have a very large impact on how many people take the bus. In Leeds, the HOV lane helped increase the percentage of people who take the bus from 1% to 20% in the space of 4 years! The HOV lane in South Gloucestershire increased the percentage of cars that take 2 or more people from 20% to 27%. The model that is created in chapter five will calculate more precisely the shift to carpoolers due to the HOV lanes, based on commuters' preferences.

### 7.2.2. Allowed vehicle types and enforcement

Different categories of vehicles are allowed to drive on HOV lanes in each country. Most allow motorcycles besides cars to drive on the lane. Buses should also be allowed to drive on the HOV lane at all times. However, taxis, limousines, electric or hybrid vehicles, and commercial trucks carrying the minimum amount of people are only allowed in some cases. The minimum required amount of people is set by policy making. Also, emergency vehicles should be allowed to use the HOV lane. To facilitate enforcement, no age restrictions or purposes of the trip for passengers should be in place.

Since enforcement is a critical element for obtaining a successful HOV lane, operating requirements like vehicle occupancy levels should be maintained. This discourages unauthorized vehicles to use the lane. As a result, travel time savings on the lane are safeguarded and a safe operating environment is ensured (Wikander & Goodin, 2006). Most of all, enforcement should be visible and effective so as to promote fairness and acceptance of the HOV project. A broad policy program should be developed to

ensure all appropriate agencies are involved and have a good understanding of the project and the need for enforcement. In the United States, violation rates exceeding 60% have been measured when effective enforcement is absent. Barrier-separated facilities however show lower levels of violators, since these are easier to enforce.

Powers for enforcement of an HOV lane depends to certain extent on the location (i.e. being a highway or a local/municipal road). Federal/national, state or local ordinances combined can be responsible for enforcement on the HOV lanes. In the Netherlands however, this difference is smaller. The police (either local or national) will be responsible for enforcing operating requirements. In Seattle, Washington, a special program was put in place, called HERO. Signs and communication techniques provide HOV users with a telephone number they can call to report violators. Anonymously, the time and date, location and license number is sent to the operator. In the planning stage of the HOV lane, enforcement agencies should be involved in the decision making process. The design should be tested if effective enforcement is possible. Also funding and staffing of enforcement personnel should be thought about in advance.

The penalty for driving on an HOV lane can be points on license records or a fine. In some states, like Northern Virginia, fines can rise as high as \$1039 for a fourth offense (plus 3 points) (Wikander & Goodin, 2006). In The Netherlands, during the time the lane was open, 250 people received a fine because the minimum occupancy level was not met. At this time, the cash penalty was one hundred guilders. After closing the lane, the public prosecutor ruled these people will not get their money back. Cases that were still being handled were dropped (Trouw, 1994).

Various difficulties have been encountered in trying to count passengers. Enforcement personnel have a hard time identifying the number of vehicle occupants. Poor lighting conditions, dark window tints, backseat passengers, and high vehicle speeds can impose problems. In the past, automated methods were tried as means to count passengers. However, photo enforcement was defeated in the majority of courts in since this imposed a breach of privacy. Also, and more powerful image processing should be able to recognize faces (instead of dolls as displayed in figure 8) (Wikander & Goodin, 2006). Tags on the windscreen of cars can also be used. Only allowed vehicles should be given such a tag, or vehicles paying toll.



**Using dolls to deceive police officers on the actual vehicle occupancy level**

The HOV lane alternative builds upon similar projects in other countries (mainly the United Kingdom and United States). For example, in the city of California, HOV lanes have effectively been implemented since 1969 (Kwon & Varaiya, 2008). The first HOV lane was a two lane 3+ facility shared by busses and carpools. The average travel time on the

HOV lane was 29 minutes compared to 64 minutes on the general traffic lanes. In the morning rush hour, on average 31.700 people were transported in 8,600 vehicles on the two HOV lanes compared to the 3 general purpose lanes carrying 23.000 people in 21,300 vehicles (Samuel, 2005). Based on a study carried out by the Federal Highway Administration assessing HOV lane performance, in 2008 there were a total of 345 operational HOV lanes in the United States (Chang, et al., 2008). In Los Angeles more than 600 kilometers of HOV lanes are already operational (KPVV, 2006) and 89% of the local population supports the concept. California is the state with the most HOV lanes (88), followed by Minnesota (83), Washington State (41), Texas (35) and Virginia (21). These HOV facilities almost all (except one) have just one lane in each direction. The total length of all HOV lanes in the United States in 2008 equaled around 4,000 miles (almost 6,500km). This is more than two times the length of all Dutch highways).

In the United Kingdom and the United States, the creation of HOV lanes was very popular at the end of last century (Deelen, 2012). Policymakers saw these as the solutions to congestion problems. Because the amount of cars on the road was excessive, and it was hard to get people to not drive on the highway, it had to be made profitable for people to carpool. By doing so, demand would fall while everybody still could make use of the road.



**Southern California’s regional network of more than 700 miles of carpool lanes**

Examples of levels of potential travel time reduction that a HOV lane can deliver are given in the table below for multiple routes in Northern Virginia. As can be seen from this table, a decrease in travel time up to 53% is reached. However it should be notice that these figures hold for highways. It is expected realized levels on urban infrastructure will differ significantly (positively or negatively).

Route	HOV lane travel time (minutes)	Conventional lane travel time (minutes)	Minutes saved with HOV	Percentage of minutes saved
I-95/I-395 (northbound)	27	58	31	53%
I-66 (eastbound)*	41	69	28	41%
VA 267/I-66 (eastbound)	31	51	20	39%

**Potential reduction in travel time due to a HOV lane (Eichler, et al., 2008)**

### **US: Washington**

The Washington State Department of Transportation carried out a study in 2007 among carpoolers using an HOV lane to question them about how HOV lanes encouraged them to take the bus, carpool or vanpool (Washington State Department of Transportation , 2007). The main results of the study were:

- ◇ HOV lanes provide an incentive to use shared-rides: 18% said they would switch to solo driving if no HOV lane was available;
- ◇ People choose shared rides for reasons other than time savings and reliability: reduced stress, convenience, and cost and time savings cited as main reasons for using HOV facility;
- ◇ Employer incentives play a large role in the decision to take shared rides: 87% of bus and vanpoolers and 24% of carpoolers make use of flexible work hours and discounted parking;

### **UK: Leeds**

In 1998, UK's first high occupancy vehicle lane was implemented as a pilot, part of the EU research project called ICARO (Sammer, et al., 1999; Department for transport, 2004). The original route experienced severe congestion and few public transport priority measures were in place. The HOV lane with a length of almost 2 kilometers goes to the west of Leeds city center. It soon became permanent. Before implementation of the HOV lane, one-third of all vehicles carried two-thirds of all people. Main impacts of the HOV lane can be summarized as follows (KPVV Weblog, 2012):

- ◇ Immediately after opening 20% traffic reduction (driver avoidance);
- ◇ Average car occupancy rose from 1.35 to 1.43 by June 1999 and to 1.51 in 2002;
- ◇ The number of HOVs in the morning peak period increased by 5%;
- ◇ Bus usage in the morning peak increased by 1%;
- ◇ Morning peak hour travel time savings for HOVs and buses on average 4 minutes;
- ◇ Support for HOV lane grew from 55% to 66%.

The most important finding however was that by giving priority to HOVs, two equal length queues were transformed in a longer queue in the non-HOV lane and a short queue in the HOV lane. There was no evidence that non-HOV queues were extending.

### **UK: Bristol**

The city council of Bristol was planning to implement a bus lane on the ring road near the city center. However, bus frequencies were too low to justify reallocating road space to buses alone. Therefore the HOV lane was opened to buses, taxis, and cars with 2+ occupants. Main results were a drop in single occupancy vehicles from 80% to 68% and a decrease in journey times from 20 to 6 minutes in the HOV lane, and 12 minutes in the general lane (Knowledgebase on sustainable urban land use and transport, 2005).

### **Spain: Madrid**

A 16 kilometer motorway two-lane HOV scheme on the N-VI motorway into Madrid was opened in January 1995. The two HOV lanes carry 59.3% of the morning rush hour travelers, while the 3 general lanes carry only 40.7% of travelers. The lanes attracted a growth in public transport mode share, rather than car sharing. Average occupancy in cars increased from 1.36 in 1991 to 1.67 in 1997. The modal split changed so that the use of buses had increased from 17% before opening the HOV lanes to 26% in 1997. Reduced travel times were measured in and out of Madrid as a result of the HOV lanes.

### **Greece: Thessaloniki**

Implementation of an HOV lane from an open area at the south-east part of the city running towards the city center had some unintended results. A slight rise in pollutant emissions and a drop in bus travelers were noticed. However, when the implementation of the HOV lane was combined with supplementary traffic management measures and facilities, it showed a positive impact on the overall road network (Sammer, et al., 1999). For example, the open area at the beginning of the HOV lane might be used as a park and ride facility or as a car pooling facility. A rise in the average occupancy of HOV's was observed.

### **Toronto: Canada**

In 2007, the government of the province Ontario, Canada, released an ambitious plan to add over 450 kilometers of HOV lanes. Its main goals were a reduction in travel time and a decrease of 20% in the province's total carbon footprint. However, if these goals could be used were not sure, because there wouldn't be an increase in law enforcement. The plan therefore depends on good behavior from drivers. In 2014 the first 150 kilometers of these lanes were proposed (Criger, 2014).

### **Belgium: Brussels**

At the end of October 2013, the Flemish government announced plans to restructure parts of the ring around Brussels. The idea was to separate local and passing traffic on different lanes. The chairman of the Centre Démocrate Humaniste (CDH) is advocating for the implementation of a carpool lane. He delivered a plan that promotes carpooling and the construction of special carpool lanes (Nieuwsblad.be, 2013).



**Freeway HOV Lanes in North America (Fuhs & Obenberger, 2002)**

## Appendix D – Overview of important variables affecting choice to carpool

Attribute	Sources (literature)
Household car ownership	Dahlgren (1998) ; Katzev (2003); Huwer (2004); Crockett, et al. (2010)
Interest in carpooling	Katzev (2003); Crockett, et al. (2010);
Sharing with family/friend versus stranger	Crockett, et al. (2010)
Reduction of yearly emissions because of	Beirão & Sarsfield Cabral (2007); Anwar (2009)
Desire to contribute to a better environment	Katzev (2003); Huwer (2004); Beirão & Sarsfield Cabral (2007); Li et al.
Reduction in nuisance level due to	Federal Highway Administration (1996); Katzev (2003)
Availability of other modes of travel	Federal Highway Administration (1996); Fujii, et al. (2001); Kennisinstituut
Purpose of trip	Huwer (2004); Crockett et al. (2010)
Satisfaction with public transport	Huwer (2004); Beirão & Sarsfield Cabral (2007)
Need vehicle at work location	Katzev (2003)
Sharing vehicle costs	Dahlgren (1998); Katzev (2003); Li et al. (2007); Beirão & Sarsfield Cabral
Reliability of travel time	Li et al. (2007); Beirão & Sarsfield Cabral (2007) ; Crockett et al. (2010)
Level of comfort in vehicle	Beirão & Sarsfield Cabral (2007); Anwar (2009); Crockett et al. (2010)
Autonomy / freedom / flexibility	Crockett et al. (2010); Beirão & Sarsfield Cabral (2007); Anwar (2009)
Guaranteed trip home	Federal Highway Administration (1996)
Information provision pre-journey	Crockett et al. (2010); Kennisinstituut voor mobiliteitsbeleid, 2008
Promotion/ awareness / familiarity	Crockett et al. (2010); Kennisinstituut voor mobiliteitsbeleid, 2008;
Vehicle expenses (incl. parking)	Dahlgren (1998) ; Crockett et al. (2010)
Travel time saving	Giuliano et al. (1990); Dahlgren (1998); Li et al. (2007); Li et al. (2007);
Carpool travel time/in-vehicle time (IVT)	Train (1979); Beirão & Sarsfield Cabral (2007)
Time required arranging the carpool and reaching	Dahlgren (1998) ; Crockett et al. (2010)
Designated parking space	Li et al. (2007); Beirão & Sarsfield Cabral (2007); Anwar (2009) ; Crockett et
Existing travel patterns	Kennisinstituut voor mobiliteitsbeleid, (2008) ; Crockett et al. (2010)
Frequency of trip	Crockett et al. (2010)
Expected violation rate	Federal Highway Administration (1996)
Number of transfers	Train (1979) ; Ben-Akiva (2002)
Desired ambience/safety in waiting area and	Dahlgren (1998); Katzev (2003); Huwer (2004); Beirão & Sarsfield Cabral
Opportunity to carry luggage	Dahlgren (1998); Li et al. (2007)
Driving conditions (weather)	Crockett et al. (2010)
Number of required occupants per HOV	Giuliano et al. (1990); Ben-Akiva (2002); Crockett et al. (2010)
Distance/vehicle miles traveled (VMT)	Giuliano et al. (1990) ; Dahlgren (1998) ; Huwer (2004)
Consideration of public transport alternatives and	Crockett et al. (2010)
Presence of children	Huwer (2004) ; Li et al. (2007) ; Crockett et al. (2010)
Toll costs	Li et al. (2007)
Access to HOV lanes	Beirão & Sarsfield Cabral (2007); Li et al. (2007)
Initial number of carpoolers (HOVs)	Dahlgren (2002)
Opportunity to work, relax and socialize while	Li et al. (2007)
Carpool partner matching program at work	Li et al. (2007); Kennisinstituut voor mobiliteitsbeleid, (2008)
Flexible working hours	Dahlgren (2002)
Difference in work times carpoolers	Dahlgren (2002)
Routine habits	Fujii, et al. (2001); Beirão & Sarsfield Cabral (2007); Kennisinstituut voor
Induced demand	Dahlgren (1998)

## Appendix E – Random Utility Theory

In random utility models, a decision maker ( $n$ ) faces a choice among  $J$  alternatives. From each alternative, a specific level of utility can be obtained. In random utility theory, the respondent will only choose a certain alternative, if the utility he or she derives from this alternative is greater than all other alternatives in the choice set (Akiva & Lerman, 1985; Louviere, et al., 2007; Train, 2009):

$$P_n(i) = P(U_{in} \geq U_{jn}, \forall j \neq i)$$

where  $P_n(i)$  is the probability that decision maker  $n$  chooses alternative  $i$ , and  $U_{in}$  and  $U_{jn}$  are respective the utilities of alternative  $i$  and  $j$  in the decision maker's perspective.

The next formula describes the utility function, as used above, for a certain alternative ( $i$ ) for a certain decision maker ( $n$ ). The utility function is dependent on a certain list of factors ( $x$ ).

$$U_{in} = f(X_{in})$$

where  $X_{in}$  is one of the factors belonging to alternative  $i$ , making up the utility for decision maker  $n$ .

The utility of a certain alternative usually is expressed as a linear combination of factors. The relative effect of each factor is expressed by its coefficient ( $\beta$ ). The word 'relative' is used to express this coefficient is different for every alternative. The value of the coefficient for each factor and alternative will be calculated by using multinomial logit (MNL) regression and are often based on the maximum likelihood principle. When the relative effects or importance of various factors, multiplied by their values, are summed up, the utility of a certain alternative for a decision maker is determined (Gul & Pesendorfer, 2006):

$$U_{in} = \sum_k \beta_k * x_{ink}$$

where  $\beta_k$  is the relative coefficient belonging to factor  $k$ , and  $x_{ink}$  is the value of factor  $k$  for alternative  $i$  in the perception of decision maker  $n$ .

The parameters of the model (i.e. the coefficients) are derived by making use of multiple regression analysis. The resulting utility for all alternatives can depend on the same generic variables, but coefficients will be different for each alternative (Train, 2009). It is also possible that alternative-specific attributes exist. Because the principle of maximum likelihood is used in estimating the coefficients in the multinomial logit regression model, it should be kept in mind an error term will exist because either the model is not complete since factors will be missing, or factors will exist that are not correctly measured or exactly estimated.

The utility function as presented above therefore exists of two parts: the accountable or predicted part and the error term. The error term is included because consumers may not choose what seems to the analyst to be the preferred alternative. These variations in choice can be explained by proposing a random element as a

component of the utility function (Adamowicz, et al., 1998). It is not known how the unobserved component is distributed across the sampled population (Bliemer & Rose, 2005). This error term is given in the following equation:

$$U_{in} = V_{in} + \varepsilon_{in}$$

where  $V_{in}$  is the original utility function as presented above and  $\varepsilon_{in}$  is the error term; both hold for alternative  $i$  and decision maker  $n$ .

Utility is a dimensionless variable. Only differences in utility matter and the scale of utility is arbitrary. Now, after the utility function is derived, the probability that a respondent will choose a certain alternative can be calculated as follows:

$$\begin{aligned} P_n(i) &= P(U_{in} > U_{jn}, \forall j) \\ P_n(i) &= P(V_{in} + \varepsilon_{in} > V_{jn} + \varepsilon_{jn}, \forall j \neq i) \\ P_n(i) &= P(V_{in} - V_{jn} > \varepsilon_{jn} - \varepsilon_{in}, \forall j \neq i) \end{aligned}$$

It is assumed that the ratio of probabilities of choosing any two alternatives is independent of the choice set, so the property of *independence of irrelevant attributes* (IIA) holds (Train, 2009). This principle is one of the main assumptions of the MNL model and implies there is no correlation among alternatives. This leads to the assumption that the error term ( $\varepsilon$ ) is also independent and identically distributed, and the difference between both error terms is logistically divided. *'The critical part of the assumption is that the unobserved factors are uncorrelated over alternatives, as well as having the same variance for all alternatives'* (Train, 2009). The observable or accountable part ( $V$ ) can be expressed in the following exponential function, where  $P_n(i)$  is calculated, i.e. the probability respondent  $n$  will choose alternative  $i$ .

$$P_n(i) = \frac{e^{V_{in}}}{\sum_j e^{V_{jn}}} = \frac{1}{\sum_j e^{-(V_{in}-V_{jn})}} = \frac{1}{\sum_j e^{-\sum_k \beta_k (x_{ink} - x_{jnk})}}$$

The multinomial logit model is one of the most widely used discrete choice models in the transportation research field. It is used for among others: mode choice, road pricing, and evaluation of environmental impacts of transportation studies (Hensher, 1994; Louviere, et al., 2000).

Appendix F – Orthogonal design and choice set distribution

Travel- and wait time meeting location	Travel time (carpool) vehicle	Uncertainty trip travel time	Costs of trip	Number of persons in (carpool) vehicle	Availability and distance parking	Availability car/bicycle at work location	Flexibility of trip times	CHOICE SET	question group
1	2	5	6	10	11	12	13		
0	0	0	0	0	0	0	0	2	1b
0	0	1	1	1	2	1	2	1	1a
0	0	2	2	2	1	2	1	3	7c
0	1	0	0	1	1	2	2	1	2a
0	1	1	1	2	0	0	1	3	1c
0	1	2	2	0	2	1	0	2	8b
0	2	0	0	2	2	1	1	3	5c
0	2	1	1	0	1	2	0	2	5b
0	2	2	2	1	0	0	2	1	5a
1	0	0	1	1	1	1	1	3	9c
1	0	1	2	2	0	2	0	1	6a
1	0	2	0	0	2	0	2	2	9b
1	1	0	1	2	2	0	0	2	6b
1	1	1	2	0	1	1	2	3	3c
1	1	2	0	1	0	2	1	3	2c
1	2	0	1	0	0	2	2	1	9a
1	2	1	2	1	2	0	1	2	4b
1	2	2	0	2	1	1	0	1	4a
2	0	0	2	2	2	2	2	2	2b
2	0	1	0	0	1	0	1	3	8c
2	0	2	1	1	0	1	0	3	6c
2	1	0	2	0	0	1	1	1	8a
2	1	1	0	1	2	2	0	1	7a
2	1	2	1	2	1	0	2	2	7b
2	2	0	2	1	1	0	0	3	4c
2	2	1	0	2	0	1	2	2	3b
2	2	2	1	0	2	2	1	1	3a

## Appendix G - Questionnaire



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### Welkom!

Eerst worden drie selectievragen gesteld om te bepalen of u tot de doelgroep van deze enquête hoort. Bij elke vraag wordt direct getest of u tot de doelgroep behoort. Is dit niet het geval dan wordt u teruggeleid naar de pagina van PanelClix. Hieronder volgt de eerste vraag.

#### Hoe is uw werksituatie?

Ik werk

- altijd thuis of in mijn eigen woonplaats
- altijd in een andere plaats dan mijn eigen woonplaats
- afwisselend in mijn eigen woonplaats en een andere plaats

[Start vragenlijst](#)

---

Aan de hand van onderstaande vragen wordt bepaald of u behoort tot de doelgroep van deze vragenlijst.

#### In welke stad (naast uw eigen woonplaats) bent u werkzaam?

Eindhoven ▼

#### Hoe reist u normaal naar uw werk?

Ik reis (vrijwel) altijd:

- met het openbaar vervoer naar mijn werk
- met de auto naar mijn werk
- carpoolend naar mijn werk
- op een andere manier naar mijn werk

[Vorige](#)

[Volgende](#)

## 1. Kenmerken van uw huidige woon-werk verplaatsing

### U voldoet aan de selectiecriteria van deze vragenlijst.

In deze vragenlijst wordt onderzocht in welke mate het gedrag en de beslissingen van forensen beïnvloed wordt door een carpoolstrook. Dit is een aparte rijstrook waar forensen alleen op mogen rijden indien zij carpoolen en dus met meerdere personen in het voertuig zitten. Omdat momenteel het grootste deel van de forensen zonder medepassagiers naar het werk reist, kan deze strook carpoolers specifieke voordelen bieden ten opzichte van de normale rijba(a)n(en), zoals een kortere reistijd en minder onzekerheid in de reistijd. Tevens gelden de conventionele voordelen van carpoolen zoals het delen van de reiskosten.

### De vragenlijst zal nu starten en bestaat uit vier delen:

1. Kenmerken van uw huidige woon-werk verplaatsing
2. Keuzemogelijkheden huidige woon-werk verplaatsing en carpool alternatief
3. Vragen om uw houding ten opzichte van carpoolen in kaart te brengen
4. Enkele persoonskenmerken zoals uw leeftijd en geslacht

In het eerste deel van de vragenlijst wordt u gevraagd de kenmerken van uw huidige woon-werk verplaatsing te selecteren. Graag gemiddelde waarden invullen van uw gangbare woon-werk reis.

Bedankt voor uw aandacht en veel succes bij het invullen!

Andreas Lem  
Student Construction Management & Engineering  
Technische Universiteit Eindhoven

*Uw gegevens zullen niet gepubliceerd of voor commerciële doeleinden gebruikt worden. Alle data wordt vertrouwelijk en anoniem verwerkt en enkel voor dit afstudeeronderzoek gebruikt.*

## 1. Kenmerken van uw huidige woon-werk verplaatsing

### Hoe lang doet u gemiddeld over een enkele woon-werk verplaatsing van deur tot deur?

- Minder dan 20 minuten
- Tussen 20 en 40 minuten
- Tussen 41 en 60 minuten
- Meer dan 60 minuten

### Hoe is de parkeersituatie momenteel op uw werklocatie?

- Uitstekend, ik heb een gereserveerde parkeerplek of er is voldoende gelegenheid dichtbij
- Voldoende, een parkeerplek is makkelijk te vinden en/of ligt dichtbij
- Slecht, een parkeerplek is moeilijk te vinden en/of ligt ver weg

### Hoeveel tijd calculeert u in bovenop de reistijd om (eventuele) vertraging(en) onderweg te compenseren?

- Minder dan 5 minuten
- Tussen 5 en 10 minuten
- Tussen 11 en 15 minuten
- Meer dan 15 minuten

Vorige

Volgende



### 1. Kenmerken van uw huidige woon-werk verplaatsing

Combineert u een woon-werk verplaatsing wel eens met andere activiteiten (meerdere antwoorden mogelijk)?

- Nee, geen andere activiteiten
- Ja, winkelen
- Ja, bezoek aan vrienden/familie
- Ja, familieleden ophalen of wegbrengen (werk/school)
- Ja, sportschool/vereniging
- Ja, andere reden, namelijk:

[Vorige](#)[Volgende](#)

### 1. Kenmerken van uw huidige woon-werk verplaatsing

Als u met de auto naar uw werk reist, is dit met uw eigen auto of een bedrijfsauto?

- Eigen auto
- Bedrijfs- of leaseauto

Ontvangt u een kilometervergoeding of andere bijdrage in de reiskosten van uw werkgever?

- Ja
- Nee

In deze vragenlijst is er meer informatie nodig over de brandstof-, parkeer- en tolkosten van uw enkele woon-werk rit. Wilt u deze zelf invullen of het programma laten schatten? Indien u niet met uw eigen auto reist gaat het om de kosten alsof u deze zelf zou moeten betalen (in gehele cijfers).

- Ik wil dat de kosten worden geschat
- Ik wil deze kosten zelf invullen

[Vorige](#)[Volgende](#)

Wat is ongeveer de afstand tussen uw woon en werk locatie (in gehele kilometers)

 kilometer

Wat voor type auto heeft u?

- Mini/compacte klasse (energielabel A/B)
- Middenklasse/MPVs (energielabel C/D)
- Hogere klasse/SUVs (energielabel E/F)
- Top klasse/sportwagens (energielabel G)

Als u naast brandstofkosten ook parkeer- of tolkosten maakt, vul deze hier in:

[Vorige](#)[Volgende](#)



### 1. Kenmerken van uw huidige woon-werk verplaatsing

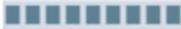
Uw totale reiskosten voor een enkele woon-werk rit zijn (geschat op): **11 euro**

Als u het hier niet mee eens bent, gaat u alstublieft terug om deze aan te passen.

Om verder te gaan met de vragenlijst, klik op volgende.

Vorige

Volgende



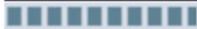
### 1. Kenmerken van uw huidige woon-werk verplaatsing

**Mijn werkgever stimuleert mij (meerdere antwoorden mogelijk):**

- niet om een andere vervoerswijze te gebruiken of ik ben hiervan niet op de hoogte
- om gebruik te maken van het openbaar vervoer
- om de spits te mijden
- om te carpoolen
- om met de fiets of lopend naar het werk te komen
- op een andere manier, namelijk:

Vorige

Volgende



### 1. Kenmerken van uw huidige woon-werk verplaatsing

**U heeft aangegeven dat uw werkgever invloed probeert uit te oefenen op uw forensgedrag. Dit gebeurt doordat mijn werkgever (meerdere antwoorden mogelijk):**

- vergoedingen beschikbaar stelt (bijvoorbeeld voor openbaar vervoer)
- flexibele werktijden aanbiedt
- een gereserveerde parkeerplaats aanbiedt
- mij de beschikking over een bedrijfsauto of fiets biedt
- mij de mogelijkheid biedt om (af en toe) thuis te werken
- mij een bijdrage in de aanschaf van een fiets biedt
- een carpool matching programma aanbiedt
- mij een andere stimulans biedt, namelijk:

Vorige

Volgende



### 1. Kenmerken van uw huidige woon-werk verplaatsing

**Carpoolt u wel eens naar uw werk? (u carpoolt als meerdere inzittenden in een auto op weg zijn naar hun werk)**

- Nee, nooit
- Ja, sporadisch (minder dan 1 keer per maand)
- Ja, af en toe (tussen 1 en 5 keer per maand)
- Ja, regelmatig (meer dan 5 keer per maand)

Vorige

Volgende

## 1. Kenmerken van uw huidige woon-werk verplaatsing

U heeft aangegeven dat u (wel eens) carpoolt naar uw werk, met wie is dit meestal?

- Collega's van mijn eigen werk
- Werknemers van een bedrijf in de buurt
- Vrienden of familieleden die in de buurt werken
- Andere personen, namelijk:

Vorige

Volgende

## 2. Keuzesituaties

U bent aangekomen bij het tweede deel van deze vragenlijst. Hier wordt u gevraagd om negen keer een keuze te maken tussen twee verschillende vervoerwijzen om uw werklocatie te bereiken: 'solo rijden' of 'carpoolen'. Nadat u een keuze heeft gemaakt wordt u gevraagd het gepresenteerde carpoolalternatief te beoordelen.

### Solo rijden

U reist zonder medepassagiers naar uw werk. De herkomst van uw rit is uw woonlocatie en de bestemming is uw werklocatie. De variabelen zijn gebaseerd op uw huidige woon-werk verplaatsing

### Carpoolen

U reist met andere personen naar uw werk. De herkomst van uw rit kan uw woonlocatie zijn, maar kan ook een (centrale) opstaplocatie zijn. Extra variabelen zijn: het wachten op medepassagiers of een minimum aantal personen om op de carpoolstrook te mogen rijden.

In het vervolg van deze vragenlijst mag u aannemen dat:

- u in de huidige situatie alleen naar uw werk rijdt;
- de rit telkens rechtstreeks van uw huis naar uw werk is;
- u in eerste instantie zelf de kosten betaalt van deze reis;
- reiskostenvergoedingen blijven bestaan wanneer u gaat carpoolen;
- ook als u carpoolt dient u zelf de auto te parkeren.

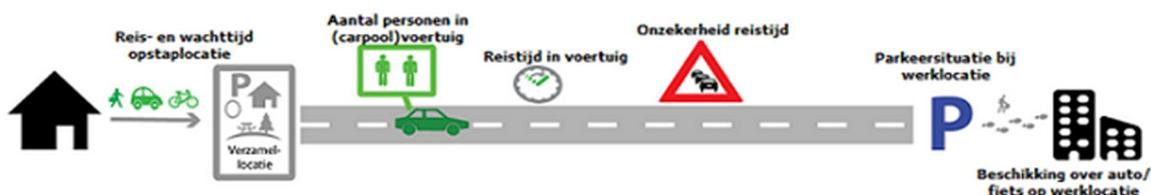
Vorige

Volgende

## 2. Keuzesituaties

De alternatieven in de keuzesituaties zijn telkens opgebouwd uit 8 variabelen (zoals hieronder weergegeven). Elke variabele kan 3 verschillende waarden aannemen. Het carpoolalternatief wordt nu nader toegelicht:

### Uitleg carpoolalternatief



#### Naam van variabele

1. Reis- en wachttijd opstaplocatie
2. Reistijd in carpoolvoertuig
3. Onzekerheid in reistijd
4. Kosten van enkele reis
5. Aantal personen in voertuig
6. Parkeersituatie op werklocatie
7. Beschikking over auto/fiets
8. Flexibiliteit van rittijden

#### Omschrijving

- : benodigde tijd om een (eventuele) opstaplocatie te bereiken en te wachten op medereizigers
- : daadwerkelijke reistijd van woon- of opstaplocatie tot werklocatie
- : ingecalculeerde extra tijd om vertragingen onderweg op te vangen
- : directe kosten van enkele reis (benzine, tol, parkeren)
- : het totaal aantal inzittenden van het (carpool)voertuig gedurende de rit
- : parkeerplek op werklocatie (afstand en vindbaarheid)
- : beschikking over (bedrijfs)auto of fiets op werklocatie gedurende werkdag
- : mogelijkheid/ruimte om eerder of later te vertrekken dan gepland (flexibiliteit medepassagiers)

Bent u tijdens het doorlopen van de enquête vergeten wat precies wordt bedoeld met de genoemde variabelen, dan kunt u op elke pagina op het icoontje onderaan de tabel klikken om de instructie nog eens te bekijken.

Op de volgende pagina volgt nu eerst een [keuzevoorbeeld](#).

Vorige

Volgende

## 2. Keuzesituaties



Op deze pagina wordt een [voorbeeld](#) keuzesituatie gepresenteerd.

In elke situatie heeft u de keuze tussen een alternatief gebaseerd op uw huidige rit waarin u solo naar uw werk rijdt ([links, blijft telkens hetzelfde](#)) en een alternatief waarbij u naar uw werk carpoolt. Beide alternatieven zijn omschreven middels de hiervoor gepresenteerde variabelen. Welke vervoerwijze kiest u in de volgende situatie?

Kenmerken	Solo rijden	Carpoolen
Reis- en wachttijd opstaplocatie	0 minuten	4 minuten
Reistijd in (carpool)voertuig	30 minuten	21 minuten
Onzekerheid reistijd	8 minuten	6 minuten
<b>Totale geplande reistijd</b>	<b>38 minuten</b>	<b>31 minuten</b>
Kosten van enkele reis	9 euro	6 euro
Aantal personen in voertuig	1	3
Parkeersituatie bij werklocatie	<i>Uitstekend</i>	<i>Uitstekend</i>
Beschikking over auto/fiets op werklocatie	<i>Auto</i>	<i>Geen</i>
Flexibiliteit rittijden (ruimte om eerder/latere vertrekken)	<i>Hoog</i>	<i>Laag</i>
Welke vervoerwijze kiest u?	<input type="radio"/>	<input checked="" type="radio"/>
Welke score geeft u het carpoolalternatief?		Goed <input type="button" value="v"/>

Klik hier voor uitleg over de variabelen:

Vorige

Volgende



## 2. Keuzesituaties



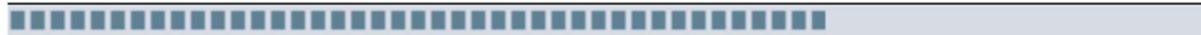
Op deze pagina wordt de eerste (van negen) keuzesituatie gepresenteerd.

U hebt de keuze tussen een alternatief gebaseerd op uw huidige rit waarin u solo naar uw werk rijdt (links, blijft telkens hetzelfde) en een alternatief waarbij u naar uw werk carpoolt. Welke vervoerwijze kiest u in de volgende situatie?

Kenmerken	Solo rijden	Carpoolen
Reis- en wachttijd opstaplocatie	0 minuten	0 minuten
Reistijd in (carpool)voertuig	30 minuten	30 minuten
Onzekerheid reistijd	8 minuten	6 minuten
<b>Totale geplande reistijd</b>	<b>38 minuten</b>	<b>36 minuten</b>
Kosten van enkele reis	9 euro	6 euro
Aantal personen in voertuig	1	3
Parkeersituatie bij werklocatie	Uitstekend	Slecht
Beschikbaarheid over auto/fiets op werklocatie	Auto	Fiets
Flexibiliteit van rittijden	Hoog	Laag
Welke vervoerwijze kiest u?	<input type="radio"/>	<input checked="" type="radio"/>
Welke score geeft u het carpoolalternatief?		Neutraal ▼

Klik hier voor uitleg over de variabelen:

Vorige **Volgende**



## 3. Houding ten opzichte van carpoolaspecten

U bent aangekomen bij het derde deel van deze vragenlijst. In dit deel wordt u gevraagd kort aan te geven hoe belangrijk u onderstaande aspecten vindt bij uw afweging om te carpoolen. De aspecten zijn gegroepeerd in vijf onderdelen, namelijk:

- : *Formatie en organisatie carpoolrit*
- : *Kenmerken van de carpoolrit*
- : *Psychologische aspecten van carpoolen*
- : *Economische aspecten van carpoolen*
- : *Kenmerken van een carpoolstrook*

Vorige **Volgende**

### 3. Houding ten opzichte van carpoolen

Formatie en organisatie van de carpool (1/5)

Geef aan hoeveel waarde u hecht aan onderstaande aspecten in uw keuze om te carpoolen

Aspect	Zeer beperkt belang	Beperkt belang	Gemiddeld belang	Redelijk belang	Zeer veel belang
Hoog niveau van veiligheid op verzamellocatie	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Gemoedelijke sfeer op verzamellocatie	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Uitgebreide voorzieningen op verzamellocatie	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Gemak en mogelijkheden om carpool te organiseren	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beschikbaarheid en eenvoud digitaal of door werkgever geboden matching programma	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Aanwezigheid van centrale opstaplocatie of carpooplein	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Vorige

Volgende

### 3. Houding ten opzichte van carpoolen

Kenmerken van de carpoolrit (2/5)

Geef aan hoeveel waarde u hecht aan onderstaande aspecten in uw keuze om te carpoolen

Aspect	Zeer beperkt belang	Beperkt belang	Gemiddeld belang	Redelijk belang	Zeer veel belang
Hoog niveau van veiligheid in carpoolvoertuig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Gemoedelijke sfeer in carpoolvoertuig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Hoog comfort van het carpoolvoertuig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Mogelijkheid om onderweg te werken	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Een vermindering van schadelijke uitlaatgassen door samen reizen	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Carpoolen met een vaste groep	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Carpoolen met een bekende	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

Vorige

Volgende

**3. Houding ten opzichte van carpoolen**

Psychologische aspecten van carpoolen (3/5)

Geef aan hoeveel waarde u hecht aan onderstaande aspecten in uw keuze om te carpoolen

Aspect	Zeer beperkt belang	Beperkt belang	Gemiddeld belang	Redelijk belang	Zeer veel belang
Afwisselen van de carpoolrol (chauffeur of passagier)	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gebruik van de auto als vorm van status	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Flexibiliteit en verplaatsingswens (autobezit) gedurende werkdag	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Mogelijkheid tot sociale interactie met medereizigers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>

Vorige

Volgende

**3. Houding ten opzichte van carpoolen**

Economische aspecten van carpoolen (4/5)

Geef aan hoeveel waarde u hecht aan onderstaande aspecten in uw keuze om te carpoolen

Aspect	Zeer beperkt belang	Beperkt belang	Gemiddeld belang	Redelijk belang	Zeer veel belang
Fiscale voordelen voor carpoolers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Verdeling van de kosten over inzittenden	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>

Vorige

Volgende

**3. Houding ten opzichte van carpoolen**

Kenmerken van een carpoolstrook (5/5)

Geef aan hoeveel waarde u hecht aan onderstaande aspecten in uw keuze om te carpoolen

Aspect	Zeer beperkt belang	Beperkt belang	Gemiddeld belang	Redelijk belang	Zeer veel belang
Aanwezigheid van een aparte rijstrook voor carpoolers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Tolheffing op overige rijbanen, carpoolstrook vrij van tol	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Strenge naleving minimum inzittenden van carpoolvoertuig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>

Vorige

Volgende

In dit laatste deel van de vragenlijst worden van u enkele persoonskenmerken gevraagd. De door u gegeven informatie wordt uitsluitend gebruikt om de resultaten op groepsniveau te verwerken. Antwoorden worden anoniem verwerkt en de resultaten zijn niet terug te leiden naar individuen.

**Wat zijn de vier cijfers van uw postcode (woonadres)?**

Postcode

**Wat is uw leeftijd?**

- Jonger dan 25 jaar
- Tussen 25 en 35 jaar
- Tussen 36 en 45 jaar
- Tussen 46 en 55 jaar
- Tussen 56 en 65 jaar
- Ouder dan 65 jaar

**Wat is uw geslacht?**

- Man
- Vrouw

Vorige

Volgende

**Wat is uw hoogst afgeronde opleiding?**

- Geen
- Basis onderwijs
- Lager middelbaar onderwijs
- Hoger middelbaar onderwijs
- Hoger niet-universitair onderwijs
- Universitair onderwijs
- Anders

**Hoe is de verhouding mensen met rijbewijs en aantal auto's binnen uw huishouden?**

- Meer personen met rijbewijs dan aantal auto's
- Evenveel personen met rijbewijs dan aantal auto's
- Meer auto's dan aantal personen met rijbewijs

Vorige

Volgende

**Bent u full- of part-time werkzaam?**

- Full-time (Minimaal 36 uur per week)
- Part-time (Minder dan 36 uur per week)

**In welke sector/bedrijfstak bent u werkzaam?**

- Ambachten
- Bouwnijverheid
- Detailhandel
- Dienstverlening
- Groothandel
- Horeca/catering/verblijfsrecreatie
- Informatietechnologie/ICT
- Land en tuinbouw
- Onderwijs
- Overheid
- Procesindustrie
- Schoonmaak
- Vervoer en opslag
- Welzijn, jeugd en kinderopvang
- Wetenschap
- Zorg

**Wat is ongeveer het gezamenlijke bruto jaarinkomen van uw huishouden?**

- Minder dan €20.000
- Tussen €20.000 en €40.000
- Tussen €40.000 en €60.000
- Tussen €60.000 en €80.000
- Meer dan €80.000
- Zeg ik liever niet

Vorige

Volgende

**Omschrijf alstublieft in enkele woorden hoe u tegen een carpoolstrook aankijkt:**

Positief, als het tijdwinst oplevert. Echter vind ik het gemak van mijn eigen voertuig (thuis direct in de auto stappen, eigen muziek, rustmomentje) zwaarder wegen dan een paar minuten tijdwinst of een paar euro financiële winst.

Vorige

Volgende

## Appendix H – most important findings from the initial data analysis (without model)

- ◇ 59% of all respondents is male;
- ◇ 55% has a commuting time from door to door between 20 and 40 minutes;
- ◇ Nearly 70% schedules between 5 and 15 minutes extra travel time for uncertainty;
- ◇ Almost 40% indicate that they carpool at least sometimes, of which 10% do this between 1 and 5 times a month and 6.1% carpool occasionally (more than 5 times a month);
- ◇ Over 80% of all carpoolers stated they carpool with colleagues from their own company, 8.0% with workers from another company in the direct neighborhood and 10.2% with family or friends who are working in the neighbourhood;
- ◇ Over 75% indicated that facilities at the meeting location or the possibility to work during the trip are either neutral or not important factors to choose for carpooling;
- ◇ 65% stated that both safety and ambience of the trip are either neutral or important;
- ◇ Almost 29% is working in the (financial) services sector, 12% in ICT and 11.2% in healthcare;
- ◇ Nearly 70% of the sample is working full-time employment;
- ◇ Amsterdam, Rotterdam and Utrecht constituted the top-3 of work locations expressed in the number of respondents (together 27.7%);
- ◇ Only 5% of all respondents are working in Eindhoven;
- ◇ Only 7.5% of all respondents stated their current parking situation is 'bad';
- ◇ Three persons are currently making toll expenses for their commute trip;
- ◇ 13.3% of all respondents uses a company or lease vehicle for their commute trip;
- ◇ Almost 75% receives a travel cost reimbursement;
- ◇ About 40% of the respondents live in a household with more people having a drivers license than the number of cars;
- ◇ 86.3% of all respondents drive their own car to work, in almost 92% this car is a compact, mini or medium class;
- ◇ In 130 cases (around 38%) no carpool alternative was chosen in any of the nine choice situations;
- ◇ The average travel time to a work place from door to door is almost 34 minutes and 58 seconds and the average scheduled safety time is 10 minutes and 20 seconds.
- ◇ The average distance from home to work location is 42.40 with an average total cost (fuel, parking, toll, other) of €6.68.
- ◇ Respondents driving a luxury car do not rate the importance of environmental effects differently

## Appendix I – SPSS Output tables, general sample information

### I.I Duration of completing questionnaire

	N	Minimum	Maximum	Mean	Std. Deviation
Duration	346	3,55	839,10	16,9488	51,21795
Valid N (listwise)	346				

### I.II Age frequency distribution

	Frequency	Percent	Valid Percent	Cumulative Percent
Jonger dan 25 jaar	29	8,4	8,4	8,4
Tussen 25 en 35 jaar	124	35,8	35,8	44,2
Tussen 36 en 45 jaar	92	26,6	26,6	70,8
Tussen 46 en 55 jaar	67	19,4	19,4	90,2
Tussen 56 en 65 jaar	34	9,8	9,8	100,0
Total	346	100,0	100,0	

### I.III Gender frequency distribution

	Frequency	Percent	Valid Percent	Cumulative Percent
Male	204	59,0	59,0	59,0
Female	142	41,0	41,0	41,0
Total	346	100,0	100,0	

### I.IV EducationLevel frequency distribution

	Frequency	Percent	Valid Percent	Cumulative Percent
Basis onderwijs	2	,6	,6	,6
Lager middelbaar onderwijs	37	10,7	10,7	11,3
Hoger middelbaar onderwijs	126	36,4	36,4	47,7
Hoger niet-universitair onderwijs	126	36,4	36,4	84,1
Universitair onderwijs	47	13,6	13,6	97,7
Anders	8	2,3	2,3	100,0
Total	346	100,0	100,0	

### I.V RatioDriverLicenseCarOwnership frequency distribution

	Frequency	Percent	Valid Percent	Cumulative Percent
More persons with a driver's license than number of cars	137	39,6	39,6	39,6
Equal number of persons with a driver's license and cars	197	56,9	56,9	96,5
Meer auto's dan aantal personen met rijbewijs	12	3,5	3,5	100,0
Total	346	100,0	100,0	

### I.VI FullvsParttime frequency distribution

	Frequency	Percent	Valid Percent	Cumulative Percent
Part-time (less than 36 hours per week)	105	30,3	30,3	30,3
Full-time (Minimum of 36 hours per week)	241	69,7	69,7	100,0
Total	346	100,0	100,0	

#### I.VII WorkSector frequency distribution

	Frequency	Percent	Valid Percent	Cumulative Percent
Ambachten	6	1,7	1,7	1,7
Bouwnijverheid	21	6,1	6,1	7,8
Detailhandel	17	4,9	4,9	12,7
Groothandel	15	4,3	4,3	17,1
Horeca/catering/verblijfsrecreatie	11	3,2	3,2	20,2
Informatietechnologie/ICT	41	11,8	11,8	32,1
Land en tuinbouw	2	,6	,6	32,7
Onderwijs	13	3,8	3,8	36,4
Overheid	24	6,9	6,9	43,4
Procesindustrie	21	6,1	6,1	49,4
Schoonmaak	4	1,2	1,2	50,6
Vervoer en opslag	21	6,1	6,1	56,6
Welzijn, jeugd en kinderopvang	13	3,8	3,8	60,4
Wetenschap	1	,3	,3	60,7
Zorg	37	10,7	10,7	71,4
Dienstverlening	99	28,6	28,6	100,0
Total	346	100,0	100,0	

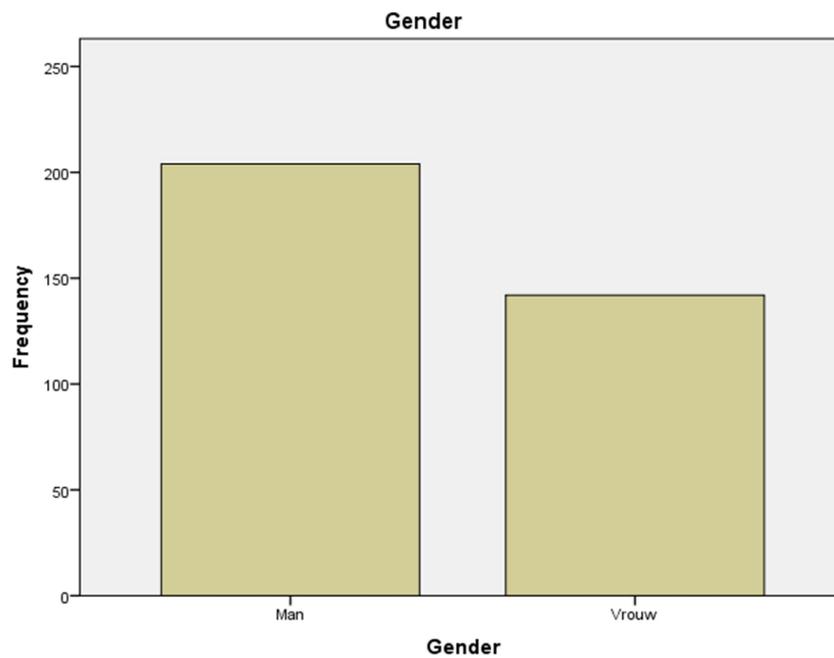
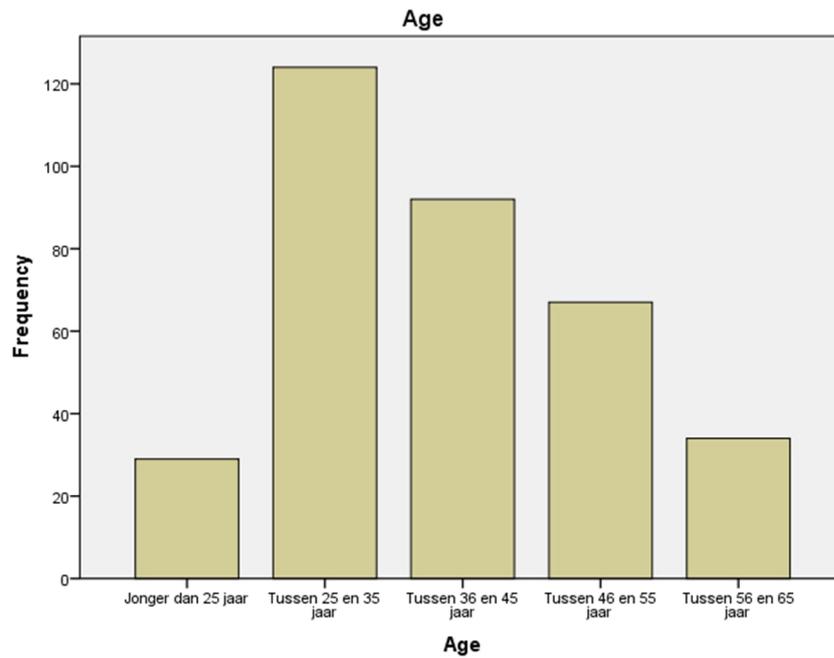
#### I.VIII Income frequency distribution

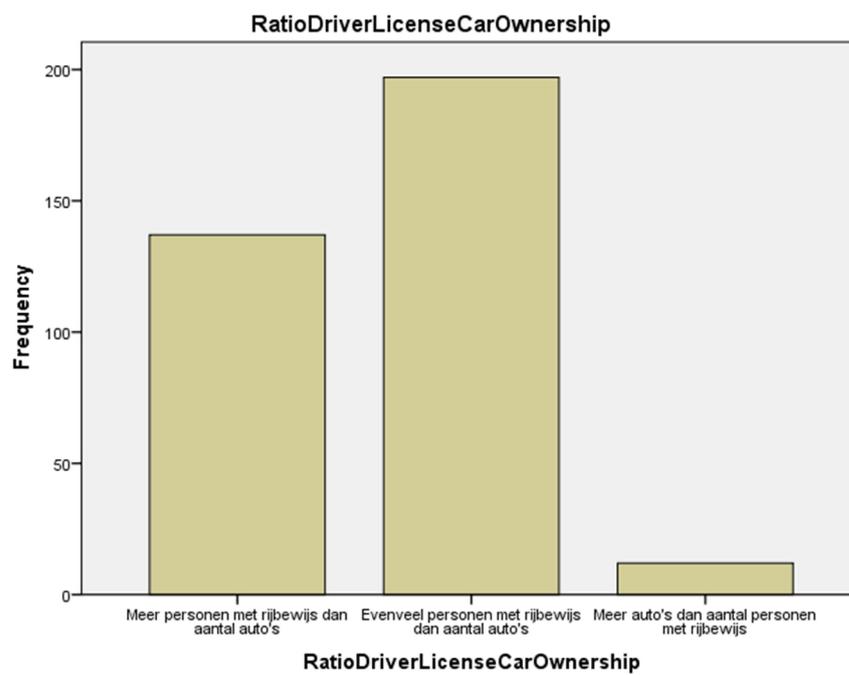
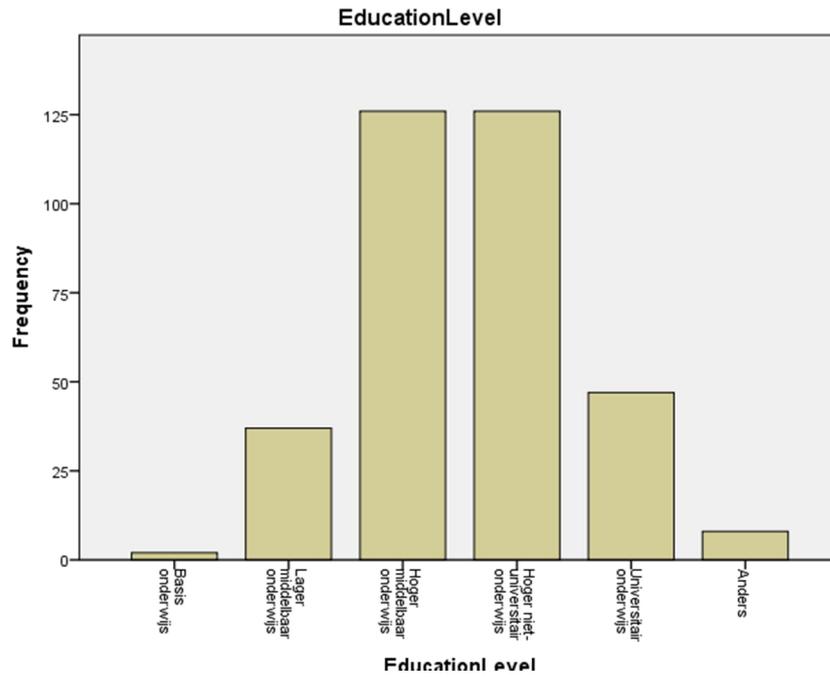
	Frequency	Percent	Valid Percent	Cumulative Percent
Less than €20.000	20	5,8	5,8	5,8
Tussen €20.000 and €40.000	101	29,2	29,2	35,0
Tussen €40.000 en €60.000	92	26,6	26,6	61,6
Tussen €60.000 en €80.000	48	13,9	13,9	75,4
More than €80.000	26	7,5	7,5	82,9
I'd rather not say	59	17,1	17,1	100,0
Total	346	100,0	100,0	

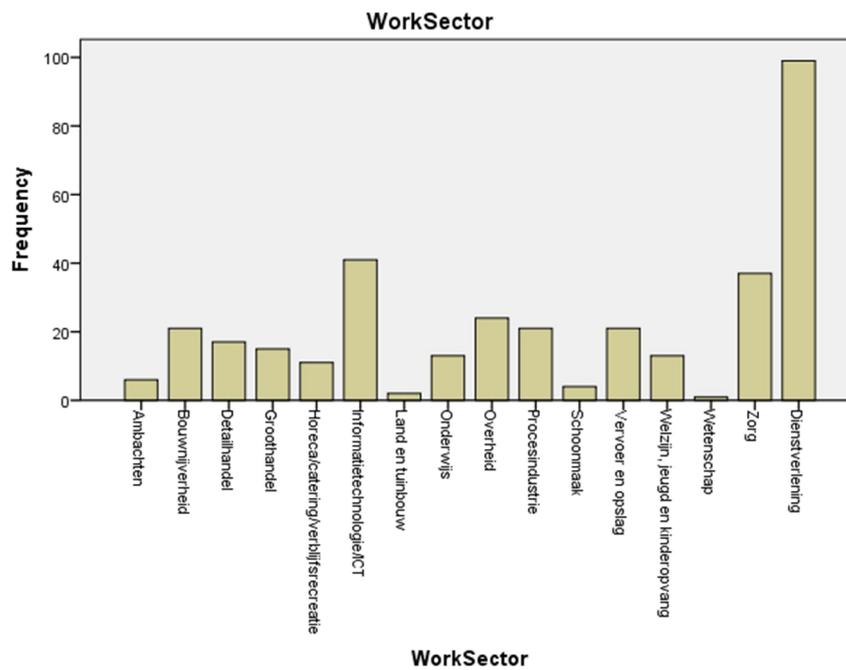
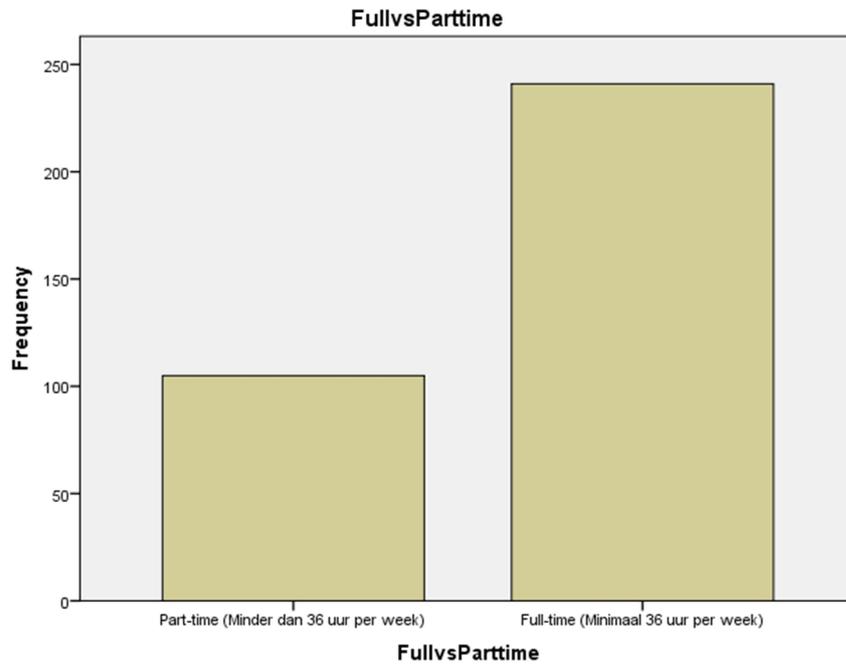
#### I.IX Current stimulating policies to change commute behavior offered by employer

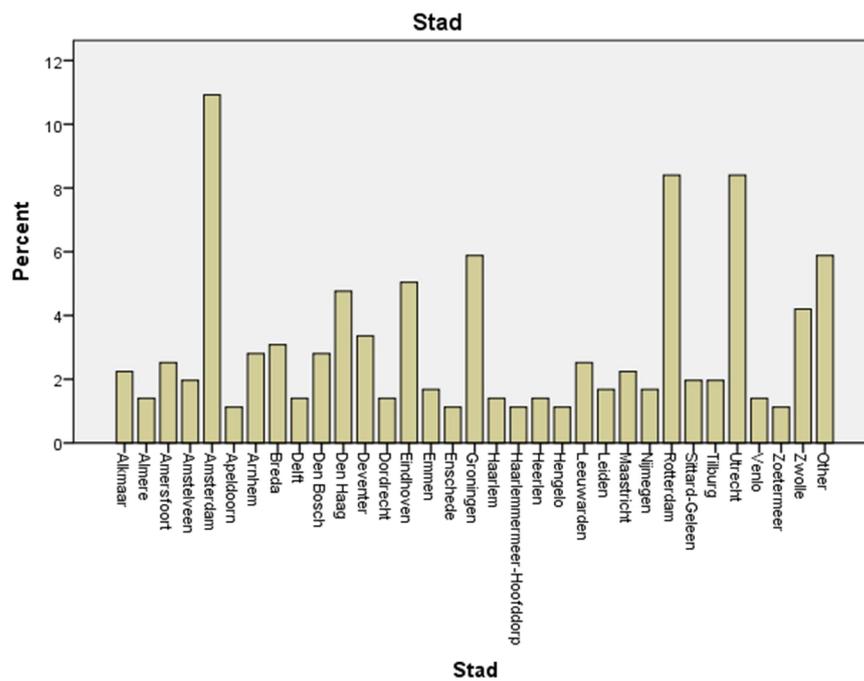
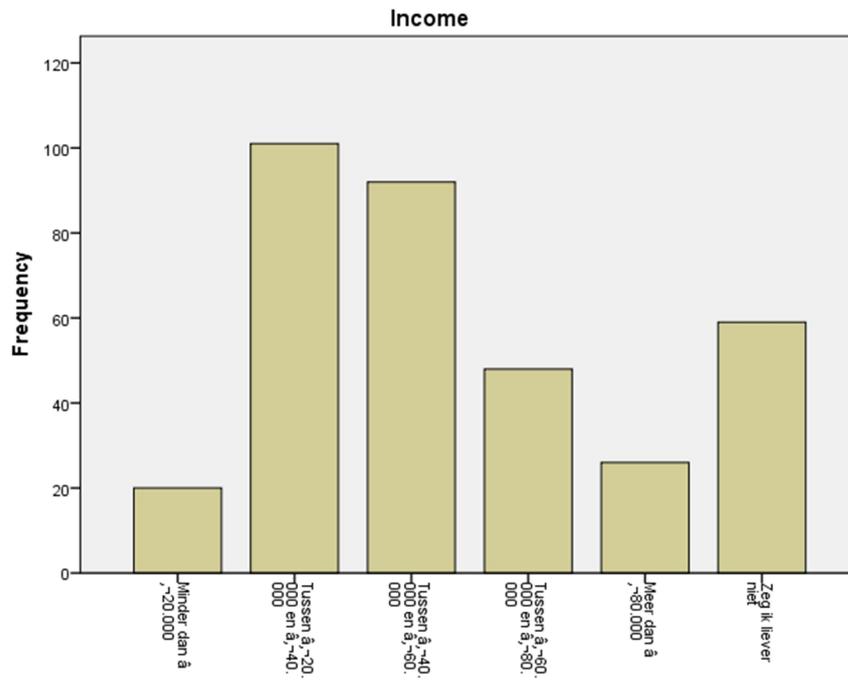
	Frequency	Percent	Valid Percent	Cumulative Percent
None	204	59,0	59,0	59,0
Public transport	36	10,4	10,4	69,4
Avoid rush hour	21	6,1	6,1	75,4
Carpool	17	4,9	4,9	80,3
Bicycle/walking	19	5,5	5,5	85,8
Other	7	2,0	2,0	87,9
Multiple	42	12,1	12,1	100,0
Total	346	100,0	100,0	

### Appendix J – Graphs illustrating the SPSS output









## Appendix K – Answer frequency on attitude questions

Attitude related factors	N	Sum	Mean	Std. Deviation
TripSafety	346	1309	3,78	1,166
TripAmbience	346	1278	3,69	1,054
OrganizationEasabilityAndPossibilities	346	1272	3,68	1,063
TripTypePassenger	346	1264	3,65	1,072
EconShare	346	1250	3,61	1,162
FlexibilityFreedom	346	1187	3,43	1,173
TripComfort	346	1179	3,41	,935
SafetyMeetingLocation	346	1170	3,38	1,157
TripTypeGroup	346	1153	3,33	,991
PresenceCentralMeetingArea	346	1152	3,33	1,099
EconFiscal	346	1130	3,27	1,174
AvailabilityDigitalEmployerScheme	346	1117	3,23	1,102
SocialAspect	346	1102	3,18	1,005
AmbienceMeetingLocation	346	1098	3,17	1,092
TripEffectEnvironment	346	1074	3,10	1,125
HOVlanePresence	346	1045	3,02	1,163
CarpoolRole	346	1013	2,93	1,040
HOVlaneEnforcement	346	988	2,86	1,102
HOVlaneTax	346	970	2,80	1,238
FacilitiesMeetingLocation	346	967	2,79	1,036
TripPossibilityWork	346	859	2,48	1,185
PrivateCarImage	346	740	2,14	1,065

## Appendix L – Travel time, uncertainty and parking situation answer distribution and correlations

L.I Travel time from door to door				
	Frequency	Percent	Valid Percent	Cumulative Percent
Minder dan 20 minuten	53	15,3	15,3	15,3
Tussen 20 en 40 minuten	191	55,2	55,2	70,5
Tussen 41 en 60 minuten	65	18,8	18,8	89,3
Meer dan 60 minuten	37	10,7	10,7	100,0
Total	346	100,0	100,0	

L.II TravelTimeUncertainty				
	Frequency	Percent	Valid Percent	Cumulative Percent
Minder dan 5 minuten	51	14,7	14,7	14,7
Tussen 5 en 10 minuten	135	39,0	39,0	53,8
Tussen 11 en 15 minuten	107	30,9	30,9	84,7
Meer dan 15 minuten	53	15,3	15,3	100,0
Total	346	100,0	100,0	

L.III ParkingSituation				
	Frequency	Percent	Valid Percent	Cumulative Percent
Slecht	26	7,5	7,5	7,5
Voldoende	173	50,0	50,0	57,5
Uitstekend	147	42,5	42,5	100,0
Total	346	100,0	100,0	

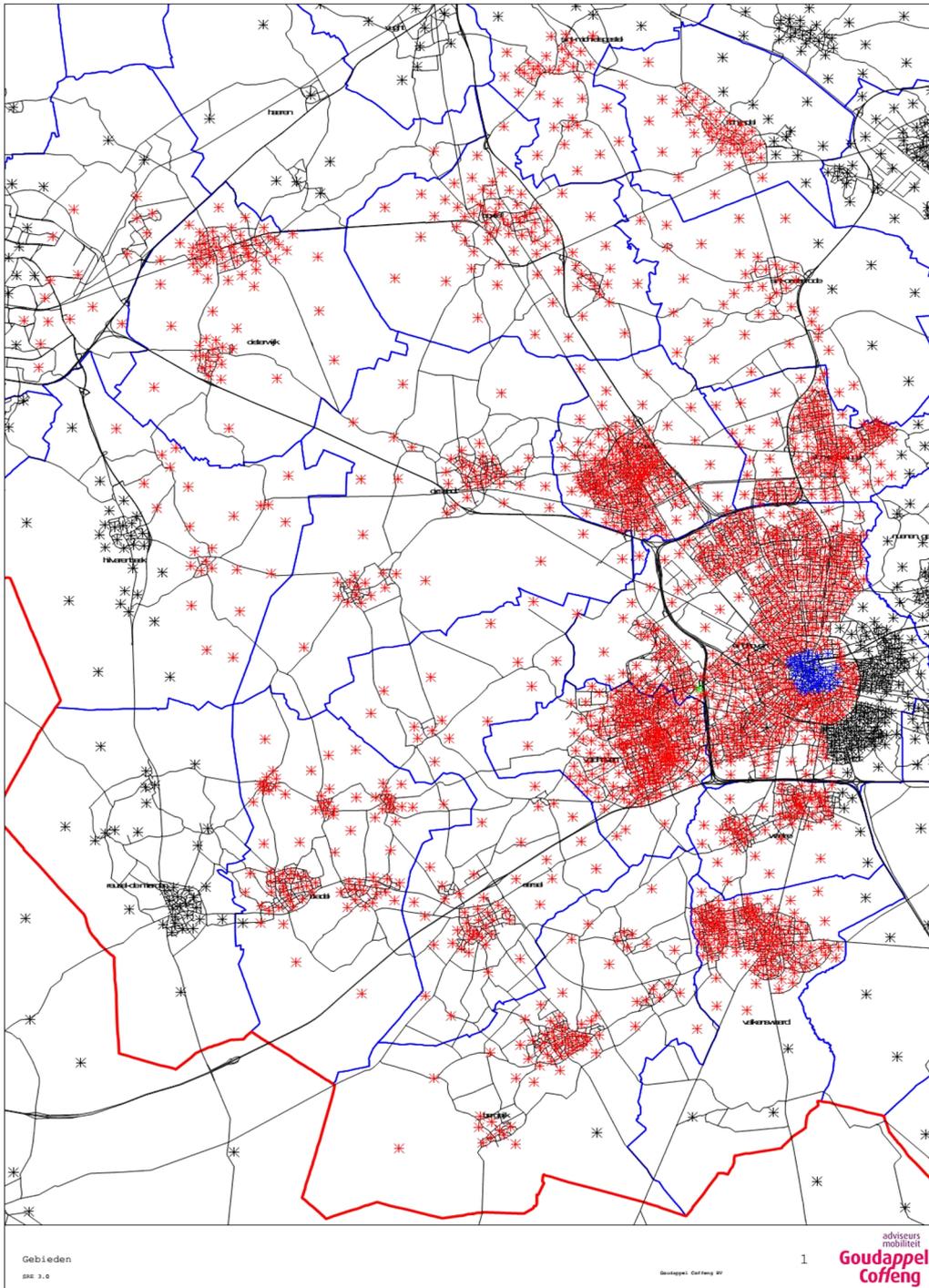
L.IV Correlations				
		TravelTimeDoorToDoor	ParkingSituation	TravelTimeUncertainty
TravelTimeDoorToDoor	Pearson Correlation	1	,000	,450**
	Sig. (2-tailed)		,994	,000
	N	346	346	346
ParkingSituation	Pearson Correlation	,000	1	-,095
	Sig. (2-tailed)	,994		,077
	N	346	346	346
TravelTimeUncertainty	Pearson Correlation	,450**	-,095	1
	Sig. (2-tailed)	,000	,077	
	N	346	346	346

\*\* . Correlation is significant at the 0.01 level (2-tailed).

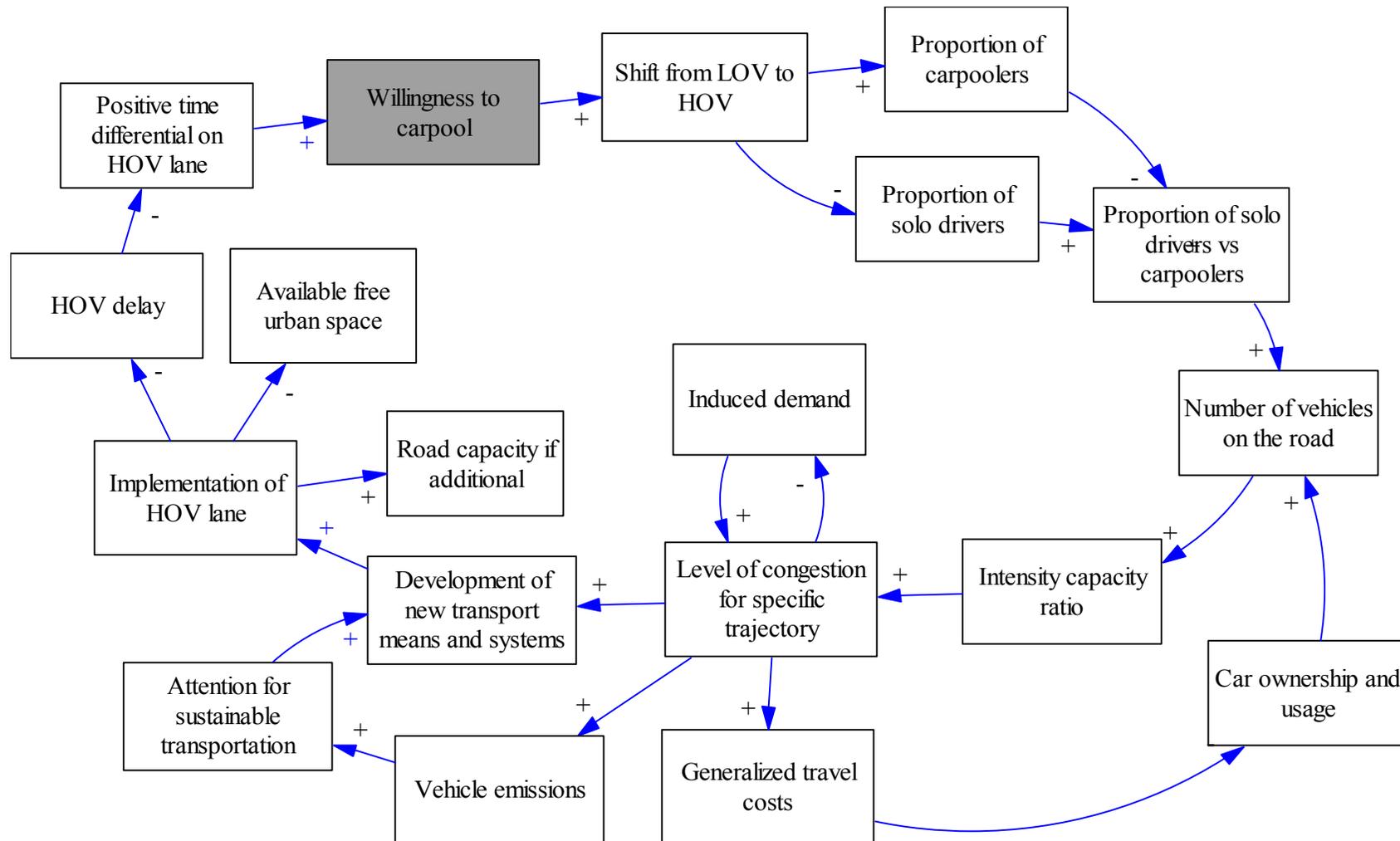
## Appendix M – Carpool proponents versus opponents distribution

Group Statistics					
	sum_solo	N	Mean	Std. Deviation	Std. Error Mean
CityOfEmployment	>= 4,50	286	21,34	13,248	,783
	< 4,50	71	20,03	12,893	1,530
Travel time from door to door	>= 4,50	286	35,31	16,830	,995
	< 4,50	71	33,10	16,440	1,951
timeparkeren	>= 4,50	286	2,40	,612	,036
	< 4,50	71	2,13	,584	,069
TravelTimeUncertainty	>= 4,50	286	10,31	4,637	,274
	< 4,50	71	10,54	4,541	,539
janeekosten	>= 4,50	286	,15	,355	,021
	< 4,50	71	,10	,300	,036
janeevergoeding	>= 4,50	286	,74	,441	,026
	< 4,50	71	,79	,411	,049
freq_carpool	>= 4,50	286	,48	,802	,047
	< 4,50	71	1,14	1,032	,123
Age	>= 4,50	286	2,88	1,155	,068
	< 4,50	71	2,85	,966	,115
Gender	>= 4,50	286	,42	,494	,029
	< 4,50	71	,35	,481	,057
Education	>= 4,50	286	4,59	,954	,056
	< 4,50	71	4,59	,950	,113
RatioDriverLicenseCarOwnership	>= 4,50	286	1,64	,555	,033
	< 4,50	71	1,59	,523	,062
FullvsParttime	>= 4,50	286	,69	,464	,027
	< 4,50	71	,73	,446	,053
WorkSector	>= 4,50	286	10,92	5,428	,321
	< 4,50	71	9,85	5,106	,606
Income	>= 4,50	286	3,43	1,545	,091
	< 4,50	71	3,28	1,495	,177

### Appendix N – Geographical distribution of selected carpool meet location, origins and destination zone



Appendix O – Dynamic causes, effects and links between the implementation of HOV lanes and willingness to carpool





# **ENGLISH SUMMARY**

## **MOTIVATING CITY-COMMUTERS TO CARPOOL**

### **Exploring the stimulus of various factors and policies**

Author: A. (Andreas) Lem

#### **Graduation program:**

Construction Management and Urban Development 2013-2014

#### **Graduation committee:**

Prof. dr. ir. W.F. (Wim) Schaefer

Dr.ing. P.J.H.J. (Peter) van der Waerden

Ir. A.P. (Peter) Baas

#### **Date of graduation:**

15-07-2014

#### **ABSTRACT**

Congestion on urban main roads occurs due to a limited infrastructural capacity as compared to the supply of vehicles. Two action plans exist to reduce the magnitude of congestion issues on urban main roads: reducing the supply of vehicles and thus the demand for infrastructure, or expanding the size of the network's capacity by constructing new roads. Since space scarcity is opposing a problem in densely populated urban centers, the first option is considered a more promising alternative in this context. Reducing the supply of vehicles can be achieved by combining trips and increasing the average vehicle occupancy. Factors and policies are studied that affect the commuter's travel mode. Incentives for carpooling (sharing vehicle capacity) and the link with travel time (uncertainty) savings caused by a reserved high-occupancy-vehicle lane are researched. Travel time, waiting time and trip costs have the most (negative) impact on the probability that carpooling is chosen as the travel mode. A tool is created that is able to predict the proportion of commuters that will carpool when certain physical facilities, policies or a combination of the two are in place.

**Keywords:** carpooling, urban congestion, average vehicle occupancy, multinomial logistic regression, stated adaptation, Eindhoven

#### **INTRODUCTION**

In this study, structural bottlenecks on the outskirts of the city, where multiple provincial roads and highways converge, are of main focus. Various trends in The Netherlands give cause to the belief that congestion problems will continue to grow in the coming years. Car ownership and use of private motor vehicles is growing and recent active carpool policies failed. At the same time, the attention for sustainable ways of transportation is widely increasing. Most private cars are occupied by a single person, meaning a high amount of underutilized capacity. In this study ways to motivate travelers to change their travel habits are identified. As many different factors and public policies affect travel patterns, this study tries to estimate their relative importance.

## **Problem definition**

The trends described in the introduction are expected to result in an increased level of congestion, which in turn lead to increased travel times (uncertainty), increased vehicle emissions and nuisance, reduced urban accessibility and a decrease in the level of environmental quality and available green space. Especially when new infrastructure is to be constructed, scarce urban space will need to be used. As the level of congestion will drop, travel times are reduced and more people will as a result make use of the newly created infrastructure, leading to a new equilibrium with a fixed intensity/capacity level. Clearly, this is not the right way forward (think of land scarcity, air pollution and energy use issues). Therefore, the focus of this study is on improving the utilization of existing – unused – capacity to reduce congestion. The exact problem definition can be described as follows:

### **‘A low average vehicle occupancy causing congestion on urban main roads’**

As policies aimed at stimulating the use of public transport are not achieving their desired effects, some intermediate form of transportation (between driving alone, associated with privacy and freedom, and driving with a group of strangers, associated with dependency and discomfort) will have the best chances in solving congestion problems (whether combined with the aforementioned types of transportation or not). Carpooling and car-sharing are two examples. However, the everyday potential and effect of carpooling will be much larger than car-sharing. Carpooling is a way of sharing already available capacity of commuting vehicles (which are mainly responsible for congestion issues). It combines multiple trips that would have been carried out independently into one single trip. As carpooling fills this already available capacity, the average vehicle occupancy of cars that are currently on the road. This will result in fewer cars on the road and a smaller requirement for infrastructure.

## **Research questions**

The research objective of the report is to study which factors can stimulate city-commuters to carpool in order to increase the average occupancy rate of vehicles. As a result, the amount of vehicles per piece of infrastructure (intensity/capacity ratio) is reduced. The main research question that corresponds with the identified research objective is:

### **‘What are the most important factors influencing the travel mode choice made by city-commuters, between solo driving and carpooling?’**

Sub-research questions are derived to find an answer on the question above, of which some will be answered mainly by literature, and other questions will be dealt with based on survey results or by using the created tool for predicting the number of carpoolers for a specific case-study. These questions are at a lower abstraction level and focus on defining carpooling with its main characteristics, stimulating factors and policies, and the definition and benefits of a HOV lane. Furthermore, hypotheses regarding the expected importance of trip characteristics are derived.

## **Research structure**

In the first chapter of the thesis, some general trends in the recent past and for the short-term future of the Dutch mobility sector are sketched. The current importance of reducing congestion issues and its negative effects on the environment and economy is emphasized. 'Sustainabilizing' today's transport is the right way forward, since this sector is responsible for a large part of the national CO<sub>2</sub> and NO<sub>x</sub> emissions. The same chapter describes the research objective, research questions, hypotheses, limitations and used methodologies.

The report continues with a literature review that focusses on urban congestion, structural bottlenecks, carpooling typology, and researches important motivation factors for commuters to switch to carpooling. As the HOV lane is expected to be such an important factor in this light, an elaborated review of these lanes including its characteristics, implementation examples and success and failure factors of implementation are presented.

The next chapter explains the discrete choice modeling methodology and applies it in the context of this study. A stated adaptation based questionnaire is developed in which respondents are asked to make a choice between their current trip and making the same trip in carpool formation. The questionnaire development, selection of respondents and data collection processes are presented. Expected results are formulated as well. In the following chapter, the obtained data is analyzed and a sample description is given. Analysis of the stated adaptation results is carried out by estimating a multinomial logistic model, which describes the relative importance of all identified variables on the choice behavior of commuters to select their commute travel mode. These estimates are subsequently compared to figures obtained from literature sources. The obtained estimates of the MNL model are the basis of a created tool that is able to predict the proportion of commuters that are motivated to carpool for any case-study. This case-study should be a large Dutch city currently encountering congestion on its main roads. The tool can predict the effect on the number of carpoolers of for example a travel time saving in minutes due to HOV lane construction to the city center. From this predicted switch from driving solo to carpooling, and knowing the origin-destination pairs of commuters, the reduction in vehicle kilometers traveled can be calculated, together with the effects of this reduction of both trips and total kilometers traveled on the level of vehicle emissions.

The two final chapters present a conclusion of the report, including an answer on the research questions and hypotheses. A discussion is started on the subject questioning the assumptions that were done during the study, its (prediction) results, expectations, and a trade-off of investment – benefits of a HOV lane, when it is to be implemented. Limitations and recommendations for further research and recommendations for potential applications the study results can be of added value are discussed.

## **THEORETICAL FRAMEWORK**

The literature review build on the problem background as sketched in the introduction. The section is basically divided into two main parts: urban congestion and bottlenecks, and carpooling. These two constructs will be separately explained below.

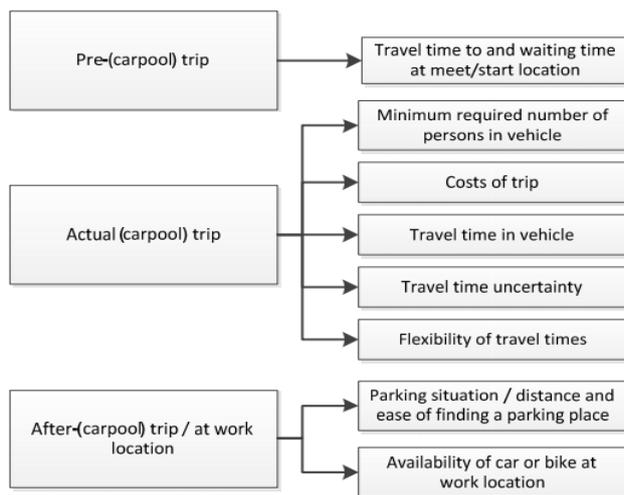
### **Congestion**

Congestion is defined as *'an excess of vehicles on a roadway at a particular time, resulting in speeds that are slower than the normal or free flow speed'*. Direct effects of congestion for its users consist of a loss of time and increased travel time uncertainty. However, indirect effects like nuisance for local residents, decreased accessibility of the urban center for local municipalities, and lost time (which can be translated in money) for the national economy are also a result. A wide variety of causes exist for congestion to occur, which can be grouped to i) traffic-influencing events, ii) variations in traffic demand and iii) physical infrastructural features (also known as structural bottlenecks). Potential solutions for reducing congestion and its negative side-effects range from increasing infrastructure capacity to decreasing the supply of vehicles. The option of adding capacity is often hampered by either a lack of resources, a lack of space, or environmental or political issues. Therefore, other solutions to change the demand for infrastructure by decreasing the total amount of vehicles on the route in a certain timespan have been proposed in literature. These include: charging peak-time tolls, using intelligent transportation devices, restricting the outward movement of new developments, stimulating transit oriented (parking) programs, and creating HOV lanes. Many of these options are focused on increasing the average vehicle occupancy of vehicles by motivating people to drive together. To make this solutions work, car-sharing or carpooling has to be stimulated.

### **Carpooling**

Different definitions of carpooling exist. In The Netherlands, a person is considered a carpooler when he or she drives at least two times a week to work, in one vehicle, with other occupants that are also on their way towards work. Two main groups of carpoolers can be identified: internal or fam-pooling, and external carpooling. The latter excludes household or family members driving together in one car as to be labeled carpoolers. Hitchhiking, slugging, flexible carpooling, real-time ridesharing and traditional carpooling are different forms of external carpooling. As can be seen, many different forms of carpooling exist. However, literature sources do present some general characteristics. On average, carpoolers work full time, are living further away from their work location as solo drivers, are mainly originating from densely populated areas with a bad public transport connection, have a lower education level and income as solo drivers, drive a less expensive car, have a hard time finding a parking spot and are originating from households with low levels of vehicle ownership. Commuters assign different values to various stimulating factors for carpooling, therefore, a wide variety of factors need to be studied and targeted to motivate commuters to carpool.

The most important carpool stimulating factors that are influencing or can be combined with this physical possibility to stimulate carpooling are identified. A total of eight variables grouped in three larger constructs are established. Travel time to and waiting time at the meeting location is the first variable, which is an aspect of the pre-carpool trip. The minimum required number of occupants to drive on the HOV lane, travel time in the carpool vehicle, travel time uncertainty, costs of the trip, and flexibility of the carpool travel times can be grouped as aspects being part of the actual (carpool) trip. The parking situation (distance and ease of finding a parking place) and availability of a car or bike at the work location are labeled as aspects belong to the after-(carpool) trip or at the work location. In figure 1 all attributes are displayed.



**Figure 1: Identified important variables in stimulating commuters to carpool**

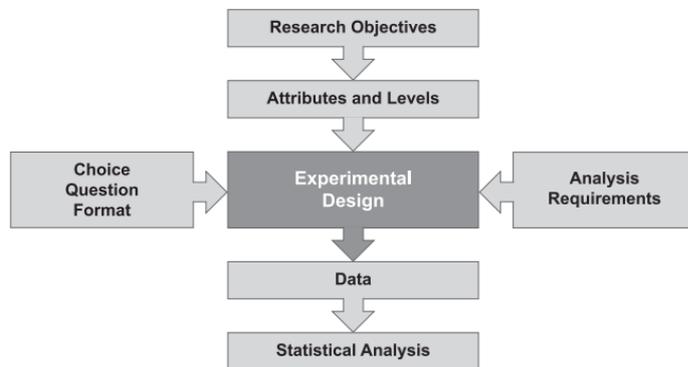
## RESEARCH METHODOLOGY

To study the importance of carpool stimulating factors in the perceptions of commuters currently driving solo in their vehicle towards work, multiple techniques are used. The literature review as explained in the previous section was the first step. The report continues with using the constructs identified from literature sources and expert interviews to create a stated adaptation based questionnaire, in which respondents are asked to choose if they would solo drive or carpool to work when different trip characteristics are presented. Those trip characteristics are created by using the identified variables and predetermined levels. Stated adaptation leans on the theories of discrete choice modeling and random utility theory. All mentioned techniques are shortly discussed.

### Discrete choice modeling

This technique attempts to model the decision process of an individual in a particular context. In this case, the available alternatives the respondent can choose between are driving solo and carpooling. Discrete choice modeling enables the use of an experimental design to reduce the number of choice profiles that need to be surveyed to capture all relevant scenarios and combination. In this report, a fractional orthogonal design was used. Using discrete choice modeling enables implicit coefficient to be estimated for attributes. It

reduces the possibility of a respondent to behave strategically and therefore it can be used to estimate the value of the carpooling alternative in the perception of the respondent. Outputs of the discrete choice model are a utility model equation and a set of marginal utilities for each identified attribute of interest, describing the relative importance of each variable. In figure 2 below, required input data and decisions are displayed together with the outputs the discrete choice model delivers.



**Figure 2: Key stages for developing a discrete-choice experiment**

Two mainstream discrete choice based research types can be identified to carry out effective behavioral research on the potential effects of their choices. Revealed preferences (RP) observes actual behavior of the respondent, whereas stated preferences (SP) asks what a respondent would do in a fictitious situation. The method that is used in the report, i.e. stated adaptation is largely based on this latter type, as explained in the next paragraph.

### **Stated adaptation**

Stated adaptation presents choice experiments in which one alternative that the respondent can choose is based upon information of the current commute trip he or she is making, provided at the first part of the questionnaire. This alternative does not differ between the choice profiles. The other alternative that is presented is the carpooling alternative, in which the levels of the various identified variables are altered. The respondent compares both configurations to what best fits his or her preferences. The central question in the presented stated adaptation based survey is (xxx Arentze, et al., 2003):

**“Would you, as a consequence of the presented scenarios with corresponding parameters, choose [carpool option] instead of your current mode of travel, for conducting your home-work trip? How would you rate [carpool option]?”**

The study assumes answers on the above questions are given by respondents on the basis of random utility theory, which entails a maximization of their individual utility.

### **Questionnaire development**

The developed questionnaire consists of four main parts. The first is about asking respondents how they are currently commuting. Their current travel mode, travel distance,

costs, type of car, current carpool frequency, etc. are captured. In the second part of the questionnaire, respondents are presented the stated adaptation choice tasks. To develop this part of the questionnaire, a choice needs to be made on the model type that will later be used to estimate variable's importance. In the report, a multinomial logistic model will be used. Two labeled alternatives (driving solo and carpooling) are considered, and eight attributes with three levels each. This resulted in a total of 6,561 choice tasks to be evaluated by respondents, which could be reduced to 27 by employing an orthogonal design. The 27 choice tasks were divided over three choice sets. Effect coding was used for the ordinal variables.



**Figure 3: Illustration of the carpool alternative in the stated adaptation choice situation**

The third part of the questionnaire captures attitudes of respondents towards five main aspects: organization and formation of the carpool trip, characteristics of the carpool trip itself, psychological factors of carpooling, economic factors of carpooling and characteristics of the special HOV lane. This information can be used in later studies to segment commuter groups and to build separate models for each segment. The last part of the questionnaire captures socio-demographic factors like gender, age, city of employment, car availability in the household, etc.

### Data collection

As the questionnaire had a quite strict target audience, selection questions to determine if a respondent belonged to the target group were necessary at the beginning of the questionnaire. Only respondents were selected that work in a relative large city (>75.000 residents) which is not the city they live in, and drive at least one time per week to work alone in a private motor vehicle. The questionnaire was sent out to commuters working in large cities all over The Netherlands. Datasets from different sources (personal network, company's network and other sources) was combined and the dataset was cleaned by removing extreme outliers.

### Analysis of the data

Basic findings include an average commute time between 20 and 40 minutes and a scheduled extra time for uncertainties between 5 and 15 minutes. When a parking spot is difficult to find, travel time uncertainty increases. The safety and comfort of the trip is valued as being very important when choosing the travel mode. 38% of all respondents did never choose the carpool alternative. From this it can be concluded that a certain amount of

commuters will never be motivated to carpool. Reasons can be a strong attachment to the luxury and privacy of the private car, or the ‘impossible’ nature of their job to carpool.

Two different MNL models are estimated. The first uses effect coding for all identified attributes, since pre-defined levels for variables were used. This is the more traditional method as substantiated in literature. In this model the utility for the solo alternative is fixed at zero, making the coefficient estimates for all attributes in the carpool alternative totally relative to the solo alternative. Since the scale of this model corresponds closely to the scale of values that can be realized in real life, it is possible to directly compare coefficients as displaying the importance of the different variables. Results that can be derived from this model, the travel time and waiting time at the meet location is the most important factors influencing the choice of commuters to carpool. Secondly important is the actual travel time in the carpool vehicle. Subsequently, costs of the trip, the parking situation and policy in place and the level of flexibility in travel times are important. Less important are the required minimum number of persons in the carpool vehicle, the uncertainty in the travel time and car or bike availability at the work location. As the variables in the carpool alternative are derived from the current (reference) commute trip, these variables can take any value. The second model uses the exact figures as presented to the respondent, instead of the percentage levels in the effect coded model. The model is estimated on the basis of these values, resulting in coefficient estimates that reflect an increase of ‘one’ in the considered variable. The estimates of this model are displayed below in figure 4.

Variable name	SOLO	CARPOOL
<b>Alternative specific constant</b>	Fixed (0)	-0.953
<b>Travel and waiting time start location</b>	Fixed (0 min)	-0.0760
<b>Travel time in (carpool) vehicle, main route</b>	-0.0626	-0.0737
<b>Uncertainty in travel time</b>	-0.0562	-0.0446*
<b>Costs of trip</b>	-0.0923	-0.104
<b>Number of persons in vehicle</b>	Fixed (1)	-0.0209*
<b>Parking situation at work location</b>		
Good	0.392	0.130
Average	-0.194	0
Bad	-0.198	-0.130
<b>Car/bike availability at work location</b>		
Car or bike		0.0855*
Bike only	Fixed (car)	0
None		-0.0855*
<b>Flexibility of travel times</b>		
High		0.138
Average	Fixed (high)	0
Low		-0.138
<b>Null log-likelihood: -2158.460</b>		
<b>Final log-likelihood: -1638.512</b>		
* means insignificant effect level at 95% confidence level		

**Figure 4: Estimates for the MNL model in which original attribute values were used**

### Tool development and application

For application purposes it is possible to use the model’s results for predicting the proportion of carpoolers for a specific case-study. This is because input data that is available for each case-study consists of distances, travel times and the number of trips. This data is expressed in kilometers, minutes and numbers. Filling in these values in the MNL model estimation results in a utility for a specific commuter, originating from a location with a specific distance and travel time to the city center and when certain parking and other

policies are in place. This utility can be translated into a probability that he or she will choose to carpool. As the number of trips from each origin to each destination is known, the total carpool trips from a certain geographical zone to the city center can be calculated. Since origin-destination pairs and distances are known, a total reduction in vehicle kilometers traveled and thus vehicle emissions can also be predicted. First a universal model is created, which can be applied to any case-study resembling a large city in The Netherlands. The tool that is created in the study is applied to the implementation of a HOV lane at the Noord-Brabantlaan in Eindhoven, The Netherlands. Since bus lanes already exist at this location, investment costs are expected to be low. However the intensity on the bus lane that is currently reserved for busses only will increase drastically as a result of allowing HOVs on this lane as well. Other implications exist as when a bus requires stopping at frequent intervals and the current priority that is given to busses. When all HOVs on this lane receive priority at junctions, the normal functioning of junctions will be seriously hampered. Reducing the original travel time by 50% motivates 128 commuters driving solo in the current situation to carpool (15%). When the parking situation is improved to good (e.g. a reserved parking location close to the work location) this motivates 12% to carpool, and changing the meet location can motivate up to 26% of current solo drivers to carpool when the location is at the home of the commuter. Also, a combination of the most optimal attribute levels is studied, resulting in a theoretical maximum of 57% of respondents that can be motivated to start carpooling for the Noord-Brabantlaan case-study.

## **Results**

A standard aversion for carpooling exists in the perception of city-commuters; this negative utility for carpool equals -1.06. This value is derived from the alternative specific constant in the MNL model. This value represents the basic utility level if no other factors are considered. A negative utility of -1.06 can be translated into a change that someone driving in a private car to work will carpool of 26%; meaning 74% will drive solo. 38% of all commuters state it is not possible to carpool or they will never be motivated or willing to carpool, this corresponds to about the same percentage as found in literature. As stated, the most important variables that have been identified in this study that influence the decision to carpool are (in order of most to least important): travel and waiting time at/to carpool meet location, actual travel time in (carpool) vehicle, costs of the trip, the parking availability and distance at work location, and the level of flexibility in travel times. Not significantly important are: the number of required persons in the vehicle (minimum occupancy level), the availability of a car or bike at the work location, and (reduction of) uncertainty in travel time. In the stimulated base scenario, the average vehicle occupancy is 1.12, in the most optimal scenario this level can be increased up to 1.41 people per private vehicle. The stimulating effect of separate policies (HOV lane with travel time savings, parking policy, number of persons) on the achieved number of additional carpoolers relative small (AVOs between 1.14 and 1.19 compared to the original 1.12) however combined with other facilities this effect (and the proportion of carpoolers) can be increased. Vehicle kilometers traveled savings of 20% to 50% can be achieved by motivating sufficient commuters to

carpool and when meeting closer to home (i.e. traveling largest proportion of commute trip in carpool formation). This VKT savings can be directly translated in about the same degree of savings in CO<sub>2</sub> and NO<sub>x</sub> emissions caused by road traffic.

## **CONCLUSIONS AND RECOMMENDATIONS**

Since a more sustainable approach in reducing congestion issues is desired and urban space is becoming scarcer due to increase urbanization, reducing the amount of vehicles by raising the average vehicle occupancy is the right way forward. Carpooling is an intermediate form of transport between the luxury private car with feelings of freedom and flexibility associated with it, and the public transport system which is not utilized at the desired level due to its unattractiveness. Carpooling combines both methods by keeping some form of independency while at the same time increasing the average vehicle occupancy. Physical, political, procedural and fiscal measures exist that are able to stimulate carpooling of which the most important are travel, waiting and deviation time, and cost reduction. A HOV lane can be an extra stimulus by avoiding congested roads and achieving free flow speeds and priority at junctions. A tool is created that can predict the proportion of commuters that is motivated by different factors and policies to carpool, which can at the same time estimate total vehicle kilometer traveled and emissions reductions. Municipality and traffic advising agencies like Goudappel Coffeng can use this tool and other knowledge gained in this report to start thinking about giving carpooling a more active role in the planning and decision-making process of new (public) transportation systems. For example, the new bus lane plans of the city of Eindhoven can perfectly be combined with HOV lanes if proper research is done. The creation tool can serve as starting point in this context.



### **A. (Andreas) Lem, BSc.**

This report is the result of a six month graduation project carried out in collaboration with Eindhoven University of Technology and Goudappel Coffeng BV, advisors in mobility. This report signals the end of a genuinely learnful five and half years that I have been a student at the TU/e. This graduation process helped me to experience the everyday life in a company, and I have to admit that I enjoyed putting what I have learned during my time at the TU/e into practice. As this report will signal the start of my working career, it will at the same time help me to remember that learning new things will never stop being part of my job, wherever I may go next.

## **EDUCATIONAL CURRICULUM VITAE**

2009 – 2012 Bachelor Industrial Engineering

2010 – 2011 Minor Economics

2012 – 2012 Bachelor graduation project at Scholtze Horecagroothandel VOF

2012 – 2014 Certificate program Technology Entrepreneurship

2012 – 2014 Master Construction Management and Engineering

2014 – 2014 Internship at Goudappel Coffeng BV

## **DUTCH SUMMARY**

## **Identificatie van mogelijke infrastructurele toepassingen en beleidsmatige veranderingen om de carpoolbereidheid van stedelijke forenzen te verhogen.**

Het afstudeerproject onderzoekt of carpoolen congestieproblemen in de stedelijke omgeving kan terugbrengen door het stimuleren van carpoolen. Omdat het toevoegen van extra capaciteit aan het wegennetwerk niet altijd mogelijk is, bijvoorbeeld door toenemende urbanisatie en ruimtegebrek in het stedelijke centrum, zijn gemeenten druk met het zoeken van andere methoden om de congestieproblematiek aan te pakken. Veel van deze maatregelen zijn gericht op het verbeteren en aantrekkelijker maken van het openbaar vervoer. Beoogde doelen worden echter vaak niet gehaald, en de capaciteit van het OV wordt vaak niet ten volle gebruikt. De probleemstelling is als volgt vormgegeven: *‘een lage gemiddelde voertuigbezetting dat ten oorzaak ligt aan congestie(problemen) op stedelijke hoofdwegen’*. Carpoolen dient als een soort tussenvorm van solo rijden en het openbaar vervoer. Carpoolen verhoogt het gemiddeld aantal inzittenden van een voertuig door het combineren van separate verplaatsingen. Het totaal aantal auto's op de weg wordt op deze manier verminderd. Dit resulteert in een betere bereikbaarheid van het stedelijke gebied, een hogere stedelijke kwaliteit van leven, en een reistijdwinst voor de woon-werk reiziger door minder congestie.

Het rapport schat het effect van verschillende factoren en potentieel gevoerd beleid gericht op het stimuleren van forenzen om te carpoolen. De vraag die hierin centraal staat is: *‘wat zijn de belangrijkste factoren die de vervoersmiddelkeuze van forenzen tussen solo rijden en carpoolen beïnvloeden?’* Onder andere wordt het stimulerende effect van een gereserveerde rijbaan voor auto's met een beleidsmatige vastgestelde bezettingsgraad onderzocht. Het toestaan van alle voertuigen met een bepaalde minimale bezettingsgraad op de vrije busbaan is een voorbeeld. Reistijdwinst is hier te behalen indien de carpooler ook via de vrije busbaan mag rijden en ook de prioriteiten van de huidige bussen heeft.

De structuur van het rapport is als volgt: eerst worden recente ontwikkelingen in de Nederlandse mobiliteitssector geschetst, waarna het belang van de studie voor reizigers, omwonenden, het milieu en de economie op zowel stedelijk als op nationaal gebied wordt toegelicht. De volgende stap is het opzetten van een discreet keuzemodel waarin respondenten worden gevraagd een keuze te maken tussen hun huidige woon-werk reis en een fictief carpoolalternatief. Op basis van de verzamelde resultaten wordt later een multinomiaal logit (MNL) model geschat. De coëfficiënten die hieruit voortvloeien worden vergeleken met resultaten uit de literatuur. Vervolgens worden de schattingen van het MNL model gebruikt als basis voor een tool die gebruikt kan worden om het effect te schatten van het veranderen van de geïdentificeerde factoren (of een combinatie hiervan) op het aantal personen dat bereid is te carpoolen. Uiteindelijk wordt de onderzoeksvraag beantwoord en worden beperkingen en aanbevelingen voor toekomstig onderzoek of gebruik van de resultaten gepresenteerd.

De eerste stap in het onderzoek is een literatuuronderzoek gericht op de huidige congestieproblematiek in de stedelijke omgeving (o.a. knooppunten op hoofdwegen). Een

typologie van carpoolen, samen met kenmerken van carpoolers en succes en faal factoren om carpoolen te stimuleren worden uitgebreid behandeld. Hieruit vloeien acht variabelen voort die naar verwachting het grootste effect hebben op de keuze van forensen om te carpoolen. Deze variabelen zijn: de reistijd naar en wachttijd op de carpool verzamellocatie, de actuele reistijd in carpoolformatie, de reistijdonzekerheid, kosten van de woon-werk verplaatsing, het minimum aantal personen dat vereist is om op de gereserveerde strook te mogen rijden, de parkeervoorzieningen op de bestemmingslocatie, de beschikbaarheid van een auto of fiets op de bestemmingslocatie, en de mate van flexibiliteit in de carpooltijden. Verder onderzoek naar de (relatieve) belangrijkheid en het effect op het verhogen van de carpoolmotivatie van deze factoren is noodzakelijk. Het gebruik van de gereserveerde rijstrook of busbaan is in deze variabelen gevangen (o.a. reistijdwinst). In het literatuuronderzoek worden verder voorbeelden van toepassingen in het buitenland van een gereserveerde rijbaan voor voertuigen met een beleidsmatig bepaalde minimum bezettingsgraad behandeld en de geboekte resultaten hiervan toegelicht. Dit vooral in termen van reistijdwinsten, mate van verlichting van de congestie en het effect van minder verplaatsingen op het milieu. Deze toepassingen zijn voornamelijk gebaseerd op snelwegen, waar reistijdwinsten van 50% herhaaldelijk worden gerealiseerd. In stedelijke toepassingen van een carpoolstrook zijn deze resultaten discutabel. De afstand waarover een reistijdwinst kan worden gerealiseerd is namelijk korter, terwijl de mate van reistijdverlies door congestie en overige opstoppingen zoals verkeerslichten hier tegelijkertijd veel hoger kan zijn, voornamelijk door de korte afstand en lage oorspronkelijke reistijd.

Om erachter te komen welke variabelen in welke mate de bereidheid en dus de keuze om te carpoolen beïnvloeden is een vragenlijst gecreëerd. Deze is gebaseerd op de 'stated adaptation' methode, dat wil zeggen dat eerst kenmerken van de huidige woon-werk verplaatsing van de respondent worden bevraagd. De verkregen antwoorden op deze vragen worden vervolgens gekoppeld aan de hierboven beschreven variabelen. Op deze manier wordt het soloalternatief samengesteld. Van deze huidige reis wordt vervolgens een fictief, maar realistisch carpool alternatief afgeleid. De waarden van de variabelen in dit alternatief zijn gebaseerd op een orthogonaal experimenteel design. Dit wil zeggen dat niet alle  $3^8 = 6561$  mogelijke scenario's aan de respondent hoeven te worden voorgelegd, maar dat dit gereduceerd kan worden tot een totaal van 27 profielen verdeeld over 3 keuzesets. Respondenten wordt een keuze tussen de beide alternatieven (solo en carpoolen) voorgelegd. De vraag hierbij luidt als volgt: *'zou u voor het maken van uw woon-werk verplaatsingen, op basis van de gepresenteerde scenario's met bijbehorende parameters, kiezen voor [carpool optie] in plaats van uw huidige vervoersmiddel?'*. Onderstaand volgt een illustratie van het carpoolalternatief met bijbehorende variabelen zoals deze in de vragenlijst is voorgelegd.



Het derde deel van de vragenlijst omvat enkele vragen die de houding van de reiziger ten opzichte van 5 gerelateerde carpoolconstructen bevangen, te weten: organisatie en formatie van de carpoolrit (online platform, matching programma, carpoolplein), kenmerken van de carpoolrit zelf (veiligheid, comfort), psychologische factoren (type passagier, auto als statussymbool), economische factoren (delen van kosten, fiscale voordelen), en kenmerken van de carpoolstrook (taks betalen om solo erop te mogen rijden, naleving en toezicht). Het laatste deel van de vragenlijst betreft socio-economische factoren (zoals leeftijd, geslacht en autobezit). Delen drie en vier van de vragenlijst kunnen worden gebruikt voor segmentatie van respondenten en het creëren van verschillende modellen voor iedere groep.

Door de aangeboden stated adaptation keuzeprofielen wordt de voorkeur en het verwachte keuzegedrag van forensen voor een vervoermiddel voor de woon-werk reis bevangen. Op basis van de gegeven antwoorden wordt onderzocht welke factoren de meeste invloed hebben op de vervoerskeuze van forensen tussen solo rijden en carpoolen. Dit gebeurt door het schatten van een multinomiaal logit model. In orde van belangrijkheid van meest naar minst effect, heeft het reizen naar een carpool ontmoetingsplek en de wachttijd op deze plek het meeste (negatieve) effect op de carpoolmotivatie, gevolgd door de actuele reistijd in het carpoolvoertuig en een eventuele afname hiervan door het gebruik van de gereserveerde rijbaan, vervolgens de kosten van de reis, de parkeersituatie op de werkplek en de mate van flexibiliteit in de reistijden. Significant minder belangrijk zijn de factoren: beschikking over een auto/fiets op de werklocatie, de reistijdbetrouwbaarheid of het minimum aantal personen in de auto om in aanmerking te komen op de gereserveerde rijbaan te rijden.

Uit het geschatte MNL model wordt een standaard afkeer voor carpoolen afgeleid, gebaseerd op een negatieve utiliteit van -1.06 wanneer de utiliteitsfunctie van het solo rijden is vastgesteld op 0. Deze utiliteitswaarden kunnen worden vertaald in een bereidheid dat iemand solo naar zijn werk rijdt van 74% en een bereidheid van 26% om te carpoolen. Als er geen standaard onderscheid bestond tussen solo rijden en carpoolen zou elk alternatief met een kans van 50% moeten worden gekozen. Dit betekent dat er een standaard afkeer voor carpoolen is van 24% ten opzichte van de evenwichtssituatie. 38% van de respondenten geeft aan in geen enkele gepresenteerde situatie bereid te zijn om te carpoolen. Op basis van de schattingen van het MNL model is vervolgens een tool gecreëerd en toegepast op de case-study Noord-Brabantlaan, Eindhoven. Data voor dit gebied betreffende aantal verplaatsingen, reistijden en afstanden is verkregen uit verkeersmodellen. Door het invullen van deze data in het model is het mogelijk een schatting te maken van de proportie van forensen dat bij verschillende scenario's en combinaties van factoren bereid is om te carpoolen.

De applicatie van de gecreëerde tool op de Noord-Brabantlaan in Eindhoven vertaalt de hierboven afgeleide kansen verder in verwachte volumes en proporties in termen van solo rijders en carpoolers voor deze specifieke route. Vier scenario's zijn geconstrueerd waarin de verzamellocatie vastligt aan het einde van het traject waar een carpoolstrook ligt. Het basisscenario beschrijft de situatie waarin een deze verzamellocatie en de carpoolstrook aanwezig zijn, maar verder geen reistijdwinst of andere voordelen gerealiseerd worden. In dit geval is de gemiddelde voertuigbezetting 1.12 (21% van alle forenzen carpoolt). Wanneer de reistijd op het carpoolstrooktraject gereduceerd kan worden met 50% worden 224 forenzen (27% van alle forenzen die momenteel met de auto naar hun werk reizen) gemotiveerd om te carpoolen. De gemiddelde voertuig bezettingsgraad is dan 1.16. Wanneer de parkeersituatie verbeterd wordt (dichterbij, makkelijker een vrije plek te vinden) is dit 1.13. Een verhoging van de minimum bezettingseis voor het rijden op de carpoolstrook van 2 naar 4 personen resulteert in een bezettingsgraad van 1.19. Dit komt deels omdat elk HOV voertuig meer inzittenden heeft, maar tegelijkertijd zijn er minder mensen geneigd om te carpoolen. Vervolgens zijn vier scenario's geconstrueerd waarin de verzamellocatie wordt verplaatst. Dichter bij huis resulteert in een grotere besparing op financieel en milieu gebied. De ordergrootten van bezettingsgraden en de proportie van het aantal personen dat gemotiveerd wordt om te carpoolen blijft ongeveer hetzelfde. In het meest optimale scenario waarbij alle variabelen de meest gunstige waarde krijgen kan een gemiddelde voertuigbezetting van 1.41 behaald worden, een forse winst dus.

Gemeenten zijn steeds meer op zoek naar duurzame oplossingen voor het verminderen van stedelijke congestie en haar effecten. Tevens wordt de vrije stedelijke ruimte steeds schaarser. Het beter benutten van ongebruikte capaciteit tijdens woon-werk ritten is een goede oplossing om tegelijkertijd het aantal ritten en dus het aantal voertuigen op de weg en het aantal benodigde parkeervoorzieningen te verminderen. Tegelijkertijd draagt het verplaatsen van meerdere personen met minder voertuigen bij aan het verbeteren van de stedelijke leefkwaliteit doordat uitlaatgassen worden verminderd (door minder auto's die minder kilometers afleggen en minder lang stationair draaien). Omdat vooral in de spits een lage voertuigbezetting voorkomt (1.12 personen/voertuig in Nederland, 2012) is carpoolen naast openbaar vervoer een belangrijke potentiële oplossing om dit te bewerkstelligen. Carpoolen combineert de privacy en het comfort van het solo reizen met een goedkopere, gedeelde manier van reizen zoals het openbaar vervoer. Zowel infrastructurele, politieke, fiscale, en andere maatregelen bestaan om mensen te motiveren om te carpoolen. Een reductie van reis- en wachttijden en het verlagen van de reiskosten zijn hierbij belangrijk. In dit licht kan een carpoolstrook uitkomst bieden, aangezien deze onzekerheden in de reistijd weg kan nemen door opstoppingen te omzeilen en door het verkrijgen van prioriteit op kruisingen. De tool die in dit rapport is ontworpen kan dienen om gemeenten en adviseurs op het gebied van mobiliteit kennis te geven over hoe carpoolen succesvol gestimuleerd kan worden. Het doel van de studie is om deze belanghebbenden te laten nadenken over de potentie van carpoolen in het reduceren van congestie en om carpoolen als oplossing voor dit probleem meer aandacht krijgt in het plan- en beslissingsproces van nieuwe transport- en verplaatsingsystemen.