Understanding the commuters' choice for HOV bus services in regards to regular bus services in the Netherlands

by

Aaron S. Eichler
Delft University of Technology
Master of Science Transport, Infrastructure and Logistics

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Understanding the commuters preference and choice
for high-level of service buses in the Netherlands

Aaron Stephen Eichler

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Evaluation committee:	B. van Arem	TU Delft (Chairman)
	Dr. ir. N. van Oort	TU Delft (CEG)
	Dr. E. Molin	TU Delft (TPM)
	Ir. W. te Morsche	Movares Nederland

Preface

The past year I have dedicated my time to working on this final assignment. With this final assignment I am finishing a big chapter of my life. I took the chance to dive into a new topic to widen my horizon even further and therefore chose a topic I was interested. Additionally, I was able to have first experiences of how it would be to work as an engineer in the field. I was given the opportunity by Movares Nederland to conduct a research on the HOV bus service. They gave me a lot of freedom in the choice of topic and I was given a starting point to embark on this final quest. The result of this assignment was not possible solely by own efforts. I received a lot of support from many different parties. I want to take this opportunity to thank everyone that has contributed to this research, either directly or indirectly.

I first want to thank my family for supporting me in my endeavors and pushing me forward, to challenge myself over and over again and to surprise myself of what I am capable of. I want to thank my girlfriend in encouraging me and reminding me what I am capable of and supporting me throughout the journey. Thank you for all their patience and efforts in supporting me.

Next I want to thank the examination committee. I want to thank Bart van Arem for taking upon him the task of becoming the chair of my examination committee. I want to thank my university supervisors Eric Molin and Niels van Oort for their patience, support, and time. I want to especially thank them for their vast knowledge and sharing this with me for my research. I want to thank my company supervisor Wietse te Morsche guiding me during the process and involving me in company matters. I want thank him for his input and flexibility. I want to thank Movares Nederland for allowing me doing this research within their company and allowing me to use company resources. I want to thank Smartwayz and Moventem for supporting me in setting up and distributing the survey, which was a big part of this research. I want to also thank all the people that agreed to interviews and that where willing to provide me with resources through e-mail.

Overall, the research was very interesting. A topic was chosen which was not familiar allowing to learn a lot. However, this also caused that more time had to be spend on understanding certain concepts more thoroughly or spending more time on figuring out software packages. But eventually a way has been found to a survey, collect the data, estimate a model and producing useful results. It was a great experience and I have learned a lot on the way. Not only on knowledge and insight, but also in personal development and experience.

Thank you.

Aaron Eichler
ORCID: 0009-0004-7564-5169

Summary

In the Netherlands, a high level of service with buses can be found which is being referred to as HOV ('Hoogwaardig Openbaar Vervoer), high level service public transport. There is a growing need for a transportation system which can be quickly introduced and flexibly adjusted over the years. With HOV bus services transport authorities and carriers promise a service which should provide higher quality than the regular bus service. However, decision makers involved in the organization, design, planning and operation of HOV services have different interpretations of what HOV should be and what "higher quality" means in terms of operational aspects. More importantly, what do travelers see as "higher quality" as they are they will be the user of the system. Literature suggests that there is a misalignment in terms of the definition of this higher level of service as authorities and travelers use different aspects to make a choice for a transportation system. Additionally, the Dutch HOV bus service is not synonymous with bus rapid transit (BRT) although the terms are being more and more used as such in the Netherlands. This makes the availability of relevant literature specifically for the Dutch HOV bus service limited. It is important to understand the differences such that successful high level bus systems can be introduced which fit into the Dutch landscape, figuratively and literally.

This research aims to identify the characteristic level of service attributes for HOV which are promised to be of higher quality to the Dutch commuter and understand how these aspects influence the choice probability of the Dutch commuter choosing this kind of bus service. Additionally, it will give insight into the modal split with which ridership gains can be predicted. Decision makers promise this higher quality to be at its best during the peak hours of the day. Therefore, the commuter is of interest because they travel regularly during peak hours. This knowledge will support decision makers in allocating investments effectively, improving current bus services and introducing new services that align with the commuters needs. The goal is to provide decision makers with practical knowledge that can be used for such evaluations. Additionally, the insights and results will contribute to the ongoing discussion in the Netherlands about the definition of high level bus services in the Netherlands.

The goal was translated into a research question: *How do the characteristic level of service attributes of HOV bus* service *affect the commuter's choice on choosing an HOV service for their commute?* This question will be answered by conducting a stated choice experiment of which the results can be used to estimate a Multinomial Logit Model. Further analysis gave insight into how the aspects affect the choice probability choosing between the commuters current commute and the HOV bus service.

First the current state of HOV was analyzed which revealed that Dutch HOV bus services have no standard configuration. The configuration depends on the length of the route provided by the bus but between the revealed HOV types there is overlap and also outliers in service configuration. Interviews were conducted as well which showed that decision makers do not have a fixed definition for the HOV bus service. It was also seen that there were mixed opinions promoting the HOV bus service actively to potential users. Interviews were conducted, current HOV brands were analyzed and literature on travel satisfaction was reviewed which revealed that: frequency, directness, reliability, recognizability, comfort and speed are the most characteristic attributes of HOV. These aspects were translated into attributes relatable to commuters: access time, egress time, in-vehicle time, frequency, reliability and seating. Commuters were asked to fill in a survey which revealed how they choose between a regular bus service, an HOV bus service and their current commute. It was important that the buses had the same configuration, only the label was different to identify the exist of an underlying preference for the HOV

bus service. For this a stated choice experiment was set up which included a pivot design such that choice scenarios were more relatable for the commuter.

With the data of the survey, a discrete choice model could be estimated. A model was estimated which allows for the prediction of the modal split between a regular bus service and the current commute or between the HOV bus service and the current commute. This way it can be evaluated what the growth or decline is in modal split when changing a regular bus to an HOV bus service. the analysis of the model revealed that the regular bus service and the HOV bus service are differently valued. The HOV bus is more negatively valued for “seat with a neighbor” (59% more negative), egress time (44% more negative), access time (31% more negative), ASC (27% more negative) and “standing (20% more negative). The HOV bus and the regular bus are valued equally for frequency, in-vehicle time and “stand; than sit”. The HOV bus is more positively valued for reliability (100% more positive, twice as much). It was notable that most parameters were more negatively valued for the HOV bus then they were for the regulars bus. Yet, the reliability mostly compensates for the difference in utility between the regular bus service and HOV bus service. In addition this means that improvement that are being made to the seating configuration, egress time and access time are more positively valued then doing so for the regular bus line. When relating this to modal split then the conclusion is that the impact of the characteristic attributes on the modal split change depends on the context of the case that is being evaluated. If utility differences between the regular bus service and the current commute are large, introducing an HOV bus service with the same attribute will not change the modal split by much and thus are the regular bus service and the HOV bus service almost valued equally. However, when the utility difference with the current commute is smaller than improving the promoting the bus service as an HOV bus service can lead to higher modal splits. Reliability has the largest impact on the market share when changing a regular bus service to an HOV bus service. Then the largest changes in utility can be achieved by improving the seating comfort. However, depending on how much improvement can be made in terms of travel time, the travel components could out perform the contribution. The same can be said about frequency. Changing the reliability further does not further improve the modal split significantly. Overal, it was seen that promoting the a bus line as an HOV line has a positive impact.

The output of the research is an MNL model with which modal splits can be predicted and insights into the differences in valaution between the regular bus service and HOV bus service are provided. This insight can be used to evaluate and improve planned and existing bus services and can be the starting point of creating public transport services that align well with the mobility needs of the dutch commuter.

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Table of contents

List of Figures

List of Tables

List of Equations

Glossary

The glossary also includes abbreviations

BHLS Buses with High Level of Service

BRT Bus Rapid Transit

Commuter A person travelling regularly the same trip during rush hours.

Rush-Hour Period of day with highest traffic, in the morning between 7 and 9 o'clock ("ochtendspits") and in the evening between 16 and 18 o'clock ("avondspits")

HOV Hoogwaardig Openbaar Vervoer (dutch, english translation: "High value Public Transport")

PvE Programma van Eisen ("Program of Requirements")

MNL Multinomial Logit

ASC Alternative Specific Constant

LRS Likelihood Ratio Test

1

Introduction

In the Netherlands, a higher level of service of public transport exists, which is known as HOV (Dutch: Hoogwaardig Openbaar Vervoer). Transport authorities and public transport carriers promise the commuter that this type of service offers a higher level of service than regular buses, especially during rush hours. It is promised to offer a higher frequency service at higher speeds with better comfort and reliability. Additionally, it is often promoted as an alternative to the car. However, these aspects are specified in different ways among transport authorities in the Netherlands where HOV bus lines exist. Parties involved in the planning and operation of HOV bus services have expressed a need to better understand in what ways these aspects influence the commuter's choice. It is known in the field of transport planning that a higher frequency, higher speed, better comfort and greater reliability contributes to more satisfaction in many cases. It is lesser known what "more & higher" exactly means in terms of operational levels and when further improvement is not needed. Not all improvements in level of service contribute equally to the commuter's choice. Decision makers want to maximize the impact that can be made with investments. Therefore, changes to the transport system should be made in such a way that maximum impact can be achieved with the investments that are being made. The HOV bus service is not a one-solution-fits-all, although in some cases it is being used so. The implementation of a HOV bus service should be well considered since HOV lines can have higher investments and operational costs depending on the configuration compared to regular buses. To make good decisions, it is important to better understand the preferences of commuters regarding HOV services and identify the changes that have the greatest impact on increasing the probability of both current and potential users choosing the HOV bus service. This research focuses on understanding how variations in the characteristic HOV attribute levels affect the choice probability of choosing the HOV bus service over the commuter's current commute. In other words: are the promises of HOV worth to be kept?

1.1 Context

The HOV bus service is a type of bus service which promises the commuters a service at a higher level than the regular bus. A commuter is a traveler who travels on a regular basis for work or education during rush hours. They travel by bus, train, bike, car, or a combination of these modes. It is during this period that HOV buses deliver the higher level of service. This higher level of service can consist of a high frequency, a high average operational speed, more direct routes, a reliable service, more comfort or being better connected to other modes of transport (Witte & Kansen, 2020). All HOV bus services are set to deliver a service better than regular bus services. In the Netherlands, different HOV bus service configurations exists because different measures can be taken to increase the level of service of a regular bus service. Decision makers see the HOV bus service as a service of higher quality and consider it often as an alternative to rail-bound systems because a similar quality is delivered with the HOV bus service at a fraction of the cost and with a shorter lead time. They are frequently considered in alternative analysis along with tram and metro options. The HOV Bus service is a flexible solution that can be adjusted to mobility needs while in operation and can be scaled accordingly with changing demand over time because of the nature of a bus vehicle. This makes the solution attractive to decision makers to implement a high-capacity system in a short amount of time with possibilities to upgrade the service in capacity or even to a rail-bound system in the future if necessary. The HOV bus service is considered in situations where investments are not justified for a rail-system, but a regular bus service is insufficient for the expected demand.

HOV is a Dutch term and therefore rarely used in English academic literature. The term BRT ("Bus rapid transport") is more commonly used internationally for such a high level bus system. BRT is a bus system which runs at very high frequency on dedicated infrastructure and delivers a high capacity. BRT is mostly used in cities with large populations. BRT, as it is seen around the world, is uncommon in Europe due to the lack of space and less flexibility in fitting in dedicated infrastructure in the historical urban environment. In 2012 a term was introduced for BRT in Europe which would better describe this kind of bus system: BHLS, buses with high level of service. This term refers to bus systems which fit between regular bus services and BRT. This term was supposed to describe BRT better in the European context. However, the term was not very clear and has not been adopted by the masses. Therefore, the term BRT is used but a distinction between different levels of BRT exists. Also, in the Netherlands the term BRT is used more and more to refer to HOV bus services. In the Netherlands HOV has been proposed to describe HOV as BRT-light or BRT-comfort, though it is still being experimented with other categorizations. The conventional description is not suitable since Europe seems to focus more on delivering a higher level of service with comfort opposed to delivering a higher level of service with high capacity.

A growing interest for HOV bus services can be seen as it is a short-term answer to fulfilling the mobility needs of future housing projects. For example, in the MIRT ("Meerjarenprogramma Infrastructuur, Ruimte en Transport" – "Multi-Year Program for Infrastructure, Spatial Planning and Transport") the Dutch government presents their plans for the next year in terms of the allocation of investments for infrastructure, spatial planning and transport projects in the Netherlands, as well as presenting the progress made with previously announced projects. It includes several projects in which HOV bus receives additional funding (Rijksoverheid, 2022). In addition, the Dutch government published multiple white papers presenting the chances for BRT in the Netherlands, as well as proposing different ways of describing this transport service. Included in this description where the HOV bus services. Greater knowledge on BRT needs to be collected as it gains more interest and is used synonymous for HOV bus services.

1.2 Problem

The starting point of this research was found during a conversation with Movares Nederland. Movares Nederland is regularly supervising projects involving the realization of HOV services. Movares Nederland is a company headquartered in Utrecht, The Netherlands, that provides advice, guidance and engineering services to municipalities, governmental bodies, transport authorities and private companies mostly in the transportation and mobility sector. They expressed the need for a better understanding of the preferences of the commuter for certain aspects of HOV. In several projects they had noticed that the way HOV bus services are provided differs amongst the transport authorities and that the standards for the different aspects also vary. They mostly noticed this with the aspects such as frequency, speed and travel time ratio opposed to car which are interpreted and set differently by the parties. This raised the question: What preferences does the traveler have for HOV Bus services? Does the traveler value the higher quality delivered by HOV Bus lines? Transport authorities do see ridership gains with when introducing HOV bus services, however there is still uncertainty in knowing which aspects exactly make commuters choose an HOV service. Understanding this would support transport authorities and other stakeholders in allocating investments correctly and improve the relevant aspects of a service so that it aligns with the commuter's preferences. Transport authorities and governmental bodies should use investments efficiently such that mobility needs can be fulfilled as efficiently as possible. This requires great knowledge and a good understanding of different systems that can be used to fulfill mobility needs. The objective of organizational bodies is to increase accessibility in their area. Understanding the commuter's preferences gives transport bodies and carriers insight into what aspects of their service should be prioritized so that commuters will be satisfied, potential commuters can be attracted, and investments are used efficiently.

1.3 Objective

The objective of the research is to understand how changing the levels of the characteristic level of service attributes of HOV affects the commuter's choice of choosing the service. The output of the research should be usable by decision makers to improve existing HOV bus services or design new bus services which align with the preferences of the commuter. This research is focusing on revealing these characteristic level of service attributes, identifying the common levels for these attributes and relating the change on these levels to the commuter's choice probability for a HOV service.

1.4 Research Questions

Research questions have been formulated to conduct the research in a structured way which addresses all important aspects that contribute to fulfilling the research objective. The main research question describes the main interest of the research. Sub research questions are established so that the main research question can be answered in a structured way, having all the important aspects taken into account which are needed to construct a clear answer to the main research question.

The following main research question has been formulated:

How do the characteristic level of service attributes of HOV bus affect the commuter's choice on choosing an HOV bus service for their commute?

1. What is the current situation of HOV buses in the Netherlands?
2. How does the decision maker define HOV Buses in the Netherlands?
3. Which attributes are relevant to the commuter?
4. Which attributes are characteristic for HOV Bus services?
5. Which variations exist in the levels of the characteristic attributes of HOV Buses?
6. Which variations exist in the trip characteristics of the commuters?
7. How do commuters choose between an HOV bus and regular bus for their commute?

1.5 Methodology

The main research question will be answered by making use of expert interviews, desk research, literature, conducting a stated choice experiment and estimating a logit model. The first part of the research focuses on understanding the current landscape and revealing the attributes that are characteristic for HOV services. They will be revealed by looking at aspects which influence traveler satisfaction and other aspects which have been identified as important by other literature. Additionally, interviewing experts, analyzing current HOV product formulas and HOV lines, those aspects can be revealed too. The attributes will be used as the input for the stated choice experiment from which the output can be used to estimate a discrete choice model.

This approach is related to a method that is being taught amongst engineering and design students: the triple diamond technique. This methodology proposes to diverge and converge in different aspects throughout the research however moving closer to the answer to the research question. The triple diamond starts with a divergence. This means one will look broadly at a topic and understand the whole picture. It will be looked at as a theme more generally. After having diverged enough, it will converge. This means one will look more specifically and deeply at certain aspects one has found during the convergence. After this another divergence will take place looking more broadly at the found topics followed by a convergence such that the analysis can be concluded with specific conclusions. Figure 2 shows how the triple diamond technique is being applied to this research.

Figure 1 Triple diamond technique

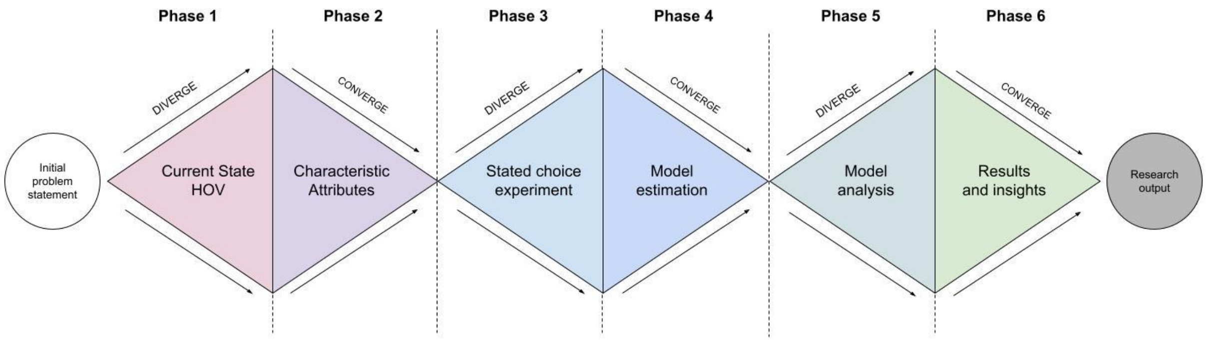

Figure 2 Triple diamond technique applied to this research

Phase 1 is the analysis of the context. This includes the current state of HOV, HOV in practice, decision makers perspective, commuters' perspective, and travelers' preferences. In phase 2 it will be converged based on this information to identify the characteristic attributes. In phase 3 it will be diverged based on these characteristics by collecting data on commuters choosing between the characteristics. In phase 4 the model will be estimated which will give a more specific results on how important the characteristics attributes are. In phase 5 the model will be analyzed to understand how the characteristic attributes relate to the commuters choice and probability of choosing the HOV bus. In Phase 6 it can be converged from all the insights and results to the answer of the main research question.

1.6 Sub Questions

To answer each sub question different methods will be used to find the knowledge that is needed to answer the main research question.

Sub question 1

What is the current situation of HOV buses in the Netherlands?

To answer this question, desk research will be conducted and literature will be analyzed. It will be looked into the current state of HOV buses in the Netherlands. This will reveal what HOV buses are, how HOV buses are organized, how they compare to other high level service buses and reveal other aspects that are important to understand about the nature of HOV buses.

Sub question 2

How does the decision maker define HOV Buses in the Netherlands?

To answer this question different experts in the field will be interviewed to understand the motivation for such systems, to understand the goals they want to achieve, to understand their overall opinion, and the impact in practice and to reveal potential problems regarding HOV buses. From this it can then be derived what the decision maker defines as HOV.

Sub question 3

Which attributes are relevant to the commuter?

To answer this question a literature review will be done on public transportation satisfaction. Through analyzing different literature, attributes can be revealed which are found to be relevant to commuters. This information can then be used to verify the relevance of the distinctive attributes.

Sub question 4

Which attributes are characteristic for HOV Bus services?

To answer this question desk research will be done and insight from SQ1 and SQ2 will be used. Different HOV product formulas will be analyzed on the HOV service they want to deliver. From the interviews it can be derived which aspects decision makers find important for HOV bus. Combining these two sources will reveal the most distinctive attributes for HOV buses.

Sub question 5

Which variations exist in the levels of the characteristic attributes of HOV Buses?

To answer this question, different HOV Bus configurations will be analyzed from which it will be derived how the levels vary. This is to understand what operational characteristics HOV lines have and how these aspects differ amongst the different services.

Sub question 6

Which variations exist in the trip characteristics of the commuters?

To answer this research question, data from Dutch commuters will be analyzed which will give insight into their commute. The results from answering these research questions will be taken as input for the stated choice experiment to design realistic choices and ask relevant questions.

Sub question 7

How do commuters choose between an HOV bus and regular bus for their commute?

To answer this question, a survey will be conducted which includes a stated choice experiment. The stated choice experiment will be conducted to capture how commuters choose between a regular bus, a HOV bus and their current commute. Multiple choice sets will be presented which present different bus configurations. The survey participant is then asked to choose an option they would consider choosing. The bus configurations vary in different attributes. These attributes are distinctive for HOV Bus and have been revealed through answering previous research questions. The commuter can choose the configuration they prefer.

The stated choice experiment is part of a survey. The survey will be used to collect data on the commuters' demographics, the commuters most made journey and the commuters' familiarity of HOV bus. Aspects such as age, sex, occupation, travel frequency, travel purpose, frequency of use, most used mode, travel time, waiting time, door-to-door time, etc.

After the results of the stated choice experiment have been collected, a Logit Model can be estimated to predict the impact of the attributes on the choice probability. Doing further analysis on this data through a sensitivity analysis will show how changing the attribute levels influences the choice probability and therefore answers the research question.

1.7 Scope

The scope of this research is limited to BRT-lite in the Dutch context known as "HOV Bus". The research will not focus on full BRT systems but only systems that can be found in the Netherlands. The studied BRT-lite lines may make use of bus lanes or dedicated infrastructure, but it is not a requirement for HOV bus services. This study is focusing on the lower end of the spectrum at which HOV bus services and regular bus services overlap. The focus of the study is on the service provision defined by operational aspects. This study is not a definition study of BRT, but rather to provide additional insight to the discussion by analyzing the commuters preferences for HOV. The "Snelbus" is not considered in this research since it is being described as delivering a direct service between two points. BRT-lite services still make multiple stops. The research is focused on the service aspect of public transport. A main distinction about BRT and HOV is that HOV does not always make use of bus lanes, but provides a higher level of service through operational aspects like frequency, reliability, comfort and speed. Bus lanes is seen are used as a possible mean to achieve the higher level in some cases. It will be further elaborated on the differences between BRT and HOV in chapter 3.

1.8 Relevance and gap

The scientific contribution of this research is to increase the knowledge on how factors impact the commuters' choice of buses which deliver a higher level of service than regular buses. The method can also be applied to other areas. Additionally, the perspective of users and potential users has not been taken up much in the discussion of defining BRT. Something that is seen as important as the user and potential users are the end-user and the group that is being attracted to achieve ridership gains. Most literature focuses on the decision makers' perspective, but not much literature has been found talking about the travelers' perspective. The question still remains on whether the traveler values the higher service provided as well as if they are aware of the provided service. As BRT seems to get back into the picture more recently, it gives the chance to contribute to this discussion from the traveler's perspective. That is why this research wants to help fill this knowledge gap.

Societal relevance

When looking into the available literature on how the travelers' perspective is being analyzed, it can be seen that most literature investigates what factors influence travel satisfaction and which factor is found to be most important. However, less literature can be found on how much certain aspects influence travel satisfaction. The literature mostly looks into attributes that are about the experience of the passenger and less at the technical operational attributes. Literature does mention the importance of including passenger perspective on the technical operational aspects of a public transport service. However, it is unclear how this can be effectively done. It is mentioned that the traveler perspective on the level of service attributes could benefit designing services which provide a higher travel satisfaction (Tyrinopoulus et al. (2008), Nathanail (2008)).

Practical relevance

Each year the Dutch government assigns specific budgets to different infrastructure and transport projects. A report is released every year in which new projects as well as the status of previous projects are presented. This is the so-called MIRT ("Meerjarenprogramma Infrastructuur, Ruimte en Transport" – "Multi-Year Programme for Infrastructure, Spatial Planning and Transport") (IenW et al., 2022). This year the government assigned an additional 1,5 trillion euro to spatial planning projects including public transport projects (Rijksoverheid, 2022). The reason for this, is growing demand for houses which require good accessibility to shops and workplaces, as well as the need to decrease carbon footprint. From the statement it can be derived that there is a need for fast and more reliable connections as the demand for transport is growing and to create a more interconnected country. Investments should be allocated in such a way that the impact of the investments will be maximized and that the demand can be fulfilled as much and as quickly as possible. Therefore, it is important to understand the true impact of new mobility projects such that investment can be correctly assigned.

The initial research direction has been provided by Movares Nederland as they are interested in how the user values the higher quality delivered by HOV Bus and what the travelers opinion is on the technical aspects of this service. Movares Nederland was especially interested in what preferences the traveler has for the higher quality attributes. What they noticed in their consultation is that different transport authorities and other stakeholders have a different understanding of HOV bus services. Different transportation bodies have different requirements for HOV Bus lines. This left the Movares Nederland interested in knowing what the passenger is actually thinking of this. Companies want to be better aware of the BHLS landscape and the passenger perspective. With this knowledge they want to be able to provide better advice to transport authorities and governmental bodies who are considering HOV Bus services and lines as alternatives. Additionally, companies working in the field it important to be up-to-date of all the developments taking place in the public transport sector such that they are able to respond immediately and insightful to request coming from the industry. This will also give them an advantage over their competitors.

1.9 Thesis outline

In the first chapter of the thesis, the research has been introduced with the research context, goal, objective, questions and the methodology used to answer the main research question. In the second chapter, the theoretical framework supporting the research will be introduced. In the third chapter, SQ1, SQ2, SQ3 and SQ4 will be answered. Chapter 3 focuses on collecting background information on the current state of HOV in the Netherlands and gaining a better understanding of the commuter. In chapter 4, the stated choice experiment will be developed. Data collected in chapter 3 will be used to answer SQ5 and SQ6. In this chapter it is explained which decisions have been made for the stated choice experiment and how the survey has been developed. In chapter 5, it is explained how respondents have been collected and how each question of the survey has been answered. In this chapter SQ7 can be answered as it has been recorded how commuters choose. In chapter 6, the collected data from the stated choice experiment will be further analyzed by estimating a logit model. Through this logit model the effect of changing attribute levels on the commuters can be evaluated. In chapter 7, the model will be further analyzed to reveal the differences in valuation and the relations with modal split. The results will be presented and practical implications discussed. In chapter 8, the answer to the final research question will be given as well as recommendations. Limitations will provide insight into which topics more research should be done. Figure 3 Research Structure shows how the research structure is translated into the thesis report.

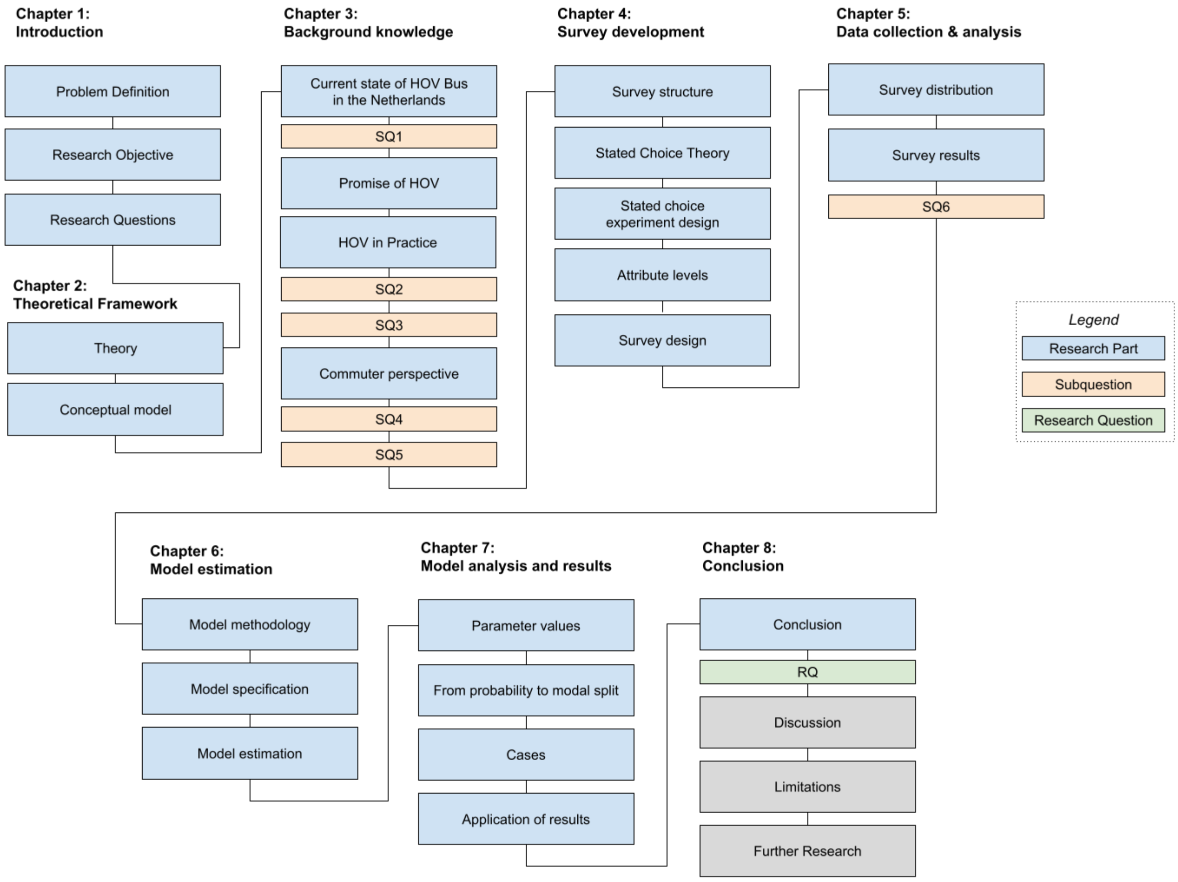

Figure 3 Research Structure

2

Theoretical Framework

The theoretical framework will present the theoretical assumptions that were made during this research. The fundamental theories are presented used during this study.

Travel choice behavior

This research looks into how people choose a mode of transport to fulfill their mobility need. In the field of transportation this is a common problem that is being researched as well as a field in which a lot of research has been done. Understanding why travelers travel the way they do will contribute to designing passenger services which optimally fulfill the traveler's needs. The research is also interested in understanding how traveler trades off between different aspects that influence their travel choice.

There are different aspects that influence how a traveler makes the choice. It is well known that socio demographics such as age, gender, living area, income influence how people travel. This mostly affects the travel needs. Dependent on what services are available, the traveler chooses the option that fits the most to their needs. One theory in the field of transportation explains this behavior through utility theory. Utility theory is based on the assumption that travelers want to maximize the utility of what they choose. Therefore, when being presented with different alternatives, according to this theory the option will be chosen which gives the traveler the highest alternative. The utility is determined by many different factors regarding that alternative that all contribute differently to the utility. These can vary from alternative to alternative and from individual to individual.

There are different methods that can be used to predict which options travelers use in the end. For one this can be based on historical data, revealed choice data. This data entails the mode of travel, the time of travel and the distance travelled. However, this data does not show why travelers made the decision they made. Another option is through surveys. Travel surveys are very popular amongst travel carriers to find out how satisfied their customers are with the service. The downside with surveys is that they do not capture the satisfaction of travelers who did not choose the option in the first place. Additionally, the survey can be biased because it is likely that either a very satisfied or a very unsatisfied customer will do the survey. With the right questions it is however possible to capture the satisfaction as well as the importance of different factors that determine a service. The only risk is that respondents may get introduced to considerations they would not have considered before. This can introduce errors in the validity of the results.

Researchers are interested in understanding travel choice behavior such that it can be used for prediction. Through understanding what makes a traveler choose an option or not, it can be predicted how well a new service fits to the needs of the traveler and how many travelers will end up using the service. The field of choice modelling is looking deeper into this. A discrete choice model can be estimated to predict the probability that travelers choose a certain option. The estimation is based on choice data through which weights for different attributes can be estimated. This data is captured through stated choice experiments. In a stated choice experiment, hypothetical choices are presented to a fitting population. In each choice, alternatives are presented. Each alternative is described by attributes. Per choice the levels of the attributes differ from the other choices. Respondents are then asked to make a choice. From the collected data a model can then be estimated which will show which attribute contributes the most to the user's choice.

Figure 4 presents the assumption that people choose the option which provides the highest utility. The individual socio demographics as well as the trip characteristic influence how the attributes of the alternatives are perceived. The current commute as well as the HOV bus has specific attributes which influence the utility. This utility then determines the mode choice and also reveals the preferences of commuters.

The goal of the research is to provide decision makers with knowledge on how to align the delivered quality as closely as possible with the desired quality of potential and current commuters. The desired quality, as the figure shows, can be derived from stated preference data hence stated choice experiment data. From this data a model can be estimated which allows decision makers to predict the alignment of the delivered quality with desired quality of their new or existing services. Identifying the relevant attributes, setting up the stated choice experiment, estimating a model and giving insight on how this knowledge can be used is at the core of this research.

The mathematical background of this theory and its relation to probabilities and modal split will be further discussed in chapter 6 in which a choice model will be estimated for this research.

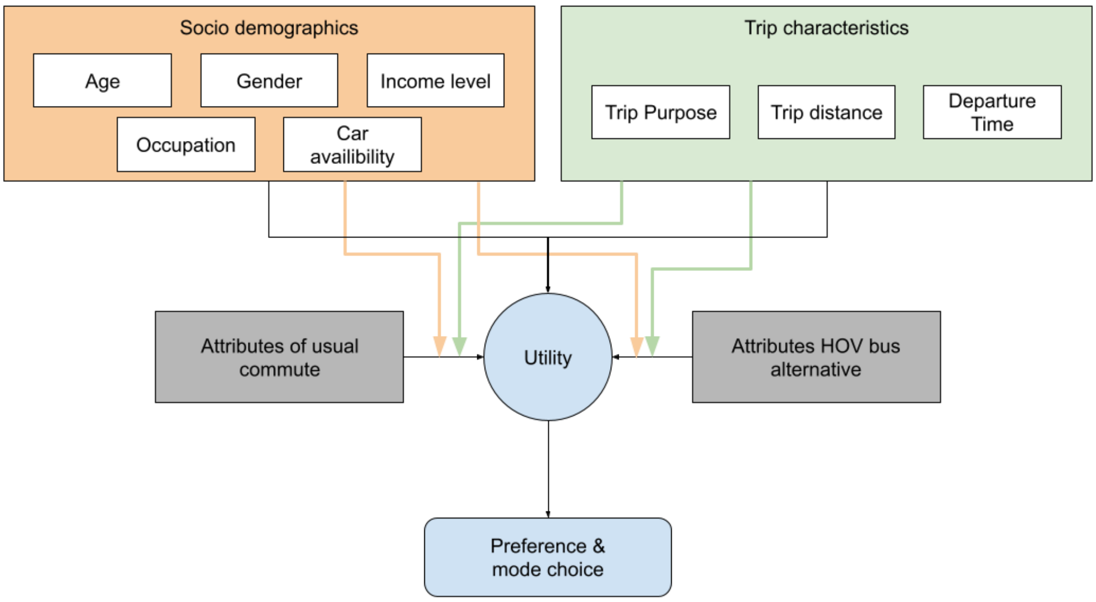

Figure 4 Theoretical Framework

Service quality loop

The European Committee for Standardization introduced the service quality loop under EN13816 (Mohammed, et. al., 2020). This quality loop shows how different services are related to each other. Mohammed et al. (2020) has related this service loop to public transport bus services. It shows how stated and revealed preference data relate to this loop. The decision maker can be assigned to be responsible for the targeted quality. They introduce the quality standards for a service. This quality is then delivered by the assigned carrier. Through surveys, perceived quality of customers can be measured. However, the loop should start with the desired quality such that a service is in place which fulfills the travelers expectations and needs. Then over time it can be measured what are improvements should be made. This research focuses on starting the loop with the desired quality and how decision makers can translate this to the targeted quality which can be realistically delivered by carriers.

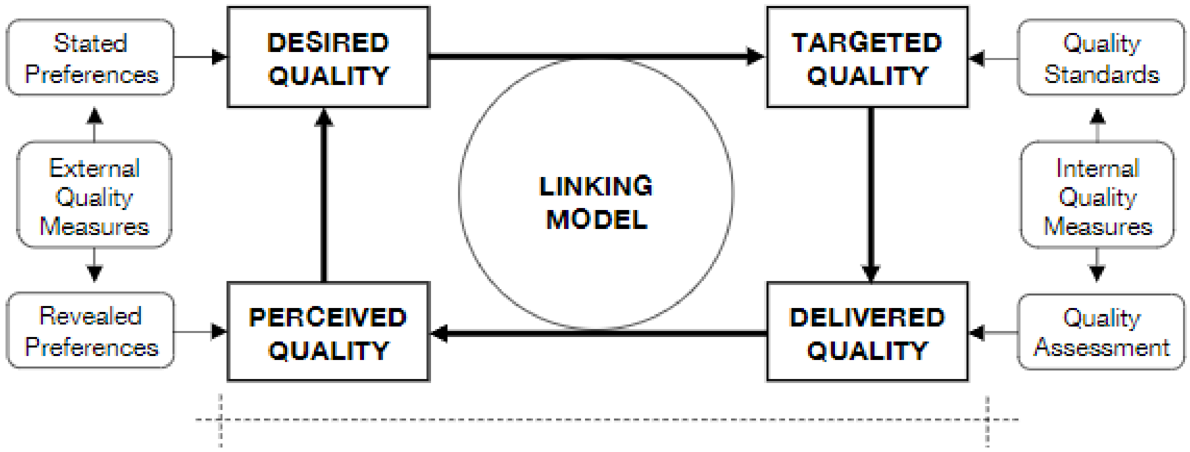

Figure 5 Quality loop

Traveler satisfaction

It is important to know what influence the choice of the traveler. Especially when wanting to satisfy users that are not using a system yet. Traveler satisfaction is insightful for carriers to understand which aspects of their service should be improved and which aspects are satisfactory. Different factors influence how satisfied travelers are with a service. Existing research on travel satisfaction can give a guidance on what aspects potential users might find important. But the factors can differ between existing and potential users since there is a reason behind why potential users are not an existing user yet. For this research, literature on travel satisfaction will be assessed to reveal this factors.

A well-established theory in the field of travel satisfaction is the Customer Wish Pyramid (van Hagen & van Oort, 2019). It shows which attributes of a service contribute to the traveler satisfaction and the order of importance by the customer. The traveler has certain minimum expectations that should be fulfilled. The diagram makes a distinction between satisfiers and dissatisfiers. Experience and comfort are seen as the satisfiers and ease, speed, reliability and safety are the dissatisfiers. The order of importance is from the bottom to the top. Meaning that carriers should concentrate on reliability and safety first, followed by, speed, ease, comfort and experience. If the dissatisfiers, the lower part of the pyramid, is not satisfactory then an improvement in the satisfiers does not contribute very much to overall satisfaction. First and foremost, the traveler wants a safe and reliable service. Then the traveler wants a service which minimizes the door-to-door travel time as much as possible. Then the traveler wants the service to induce minimum hassle and stress, so that the mental effort is minimal. A lack in quality in these aspects makes the customers dissatisfied with the service. After ease the traveler wants a comfortable service which minimizes physical effort. At the top of the pyramid is experience. The pyramid shows that carriers should concentrate mostly on delivering a reliable, fast and mentally comfortable service as they weigh the most in travel satisfaction. After this the carrier can concentrate on making the service more comfortable and creating an experience around it. In practice this is being done through branding or providing special searches such as Wi-Fi and USB-ports in the bus.

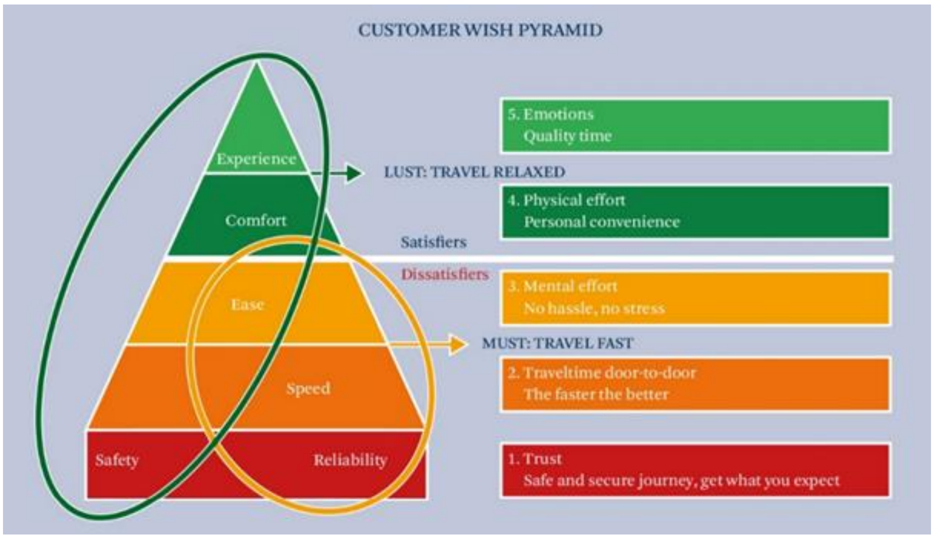

Figure 13 Customer wish pyramid (van Hagen & van Oort)

3

The HOV bus service and the commuter

This chapter services the purpose of getting a better understanding of HOV bus services and how it differs from BRT and BHLS. The chapter will give insight into how HOV is being used in the Netherlands and how it is defined. Additionally, it will be looked into the Dutch commuter and their trip characteristics. The defined sub-questions will give a guideline for the information that is relevant to the research. The following sub-questions will be answered:

1. What is the current state of HOV buses in the Netherlands?
2. What is the decision makers' perspective on HOV Buses in the Netherlands?
3. Which attributes are distinctive for HOV Bus services?

3.1 HOV, BRT and BHLS

Buses with high level of service are differently referred to in literature. In the Netherlands, these types of services are referred to as HOV but more the term "BRT" is being used. The term "BRT" can again be different. The research is not focusing on finding a clear definition of literature revealed that within BRT different distinctions can be made. This section is to show the different definitions and which definition this research will use.

3.1.1 Buses with high level of service

When talking about a bus which provides a higher level of service than the regular bus, BRT is the most known version in literature and amongst decision makers. BRT stands for "Bus Rapid Transport". BRT is a service with buses that runs on bus-only infrastructure dedicated to the BRT lines. Buses run at high frequencies and at high speeds. Most BRT systems reach high capacities and move many passengers. The main advantage of this system is the reduced cost compared to rail-bound systems, such as light-rail and metro. BRT is often considered as a middle way when decision makers are in search of high-capacity systems.

BRT is a North American concept which aims at providing a rail like service with buses. Rail services are characterized by running on their own infrastructure which allows them to provide a more reliable and uninterrupted service. BRT is applying this principle to buses. Well-known successful BRT systems transport many passengers and run on fully dedicated infrastructure.

In Europe these kinds of BRT systems are less common and exist at a much smaller scale compared to other systems around the world. There are bus systems in Europe making use of bus lanes just like BRT and bus systems that have some operational characteristics of BRT, but they are not fully considered as BRT. The Europe Union initiated research which should look into what better name this kind of bus systems can be given in Europe as BRT was not the right description.

3.1.2 HOV, BHLS and BRT

When looking in literature specifically for HOV, the literature available is limited. There is more literature available on BRT, but most descriptions of HOV align with the description of BHLS rather than BRT. BHLS is a terminology developed specifically for European high capacity bus systems (Heddebaut et al., 2010). Different publications were presented around that time to explore the potential of BHLS. The papers mostly highlighted the missing clarity on the definition of BHLS, but were positive that this system has potential in achieving ridership gains and attract more people to use the bus (Hidalgo et al, 2013; Heddebaut et al., 2010; Lambas et al, 2010; Bodok et al, 2011). In many cases BHLS is also seen as an intermediate application rather than the definite option (Hidalgo et al, 2014).

When referring to a higher quality bus system, it is often called Bus Rapid Transit (BRT). Many successful BRT systems can be found around the world, which run on dedicated infrastructure and transport a high number of passengers every day. However, bus systems of higher quality in the Netherlands have different system characteristics than BRT and significantly less passengers are being transported. In the Netherlands, higher quality bus transportation is being referred to as "Hoogwaardig Openbaar Vervoer"(HOV), which means High-value Public Transport. Through literature it was discovered that this term is equal to the term buses with high level of service (BHLS) (Heddebaut et al., 2010). BHLS focuses more on the service aspect rather than the infrastructure aspect. BHLS systems can make use of dedicated infrastructure, but this can be partially the case. BHLS is a much broader term than BRT, meaning that between the different bus services that are referred to as BHLS variations exist. In literature efforts are being made to set up a categorization system which gives more insight into the level of the higher quality of service that is being delivered. Specifically, for BHLS there does not seem to be a clear categorization. It is taken into the categorization of different bus systems, which varies from regular bus to Heavy-BRT In which the description of BHLS comes closest to "BRT-Lite" and "Understatement Bus". Hidalgo et al (2013) suggests a categorization based on objective performance measures. The authors also mention that categorization would improve understanding amongst planners and decision makers. However, Lopez et al (2010) questions the categorization of BHLS as there are lots of different configurations.

In a European context BHLS and BRT Lite are described in terms of operational characteristics as most existing European cities do not have the space for building independent busways along the entire route of the bus service. In Dutch context: the Witte et. al (2020) describes BRT as a service providing a higher frequency at higher speed, which delivers reliable travel time with high corridor capacity and allows the passenger to travel comfortably on a service which is clearly distinguishable from the regular bus. However, this description aligns more with the description of BHLS. The report mentions that the traditional BRT description is not fitted for the Dutch landscape and has therefore been altered. In another report, the definition of BRT (Rijksoverheid, 2022) has been extended to include being well-connected to other modes of transportation. In other terms, being connected to Hubs. In this report the definition of BRT has been altered as well. CROW (CROW, 2012) describes HOV Bus as a service with high frequency, high speed, optimal accessibility, reliability, comfort, distinguishable and an acceptable price. HOV Bus and BRT is being introduced as a service which could compete with the car.

3.1.3 Categories for high level of bus services

As highlighted by literature, BHLS should not be seen on its own but as a supporting link in the entire network and as a goal to connect the complete transport availability. BHLS is one formulation for describing the type of bus system that can be implemented as BHLS. In literature, different categorizations of bus systems can be found. They either include BHLS, or do not include BHLS. As you look for different categorizations in literature, it was found that the number of categorizations made was limited. Hidalgo & Gutiérrez (2013) highlighted that there is a need to categorize the different bus systems as this will "improve the understanding among planners and decision makers". As an example, was presented by Muñoz & Hidalgo (2011) in which BHLS is placed between the regular bus and a medium BRT system with a throughput of 500 to 2500 people per hour per bus, running at a speed 15 to 35 km/h. The application is for small urban areas, historic downtown and suburbs.

Type	Main features	Throughput/performance	Application
Basic bus corridor	Median or curbside lanes, on board payment, conventional buses	500 - 5000 pphpd 12 – 15 km/h	Low density corridors suburbs
Bus of high level of service BHLS	Infrastructure, technology and advanced vehicles for enhanced service provision	500 – 2500+ pphpd 15 – 35 km/h	Small urban areas History downtown suburbs
Medium BRT	Single median lanes, off board payment, information technologies	5000 – 15000 pphpd 18 – 23 km/h	Medium density corridors Suburb/center connections
High capacity BRT	Dual median lanes physically separated, large stations with prepayment, large buses, information technologies combined services	15000 – 45000 pphpd 20 – 40 km/h	High demand Dense, mixed use corridors Central city

Table 1 Bus categorization

Another example introduces more categories but does not use the term BHLS. The categorization mentions "Informal Transportation", "Basic bussystem", "BasicPlus Bussystem", "BRT-light", "BRT" and "BRT-Plus". Previous descriptions of BHLS best align with "Basic Plus Bussystem". Again, different types of BRT have been described. This categorization was developed for a project in the Netherlands. It shows how in steps a informal transport system is being formed into a BRT-Plus system. When analyzing this categorization, it can be seen that for each transition to the next BRT type a change is being made in the type of schedule, in the type of priority, in the type of stops, the ticketing, quality of customer service, type of vehicles and branding. Each time one or more aspects improve and increase in level of quality. It's worth noting that branding is also utilized.

Table 2 Bus Categorization

Informal Transport	Basic Bussystem	BasicPlus Bussystem	BRT-light	BRT	BRT-Plus
Unoffical carrier	Public or Private carrier	Public or Private carrier	Public or private carrier	Public or private carrier	Public or private carrier
Taxi-like system	System with fixed schedule	System with fixed schedule	System with fixed schedule or regularity	System with regularity (ex. Every 2 minutes	System with regularity (ex. Every 2 minutes
No priority	No priority	Sometimes (separated) bus lanes / corridor service	Priority, mostly (separated) bus lanes /	Priority, dedicated infrastructure / corridor service	Priority, dedicated infrastructure / corridor service

			corridor service		
No marked stops	Stops with simple bus shelters or stopping posts	Stops with simple bus shelters	Bus stops of high quality with improved facilities	Bus stops of high quality, extensive amenities	Metro-like closed-off stations
On-board ticketing	On-board ticketing	On-board ticketing	On-board ticketing	Ticketing at bus stop	Ticketing at bus stop
Bad or non-existend customer service	Mediocre customer service	Sufficient customer service	Good customer service	Good customer service	Excellent customer service
Vehicles (strongly) deprecated	Standard (city) bus vehicles	Standard bus vehicles	Bus vehicles with high comfort level	Bus vehicles with high comfort level	Bus vehicles with high comfort level
			Own brand, recognizable and marketing identify	Own brand, recognizable and marketing identity	Own brand, recognizable and marketing identity

In the categorization above, it can be seen that there are again different types of higher quality buses. However, there are no clear levels as the one before. Instead, different types of BRT prioritize different aspects. One option is more flexible, another option focused on capacity and another one on comfort. There is variation in the use of dedicated infrastructure. Also, branding is used here. It can be seen that comfort is traded for a higher frequency.

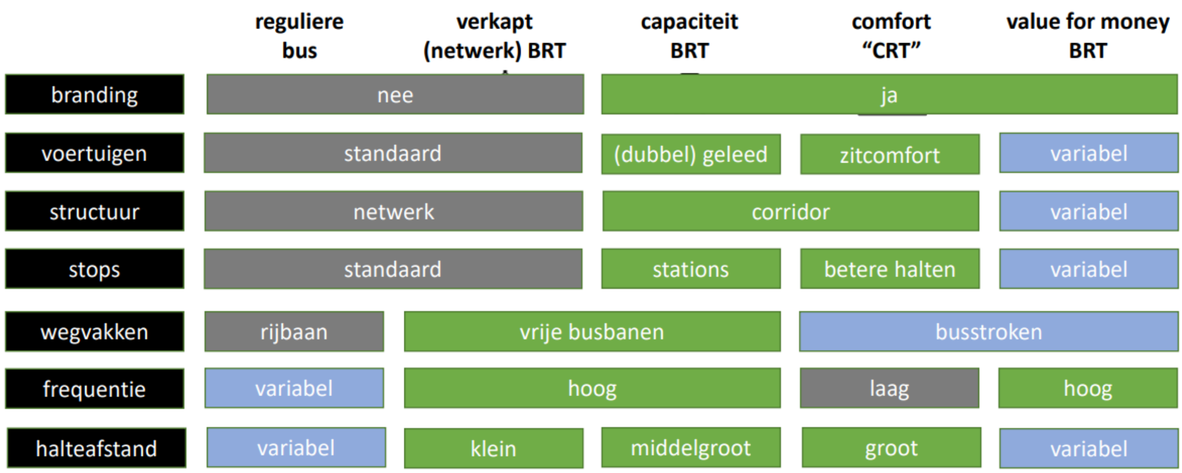

Figure 6 Categorization of bus types

By looking at the different categories it can be seen that a higher quality bus service is not a distinctive type of service, but that different types of measures can be taken to make it more high quality. Also different categories can be seen which distinguish the goal the policy maker wants to reach. This creates many different types. In most literature BHLS is positioned between the regular bus and Full-BRT.

Conclusion

It can be concluded that a bus delivering a higher level of service is mostly referred to as BRT. Within BRT, there are different levels that allow the bus to excel in certain aspects. BRT is seen as a collection of measures rather than a definite transportation mode. Different measures can be taken to improve certain aspects . All BRT systems increase ridership, the goal is to provide a service that operates at higher speeds and offers a more direct and frequent connection. The focus can be on transporting as many people as possible or delivering a higher comfort service. Buses with higher level of service mostly differ from regular buses in terms of the levels for the aspects. None of the aspects which are of higher quality with HOV are unique to HOV. Regular bus services are characterized by the same attributes. However, the difference is in actively putting more emphasis on setting higher levels for certain aspects and promoting this to the potential travelers.

3.2 The promise of HOV in the Netherlands

Buses with higher quality service then a regular bus service are referred to as HOV ("Hoogwaardig Openbaar Vervoer") in the Netherlands (Heddebaut et al., 2010). 137 HOV bus services are available in the Netherlands. Different HOV formulas are present which promise different aspects to the commuter to be of better quality than the regular bus. The carrier describes the HOV bus formula on their website. Some HOV bus formulas are also explicitly mentioned in the "Programma van Eisen". In the Netherlands the so-called snelbus exists, however it is not seen equal to HOV bus since the "snelbus" focuses on realizing the fastest route between two points without stopping and BHLS-bus stops at multiple. The term HOV is very widely used and is also used to refer to tram, train or metro. Most HOV services in the Netherlands are bus services.

The Netherlands is divided into 33 transportation regions or corridors for which contracts will be made. Every 5 to 10 years these concessions are assigned to one carrier who can bid on concessions by presenting a plan to that area. In most cases, the municipality in which this concession area is located decides which carrier is allowed to provide services in the area. A distinction is being made between area concessions and line concessions. Special lines are being assigned separately from the area to a specific carrier.

The Witte et al. (2020) distinguishes three types of BRT in the Netherlands: within city, short intercity and long intercity . Within city lines are lines operating without city boundaries. Typically, these lines connect residential areas with the city center. These lines are counted as "Stadsbus". Short-Inter-City lines are lines which connect different smaller cities to larger cities. These lines run from bus terminal to bus terminal. These lines are counted as "Streeklijn". Long-intercity lines are lines connecting multiple cities over a longer distance and they often make use of highways.

3.2.1 HOV formulas

The next step is to look at how the requirements set up by the decision makers are translated into practice. In the Netherlands, different HOV bus services can be found. Different carriers provide a bus service which differs from the regular bus. The carriers promise that buses driving on this formula deliver a higher service or put more emphasis on certain aspects of the service. In total, 10 different bus formulas have been found which promote themselves as HOV in the Netherlands. These HOV product formulas can be analyzed based on how they are advertised on their website and in company documents.

R-net

R-net first started as the Zuid-Tangent line, a BRT-like bus service running on dedicated infrastructure. As this service was successful in providing a high quality service, R-net was put into place to apply the concept on other routes as well. It should be noted that not all R-net lines run on dedicated infrastructure. R-net promises reliable, high frequency and comfortable services which can be is recognizable by the color schemes and is well connected to other mobility hubs (RNET, 2023). The municipality of Zuid-Holland can either assign R-net lines or carriers can request having a line being promoted as R-net. In the “Programma van Eisen” (Program of Requirements, PvE) de province of South-Holland mentions specific requirements to describe their ambition of delivering an attractive transportation system for the traveler (*de Winter*, 2017). These requirements are reliability, frequency, speed, interconnectivity, recognizability, attractiveness, comfort, environment , maintenance, safety and sustainability.

Q-link

Q-link operates fast buses around the city of Groningen to connect small cities around the area to Groningen. On their website they describe the following advantages of Q-link. Q-link wants to provide direct and frequent services with comfortable buses equipped with Wi-Fi and air conditioning. The service connects directly to important destinations in the city from P+R areas. Q-link wants to serve commuters and P+R shoppers. (Qbuzz, 2023a)

Q-liner

The Q-liner is the Q-link for long distances. This service is provided to connect Groningen with the surrounding area. Comfortable buses with a recognizable blue color are running the service. The service is direct, fast and only limited stopping at towns. The bus also makes use of bus lanes. During rush hour the bus drives more frequent. (Qbuzz, 2023b)

Bravodirect

Bravodirect serves in North-Brabant and is the BHLS-formula of Bravo. Bravodirect are bus lines which are fast, frequent and direct. They are connected to other bus- and train stations. These buses have comfortable seats, Wi-Fi and USB-ports. (Bravo, 2023). Bravodirect is described as high quality in terms of frequency, speed and operating times. In the Program of Requirements set by the transport authority, it is mentioned that HOV lines should have a frequency of at least 4 times per hour.

Brabantliner

The Brabantliner is a service by Bravo which wants to provide a direct, fast and comfortable connection to cities outside of the province Noord-Brabant. This connection is promoted to commuters and leisure travelers. The travel time with the Brabantliner is equal to the travel time by train but does not require a transfer on the same route opposed to the train. The ticket price is lower than the ticket price for the train. The service is provided on 4 routes. The service should be provided at a frequency of 2 times per hour. (Bravo, 2023)

Brengdirect

Breng direct is the BHLS formula of Breng operated by Hermes in Arnhem Nijmegen concession. The line consists of 3 lines providing a fast bus service. The goal is to provide good accessibility on certain routes in the region. There is no official description provided by Breng or Hermes. According to the municipality, the distinction Breng Direct is not that consistently used anymore. In the “Programma van Eisen” specific requirements are mentioned for HOV lines.

U-link

U-link is the HOV formula provided by Qbuzz in the Utrecht region. U-link has 6 lines, each with their own color. U-link promises to deliver a fast, frequent and recognizable bus service with comfortable buses.

U-liner

In the concept of the PvE of 2025, there are two lines driving for the formula Snelbuzz in the Utrecht area. Snelbuzz is a bus product which delivers direct services. Its goal is to be comparable with the Brabantliner. (Qbuzz, 2023c)

ComfortRRReis

ComfortRRReis is the HOV bus formula from RRReis. This formula provides a service which is higher in frequency, travel speed and comfort. Additionally, it aims as connecting well to ther modes and provide a direct route. The formula is recognizable by a distinct branding. (RRReis, 2023)

Allgo Metrobus

Allgo Metrobus is a system in Almere consisting of 8 lines. It is seen as a BRT system in the Netherlands as the buses make mostly use of dedicated bus lanes. However, Allgo does not seem to promote this fact with their bus service. This can be explained by the fact that AllGo is the service provider and the infrastructure is already existing. For the inhabitants of Almere having a bus on dedicated lanes is expected. Allgo itself does not specifically presents themselves as HOV system, however the bus infrastructure in Almere has been mentioned as an example of BRT in the Netherlands in several reports.

Conclusion

The different aspects that have been revealed by analyzing the PvE's of the transport authorities and websites of the carrier. Table 3 shows for which aspects HOV buses promise to be of higher quality than regular buses. It was noted which parties have mentioned which aspect. From these, counts and percentages can be derived, revealing which aspects are seen as most important as they have been most frequently mentioned.

Table 3 Characteristic attributes for HOV by HOV formulas

HOV Formula	High frequency	High speed	Reliable travel times	Comfort	Well-connected to other modes	Driving on suitable infra	Direct	Wide times of operation	Recognizable
R-net	X	X	X	X	X				X
Qlink	X			X	X		X		
Qliner	X	X		X		X	X		X
Bravordirect	X	X		X	X		X		
Brabantliner	X	X		X			X		
Breng Direct	X		X	X			X		X
U-liner	X	X		X					X
U-link	X	X		X					X
Limburgliner		X		X					
comfortRRReis	X	X		X	X		X	X	X
AllGo Metrobus	X	X			X	X		X	X
Count	10/11	9/11	2/11	10/11	5/11	2/11	6/11	2/11	7/11
Percentage	91%	82%	18%	91%	45%	18%	55%	18%	64%

The percentages result in a final ranking. The table below shows the rank of the different aspects. The percentage reflects how much agreement there is between the parties.

Table 4 Ranking of the characteristic attributes by HOV formulas

Rank	Attribute	Percentage
1	High frequency	91%
(1)	Comfort	91%
2	High Speed	82%
3	Recognizable	64%
4	Direct	55%
5	Well-connected to other modes	45%
6	Reliable travel times	18%
(6)	Driving on dedicated infra	18%
(6)	Wide times of operation	18%

It was notable during the analysis that the definite definition of aspects does not exist among these carriers as well. The aspects have only been mentioned to be of better quality than the regular bus, which in practice has not been defined.

3.2.2 Decision maker perspective

As the decision maker has the most influence on the bus service that will be put in place, it is important to understand their perspective on HOV buses. Interviews have been conducted with various parties involved in the planning, realization and maintenance of HOV services in the Netherlands. The interviews include parties from provinces, cities, carriers, and mobility consultants. During these interviews, question have been asked which reveal more information about following aspects:

- Definition of BRT-light for decision makers
- How BRT-light is being used in their area
- Their influence on the realization of BRT-light
- How BRT-light/transport services are being evaluated
- General organization of public transport in their area
- Personal opinion on potential of BRT-light systems
- Challenges around BRT-light services

The most important question that has been asked during the interviews is how the decision makers would define HOV. Similar answers were given by each party with some variation. Most mentioned aspects had only a qualitative description. For frequency, a quantitative answer was given during most interviews. The other aspects stayed more in the qualitative realm and were not exactly defined.

Table 5 Summary of interviews with decision makers

Interviewee	Roll	What is HOV bus?
Province of Gelderland	Concession manager; BRT project manager	- high quality; - relatively high processing speed - high frequency of 4 times per hour during rush hour
Keolis	Service planner	- high operational speeds - dedicated infrastructure not a must - comfortable - high frequency (minimum of 4 maximum of 8)

		- usually for longer distance, less for city services - different from BRT: BRT is more like metro system focused on fast
RNet, Province of South Holland	Public Transport Advisor	- high quality - high processing speed - high frequency 4x per hour
City of Eindhoven	Concession manager; Network planner	- buslanes - fast and frequent bus - recognizable HOV stops - dynamic traveller information - frequency throuhg network approach - comfortable, fast, easy, reliable - close contact with carrier and travellers
Province of North Brabant	Network and Service Planner	- comfort (enough seating capacity) - recognizable buses emphasizing higher quality - high speed - high frequency (4x per hour) - reliable - combination of many factors - comparable to tram or train quality - carrier responsible to develop and improve
OV Bureau Groningen/Drenthe	Concession manager and network planner	- metro like recognizability - comfortable buses - high operational speeds - direct routes - bundling lines on corridors - frequency of 4 and 6 - combining lines for higher frequencies

During the interviews some comments were given about different aspects of HOV. Several times it was mentioned that introducing an HOV line has an impact on the other non-HOV lines. Due to the appeal of this new connection to travelers, a decrease in the usage of other lines may occur soon. Another comment mentioned by different parties was that they do not have much insight into the “switchers”. Ridership gains for the HOV lines are observed but it is unknown who these new travelers are and the reason for their switch. Additionally, there is an interest in better understanding the specific aspects of HOV that attract travelers or cause commuters to switch. If asked whether it is important for the traveler to be aware of the availability, most of the interviewed parties agreed that it is not significant that the traveler knows if a line is HOV. First and foremost, the traveler cares about getting from A to B as quickly as possible. Most travelers use trip planners like 9292, NS-App or Google Maps to plan their trips. Knowing whether a bus is a HOV bus or not would not influence the traveler's choice. However, in other interviews, with for example Eindhoven and Groningen, this was perceived as more important, which is seen to be reflected in their organization of HOV. Eindhoven advertises their HOV bus services as “Bravo Direct”. Groningen advertises their HOV under Q-liner (long distance) and Q-link, which is accompanied by specific color codes and unified designs amongst the lines.

Some transport authorities look at HOV in terms of corridors. This means a high frequency can be achieved by bundling multiple lines on one corridor. Outside of these corridors the lines split up, approaching their destination with less frequency but on the corridor a higher frequency is being achieved.

Transport authorities and governmental bodies focus more on making their area accessible, they intentionally leave the task to the carriers to attract travelers. The municipality wants to offer a connection guarantee, whereas the carrier wants to maximize profit. Traveler mostly care about a good quality connection. Some parties have also mentioned that it can happen that the new HOV Bus line is competing with regular bus line, impacting ridership. This is not seen as a big problem. HOV buses have less stops, so the regular bus serves the smaller stops in between. The findings can be summarized by highlighting the most mentioned aspects, listing them and comparing how often it is being mentioned by the different parties. This can be seen in Table 6.

Table 6 Characteristic attributes for HOV by decision makers

Attribute	Frequency	Speed	Reliability	Information	Availability seating	High processing speed	Comfort	Directness	Recognizability	Dedicated infrastructure	Network approach
Provincie Gelderland	X	X	X	X		X					
Keolis	X	X					X				
Rnet	X	X	X					X	X	X	
Gemeente Eindhoven	X	X	X	X			X		X	X	X
Provincie Brabant	X	X			X		X	X	X		X
Groningen	X	X			X		X	X	X		X
Total	6	6	3	2	2	1	4	3	4	2	3
Percentage	100	100	50	32	32	16	76	50	76	32	50

The revealed aspects can be ranked based on how often it has been mentioned as a characteristic aspect of HOV. The percentage reflects how many of the interviewed have mentioned the aspect as important for HOV buses. A ranking can be derived from this which can be seen in Table 7.

Table 7 Ranking of characteristic attributes by decision makers

Rank	Attribute	Percentage
1	Frequency	100
(1)	Speed	100
2	Comfort	76
(2)	Recognizability	76
3	Reliability	50
(3)	Directness	50
(3)	Network Approach	50
4	Information	32
(4)	Availability of seats	32
(4)	Dedicated infrastructure	32
5	High processing speed	16

The Table 7 shows that all parties see frequency and speed as the most important attributes for HOV, followed by: comfort and recognizability. The other attributes are mentioned by half of the parties or less.

3.3 HOV in practice

The previous section has revealed the promises the carrier makes. It was concluded that the carrier does not have exact definitions of what "higher" means in practice. To gain more insight into what "Higher speed", "Directness", and "High frequency" means, HOV lines in the Netherlands can be analyzed. In the Netherlands, 130 lines have been found which are promoted as HOV lines by the carrier or transportation authority. The characteristics of the lines have been collected in a database. Information such as line duration, line distance, frequency, used vehicles, number of stops, speed and type of HOV have been collected. HOV lines have been found by checking the websites of different carriers in the Netherlands. Information on line specifications could be retrieved from the timetables (Hermes, 2023) as well as from public transport databases such as OV in Nederland Wiki (2018). This analysis will be done so it can be better understood how HOV bus services look like. Additionally, the results from this analysis will be used as input for the design of the survey. This way, realistic scenarios can be generated, and relevant results can be found. For this analysis, the timetable from 7:00 to 8:00 in the morning has been examined. The higher level of service is mostly provided during these times as most travelers travel during the morning peak time. In section 3.2 it was found that Witte et al. (2020) distinguishes between three types of BRT in the Netherlands: within city service, short intercity service and long intercity service. They correspond to the dutch descriptions: stadsbus, streekbus and liner. This description will also be adopted to describe the HOV categories. Amongst the HOV lines, most of the lines are short intercity services (Count = 85), buses that connect the outskirts to a city. Then followed by intercity bus lines (Count = 23): services that connect cities with longer distances between the stops. Closely followed by the city bus services (Count = 22): HOV bus service connecting different area's in the city.

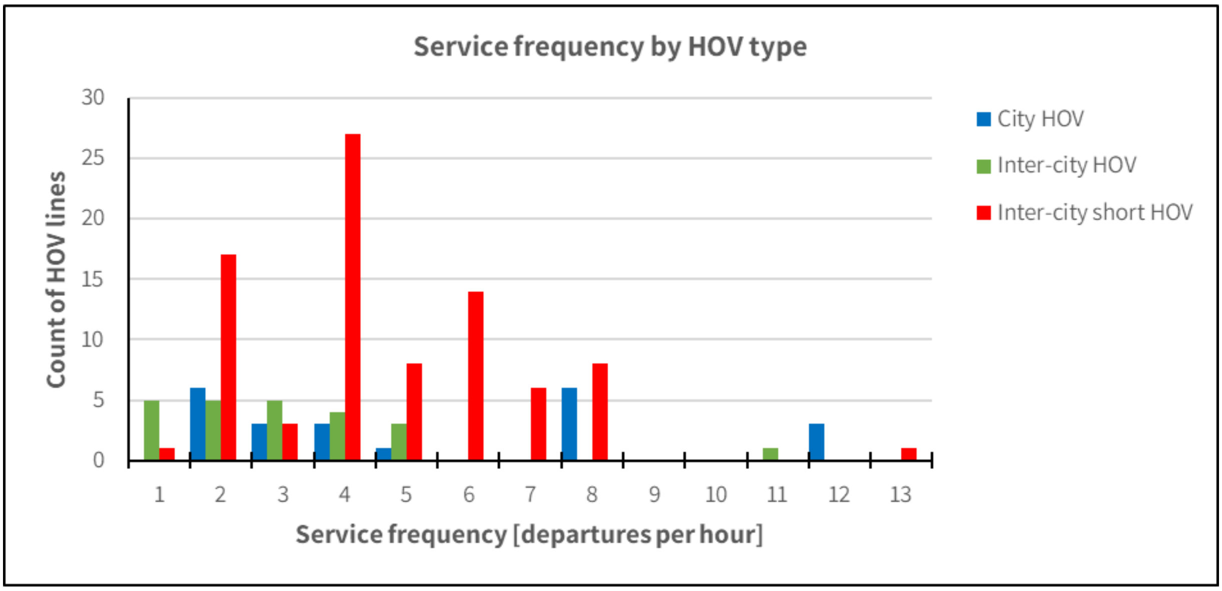

Figure 7 Service frequency of HOV lines during peak hour per HOV type

Frequency

Figure 7 shows the frequency distribution of the HOV types. The X-axis describes what frequency the service has. The Y-axis describes the occurrence of a line having a specific service frequency. The colors indicate the type of HOV bus. On average, inter-ctiy HOV bus services (green) use the lowest service frequency. The minimum is 1 and the maximum is 5. The average frequency is 3. The short intercity HOV service (red) has an average frequency of 4. The minimum is 1 and the maximum 8. However most lines have a frequency of 2, 4 or 6. The city HOV service has an average frequency of 5. Most lines have a frequency of 2 or 8. 3 services could have been found running at a frequency of 12. It can be seen that inter-city in general have lower frequency than the other types. Short inter-city HOV services have a wider variety in frequency. HOV city buses have a lower frequency (2) or a high frequency (8). Among all HOV bus services it can be seen that most lines run at a frequency of 2 or 4. The minimum is a frequency of 1 and the maximum 13. Only a few lines can be found which run at very high frequencies of 11, 12 or 13 buses per hour.

Average stop distance

In Figure 8 a histogram is being presented of the average stop distance per HOV type. During the analysis, the line's distance and number of stops were collected. Based on these values the average stop distance could be calculated. The general image is that most HOV lines have an average stop distance of 500m to 1500m. Looking at the different HOV types it can be seen that HOV city buses have the lowest average stop distance. With a minimum of 250m to 500m and maximum of 2500m to 2750m. On average HOV city buses have an average stop distance of 700m. Short-intercity lines have an average stop distance of 1270m. With a minimum of 0m to 250m and a maximum of 6250m to 6500m. Inter-city have

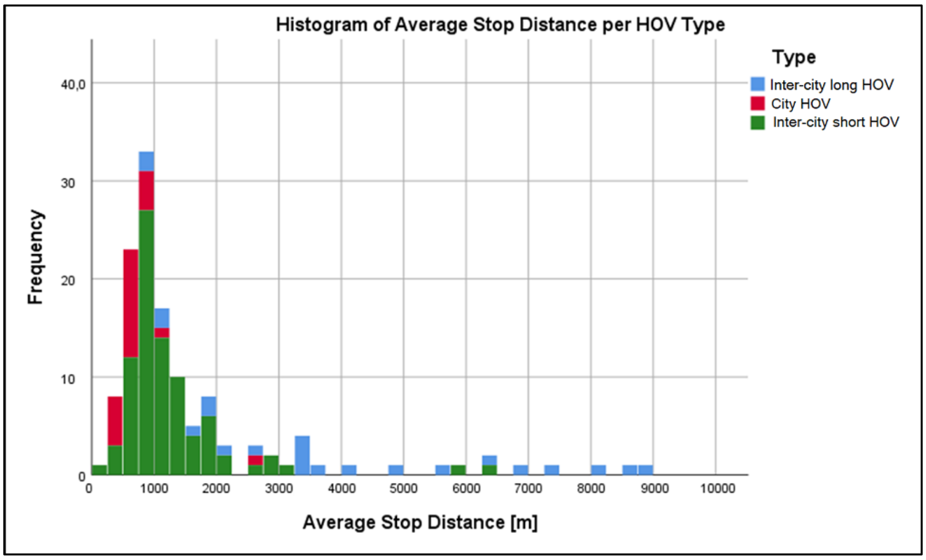

Figure 8 Histogram of average stop distance per HOV type

the highest average stop distance. On average the average stop distance is 4000m. With a minimum of 750m and a maximum of 8750m. Amongst the inter-city HOV there is much variation is average stop distance.

Average service speed

In Figure 9 a histogram of the average speed per HOV type is presented. The average service speed is the average speed that is being achieved on the line. The average service speed has been calculated by dividing the line distance by the duration of the first stop to the last stop according to the timetable. The average speed of the HOV lines is 30 km/h. When looking at the different types of HOV can be seen that city HOV drives at speeds between 10 km/h and 30 km/h, with one exception at 40 km/h. The average is 25 km/h for city HOV. When looking at intercity short HOV can be seen that they have the widest variation in terms of average speed. However, most lines achieve speeds between 25 km/h and 40 km/h. There are 3 lines that drive at speeds of 10 km/h or lower. This due to having many stops on the way. However, especially with intercity short HOV the bus does not stop at every stop, inly if people require to get off. It is however notable that to average speeds are considered of high quality. The average speed that is being achieved is 32 km/h. The inter-city HOV buses travel at the highest average speed, between 40 km/h and 65 km/h. The average is 48 km/h.

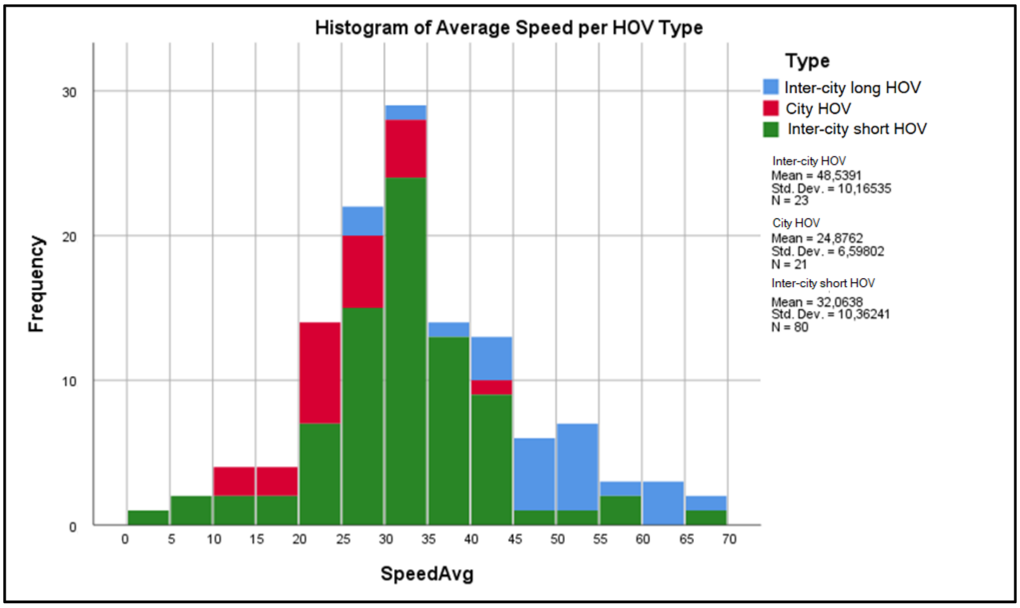

Figure 9 Histogram of average vehicle speed per HOV type

Average speed vs average stop distance

In Figure 10 a scatter plot has been created from the average speed against the average stop distance. For the different aspects analyzed in the previous section, it is possible to plot scatterplots to evaluate if there are specific correlations between them. The first scatterplot that will be analyzed is the plot of average speed and average stop distance. Lines with a short average stop distance are also those with a low average speed. Whereas the lines with a larger average stop distance are the lines achieving a higher speed. At the lower end of the spectrum are the city HOV lines, and at the higher end of the spectrum are the inter-city HOV lines.

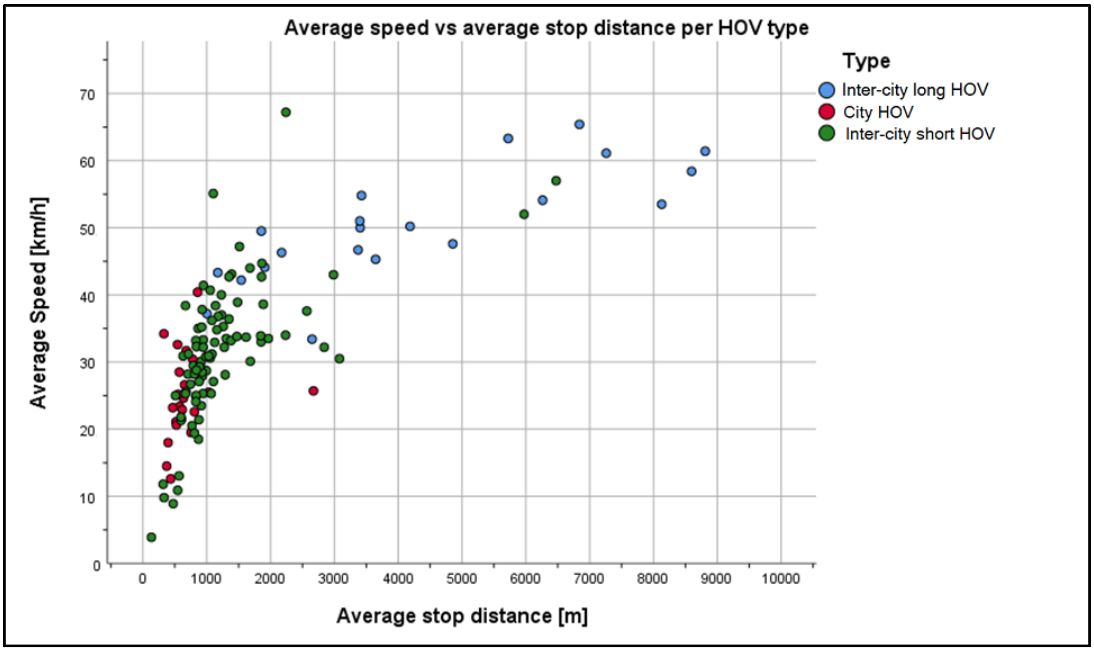

Figure 10 Average speed vs average stop distance per HOV type

Service frequency vs average stop distance and average speed
In Figure 11 a scatterplot has been create for service frequency against the average stop distance per HOV type. Figure 12 shows a scatterplot of service frequency and average speed by HOV type. When plotting the service frequency against the average stop distance and average speed there does not seem to be a significant relation. For each service frequency the variety in average stop distance and average speed is large and not constant. It can be seen in Figure 11, that for higher average stop distances, less are having a high service frequency. The maximum that can be found here is 5, whereas for average stop distances under 4000m frequency mostly up to 8 can be found.

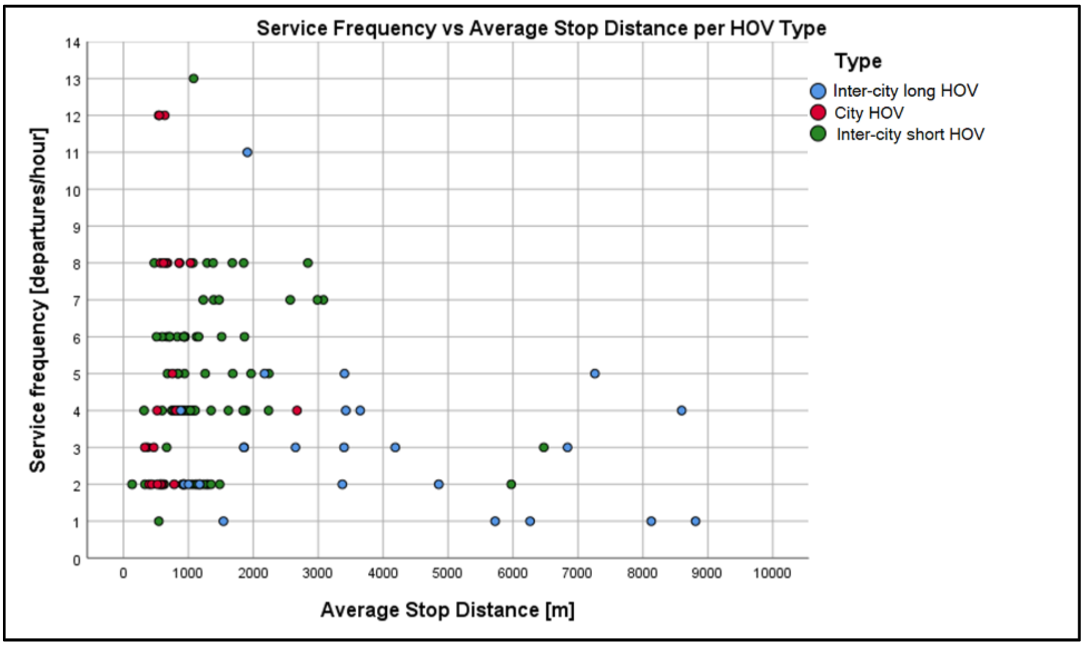

Figure 11 Service frequency vs Average Stop Distance per HOV type

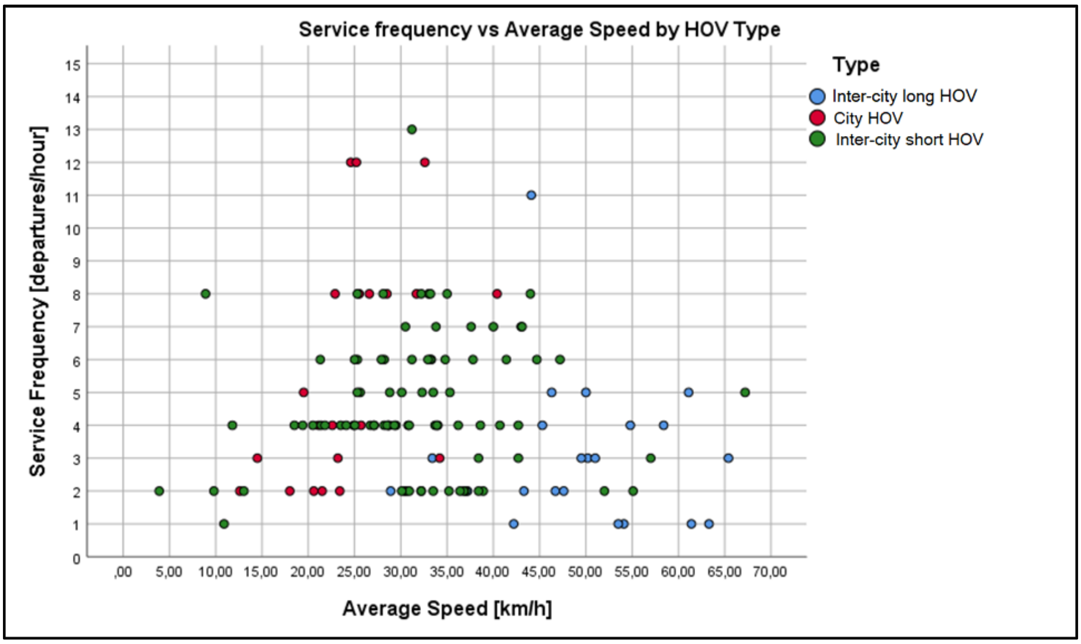

Figure 12 Service frequency vs Average speed by HOV type

Although some relations could have been found, an attempt was made at categorizing the different lines. Overall, the different bus lines differ in terms of characteristics. It does seem like that most

HOV buses indeed offer a higher level of service. A distinction can be made between the categories, but they also tend to overlap with each other. Especially, the inter-city short HOV tend to overlap with both other types. Most of the HOV buses are also categorized as Inter-city short. They are in between city buses and long distance buses, but also overlap. City buses and long distance buses form mostly the outer spectrums. The analysis did give a good impression of what the levels are in terms of average speed, distance, average stop distance and frequency. This can be used to create realistic scenario's later on in the research.

3.4 Commuters perspective

This section will take a closer look at the commuters' perspective regarding travel satisfaction and preferences. For this, the literature as well as some theory on traveler satisfaction will be analyzed.

Attributes influencing travel satisfaction

With the previous theory in mind different literature on travel satisfaction in public transport has been analyzed. In Appendix 3: Travel satisfaction attributes in literature the table with the attributes can be found. Various studies have been analyzed which include revealed choice data and stated choice data. Notably more studies focus on revealed choice data. A few studies have been found with stated choice data. In those studies, the focus was mostly on the importance of the factors. The actual effect of the attribute was not considered, but this study will address it. Dependent of the method used, it could also be specified whether an aspect was found to be of importance.

Since most of the studies found included revealed preference data, a ranking was created based on those studies. The studies that included stated choice data were used as verification. Just like before the occurrence of the attribute in the studies was counted to create a ranking. The ranking can be seen through the table below. Frequency has been found to be mentioned by most studies followed by cleanliness in the bus; then reliability, affordable fare and general information provision; then travel time; then ride comfort; the seat availability which tied with crowdedness, ticket accessibility and safety on board. Many more attributes have been mentioned by the studies, but not significantly enough. Therefore, a selection has been made for the top 11 attributes, which were also found by stated preference studies as significant.

Table 8 Attributes from travelers perspective

Rank	Attribute	Studies included	Found as significant
1	Frequency	15/18	3/5
2	Cleanliness Bus	12/18	3/4
3	Reliability	11/18	3/3
(3)	Affordable fare	11/18	1/3
(3)	General information	11/18	1/3
4	Travel time	10/18	3/4
5	Ride comfort	9/18	3/4
6	Seat availability	7/18	1/2
(6)	Crowdedness	7/18	1/3
(6)	Ticket accessibility	7/18	1/4
(6)	Safety on board	7/18	1/1

Dutch commuters

The research wants to understand how the characteristic attributes of HOV are evaluated by the commuter because HOV is promised to deliver its highest quality during rush-hour. Additionally, the HOV bus is often used as a measure to convince car user to use the bus for their daily commute. It is important to understand the patterns and the consistency of the population that will be surveyed such that it can be assured that the outcomes of the survey are valid. The Dutch government collects regular data on their commuters which includes demography and commuting characteristics. This data will be used in the design of the survey to tune the attribute levels to realistic levels as well as validating the results.

Commute characteristics

The data of the commuter characteristics was limited to data of commuters travelling during rush hour since this is when most people are travelling and also the time frame in which HOV delivers its highest quality. For the analysis of the commute characteristics, a dataset was taken from Statline (CBS, 2023) which contained the travel distance, travel time and mode used. The dataset includes 3480 data points. Different modes are taken by Dutch commuters: car as driver (22%) bus/metro (19%), bike (19%), walking (17%), and car as passenger (12%) and train (10%). Looking at the data (Figure 13) shows that different travel times can be associated with different modes. This can also be said for the travel distance (Figure 14).

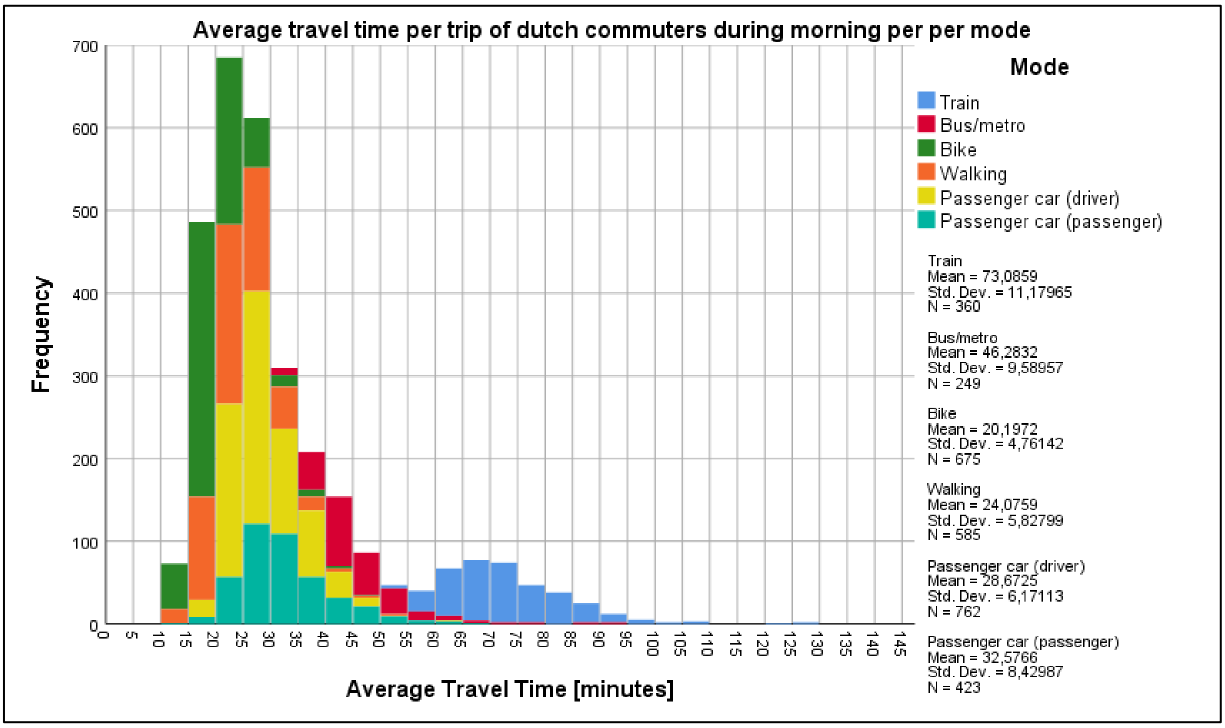

Figure 13 average travel time per trip for Dutch commuters during the morning peak per mode

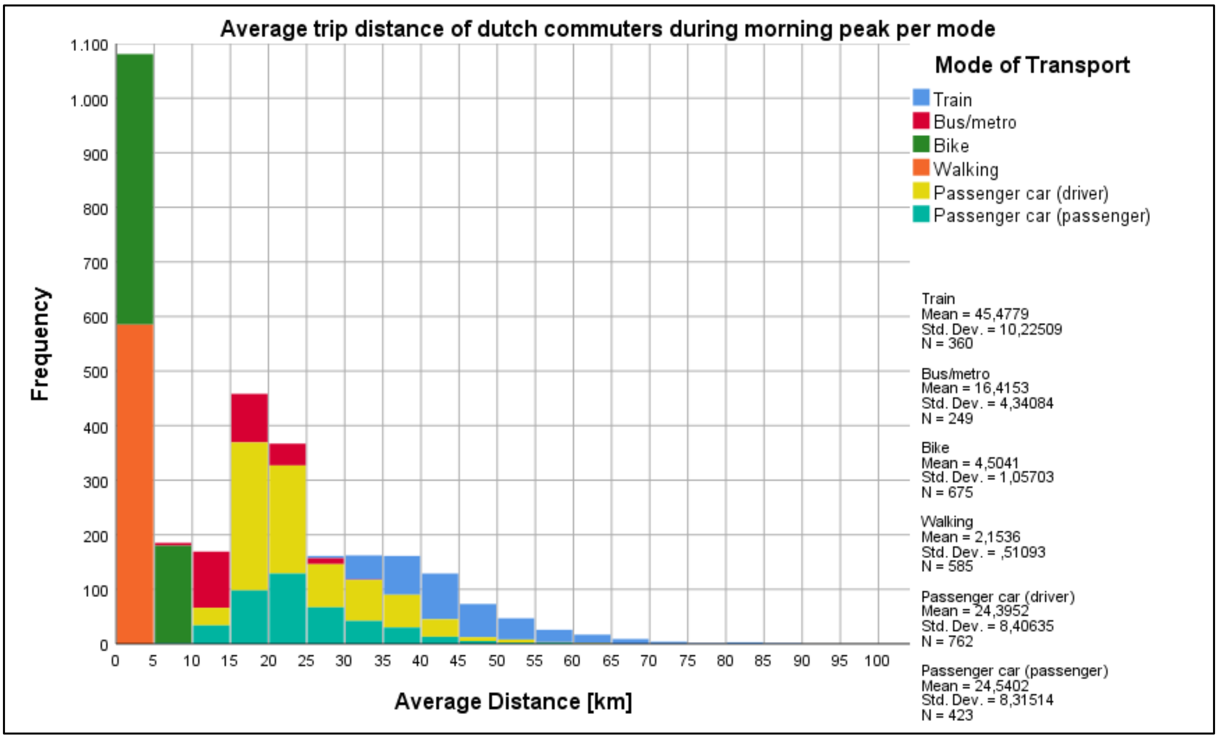

Figure 14 Average trip distance of Dutch commuters during morning peak per mode

Dutch commuters make different trips which vary in distance and travel time (Figure 13). For biking and walking, the travel time can be up to 30 minutes. For car drivers and passengers, the travel time ranges from 20 to 60 minutes. Trips made by bus have a duration of 40 to 60 minutes. The train is used for longer trips. Ranging between 55 and 100 minutes. The travel distances (Figure 14) can be analyzed in the same way. Walking trips do not surpass 5 km. Bike trips range from 0 to 10 km. Car trips range from 10 to 50 km. Bus/metro trips range from 10 to 30 km. Train trips range from 30 to 70 km.

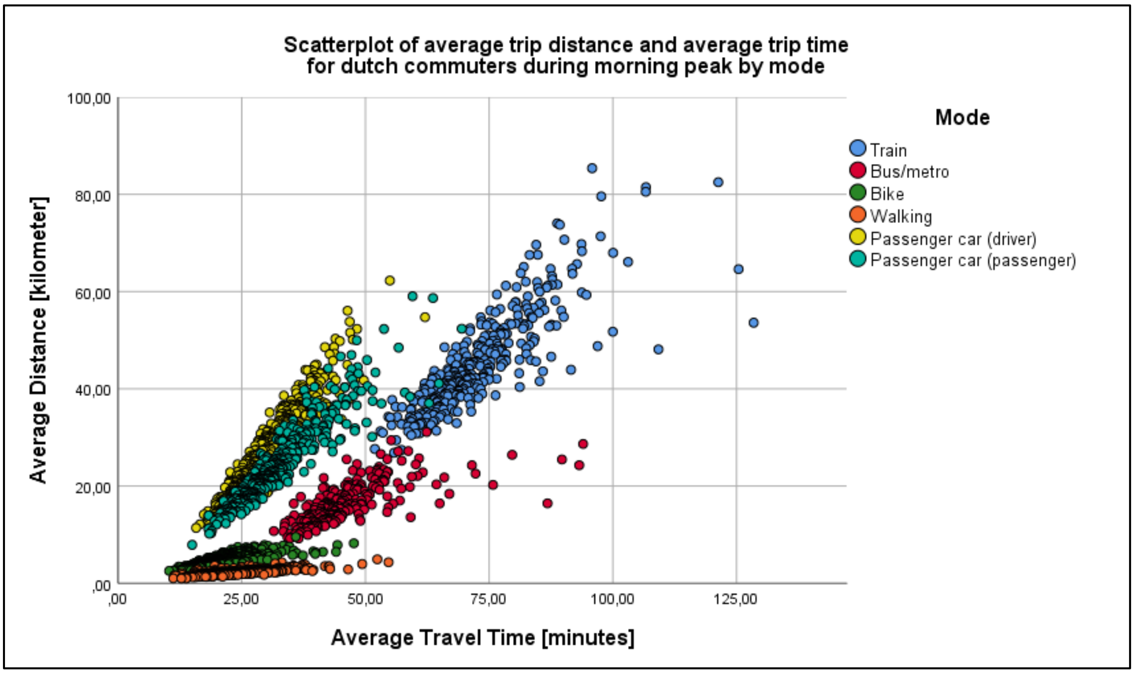

Figure 15 Scatterplot of average trip distance and average trip time for Dutch commuters during morning peak by mode

When comparing the positions and spread of the modes (Figure 13 & Figure 14) over the axis it can be seen that for some modes the position is roughly the same and for others different. For bus/metro it can be seen that even though the travel time is higher than the car, the travel distance is less. The same can be said about biking and walking, the travel time is high, but the travel distance that is being travelled during that time is small. These relationships between distance and travel time for the different modes can be more clearly presented in a scatterplot, as it has been done in the following figure. From this graph also a division can be made. For the travel time 4 categories can be determined: less than 15 minutes travel time, 15 to 35 minutes, 35 to 60 minutes" and "more than 60 minutes".

In Figure 15 a scatter plot has been created for each mode. On the Y-axis the average distance has been plotted and on the X-axis the average travel time. The steeper the trajectory of the dots, the higher the speeds are that are being achieved by the mode. The figure also shows which kind of trips are made with each mode. The figure illustrates that trips made by bus and train do not significantly overlap, indicating that they serve different needs. . The speeds are almost the same. The bus/metro is used for the same lower distance class as the car but the time spent in the bus is higher than in the car.

Conclusion
From this analysis it can be concluded that the car is a dominant choice amongst commuters. The travel distance covered with this mode compares to trips made by bus or train. However, the bus and the train travel at lower speeds.

3.5 Conclusion

After this chapter a lot of insight has been gained into HOV. This output can be taken into the next chapter in which it will be focused to develop a survey to be designed for collecting the data on understanding how the commuters' choice for a mode is influenced by these factors.

In this section most of the sub-research question have been answered as this section was dedicated to understanding the background of HOV. It is important to understand the landscape of HOV buses so that the right aspects will be researched. The following research questions have been answered in this section:

1. What is the current situation of HOV buses in the Netherlands?
2. How does the decision maker define HOV Buses in the Netherlands?
3. Which attributes are relevant to the commuter?
4. Which attributes are characteristic for HOV Bus services?
5. Which variations exist in the levels of the characteristic attributes of HOV Buses?
6. Which variations exist in the trip characteristics of the commuters?

SQ1 What is the current situation of HOV buses in the Netherlands?

The current state of HOV is that there are 130 lines which can be categorized in city HOV, inter-city HOV and long inter-city HOV. Different regions in the Netherlands have a different approach towards HOV and set different requirements. In the Netherlands, HOV is growing with the growing interest for BRT. However, BRT as it is mostly known is not feasible and needed in the Netherlands. Therefore, different kinds of categorizations are being created and tested. Additionally, it is also lesser known what the traveler thinks about HOV. This research can provide valuable insights.

SQ2 What is the decision makers perspective on HOV Buses in the Netherlands?

There are different decision makers involved regarding the organization of HOV services: transport authorities, network planners and carriers. Every party has a different responsibility at each stage. The concession managers are responsible for setting the requirements and making sure these requirements are maintained. The carrier is responsible for the actual service and is therefore the touch point with the traveler. Decision makers are interested in understanding more about HOV and how it can be effectively used. Different aspects are considered by them as characteristics of HOV. There is a need to further understand how the different attributes influence the commuter's choice as well as having clearer definition about the characteristic attributes.

SQ3 Which attributes are relevant to the commuter?

Through literature it has been found which attributes are relevant to commuters. *Frequency* is an important factor which can be derived from the different analysis. Cleanliness is not mentioned in the interviews or product formulas specifically, but can be linked to *comfort*, which is a factor mentioned in the interviews and by the product formulas. Comfort can be explained in two ways, ride comfort and travel comfort. Travel comfort also includes seating availability or *crowdedness*. *Travel time* can be linked to speed. From a passenger's perspective, travel time is discussed more often than speed. But from an operational standpoint speed determines the travel time and therefore these two factors can be linked as well. *Directness* can also be linked to travel time. Directness is the shortest travel time between origin and destination. The carrier can achieve this by balancing the number, location and the route of stops. In other literature affordable fare has been mentioned too, however this is foreign literature, so it needs to be checked whether this is relevant for the Dutch population. It is however quite common in the Netherlands to get travel expenses compensation.

SQ4 Which attributes are characteristic for HOV Bus services?

Relevant attributes have been revealed through literature, interviews and desk research. By combining the findings of all sources, the most relevant attributes can be revealed, which should be taken into consideration in the survey. In the beginning of this section, it was looked at the attributes that are promised to be of high quality by the 10 Dutch carriers. It was seen that carriers introduce special bus formulas which are assigned to lines delivering a higher level of service than regular lines. The table below shows the attributes that have been mentioned as characteristic for HOV by decision makers and HOV brands.

Rank	Interviews	Rank	HOV Brands	Rank	Literature
1	Frequency	1	Frequency	1	Frequency
(1)	Speed	(1)	Comfort	2	Bus Cleanliness
2	Comfort	2	Speed	3	Reliability
(2)	Recognizability	3	Recognizable	(3)	Affordable fare
3	Reliability	4	Directness	(3)	General information
(3)	Directness	5	Well-connected to other modes	4	Travel time
(3)	Network Approach	6	Reliable travel times	5	Ride comfort
4	Information	(6)	Dedicated infrastructure	6	Seat availability
(4)	Seat availability	(6)	Wide times of operation	(6)	Crowdedness
(4)	Dedicated infrastructure			(6)	Ticket accessibility
5	High processing speed			(6)	Safety on board

Table 9 Characteristic attributes

SQ5 Which variations exist in the levels of the characteristic attributes of HOV Buses?

The analysis showed that there is much variation in the characteristic attributes of HOV buses. Different categories exist. Instead of HOV types having fixed levels, there is a variation amongst the lines of an HOV type. One can see however that the HOV types have certain ranges. For frequency inter-city HOV is at the lower end, the inter-city short HOV and city HOV with the same spread. But for each HOV type there are always outliers not fitting into the range. The frequency range of City HOV is 2 to 8. The frequency range for inter-city HOV is 1 to 5. The frequency range for inter-city short HOV is 2 to 8 as well. City HOV has proportionally seen the most buses with a very high frequency of 8 or 12. For speed, city HOV has the lowest range (15 km/h to 35 km/h), inter-city short HOV is in the middle (20 km/h to 45 km/h). the fastest speeds are reached by inter-city HOV (45 km/h to 65 km/h). Also for average stop distance, city HOV has the lowest range (250 m to 1000m), inter-city short HOV is in the middle (500 m to 2000 m) and inter-ctiy HOV has a wide range of 3 km up to 9 km. In all categories outliers can be found. All in all clearly defined categories cannot be found and overlap between the categories exist. Also outside of the categories, HOV buses vary in terms of operational aspects.

SQ6 Which variations exist in the trip characteristics of the commuters?

Most trips of commuters are around 25 minutes, however also long trips are common. It was also seen that in terms of modes the bus is more competing with the car for the distance class then the train is with the car. In general there is a large variation in trip characteristics as well. Slow modes such as bike and walking have an average travel time range of 10 to 30 minutes, for car travelers a range of 20 to 45 can be found, for bus traveler 34 to 55 minutes and for train travelers a range of 55 minutes up to 85 minutes. The bus has overlap with the car and train. In terms of average trip distance

In the next chapter gained knowledge will be used to design a choice experiment. The data collected in this chapter will be used as reference to determine realistic scenario’s and attribute levels. The revealed attributes are the guidance for which attributes should be included in the experiment

■

4

Survey development

As it was seen in Section 3.5 Conclusion most of the sub-research question have been answered as they had a explorative character. Sub-question 7 “How do commuters choose between an HOV bus and regular bus service for their commute?” is still unanswered. To answer this question a survey will be setup. In the previous chapter, the characteristic attributes of HOV buses have been examined. A survey will be conducted to gain insight into the preferences of commuters regarding the characteristic attributes of HOV bus services . A survey will be constructed to develop data for the Dutch BRT bus landscape which does not exist yet. The survey consists of a stated choice experiment which will reveal the preferences for certain bus configurations and reveal traveler's trade-off between varying aspects of bus services. From this it can be derived how different attribute levels influence the choice probability of commuters during change in levels of operational aspects of a service.

4.1 Goal of the survey

The main goal of the survey is to capture how commuters choose between a regular bus service and a HOV bus service and reveal which trade-offs are being made. The results will be used to estimate a model and reveal through a sensitivity analysis how different aspects of the trip affect the choice probabilities.

4.1.1 Target group

The survey will be aimed at commuters travelling in rush hour with their mode of choice. Rush hour is typically when HOV buses provide the higher level of service. In the Netherlands rush hour is between 7 to 9, and 16 to 18. The respondents must be of legal age and travel frequently enough during these times.

4.1.2 Study area

A study area relevant to the research must be selected. HOV buses can be found in every region of the Netherlands. During the interviews with decision makers, it was seen that different parties have different opinions about the implementation of HOV. One of these differences was regarding the branding. Therefore it is of interest to test the effect of branding in the survey. Additionally, through the analysis of the carriers and the HOV bus lines, it was seen that there are 3 different types of HOV bus. City HOV, inter-city HOV and long inter-city HOV. Therefore, a study area should be found in which these different types of HOV are available and in which branding of HOV can be tested. In Groningen and North-Brabant a big emphasis was put on the branding of HOV buses: making sure the customer is aware of the different qualities delivered by their buses. This was seen through their branding of the buses and the introduction of bus products. Additionally, these areas also happen to offer all three types of HOV buses in their region. Through Movares Nederland the resources were provided to make use of a panel in North-Brabant. It was decided to recruit the panel in North-Brabant since this panel includes both non- and public-transport users and would therefore be more relevant for this research.

4.2 Structure of survey

Before conducting the survey, other studies were first examined to identify the types of questions used. During the survey development, it was important to keep in mind that the survey should not be too long or overwhelming for the respondent. The question had to be simple, clear and quick to answer.

The survey consists of different parts. Part 1 is about the characteristics of the commuter's current trip to work or education. Part 2 of the survey asks the respondent about their familiarity with HOV buses and whether they are familiar with specific HOV buses in their area. Part 3 is a stated choice experiment in which the respondent is asked to indicate their preference multiple times between a regular bus service and a HOV bus service with changing attributes. Part 4 is to reveal the socio-demographics of the respondents.

As can be seen, the survey consists of two different types of questions. The first type of questions are the questions that capture the respondents' current characteristics and beliefs. The other type is a choice task. The first type of questions serves the purpose of gaining a better understanding about the respondent and to capture their current behavior. This knowledge can be used for further analysis and gain more insight into the choice that was made during the choice task.

4.3 Choice task

The first step of the survey development started with designing the choice task. While developing the choice task it can then be decided which additional information is required from the respondent to understand their choice. Therefore it will be first explained how the choice task was designed. After this section the other questions will be presented as well.

The main part of the survey is the choice task. The choice task is a so-called stated choice experiment. A choice experiment presents to a person a fictional choice situation in which the person is asked to choose between different options. The person is being told in which context the choice is being made and how the different options look like. A person will make multiple choices, and the options available for selection may vary slightly. From this it can then be derived which aspects people find important and how trade-offs are made.

The main challenge when designing a stated choice experiment is that sufficient choice situation should be constructed such that the utility functions can be estimated in a way that the estimated parameters are reliable and valid. The reliability can be achieved by minimizing the standard error through choosing a suitable experimental design and creating choice tasks that do not exhaust the respondents. The number of questions in the survey should be minimized because this can increase the risk of respondents' untruthful answers or even quitting the survey for this study, leading to unreliable results. Therefore, the number of choice situations should be minimized as well as the number of attributes being tested. (Molin, 2018)

To assure that the parameters are valid, choice situations should be constructed that are realistic and resemble real world choice situations. This can be achieved by choosing relevant attributes and realistic attribute levels.

The results of the stated choice experiment are used to estimate a discrete choice model. Discrete choice models are based on random utility models. In these models it is assumed that individuals select the alternative with the highest utility. In Chapter 6 Model Estimation, it will be further explained.

ChoiceMetrics (2018) proposes 3 steps for setting up an experiment to estimate a model.

- Step 1: model specification
- Step 2: generation of experimental design
- Step 3: construction of questionnaire

Step 1: Model specification

In the model specification it should be specified which alternatives should be included for each alternative. This research focuses on the HOV bus in regard to the regular bus service, and the alternatives that are being included are “the regular bus service” and “the HOV bus service”. It could be considered to include the current trip of the commuter as an alternative. However, it has been decided to include only two alternatives and ask the respondent additionally whether the selected bus would be considered for their current trip. - This way more information can be acquired.

In literature different configurations can be found for experiments done in the public transport field. The science with choice experiments is to find the balance between constructing as many choice sets as possible to collect as much data as possible while preventing the exhaustion of respondent . Different trade-offs have to be made. Trade-offs can be made in the number of choice sets, the number of alternatives, the number of attributes and the number of levels. Examples from literature show that mostly 2 or 3 alternatives are being used, where one alternative is their current choice or ‘none of the alternatives’. Most experiments use 6 attributes with a maximum of 4 levels.

- Uses 2 unlabeled alternatives with 6 attributes and 16 choice sets. Varied in 4,4,2,2,4,4 levels. (Bourgeat, 2015)
- Uses 3 unlabeled alternatives with 6 attributes and 8 choice sets. Varied in 4,2,2,2,2,2 levels Dell’Olio et al., 2011)
- Uses 2 labeled alternatives, 5 attributes and 27 Choice sets. Varied in 3,3,3,3,3. (Gaspardo, 2019)
- Uses 3 labeled alternatives, 6 attributes (Eboli & Mazzulla, 2010)

Previously it has already been explained that two alternatives will be chosen. In the following sections the choice for the number of attributes as well as the number of levels will be explained.

Attribute selection

The attributes that are promised to be of higher quality than the regular bus have been revealed in chapter 4. The attributes that should be included need to be chosen in a way that they are relevant to the commuter as well as to the decision maker. Attributes will be selected which the decision makers in the planning and organization stage of bus services. However, attributes should also be relevant enough to the traveler to be included in the experiment. The attributes will be translated in such a way that they are understood by the commuter.

Frequency, speed, directness, reliability, recognizability and ride comfort, have been found as the characteristic HOV bus attributes. These attributes are defined from a policy makers perspective. They have been related to aspects that are relevant for commuters, since the stated choice experiment is conducted among commuters. The table below shows how this translation is done and how the values were related to the needs of commuters. The levels of the attributes for the commuter have been used in the survey. In the model some levels have been translated back to the levels of the attributes of the policy makers.

Not all attributes can be included in the experiment, as this would make the survey too exhausting for respondents or require too many respondents. Therefore, a selection needs to be made. Through testing and analyzing other papers, it was found that 6 attributes would be sufficient. In previous sections the importance of different attributes has been found as follows:

Rank	Interviews	Rank	HOV Brands	Rank	Literature
1	Frequency	1	Frequency	1	Frequency
(1)	Speed	(1)	Comfort	2	Bus Cleanliness
2	Comfort	2	Speed	3	Reliability
(2)	Recognizability	3	Recognizable	(3)	Affordable fare
3	Reliability	4	Directness	(3)	General information
(3)	Directness	5	Well-connected to other modes	4	Travel time
(3)	Network Approach	6	Reliable travel times	5	Ride comfort
4	Information	(6)	Dedicated infrastructure	6	Seat availability
(4)	Seat availability	(6)	Wide times of operation	(6)	Crowdedness
(4)	Dedicated infrastructure			(6)	Ticket accessibility
5	High processing speed			(6)	Safety on board

Table 10 Characteristic Attributes of HOV

Although different aspects can be seen, some aspects are related to other aspects or can be understood under the same aspect. It will be explained how attributes from the commuter are related to the other aspects.

Frequency

Frequency expresses the number of buses departing within an hour. Frequency can also be expressed as follow-up time which is defined by the time between the departure of consecutive buses of equal line. Frequency is used by policymakers and carriers, whereas follow-up time is more understandable for the traveler. For example, a frequency of 2 per hour is equal to a follow-up time of 30 minutes.

Reliability

Reliability is determined by the extent to which a line adheres to the schedule. Meaning to what extent does the line deviate from the specified departure and arrival times in the schedule. A more reliable service follows the departure and arrival times and drives as scheduled. A less reliable service will have delays and can even cancel the rides. Reliability can be expressed in on-time performance, which can be expressed in minutes or in percentages.

Comfort

Comfort can be expressed in different factors. It can be determined by bus driver's drive style (braking, accelerating, smoothness of steering), by the route (stop distance, number of junctions, roundabouts, straightness of route) and by the vehicle (suspension, seats, motor, noise levels, air quality, amenities (such as air-conditioning, USB-ports, Wi-Fi availability)). Cleanliness can also influence the comfort experienced by respondents.

Speed

The speeds a bus can reach on a route are determined by the infrastructure, the routing, the vehicle and the number of stops on the line. This has an influence on the journey time. For travelers, the journey time is considered to be more important than the speed. Decision makers are organizing their public transport with speed levels in mind.

Recognizability

For HOV, some decision makers have specified recognizability as a important characteristics of HOV. With recognizability, it means that there is a visual or verbal distinction between their HOV product and the regular bus products. This can be achieved through specific branding (naming, bus livery), types of vehicles (Q-liners are mostly double decker buses) or infrastructure (bus lanes).

Directness
From a decision maker's perspective, directness refers to the straightness of the route from origin to destination. Directness is influenced by the speed, the routing, the schedule and the number of stops. On the other hand, directness can be seen from an individual's standpoint, having the same definition. However, on a line level a higher directness for an individual could be achieved through more stops, as there is a higher chance the stop will be closer to the destination. However on line level this would decrease the speeds severely and therefore the directness. Which leads to the conclusion that right balance needs to be found. Usually stops will be chosen relevant for travelers as much as possible. The traveler will see it on trip level. Therefore, choosing a service which starts closest to the origin and ends as close as possible to the destination. Finding the right balance between minimizing egress/access and overall trip time. For the case of HOV 66,8% is walking, 21,8% is biking, 7,9% uses other public transport and 6,6% uses a car or motorbike to get to an HOV station (van der Blij, et al, 2010).

Based on these relations between the attributes and the number of times it was mentioned amongst the 3 sources, a selection of 6 final attributes has been made. It was also seen that some attributes are more important to the service operators than to the customers. Since the service operator is measuring the quality of the entire service whereas the customer is only interested in the service that is part of their journey. Therefore attributes need to be translated such that they are relatable to the commuter but also useful for the decision maker to design new services. In the table below it can be seen how each attribute has been translated into an attribute relevant to the commuter.

Table 11 Attribute perspective translation from decision maker terminology to traveler terminology

	Attribute	Description
	Frequency	Time between departing buses of the same line from bus stop. Used to derive frequency which expresses the number of departing buses per hour for a line.
Translation	Follow-up time "The bus departs every 15 minutes"	Follow-up time indicates how often the commuter can expect a bus, rather than saying how many buses are departing. It is being specified when the next bus is departing.
	Speed	Decision makers emphasize the speed of their line. By increasing the speed, connections will be faster. For the commuter this results in shorter journey times.
Translation	Journey time	Time between departing from origin bus stop and arriving at destination bus stop on the same line. Used to derive operation speeds.
	Directness	Directness is related to routing.

Translation	Access/Egress	Distance to bus stop from home and the distance from the bus stop to the destination.
	Comfort	Crowdedness expresses how busy it is in a vehicle. A vehicle has limited space and a maximum capacity, the closer this capacity is reached the busier it is in the vehicle.
Translation	Seat Availability	Crowdedness affects the availability of seats. If a bus is crowded and the traveler has a seat, the crowdedness is not seen as problematic as it would be when the traveler is standing.
	Reliability	Decision makers express reliability in terms of percentages. Of a certain schedule a specific percentage of the buses must arrive on time.
Translation	Delay frequency “1 in 5 buses is late”	Since percentages are difficult to understand for the commuter it is opted to indicate how often a bus is late. This gives the commuter a better feel for the reliability of the service.

Attribute level choice

After having resorted to 6 attributes, the levels can be determined for the attributes. These levels will be varied per choice per task. Attribute levels should be chosen in such a way that they result in realistic choice experiments. It was seen that the commutes of people differ in time, distance and mode choice. It was also seen that The HOV lines differ in distance travelled, speeds and number of stops. HOV buses could be divided into 3 types of buses: city, inter-city short and inter-city. It could be decided to generate separate profiles for each type of bus; however this would result in many different choice profiles, and it needs to be guaranteed that enough number of respondents can be found for each type of bus to make sure the results are statistically significant. Therefore, it has been decided to work with pivots. This way choice profiles can be tailored to the trip the commuter is used to. The choice profiles will be more realistic. Total travel time, access time and egress time will be determined based on a percentage. Access and egress usually takes only a maximum of 40% minutes of the entire journey. Therefore, access and egress percentages should be set to a maximum of 20%. The frequency levels have been derived from the analysis in Section 3.3.1 in which the minimum was 2 and the maximum 8 as well as the average speed. Reliability has been derived from the analysis in Section 3.3.

These attributes are defined from a policy maker's perspective. They have been related to aspects that are relevant for commuters, since the stated choice experiment is conducted among commuters. The table below shows how this translation is done and how the values were related to the needs of commuters. The levels of the attributes for the commuter have been used in the survey. In the model some levels have been translated back to the levels of the attributes of the policy makers. This translation can be seen in Table 12 Attribute levels translation from decision maker to commuter interpretation.

Table 12 Attribute levels translation from decision maker to commuter interpretation

Attribute Policy maker	Attribute level	Attribute commuter	Attribute level

Frequency	2 departures per hour	Follow-up time	Departure every 30 minutes
Bus departures per hour	4 departures per hour	Time in between of each bus departure	Departure every 15 minutes
	6 departures per hour		Departure every 10 minutes
	8 departures per hour		Departure every 7.5 minutes
Average Speed	Among HOV lines the average operation speed varies between 5 km/h to 70 km/h. Another measure related to this is the travel time ratio, which is by decision makers often compared to the car travel time and is aimed to be between 1.0 and 1.5	Total Travel time	20% improvement
Average operation speed of bus along the line		Travel time from origin to destination including access and egress time	10% improvement
			No travel time change
			10% increase
Directness	HOV is aiming at a egress and access of 500 to 1500 km	Access time	5% of travel time
Directness expresses how direct in terms of time and distance a destination can be reached. Network are designed in such a way that this is being minimized for most people.		Time to get from the origin to the first stop or station	10% of travel time
			15% of travel time
			20% of travel time
		Egress time	5% of travel time
		Time to get from the last stop or station to the destination	10% of travel time
			15% of travel time
			20% of travel time
Reliability	95%	Reliability	1 op de 20 keer te laat
Policy makers express the reliability of bus services in terms of percentages. The percentage indicates what percentage of buses arrived on time at each stop.	90%	Chance a bus will arrive to late	1 op de 10 keer te laat
	85%		1 op de 6 keer te laat
	80%		1 op de 5 keer te laat
Crowdedness	In HOV it is commonly promised to provide buses which have higher comfort and enough seats for all passengers	Seating	Two-seater without neighbor
Crowdedness can be related to comfort. Dependent on crowdedness passenger have to		Availability of a seat during the ride.	Two-seater with neighbor
			First half of trip standing, then two-seater with neighbor

stand or can have a seat.	On busier lines especially during rush hour that chance is higher that passengers need to stand	Standing entire trip

Attribute balance
Assuring attribute balance assures the generation of smaller designs. Attribute balance refers to the practice of making sure that all attributes have the same number of levels or that the number of levels is a multiple of the other number of levels. For example attributes can have 3 and 6 levels, or 2 and 4 levels.

Testing of levels
The levels have been tested to assure that realistic choice situations are generated. This has been done by generating choice profiles with different distances and travel times provided by a dataset Statline (CBS, 2023). From this, average speeds could be derived, giving an indication of the realism of the scenarios. The percentages have been adjusted accordingly and it has been checked for outliers in the dataset.

Step 2: Generation of experimental design

After having decided which attributes and which attribute level should be tested, the profiles can be generated. A profile includes each option and for each attribute one attribute level is set. For each profile the respondent chooses an option. To calculate the minimum number of respondents needed to test main effects only, following formula can be used (Sample Size Issues for Conjoint Analysis, 2010):

$$N \geq 500 * \frac{C}{T * A}$$

Equation 1 Minimum number of respondents

where,
N = minimum number of respondents to test main-effects
C = number of levels of attribute with highest number of levels
T = number of choice tasks
A = number of alternatives

The formula results in a minimum of 28 respondents. When working with blocks one needs to multiply this number with the number of blocks being used. When using 6 blocks this will result in a minimum amount of respondent of 168. A rule of thumb is to achieve double the amount. In this case 336.

Profile generation
Ngene is a software which allows to find fitting designs for a specified number choice profiles. Dependent on the number of alternatives, the number of attributes with their levels, Ngene can find a design which is most efficient with the specified requirements. The Ngene syntax that has been used for the construction of the profiles for this research can be found in Appendix 4: Ngene syntax.

Step 3: Construction of questionnaire

The next step is to present the generated choice profiles to the respondent. Common practice is to use a table layout, in which the attributes are the rows and the alternatives the columns. However it was seen that with too many attributes the table layout becomes unclear and overwhelming to the respondent. This needs to be avoided as respondents will postpone making a well0thought choice and go through the survey at a quicker pace influencing the results. Other visual methods should used to present the information in a more effective and condense way. It was chosen for a layout in which different visual cues are helping the respondent in at a glance how the option looks like and let them compare it easily to the other option. It can also be made use of blocking. This is a technique where the constructed choice sets will be divided into multiple groups. Each group of respondents will receive a different set of choice sets. This allows to test more different choice sets. However, a larger group of respondents is needed.

The first design of the choice profiles was a table, as it was seen that this was a common practice in other choice experiments. Figure 16 shows an stated choice experiment also with bus choice in another research. This kind of design was first adapted for this research as well. Through testing however it was discovered that respondents were overwhelmed with the amount of information being presented. It was considered to reduce the number of attributes or to present the information in a more compact format. It was opted for the later. The new design includes icons to describe the attributes. The advantage of using the table design is that it allows for easy comparison as it is shown next to each other. This has also been integrated into the new design. Additionally, to make the comparison of the total travel time easier, it was decided to have the total journey line scale with the number of minutes each leg of the journey takes. This way the respondent can quickly see which of the two options takes longer for the journey and compare access and egress time between the options. Additionally, each seating level has a custom icon that will change according to the seating level.

Testing of the survey

The design has been tested numerous times by different people on different devices, to ensure that it is clear and understandable for anyone. Several tests have been conducted by watching the respondent doing the survey and asking them to speak out loud. This way it could be checked that the respondent understood the question. Another batch of tests where send to people without supervision, after which they were asked about the clarity of the question and the felt effort of the survey. The survey software also displayed the time respondents spend on the survey. This was used as an indicator for the effort needed for the survey. There was also a requirement set by the party that would send out the survey. They required a survey between 5 to 10 minutes.

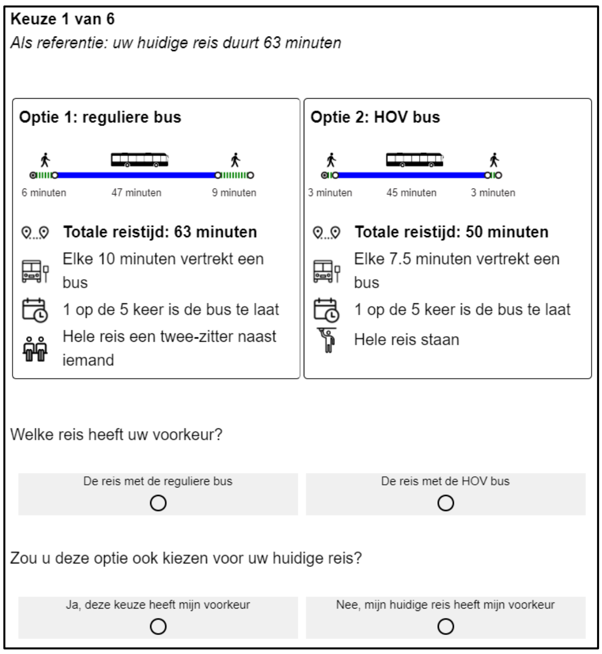

Figure 16 Final design of choice experiment question

4.4 The daily commute

The choice sets forms the third part of the survey. The survey will start with questions about the respondents daily commute. This is to understand what type of commuter the respondent is. As the research is focused on commuters, it is important to select travelers who are travelling regularly and during rush hours. Respondents that travel less than 1 time per month are not considered to be a commuter. The following questions are being asked in this section of the survey:

1. How often do you make this trip?
2. What is the purpose of your trip?
3. At what time do you depart?
4. With which mode of transport do you cover the longest distance during your trip?
5. Which additional modes of transport do you use during your trip?
6. How long does your trip take from door-to-door in minutes?
7. Do you receive travel allowance?
8. How do you rate your current trip?

Follow-up questions:

9. When travelling with public transport, what is the travel time to the boarding stop?
10. When travelling with public transport, what is the travel time to from the end stop to the destination?
11. When travelling with public transport, do you need to transfer during your trip?
12. Do you access to a car?

Follow-up questions will be asked dependent on the mode selected by the respondent. For example, selecting a public transport mode will be followed by the question how long the access and egress takes. Additionally, anyone that does not select a car will be asked whether they have access to a car in any way or not at all. In this section the respondent will also be asked to fill in their current commute time. The number entered here will be used to calculate new access, new egress and travel time. For questions where the respondent is required to answer with a number, sliders have been implemented, so that no mistypes can be made. Additionally, the slider has a max input of 180 minutes. Since for travel times with car above this number unrealistic choice sets will be generated. Trips to this range are also very rare.

4.5 Familiarity with HOV

In part 2 of the survey the respondents will be asked about their familiarity with HOV. The survey focuses on potential and current HOV bus travelers, therefore it is important to know how familiar the sample is with HOV, such that it can be verified that a relevant sample has been collected. Dependent on the area it can be asked for different HOV products. Since this survey is being conducted in the region of North-Brabant in the Netherlands the survey should include the buses “Bravo Direct” and “Brabantliner” since they are the operating HOV buses in this area. For this part, it was first asked how familiar the respondent is with HOV. Until this point HOV has not been mentioned throughout the survey. After answering this question the respondent was presented with a description of HOV buses. It was made clear to the respondent that carriers promise certain aspects to be of higher quality. The description also included pictures of the relevant HOV lines in this area. This was done so because it would show whether respondents recognize the branding of HOV buses. The following questions are included in this part:

1. Where you familiar with the term “HOV” before this survey?
2. Do you know the following or other HOV lines?

3. Have you used one of the following or other HOV lines?

Follow-up questions:

4. With which other HOV lines are you familiar?
5. Which other HOV lines have you used in the past?
6. Which other HOV lines have you used in the past?

4.6 Social demographics

In part 4 of the survey, the respondents will be asked about their demographics. Most commonly appearing demographics are age, gender, income and occupation. In the survey respondents are also asked about their geographical living situation, for the character of HOV buses. As mentioned before, there are 3 different kinds of HOV buses: HOV buses connecting within city, connecting rural to city and connecting inter-city. Asking about the urbanity of the city of the respondent will give insight into the starting point of commuters and the type of commute that is required for their commute.

1. Year of birth
2. Gender
3. Yearly income
4. Employment status
5. Postal Code
6. Population of living area

4.7 Reflection survey design

Frequency, speed, reliability, directness and crowdedness have been identified as the main characteristic attributes of HOV bus services. These attributes have been translate into attributes that are relatable to the commuter in order to present them with a understandable survey. Frequency is being expressed in departure time between bus, speed is being related to the total travel time, reliability is expressed in once in how much a bus is delayed; directness is expressed through access time to the starting station and egress time from the de-boarding station to the destination; crowdedness is related to seating comfort and is expressed in the seating configuration.

It was also found that a visual presentation of the choice profiles is easier to comprehend than presenting the information in a table. This also allowed for the addition of an additional attribute: in-vehicle time.

■

5

Data collection and analysis

After finding an effective survey design that ensures a sufficient number of respondents and collects an adequate number of data, the survey could be distributed to the respondents. Through Movares Nederland, a suitable party was found which could support in the distribution. This chapter will present how the survey was answered.

5.1 Survey distribution

The survey was distributed in cooperation with SmartwayZ. SmartwayZ has 3000 members who signed up to their platform to participate in studies about mobility. The survey developed in the previous chapter was setup, tested and distributed with their supervision, such that the maximum of participants could be expected. The survey distributed via SmartwayZ received 500 responses. The survey has been distributed on the 6th of June 2023. A reminder was sent on 13th of June 2023. The survey was active for 3 weeks.

Not all responses were useful because of not completed survey's or not being part of the target group. For the research only surveys were taken which fulfilled the following criteria:

- At least 80% completion which corresponds to answering the trip characteristics, the HOV familiarity and the choice profiles.
- Travel during morning or evening rush-hour
- Frequency of travel at least once per week or more often

This filtering resulted in a sample of 376 surveys which can be used for further analysis.

5.2 Response frequency

In this section it will be looked at the response frequency of the survey and how the respondents have answered the questions. For each segment, calculations were made for how often each alternative was chosen in the choice profiles and what the actual choice was in the end.

Trip characteristic

Most of the respondents that participated in the survey travel frequent enough (between 1 and 5 times per week). Largest part is travelling for work, and departs between 6:00 and 9:00. This aligns with the specification of a commuter. When looking at the profile choice and actual choice, it can be seen that the choice are fairly amongst the options. The research is interested in the morning peak. The sample represents equal distributions for the morning peak (Rijksoverheid, 2023).

Table 13 Frequency response of trip characteristics survey questions

		Sample composition		Dutch data
	Segments	Freq	%	
Frequency of Travel	More than 5 times per week	8	2%	
	4 to 5 times per week	143	38%	
	2 to 3 times per week	153	42%	
	1 to 2 times per week	66	18%	
Time of departure	Before 6:00	12	3%	
	Between 6:00 and 7:00	88	24%	18%
	Between 7:00 and 9:00	266	72%	81%

Mode use

The largest part of the sample makes use of the car for their commute (54%), followed by cyclist 26% and then public transport (19%). The representation of the mode aligns with the Dutch data (Rijksoverheid, 2023).

Table 14 Frequency response respondents mode use

		Sample composition		Dutch data
Variables	Segments	Freq	%	%
Main mode of transport	Car (as driver)	209	54%	60%
	Car (as passenger)	3	1%	1%
	Bus	13	3%	2%
	E-bike	41	11%	7%
	Bike	56	15%	18%
	Walking	4	1%	3%
	Tram/Metro	2	1%	2%
	Train	50	13%	6%
	Other	7	2%	1%
Additional modes of transport	I only use 1 mode of transport	233	56%	72%
	Bike	53	12%	
	Walking	62	15%	
	Car	39	10%	
	Bus	21	5%	
	Train	8	2%	

Duration and Distance

The largest part of the sample travels less than 30 minutes in total. 84% of the sample travels under 60 minutes. Compared with national data the distributions align most of the part. As for the distance the largest part of travels above 15 km. Still the distances are approximately well represented except for the lower spectrum CBS (2023a). Since this sample is from North Brabant, a region which is less dense than other areas in the Netherlands, people tend to travel longer distances than the average in the Netherlands. Travel times are represented well too (CBS, 2023a).

Table 15 Frequency response trip duration and distance of survey

Variables	Segments	Freq	%	Dutch data

Duration trip	<10 min	87	23%	13%
	10 to 20 minutes	62	16%	29%
	20 to 30 minutes	61	16%	18%
	30 to 60 minutes	111	29%	29%
	60 to 120 minutes	57	15%	9%
	More than 120 minutes	7	2%	2%
Distance trip	0 to 7,5 km	18	5%	28%
	7,5 to 15 km	40	10%	17%
	15 to 30 km	72	19%	17%
	30 to 50 km	92	24%	17%
	50 to 75 km	76	20%	11%
	75 km or more	53	14%	4%

Additional trip characteristics

As predicted, the largest part of the sample receives compensation for their travel. Of the public transport users most are not required to change during their travel. As for the people that do not use the car as their main mode, many choose to not use a car even though there is one available. The trip rating indicates that 90% are satisfied with their commute. This may also explain why people tend to still choose their current commute instead of a bus option. It was seen that the higher the rating the more likely the current commute is being chosen.

Table 16 Response frequency for additional trip characteristic

Variables	Segments	Freq	%
Transfer	No need to change	33	52%
	1 change	25	40%
	>2 or more changes	6	8%
Car availability among Public transport users	Yes, whenever I want	99	60%
	Yes, but not always	51	30%
	No	15	10%
Travel expenses compensation	Yes, I receive compensation for my trip	304	83%
	No, I do not get travel compensation for my trip	64	17%
Trip rating	10	15	4%
	8 or 9	176	48%
	6 or 7	135	36%
	Lower than 6	42	12%

Familiarity HOV

Among the sample there was almost a 50/50 split in the familiarity with HOV. It does not seem to have an effect on bus choice. Most people have not heard of any HOV products. Bravo Direct seems be known.

Variables	Segments	Freq	%
HOV term	Yes, I have heard of HOV before	182	50%

	No, I have never heard of HOV before	186	50%
Familiarity Local HOV Product	Have heard of a local HOV brand (with or without knowing it is HOV)	127	38%
	Know other HOV brands	89	27%
	Do not know any or local HOV brands	113	34%
Use of HOV	Yes, I have used HOV bus services	75	21%
	No, not that I know	269	79%

Demography

The largest part of the sample is between 55 and 65 years old. Followed by 35 to 50 years old (18%) and under 35 years old (8%). 64% are man. The most age groups are well represented by the survey. The younger group has a slight under presentment. For this group the results might not be as accurate but still valid.

Variables	Segments	Count	%	Dutch data
Age	<35 years old	33	8%	29%
	35 to 50 years old	127	36%	30%
	50 to 65 years old	167	48%	29%
	>65 years old	19	5%	11%
Sex	Man	247	64%	
	Women	110	28%	
	Other/No answer	28	8%	

5.3 Commute choice

The stated choice experiment included two questions. The first question was about the two presented services, which of those had the respondent's preference. For each choice set there was also a second question which would ask the respondent to say whether the chosen bus would also be considered in favor of their current commute. The distribution among the respondents in choosing a regular bus service or a HOV bus service is almost equal. Among all choices, the respondents slightly favored the HOV bus service over regular bus service. The regular bus service was chosen 1050 times (47%) and the HOV bus service was chosen 1186 times (53%). The equal distribution can be explained by the fact that the alternatives did not differ in terms of attributes and attributes levels. The only difference between the alternatives is the label “Regular bus” and “HOV bus”. However, there is a slight imbalance indicating that potentially there might be an underlying preference for HOV bus because of the label.

Table 17 Division of choices when choosing between a regular bus service and HOV bus service

	Regular bus	HOV bus
Number of choices	1050	1186
Percentage	47%	53%

	Regular bus	HOV bus	Current commute
Number of choices	244	300	1692
Percentage	11%	13%	76%

After respondents had specified there preference between the regular bus service and the HOV bus service, the respondents were asked to specify their preference between the chosen option and their current commute. The regular bus was chosen 260 times (11%), the HOV bus service was chosen 308 times (13%) and the current commute was chosen 1692 times (76%). Literature indicates that commuters are less likely to switch to a different way of travelling when they have been travelling with a specific mode.

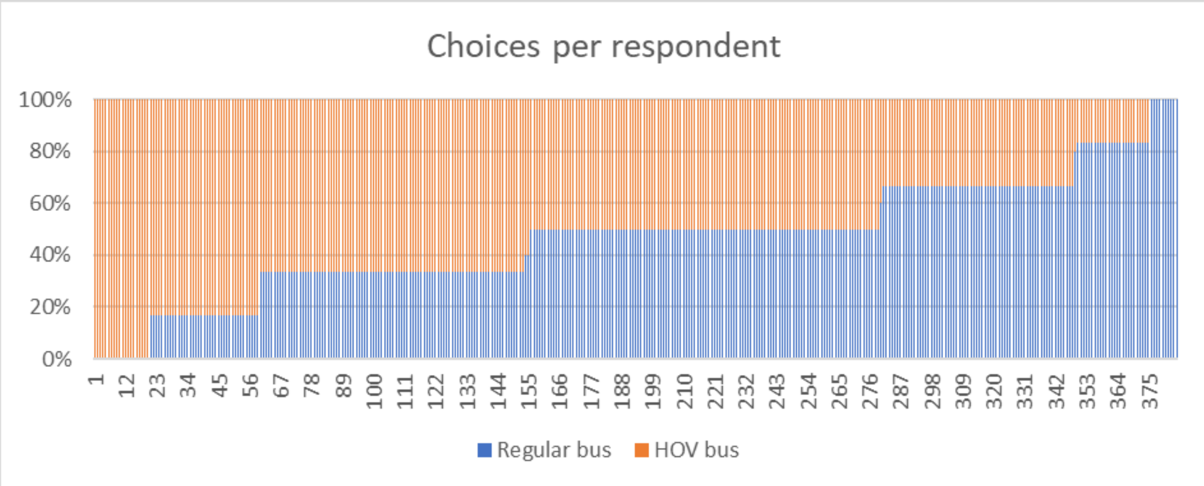

Figure 17 Choice per respondent bus choice

Figure 18 shows for each respondent how they made their choices amongst the choice profiles. Blue indicates the choice of the regular bus service; orange indicates the choice of the HOV bus service and gray indicates the choice of the current commute. For example, respondent 1 choose for each choice the HOV bus service, whereas respondent 391 choose their current commute in each case. The figure already shows that respondents are reluctant to choose one of the buses over their current commute. This can be explained by the fact that commuters are reluctant to change their current way of travel if they are used to it. It is suspected that most of the respondents that do not change at all are car users. 25 respondents would change to the bus in every case presented. 81 of the respondents would change their commute in 50% of the cases. It should be mentioned that not all choice profiles are necessarily better than their current commute. Additionally, among all the choice profiles a respondent receives, it is possible that all options are worse than their current commute. The research aims to understand how respondents make choices and how changing various aspects influences the choice probability.

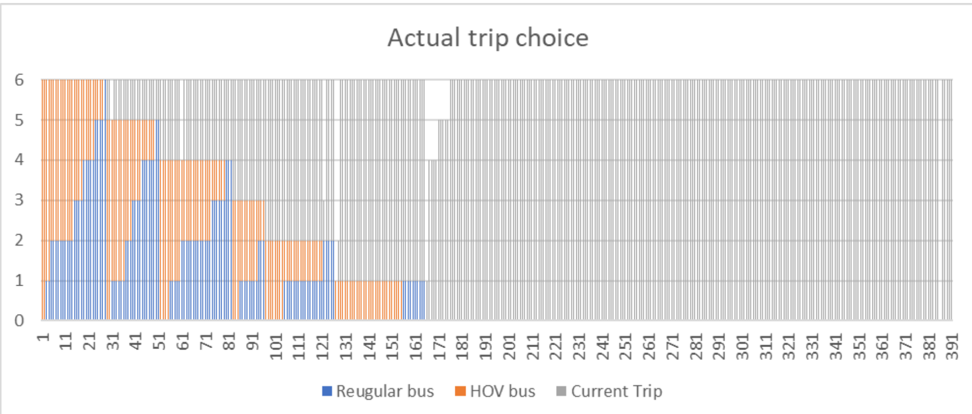

Figure 18 Distribution of choices including the current commute

5.4 Conclusion

In this chapter the last sub-research question was answered. This sub-research question has been formulated as follows:

SQ6 How do commuters choose between an HOV bus and regular bus for their commute?

It was that the two bus service equal preference between the HOV bus service and the regular bus service, with the HOV bus service slightly more often chosen. Another notable aspect is the fact that 50% of the respondents would not prefer the bus in any case over their current commute. The current commute can be a commute with bus, train, bike or car. Cases have also been included in which the travel time with the bus is lower than the current commute. It was observed that in these cases the respondent would still choose their current commute. Travel time alone does not decide which option to use. It was also observed that bike users choose a bus service the least for their current commute. Public transport users tend to choose one of the bus options more likely.

With the insights from Chapter 5 an answer can be given to sub-question 7: "How do commuters choose between an HOV bus service and regular bus service for their commute?". By looking at the survey data it can already be seen that in most cases commuters still prefer their current commute. The choice data does seem to indicate that the HOV bus service has been slightly more chosen then the regular bus even though the characteristics were the same amongst the buses. The choice experiment is designed in such a way that both options are equally as often seen as the better option. This can be further investigated.

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6

Model estimation

The next step is to estimate the model. The model should allow for the prediction of the mode split change when changing the operational aspects of a bus line. With this model it can then also be tested whether upgrading a regular bus line to a HOV bus is really seen as an upgrade from the commuters perspective. First, the modelling theory will be explained. Then the requirements for the model will be explained and at last the model will be estimated and evaluated on goodness of fit.

6.1 Modelling theory

The goal of this research is to understand how improving a bus service on specific operational attributes affects the commuters choice of choosing that service. Discrete choice modelling is an approach that can be used to answer this question. A person's choice can be explained by utility theory. This, in combination with logit analysis, forms a strong methodology to create predictive models. Each alternative has a specific utility and a person chooses the alternative with the highest utility, the option that is being perceived as most useful. Knowing the utility of different alternatives, it can then be determined what the probability is that a person chooses a specific alternative out of a selection of alternatives.

The assumption is that an individual will choose the alternative that gives the maximum utility. This theory is called the maximum utility theory (Blij, et al.). Different attributes contribute to the increase or decrease of utility. Utility consists of two components: observed utility and unobserved utility. The unobserved utility is also being referred to as “error term”. The observed utility is being referred to as the systematic utility. The systematic utility consists of different attributes and are represented as linear-in-function parameters. The utility is being described mathematically as followed (McFadden, 1975):

$$U_i = V_i + \epsilon_i$$

Equation 2 The utility function

The systematic components of the utility function ($\boldsymbol{V_i}$) consist of attributes. When an individual makes a choice they will evaluate the different attributes. Each attribute can have a different value or level. Not each attribute is equally important to the individual. Each attribute is accompanied by a parameter. The systematic component consists of the sum of all the attributes with their corresponding coefficient and level of the alternative.

$$V_i = \sum_{k=1}^{k} \beta_k \cdot x_{ik}$$

Equation 3 The systematic utility

The individual chooses the alternative if the utility of this alternative is higher than the utility of the other alternative. This can be expressed mathematically as followed. Alternative $\boldsymbol{i}$ is chosen over alternative $\boldsymbol{j}$ if the utility is higher.

$$U_i > U_j$$

Equation 4 Decision rule between an alternative i and an alternative j

$$\sum_{k=1}^{k} \beta_k \cdot x_{ik} + \epsilon_i > \sum_{k=1}^{k} \beta_k \cdot x_{jk} + \epsilon_j$$

Equation 5 Decision rule between an alternative i and an alternative j: systematic utility plus error term

Note that Equation 5 has been combined with Equation 2 to emphasize that there can be an unobserved part of the utility. This is the basis of utility maximization. The interest lies now in estimating the coefficients that are associated with the different attributes. Since this allows for the calculation of utility by filling in the levels of the attributes.

From the utility functions probabilities can be determined. These probabilities express the probability of choosing a specific alternative. To determine the probability of an alternative being chosen, one takes the exponent of the utility of that utility and divides it by the sum of the exponents of the utility of all alternatives. This can be express as Equation 6 (Bernasco & Block, 2013). It is important to understand that this probability only reflects the probability to be chosen amongst the alternatives that have been included in the probability function.

$$P_i = \frac{e^{V_i}}{\sum_{j=1}^{J} e^{V_j}}$$

Equation 6 Probability function

The utility from which the probabilities can be determined, consist of coefficients. To find the coefficients that are associated with the attributes, models can be estimated. The multinomial logit model is one of the most used forms. Multinomial Logit (MNL) is most commonly used discrete choice model because of its wide application. In most cases the MNL model is suitable enough. Unobserved error components are independently and identically distributed, meaning that each choice can be seen as independent from every other choice. The advantage of this is that the model is computationally simple.

When setting up the utility functions, one can choose different strategies in doing so. Each alternative will have their own utility function with their attributes. One can choose to describe the utility with fixed, generic or alternative-specific parameters. A fixed parameter is chosen to describe unexplained utility, so utility that is not being explained by the other parameters in the utility function. An alternative specific constant is an example of a fixed parameter one can add to the utility function. For this research, an alternative specific constant can be added to the utility function of the HOV or the current commute to test whether there is an underlying preference for those alternatives. More specifically it can be tested whether the description of HOV causes commuters to have an underlying perception of the alternative. Alternative specific parameters can be chosen to study whether there is a difference in utility contribution amongst alternatives for the same attribute. For example, does frequency contribute less to the utility of the HOV bus compared with the regular bus, because the commuter is more critical of the aspects of the HOV bus? Choosing generic parameters for the alternatives implies that the attributes are identically valued amongst people despite different alternatives.

6.1.2 S-curve

The probability function (Equation 6) can be described as a logit-function. With this function utilities can be translated to probabilities. Utility and probability are not directly related. Utility difference and probability are related. Utility in its self itself does not have a meaning unless it is being compared to other alternatives. An important characteristic about the logit function is the shape of the function. This shape can be described as an S-curve. Figure 19 shows the probability curve for a situation in which the choice is between two alternatives. The x-axis shows the difference in utility between two alternatives. The y-axis describes the probability that alternative 1 is chosen over alternative 2. The alternative with the highest utility will be chosen. A negative utility difference indicates that alternative 1 has a lower utility than alternative 2, and a positive utility indicates that alternative 2 has a higher utility than alternative 1. If the utility between two alternatives does not differ, the choice probability is 50/50. If the utility difference is very large, then there is a very low probability of choosing the alternative with the lower utility. Notice that the curve flattens out when approaching minimum or maximum probabilities. The more the curve approaches the maximum and minimum the slower the rate of change of probability. If the utility difference is small, it causes a larger probability change than when the utility difference is large.

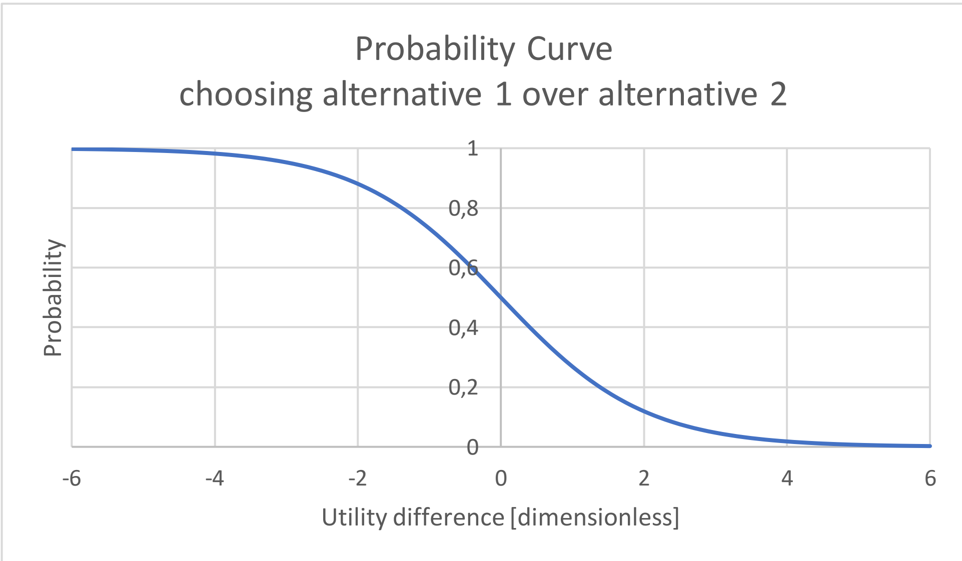


Figure 19 Probability curve when choosing between 2 alternatives

6.1.3 Goodness of fit

It is important to know whether the model fits the data well. To evaluate this, one can calculate McFadden's Rho-Square and execute a Likelihood ratio test.

McFadden's Rho Square

McFadden's Rho Square expresses how well the model fits the data and therefore indicates the goodness of fit. The Rho square is a common measure in regression analysis. It can take a value between 0 and 1. 1 indicates a perfect fit of the model and 0 the opposite. McFadden's Rho Square suggests a value of 0.2 to 0.4 of a very well fitting model for MNL. However, this value should not be taken as an absolute. (McFadden, 1977) The McFadden's Rho Square is expressed in Equation 7. Where L_C is the maximum likelihood of the model and L_{null} is the likelihood of the null model.

$$R^2_{McFadden} = 1 - \frac{\log(L_C)}{\log(L_{null})}$$

Equation 7 McFadden Rho Square

Likelihood ratio test

The likelihood ratio test can be used to compare models which have the same data. This way it can be evaluated whether a better model has been found. First the likelihood ratio statistic (LRS) will be determined. This is done by calculating the difference between the final log-likelihood of the two models that will be compared. More specifically, the log-likelihood of the unrestricted model will be subtracted from the log-likelihood of the restricted model. The restricted model is the model with the least number of parameters and the unrestricted model is the model with added parameters. The difference in log likelihood will be multiplied by 2. The following formula can be used for this:

$$LRS = -2 \cdot (LL_{model\ 1} - LL_{model\ 2})$$

Equation 8 Likelihood Ratio Statistic

The LRS should be a positive value. If it is negative then the original model remains the better model. The next step is to determine the degrees of freedom. This can be done by taking the absolute value between the difference of the number of parameters.

$$df = |\#\ parameters\ model\ 1 - \#\ parameters\ model\ 2|$$

Equation 9 Degrees of Freedom (df)

The last step is to lookup the threshold value in the Chi-Square Distribution table and find the given significance level at which model 2 is the better model. This is being done by finding where the LRS is no longer bigger than the threshold for the calculated degrees of freedom. The associated significance level is the last threshold value that was smaller than the LRS. The associated significance level will tell at what significance level model 2 is the better fit. One can disregard the first model, when the significance level is 0.99, which translates to that the chance that model 2 fits because of coincidence is less than 1%.

6.1.4 Significance of parameters

With the MNL model it is possible to estimate the coefficients for the attributes. It is important to know whether these values are correct. The t-test statistic and p-value give an indication of the significance of the coefficient. Therefore, indicating whether the estimated coefficient fits the data. Two parameters are most insightful for this: the t-test statistic and p-value.

The t-test indicates the significance of the parameters. An absolute value > 1.96 indicates a significant parameter. The p-value explains to what extent the parameters have the found value by chance. A p-value < 0.05 is admirable. However, for both parameters it is said that they are not absolute determinants of significance. This should be kept in mind during the model estimation.

6.2 Model specification

In previous chapter the characteristic attributes have been identified and a selection has been made. Two different models will be estimated since current and potential user of HOV buses are of interest. The difference between the two models is the alternatives that are in included. The model for the current users will include the regular bus and the HOV bus as an alternative. This model will provide insight into whether commuters have different perception of the attributes knowing that one alternative has been labelled as HOV. The second model includes the current commute. This allows for the evaluation of whether commuters would consider the bus for their current commute.

Attributes can be ordinal or nominal. When an attribute is nominal, one can apply dummy coding. This entails the introduction of binary parameters, over which a dummy coding scheme is used. Two nominal attributes have been included. For these attributes a coding scheme has been applied. The other attributes are ordinal. At first access, egress and travel time were inputted as percentages. With this configuration egress had an unexpected sign and was insignificant. Since respondents have also filled in the travel time in minutes, the values for this attribute could be translated from percentages to the minutes of travel time. This will also allow for better comparison between the three attributes. Additionally travel time has been replaced by in-vehicle time. Since the travel time is composed of the access and egress time, they are correlating with travel time. The in-vehicle time could be calculated by subtracting the access and egress time from the travel time. Adding this parameter to the model resulted in egress having the expected sign and being significant. Hence a clearer conclusion can be drawn. Frequency can be filled in with its corresponding levels. Reliability will remain in percentage.

Another decision that had to be made was deciding between generic parameters or alternative specific parameters for the bus alternatives. Since the research focuses on the differences between the regular bus and the HOV bus it was decided to include alternative specific parameters as these will give insight into the specific parameters for which commuters might choose differently than when they would choose for a regular bus.

6.2.1 Dummy coding

Since the levels for seating are nominal, a coding scheme can be applied. So called dummy coding. This scheme can be seen in Table 18.

	Attribute	Coding		
4 levels	Seating	ST1	ST2	ST3
0	Two-seater without neighbor	0	0	0
1	Two-seater with neighbor	1	0	0
2	Half way standing, then two-seater with neighbor	0	1	0
3	Entire time standing	0	0	1

Table 18 Coding scheme for the seating level attribute

The systematic utility contributed by a seating level can be expressed as Equation 10 Systematic utility of the seating level

$$V_{ST} = \beta_{ST1} \cdot ST1 + \beta_{ST2} \cdot ST2 + \beta_{ST3} \cdot ST3$$

Equation 10 Systematic utility of the seating level

A utility function for the current commute is determined too such that the utility of the bus alternatives can be compared with the current situation. The information that is collected for the current commute is the travel time, the travel distance and the mode of transport. For the mode of transport, a coding scheme is being applied. Car, bike, train and bus, are the most common modes in the survey. E-bike has been added under bike. Metro and tram have been added under train. Train and bus have been split as this accounts for the rail-bonus. Table 19 shows the coding scheme.

Table 19 Coding scheme main mode of current commute

	Attribute	Coding		
4 levels	Current commute main mode	Mode1	Mode2	Mode3
0	Car	0	0	0
1	Bike/E-Bike	1	0	0
2	Train, Metro or Tram	0	1	0
3	Bus	0	0	1

$$V_{MD} = \beta_{Mode1} \cdot Mode1 + \beta_{Mode2} \cdot Mode2 + \beta_{MD3} \cdot Mode3$$

Equation 11 Systematic utility of main mode current commute

6.2.2 Alternative specific constants

Alternative specific constants (ASC) have been included for the regular bus and the HOV bus. The current commute has been chosen as the base alternative. The ASC can be used if there is a preference in regards to the current commute for each bus. It also indicated whether the model accounts for effects not included in the model. The previously explained considerations, the coding schemes and the addition of ASC's result in the following systematic utility equations for the three alternatives.

6.2.3 Final utility equations

With these considerations in mind the utility functions can be set up for the three alternatives that will be included in the model: the regular bus, the HOV bus and the current commute. The utility of the regular bus (Equation 12) includes all the attributes, the coding scheme for comfort and an ASC. The utility of the HOV bus (Equation 13) includes all the attributes, the coding scheme for comfort and an ASC. Both the regular bus and the HOV bus have alternative specific parameters. This means that a parameter will be estimated which expresses the attribute of the alternative specifically. The current commute (Equation 14) is expressed in the door-to-door travel time and the coding scheme for the main mode of the current commute. Table 20 provides the descriptions of the variables and units in which they are expressed.

$$V_{reg} = \beta_{AC,reg} \cdot AC_{reg} + \beta_{EG,reg} \cdot EG_{reg} + \beta_{FR,reg} \cdot FR_{reg} + \beta_{VTT,reg} \cdot VTT_{reg} + \beta_{RL,reg} \cdot RL_{reg} + \beta_{ST1,\mathrm{reg}} \cdot ST1_{reg} + \beta_{ST2,\mathrm{reg}} \cdot ST2_{reg} + \beta_{ST3,\mathrm{reg}} \cdot ST3_{reg} + ASC_{reg}$$

Equation 12 Systematic utility of the regular bus alternative

$$V_{hov} = \beta_{FR,hov} \cdot FR_{hov} + \beta_{VTT,hov} \cdot VTT_{hov} + \beta_{AC,hov} \cdot AC_{hov} + \beta_{EG,hov} \cdot EG_{hov} + \beta_{RL,hov} \cdot RL_{hov} + \beta_{ST1,\mathrm{hov}} \cdot ST1_{hov} + \beta_{ST2,\mathrm{hov}} \cdot ST2_{hov} + \beta_{ST3,\mathrm{hov}} \cdot ST3_{hov} + ASC_{hov}$$

Equation 13 Systematic utility of the HOV bus alternative

$$V_{current} = \beta_{bike,current} \cdot Bike_{current} + \beta_{train,current} \cdot Train_{current} + \beta_{bus,current} \cdot Bus_{current} + \beta_{TT,current} \cdot TT_{current}$$

Equation 14 Systematic utility of the current commute alternative

Table 20 Description of variables

Attribute	Parameter	Attribute variable	Unit of attribute variable
Regular bus			
Alternative specific constant	ASC_{reg}	Constant	Dimensionless
Access to stop	$\beta_{AC,reg}$	AC_{reg}	Minutes [min]
Egress from end stop	$\beta_{EG,reg}$	EG_{reg}	Minutes [min]
In-vehicle time	$\beta_{VTT,reg}$	VTT_{reg}	Minutes [min]
Frequency	$\beta_{FR,reg}$	FR_{reg}	Departures per hour [dep/h]
Reliability	$\beta_{RL,reg}$	RL_{reg}	Percentage [%]
Seating			
Seat with a neighbor	$\beta_{ST1,\mathrm{reg}}$	$ST1_{reg}$	Dimensionless
Standing then seat	$\beta_{ST2,\mathrm{reg}}$	$ST2_{reg}$	Dimensionless
Standing	$\beta_{ST3,\mathrm{reg}}$	$ST3_{reg}$	Dimensionless
HOV bus			
Alternative specific constant	ASC_{hov}	Constant	Dimensionless
Access to stop	$\beta_{AC,hov}$	AC_{hov}	Minutes [min]
Egress from end stop	$\beta_{EG,hov}$	EG_{hov}	Minutes [min]
In-vehicle time	$\beta_{VTT,hov}$	VTT_{hov}	Minutes [min]
Frequency	$\beta_{FR,hov}$	FR_{hov}	Departures per hour [dep/h]
Reliability	$\beta_{RL,hov}$	RL_{hov}	Percentage [%]
Seating			
Seat with a neighbor	$\beta_{ST1,\mathrm{hov}}$	$ST1_{hov}$	Dimensionless [0 or 1]
Standing then seat	$\beta_{ST2,\mathrm{hov}}$	$ST2_{hov}$	Dimensionless [0 or 1]
Standing	$\beta_{ST3,\mathrm{hov}}$	$ST3_{hov}$	Dimensionless [0 or 1]
Current Commute			
Door-to-door travel time	$\beta_{TT,current}$	$TT_{current}$	Minutes [min]
Main mode of commute			
Bike	$\beta_{bike,current}$	$Bike_{current}$	Dimensionless [0 or 1]
Train	$\beta_{train,current}$	$Train_{current}$	Dimensionless [0 or 1]
Bus	$\beta_{bus,current}$	$Bus_{current}$	Dimensionless [0 or 1]

6.3 Model estimation

The next step is to estimate the model based on the data of the survey. A software package called Biogeme has been used to estimate an MNL model. Biogeme is a python package designed for the maximum likelihood estimation of parametric models such as MNL (Biogeme, 2023). It has a special emphasis on discrete choice models. The data of the survey has been reformatted such that it is suitable for the model estimation.

A model has been estimated which has sufficient goodness-of-fit and significant coefficients. The model has been estimated based on 2128 choices, with 22 parameters and has a rho-square of 0,441. Table 21 shows the descriptive statistics of the final model.

Table 21 Descriptive statistics final model

Datapoints used for model estimation	2128
Parameters	22
Final log likelihood	-1283,75
Rho -square	0.441

Table 22 shows the estimated parameters of the final model. There are several checks that can be made to verify the coefficients are valid. First it will be verified that the coefficients are sufficiently significant. Then the signs can be checked for any abnormalities. Looking at the signs of the parameters it can be seen that all coefficients have the expected sign. The t-test and p-value, column 5 and 6 in Table 22, indicate the significance of the parameter coefficients. Absolute t-test value is > 1.95 and the p-value is < 0.05. Almost all of the parameters are found to be significant except for the coefficients "Reliability of regular bus" and "Seat with a neighbor on the regular bus" of the regular bus. The t-test values are 1.32 and -1.55 respectively, and the p-values are 0.187 and 0.013 respectively. This indicates a significance level of 85%. It indicates that a relation can only be found at a lower significance level. In chapter 7 the model will be further analyzed.

Table 22 Parameter values of final model

Attribute	Parameter	Value	Std err	T-test	P-value
Regular Bus					
Preference (ASC)	ASC_{reg}	-3.450	1.120	-3.10	0.002
Access to stop	$\beta_{AC,reg}$	-0.106	0.026	-4.15	0.000
Egress from stop	$\beta_{EG,reg}$	-0.081	0.026	-3.12	0.002
Service frequency	$\beta_{FR,reg}$	0.188	0.032	5.87	0.000
Service reliability	$\beta_{RL,reg}$	0.016	0.012	1.32	*0.187
Seating level					
Seat with neighbor	$\beta_{ST1,\mathrm{reg}}$	-0.296	0.191	-1.55	*0.121
Seat with neighbor half way	$\beta_{ST2,\mathrm{reg}}$	-0.988	0.218	-4.53	0.000
Standing	$\beta_{ST3,\mathrm{reg}}$	-1.650	0.244	-6.79	0.000
In-vehciel travel time	$\beta_{VTT,reg}$	-0.087	0.013	-6.83	0.000
HOV Bus					
Preference (ASC)	ASC_{hov}	-4.370	1.160	-3.76	0.000
Access to stop	$\beta_{AC,hov}$	-0.139	0.027	-5.24	0.000
Egress from stop	$\beta_{EG,hov}$	-0.117	0.025	-4.69	0.000
Service frequency	$\beta_{FR,hov}$	0.182	0.034	5.35	0.000
Service reliability	$\beta_{RL,hov}$	0.032	0.013	2.48	0.013
Seating level					
Seat with neighbor	$\beta_{ST1,\mathrm{hov}}$	-0.472	0.192	-2.46	0.014
Seat with neighbor half way	$\beta_{ST2,\mathrm{hov}}$	-1.070	0.221	-4.82	0.000
Standing	$\beta_{ST3,\mathrm{hov}}$	-1.980	0.260	-7.59	0.000
In-vehciel travel time	$\beta_{VTT,hov}$	-0.079	0.013	-5.92	0.000
Current commute					
Total trip travel time	$\beta_{TT,current}$	-0.076	0.010	-7.68	0.000
Main mode of current commute					
Bike	$\beta_{bike,current}$	1.510	0.177	8.54	0.000
Train	$\beta_{train,current}$	-0.569	0.169	-3.36	0.001
Bus	$\beta_{bus,current}$	-2.080	0.284	-7.32	0.000

The parameter values can be plugged into the utility functions defined in section 6.2.3. This will result in the complete utility functions with which the utility can be predicted of the regular bus service, the hov bus service and the current commute. Equation 12 is the systemetic utility function of the regular bus service. Equation 13 is the utility function of the HOV bus service. Equation 14 is the utility function of the current commute.

$$V_{reg} = 0{,}188 \cdot FR_{reg} + 0{,}016 \cdot RL_{reg} - 0{,}106 \cdot AC_{reg} - 0{,}081 \cdot EG_{reg} - 0{,}087 \cdot VTT_{reg} \\ -0{,}296 \cdot ST1_{reg} - 0{,}988 \cdot ST2_{reg} - 1{,}650 \cdot ST3_{reg} - 3{,}450$$

Equation 15 Defined systematic utility of the regular bus alternative

$$V_{hov} = 0{,}182 \cdot FR_{hov} + 0{,}016 \cdot RL_{hov} - 0{,}139 \cdot AC_{hov} - 0{,}117 \cdot EG_{hov} - 0{,}079 \cdot VTT_{hov} - 0{,}472 \\ \cdot ST1_{hov} - 1{,}070 \cdot ST2_{hov} - 1{,}980 \cdot ST3_{hov} + ASC_{hov}$$

Equation 16 Defined systematic utility of the HOV bus alternative

$$V_{bas} = -0{,}076 \cdot TT_{bas} + 1{,}510 \cdot Bike_{bas} - 0{,}569 \cdot Train_{bas} - 2{,}080 \cdot Bus_{bas}$$

Equation 17 Defined systematic utility of the current commute alternative

■

7

Interpretation of results

In section 6.2 a model has been estimated. A parameter has been estimated for each attribute of the three alternatives. The three alternatives are the regular bus, the HOV bus and the current commute. For each alternative a utility function was set up with which the utility of that alternative can be determined. The parameter indicates the utility contribution of an attribute to the total utility of that alternative.

Table 23 Estimated parameters of final model presented with ratio's and difference

Attribute	Parameter	Value	Ratio's	Difference
Regular Bus				
Preference	ASC_{reg}	-3,450	0,79	0,920
Access to stop	$\beta_{AC,reg}$	-0,106	0,76	0,033
Egress from stop	$\beta_{EG,reg}$	-0,081	0,69	0,036
Service frequency	$\beta_{FR,reg}$	0,188	1,03	0,006
Service reliability	$\beta_{RL,reg}$	0,016	0,50	0,016
Seating level				
Seat with neighbor	$\beta_{ST1,\mathrm{reg}}$	-0,296	0,63	0,176
Seat with neighbor half way	$\beta_{ST2,\mathrm{reg}}$	-0,988	0,92	0,082
Standing	$\beta_{ST3,\mathrm{reg}}$	-1,650	0,83	0,330
In-vehciel travel time	$\beta_{VTT,reg}$	-0,087	1,10	0,008
HOV Bus				
Preference	ASC_{hov}	-4,370	1,27	0,920
Access to stop	$\beta_{AC,hov}$	-0,139	1,31	0,033
Egress from stop	$\beta_{EG,hov}$	-0,117	1,44	0,036
Service frequency	$\beta_{FR,hov}$	0,182	0,97	0,006
Service reliability	$\beta_{RL,hov}$	0,032	2,00	0,016
Seating level				
Seat with neighbor	$\beta_{ST1,\mathrm{hov}}$	-0,472	1,59	0,176
Seat with neighbor half way	$\beta_{ST2,\mathrm{hov}}$	-1,070	1,08	0,082
Standing	$\beta_{ST3,\mathrm{hov}}$	-1,980	1,20	0,330
In-vehciel travel time	$\beta_{VTT,hov}$	-0,079	0,91	0,008
Current commute				
Total trip travel time	$\beta_{TT,current}$	-0,076		
Main mode of current commute				
Bike	$\beta_{bike,current}$	1,510		
Train	$\beta_{train,current}$	-0,569		
Bus	$\beta_{bus,current}$	-2,080		

For the analysis, the parameters will be analyzed and compared to determine the impact of the attribute on the total utility of an alternative. Additionally, the parameters of the bus services can be compared with each other as they share the same attributes (preference, access time, egress time, frequency, reliability, seating and in-vehicle travel time) but with alternative specific parameters. From this it can be derived whether there are significant differences in the valuation for the HOV bus service in regard to the regular bus service.

In Table 23 can the estimated parameters of the final model be seen. This table has the same parameter values as Table 22, but 2 additional columns have been added. The first column that has been added is the “Ratio’s” column. This column describes the ratio between the parameters of the same attribute of the other bus alternative. It indicates how much larger or smaller the parameter value is. The “Difference” column shows the absolute difference between the parameter values of the same attribute. This indicators will be used in the analysis of the parameter values.

7.1 Analysis and comparison of parameters

It will first be looked at the parameters to identify the impact of the attribute on the utility and to see whether there are significant differences between the valuation of the regular bus service opposed to the HOV bus service.

Alternative specific constants

The alternative specific constants (ASC’s) can indicate an underlying preference for an alternative. This preference is independent of the attributes included in the rest of the utility function. A base alternative needs to be chosen in order to estimate the ASC. The current commute was chosen as the base alternative to which the bus alternatives are compared to. The ASC of the current commute was therefore set to 0. The estimation resulted in non-zero parameters for the ASC’s of the bus services. The ASC of the regular bus is -3,45 and the ASC of the HOV bus is -4,37. Since these values are non-zero, the ASC’s indicate that the current commute has a systematic preference over both bus services. This aligns with what has been found in literature. Commuters have the tendency to use the mode they are used to and stick to what they know. The ASC of the HOV bus is 26% more negative than the ASC of the regular bus. The ASC of HOV differs by -0,92 utilities from the regular bus service and is more negatively. This indicates that the regular bus service is preferred over the HOV bus service. This is different from what would be expected. The survey results showed that the HOV bus service was slightly more often chosen than the regular bus service when choosing between these two services. Also in regard to the current commute, the HOV bus service was chosen more often over the current commute than the regular bus service was over the current commute. HOV bus services are advertised as the higher level of service bus service, therefore it would be expected that the preference will be for the HOV bus service. The value shows that compared to the current commute, the commuter has less preference for the regular bus service and even less preference for the HOV bus service. It could be that because commuters are skeptical of the regular bus service it makes them even more skeptical of the quality provided by an HOV bus service which promises higher quality.

Another conclusion that can be derived from the ASC’s is whether the model takes into account effects that are not being explicitly modelled. Since the ASC’s are significant, these other effects are taken into account and this shows that the model is valid. This also means that the included attributes, including the attributes of the current commute, do not explain the full choice between a bus and the current commute. The current commute is also simplified and only represented by two attributes. This could also explain the more negative value for the ASC’s. It was seen in Table 22 that the ASC of the HOV bus service has the largest absolute value followed by the ASC of the regular bus service. Because the ASC is a fixed value it will also have a fixed utility. For the ASC of the regular bus service the largest utility contribution is -3,45 and for the ASC of the HOV bus service the largest utility contribution possible is -4,37. The bus alternatives therefore already starts with a disadvantage in regards of utility in regard to the current commute. The utility difference could be compensated dependent on the levels of the other attributes. In order for the HOV bus service to have a larger market share, it needs to overcome the systematic difference with other positive attributes or performing less negative with other attributes.

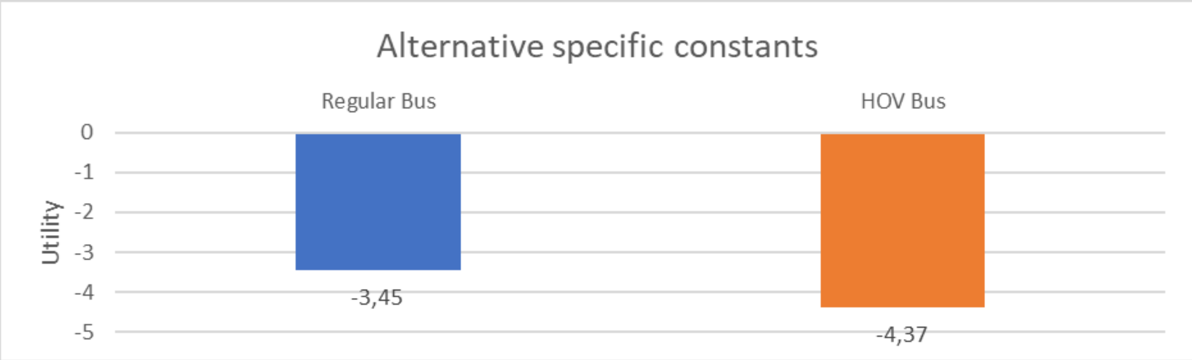


Figure 20 Utility contribution of the alternative specific constant

Time attributes

The model includes 4 attributes which are all expressed in minutes: access time, egress time, in-vehicle time and door-to-door time of the current commute. Access time, egress time and in-vehicle time are shared by the regular bus service and the HOV bus service but with alternative specific parameters. Because these attributes are expressed in minutes, the parameter values can be directly compared with each other. This will give insight into which of the time components is valued the most and whether there is a difference in valuation between the regular bus service and the HOV bus service for these attributes.

Access time

Access time is the time needed to travel from home to the boarding station of the bus service. The parameter of access time indicates the utility contribution for every minute of access time. The sign is negative for both busses and indicates that the access time is negatively valued. This means that longer access time is negatively perceived, and one wants to minimize it.

The regular bus service has a parameter value of -0,106 and the HOV bus service has a parameter value of -0,139. Every minute of access time to the regular bus service has a disutility of -0,106 and every minute to the HOV bus service has a disutility of -0,139. There is a difference of 0,033 utilities per minute. The HOV bus service has a higher disutility per minute. The parameter of the access time of the HOV bus is 31% more negative than the regular bus service. This means that access time is 31% more negatively valued for an HOV bus service than it is for a regular bus service. To put this into perspective, 8 minutes of access time for the regular bus has the same utility as 6 minutes of access time to the HOV bus service. That is a difference of 2 minutes. This difference becomes larger when the access time is longer. For example, 20 minutes of access time to a regular bus service has the same disutility as 15 minutes to an HOV bus service. This indicates that the commuter is willing to travel longer to ana regular bus service than they are to an HOV bus service. This is something one would not expect in the first place since previous research has revealed that travelers are willing to travel further if faster modes of transport can be reached (Blij, 2013). However, there are also other factors that influence the choice. Other attributes may compensate for the disutility which will make the commuter still choose the HOV bus service despite longer access time. It still can be that also in those cases the access time is more negatively valued as with lower quality services but that the gains from using a higher quality service compensate for the use of a lower quality service.

On the other hand, it also means that an improvement in access times is more positively valued for the HOV bus than for the regular bus. One minute of improvement of the access time has a utility of 0,106 and a utility of 0,139 for the HOV bus service. With increasing improvement, the utility difference between the bus alternatives becomes less and less for this attribute.

Since the parameter values differ between the regular bus service and the HOV bus service it can be concluded that there is a difference in valuation. However, how significant this difference is, depends on the magnitude of the access time.

Figure 21 illustrates the difference in utility contribution with increasing access time. It can be seen for shorter access times that the difference is not significant since the access time is valued almost equally. However, for longer access time this difference becomes more significant. From 20 minutes and onwards a utility difference of 0,5 utilities or higher can be observed. When having a long access time, the loss in utility that one has with an HOV service needs to be compensated by improving other attributes. Either with attributes that have a smaller utility contribution than access time or with attributes that have a positive utility contribution. The magnitude of the access time also influences how large the part of the total utility of an alternative is that is determined by the access time. With increasing access time, a larger part of the total utility of an alternative is determined by the access time. When comparing Figure 20 with Figure 21 it can be seen that at 30 minutes of access time the access time determines the total utility as much as the preferences for one of the alternatives does. Therefore, with longer access times, preference plays a less important role then with lower access times. Access time can have a significant influence on the utility and a larger utility contribution dependent on the trip characteristics.

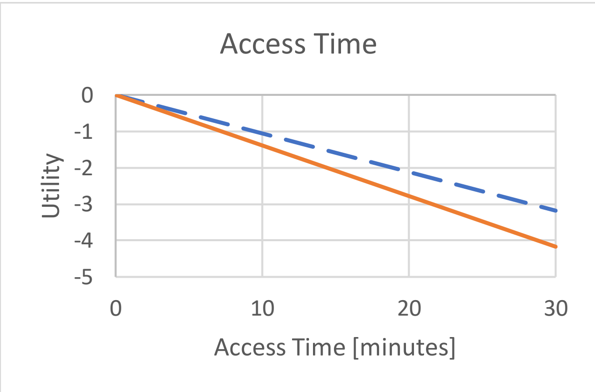


Figure 21 Utility contribution of access time

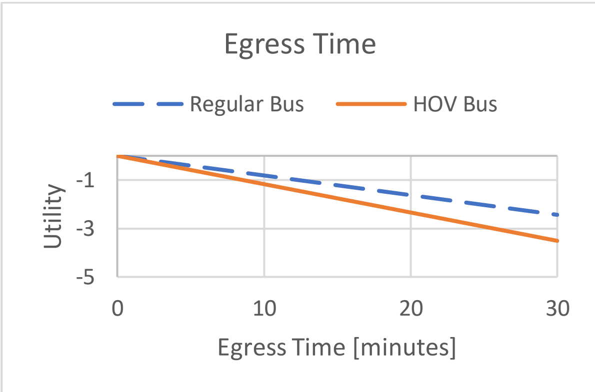


Figure 22 Utility contribution of egress time

Egress time

The parameter of egress time indicates the change in utility for every minute of egress time. An increase in egress time is seen as a disadvantage for the trip and negatively influences the utility. The longer the egress time the more the disutility. The regular bus has a value of -0,081 and the HOV bus has a value of -0,117. There is a difference in utility of 0,036. This means that every minute spent on egress time has a disutility of -0,081 for a regular bus service. Egress time is expressed in minutes. For the HOV bus service, egress time is 44% more negative than the egress time of the regular bus. It is a bigger change then it was seen with the access time (30% change). As it was the case with access time, it is also the case for egress time that egress time is perceived more negatively for an HOV bus service than it is for a regular bus service. The valuation of 8 minutes of access time for a regular bus service is equal to the valuation of 5,5 minutes of access time to the HOV bus service. This difference increases with increasing egress time. 30 minutes of egress time from the regular bus service is equal to 20,5 minutes of egress time from the HOV bus service. Also for the egress time it would have been expected that the egress time would be valued less negative for the HOV bus service then for the regular bus service. Other attributes may be able to compensate for this difference which makes the commuter still choose the HOV bus service in the end. A greater negative parameter also means that an improvement is more positively valued. Enhancing the egress time by 1 minute is more positively valued for the HOV bus service than it is for the regular bus service.

A difference in valuation between the bus alternatives can be seen for egress time. However, the significance of this difference is dependent on the trip characteristics. With higher egress times this difference becomes more significant. Meaning that at lower egress times the egress time is almost equally valued between the bus services. The magnitude of the egress time also influences to what extend the egress time determines the total utility. This is being illustrated by Figure 21. With increasing egress time the utility contribution becomes larger and therefore a larger part of the total utility can depend on egress time. From 18 minutes and onwards, an utility difference of 0,5 can be observed.

Egress time and access time have the same units therefore they can be compared. The parameters for access time (Regular: -0,106; HOV: -0,139) are lower than the parameters for egress time (Regular: -0,081; HOV: -0,117). The parameter for egress time is 31% more negative than the parameter for access time for the regular bus service. For the HOV bus service, the parameter for egress time is 27% more negative than the parameter for access time for the HOV bus service. A minute of access time is more negatively valued then the egress time for both bus services. However, the significance of the difference is dependent on the magnitude of the access and egress time. With lower access and egress time the difference is insignificant and they are valued equally. With higher access and egress times the difference becomes more significant. 20 minutes of access time has the same valuation as 26 minutes of egress time for the regular bus service. For the HOV bus service, 20 minutes of access time has the same valuation as 24 minutes of access time. That is difference of 2 minutes, which is not very significant. With the HOV bus service the difference between the valuation of access time and egress time is less. From 13 minutes of access time and onward utility differences of 0,5 can be observed.

At lower access and egress times are the access and egress time valued almost equally and no significant difference in valuation can be observed between the regular bus service and the HOV bus service.

In-vehicle time

The parameter of in-vehicle time expresses the change in utility for each minute of in-vehicle time. The regular bus has a value of -0,087 and the HOV bus has a value of -0,079. The sign indicates that in-vehicle time is valued negatively. The value of the HOV bus service is less negative then the value of the regular bus service. The value for the regular bus service is 10% more negative than the value of the HOV bus service. There is a difference of 0,008 utilities. To put this into perspective, 10 minutes of in-vehicle time on the regular bus service has the same value as 11 minutes of in-vehicle time on the HOV bus service. For a longer trip this difference becomes larger. 30 minutes spend on the regular bus service are valued the same as 33 minutes spend on the HOV bus service. The difference is not that large and as it can be seen the size of the difference depends on the magnitude of the in-vehicle time. 30 minutes of in-vehicle travel time has a utility of -2,61 for the regular bus service and -2,37. There is only a difference of 0,24 utilities. Therefore, for most trips the in-vehicle time is almost equally valued between the regular bus service and the HOV bus service. This can also be seen in Figure 23. From 62 minutes an onward utility differences of 0,5 can be observed.

Since in-vehicle time is also expressed in minutes it can be compared to access and egress time. For the regular bus service access time (-0,106) is valued the least followed by in-vehicle time (-0,087) and then egress time (-0,081). 1 minute of egress time for the regular bus service is almost valued as equally as 1 minute of in-vehicle time. There is a difference of 0,006 utilities per minute, which is very small. The parameter of access time for the regular bus service is 27% more negative than the parameter for in-vehicle time. Looking at the HOV bus service, the access time (-0,139) is also the least valued but followed by egress time (-0,117) and then in-vehicle time (-0,079). The parameter for egress time is 44% more negative than the parameter for in-vehicle time. Meaning that 30 minutes of in-vehicle time has the same disutility as 20 minutes of access time. The parameter of access time is 76% more negative than the parameter for in-vehicle time. Meaning that 30 minutes of in vehicle time has the same disutility as 17 minutes of access time for the HOV bus service.

In-vehicle time is defined as a continuous variable. Therefore, the utility contribution to the total utility of an alternative is dependent on the trip characteristics. With shorter trips less of the utility is dependent on in-vehicle time and with longer trips more of the utility is dependent on in-vehicle time. But not as much as with egress time or access time. But it also depends on the proportion between access, egress and in-vehicle time. For the HOV bus access time should be minimized the most, followed by egress time. One should maximize the proportion of the travel time spend on the in-vehicle time since in-vehicle time has the least disutility of the time components for the HOV bus service. For the regular bus access time should be minimized the most since it has the largest disutility per minute. Most of the travel time should be spend on either in-vehicle time or egress time for the regular bus service.

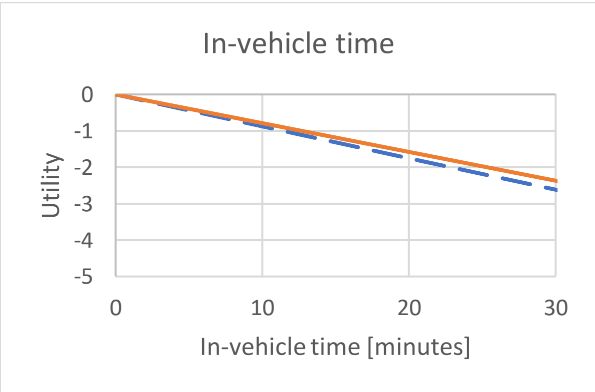


Figure 23 Utility contribution of in-vehicle time

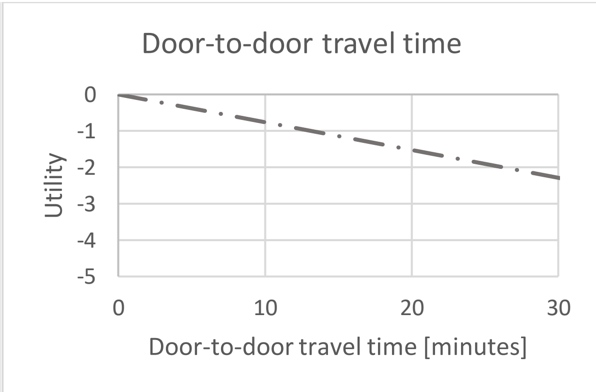


Figure 24 Utility contribution of door-to-door travel

Door-to-door travel time current commute

The parameter for door-to-door travel time is a parameter part of the utility function of the current commute. This parameter expresses the utility contribution of 1 minute of door-to-door travel time. The parameter value for the travel time of the current commute is -0,076. The door-to-door travel time is defined by a continuous scale. The utility contribution to the total utility of the current commute depends on the length of the trip because this parameter is defined as a continuous variable. For longer trips a larger part of the total utility is determined by the door-to-door travel time. For shorter trips a smaller part of the total utility is determined by the door-to-door travel time and a larger part will be determined by the mode that is being used. Figure 24 shows the utility contribution to the total utility of the current commute per minutes of door-to-door travel time. The parameter value of the door-to-door travel time can be compared to the access, egress and in-vehicle travel time since they are all expressed in minutes. Figure 25 shows the comparison between the parameter values of the attributes expressed in minutes. The parameter for the door-to-door travel time has the smallest disutility (-0,076) compared with the attributes of the bus services. The in-vehicle time for the HOV bus service (-0,079) differs by 0,003 utilities from the door-to-door travel time of the current commute. This difference is insignificant. Therefore, it can be said that the in-vehicle time of the HOV bus services is valued the same as the door-to-door travel time of the current commute.

The fact that the door-to-door travel time of the current commute as the smallest disutility amongst the time components does make it harder for the bus services to gain in modal split compared with the current commute on total travel time alone. This was already more difficult because of the ASC's which introduce a lower utility for the bus services because of the fact that it is a bus service. The travel time of the bus services needs to be significantly better than the current commute or the difference in total utility between the bus services or the utility difference with the current commute can be compensated by other attributes.

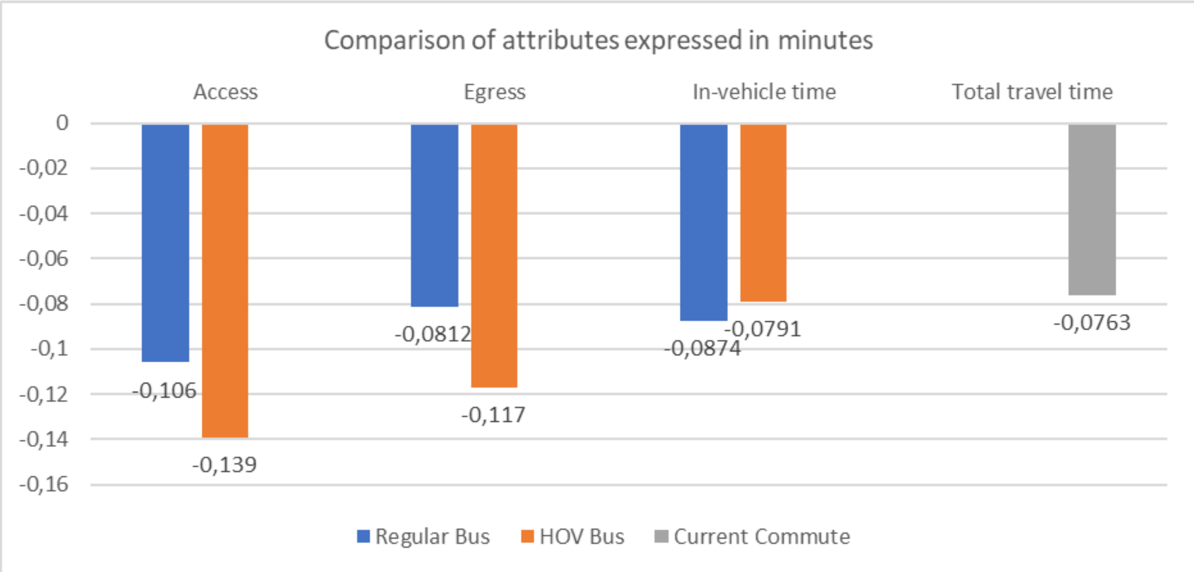


Figure 25 Comparison of the parameter values of the attributes expressed in minute

Frequency

The parameter for frequency indicates the utility contribution for 1 departure per hour. The sign indicates that frequency increase is a positive change for the commuter and has a positive impact on the utility. The higher the frequency, the more positively valued it is. The regular bus has a value of 0,188 and the HOV bus has a value of 0,182. The difference between the values of the busses is 0,006. This difference is very small and indicates that frequency is not significantly different valued for an HOV bus service then it is for the regular bus. Although frequency is a attribute with an continuous scale in practice it has its limits. As it was seen in section 3.3 the maximum frequency that has been found amongst all HOV bus lines was 12, with one exception being 13. A frequency higher than this is very unlikely in practice. Therefore a maximum utility contribution can be determined for frequency. The maximum utility contribution of frequency can be calculated by multiplying the parameter value with the highest frequency. Table 24 shows that the maximum utility possible for frequency is 2,256 for the regular bus service and 2,184 for the HOV bus service. The frequency of the regular bus service has a maximum utility which is only 3% higher than the maximum utility of the frequency of the HOV bus. Therefore, it can be concluded that the valuation of frequency for the two bus services does not differ significantly. This maximum utility also shows that frequency has more influence on shorter trips then on longer trips. On trips longer than 25 minutes, frequency becomes less important than the time components.

Table 24 Maximum utility contribution of frequency per bus service

Frequency	Parameter value	Maximum Frequency	Maximum Utility
Regular bus service	0,188	12	2,256
HOV bus service	0,182	12	2,184
		Difference	0,072

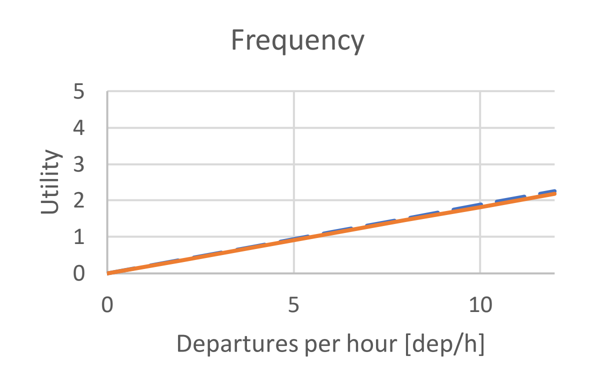


Figure 26 Utility contribution of frequency

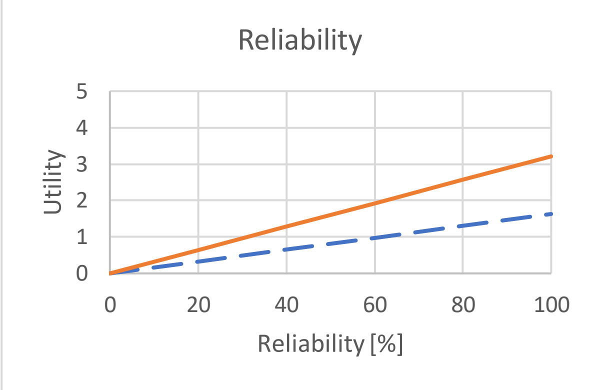


Figure 27 Utility contribution of reliability

Reliability

The parameter of reliability indicates the utility for 1% of reliability. Reliability expresses the chance of a delayed arrival of a bus at a station. A higher reliability is seen as a positive change and increases the utility. The regular bus service has a parameter value of 0,016 and the HOV bus service has a parameter value of 0,032. There is a difference of 0,016 utilities per percentage of reliability. The value for the reliability of the HOV bus is exactly 100% more positive than the value for the regular bus. This means that the reliability of a HOV bus service is twice (100% more positive) as much valued as the reliability of a regular bus service. This could indicate that the commuter has more trust in the promise that is being made for an HOV bus service, providing a reliable service. It also indicates that a decrease in reliability is more negatively perceived for the HOV bus than it is for the regular bus. Not adhering to the promised reliability is punished more with the HOV bus service then it is with the HOV bus service. Reliability varies from 0% to 100%. A maximum utility contribution of reliability can therefore be determined. For the regular bus service the maximum utility contribution is 1,600 and for the HOV bus service the maximum utility contribution is 3,200. Figure 27 Utility contribution of reliabilityFigure 27 shows how the difference in utility contribution increases with growing reliability. At higher reliabilities the difference in utility is larger than at lower reliabilities. Also for the reliability it is the case that reliability determines a larger portion of the total utility with shorter trips then it does for longer trips. The magnitude of this portion does however differ between the regular bus service and the HOV bus service for the same reliability. When looking at the maximum utility contribution it can be seen that for the HOV bus service the maximum utility is higher than the maximum utility contribution of frequency. For the regular bus service it is lower. For the HOV bus service reliability is more important than frequency. It could be concluded that for the regular bus service reliability is less important than the frequency. However, for the regular bus service a frequency of 12 is less common then for HOV bus lines additionally the reliability is at least 50%. Therefore, with those comments in mind reliability will still remain more important than frequency, also for the regular bus.

It was seen that almost all of the attributes are more negatively valued for the HOV bus service. This causes the HOV bus service to have a lower total utility then the regular bus service even if the attribute levels are the same. This gives the HOV bus service a disadvantage and will result in a lower choice probability for the HOV bus service. Previously, it was said that frequency and reliability are the only attributes with a positive utility contribution. Frequency was equally valued between the two busses therefore it cannot compensate for the difference in utility. Therefore, reliability might be able to compensate for the differences. In section 4.3 it was discussed that 95% reliability is a common adhered level for HOV bus services. The utility for the regular bus service for 95% is 1,52 and for the HOV bus service 3,04. The difference is 1,52 utilities. It was seen that the difference between the ASC's was 0,92. Reliability can compensate for this difference as well as 0,6 utilities for other time attributes. In practice it can be even more since most regular bus lines do not adhere to such a high reliability. This could potentially mean that despite of attributes that have a large negative utility contribution, reliability of the HOV bus service can compensate for the negative utilities and make the HOV bus service more likely to be chosen. When the reliability is 60% or more for the busses, the positive utility can compensate for the systematic difference in preference. The reliability at which can be compensated depends on the negative utility of other factors. For example, for longer trips for which the time components have more negative utility, this threshold value can go up to 80% at which the HOV bus service is able to overcome the difference in utility between the busses.

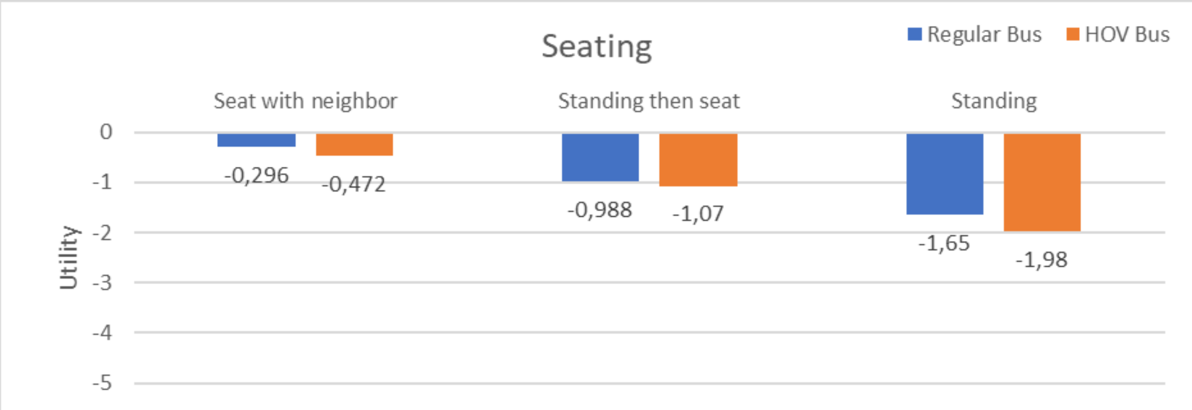
The parameter value for reliability of the HOV bus service is twice as much (100% more positively) as the parameter value for reliability of the regular bus service. Reliability is therefore differently followed amongst the two bus services. For both bus services is reliability more important than frequency. Reliability has a maximum utility contribution. For shorter trips reliability determines more of the total utility then for longer trips.

Seating level

The seating level has been expressed in 4 levels: a seat without neighbor; a seat with a neighbor; half of trip standing then a seat with neighbor; standing the entire way. "A seat without neighbor" was taken as the base level relative to which the parameters for the seating levels where estimated. This base level was set to 0. The values "seat with neighbor", "Standing half way then sitting" and "Standing" are as following for the regular bus service -0,296; -0,988; -1,650 respectively and for the HOV bus service the parameter values -0,472; -1,070; -1,980 respectively.

For both bus services, "standing the whole journey" is being perceived as the highest disutility followed by "getting a seat halfway", then "seat with a neighbor" and then the base level "seat without neighbor". Looking at the parameter values more closely, it can be seen that the seating levels for the HOV bus service have a higher disutility. Seating level is more critically assessed for the HOV bus service. This can be explained by the fact that it was mentioned in the description of HOV that HOV can provide a seat for everyone: a promise that is being made by most HOV bus services. It also means that an improvement in the seating situation is valued more for an HOV bus service than it is for a regular bus service. It can be looked again at the ratios between the parameter values to identify whether the seating levels are significantly differently assessed between the bus services. The parameter value for "seat with neighbor" for the HOV bus service is 59% more negative than the parameter of the regular bus service. "Seating with a neighbor" is in the HOV bus service less preferred then in the regular bus service. The parameter value for "standing then sitting" for the HOV bus service is 10% more negative than parameter of the regular bus service. This seating level is almost equally valued amongst the two bus services. For "Standing", the parameter value of the HOV bus service is 20% more negative than the regular bus service. Therefore there is a slight difference in the valuation of having to stand in the HOV bus opposed to the regular bus services.

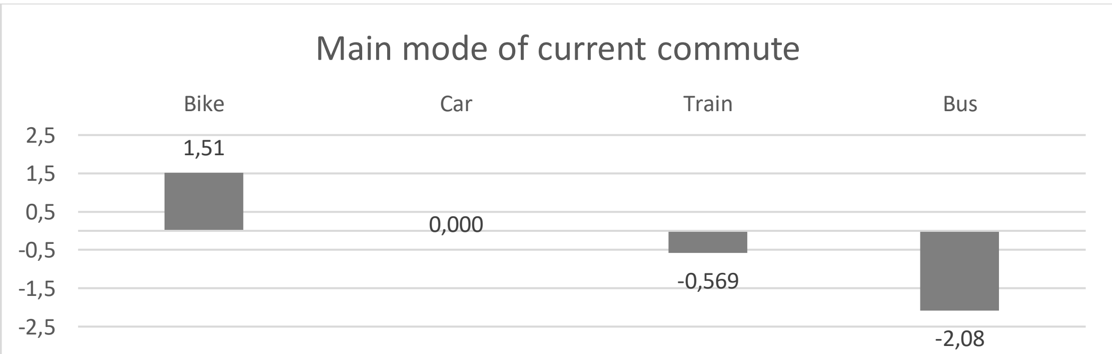
Since seating level is defined by categories it has a maximum utility contribution. For the regular bus service the maximum utility contribution is -1,65 and for the HOV bus service -1,98. Seating level determines more of the total utility on shorter trips then it does on longer trips. This also means that on shorter trips this difference in parameter values between the two busses becomes more significant.



Mode of current commute

The main mode of the current commute has been coded with 3 parameters: bike, train and bus. Car has been chosen as base mode. The parameter indicates whether the choice of the main mode of the current commute has influence on the utility and whether there is a difference between the modes in choosing a bus as an alternative for their current commute. The parameter values are 0,000 (car); 1,51 (bike); -0,569 (train); -2,080 (bus). The parameters differ for the different modes, therefore it can be concluded that the mode the commuter is currently using has influence on the likelihood of choosing a bus as alternative. The parameter for the bike has the highest value indicating that bike user have the highest preference for their current commute. After the bike users, car users have the highest preference for their current commute. The parameters for train and bus are negative. They decrease the utility difference between the bus alternatives and the current commute. The parameter for the train has a smaller disutility then bus users. This indicates that there is a difference in preference for the current mode between train and bus users. The bus users have the least preference for their current commute. However, the parameter of the bus mode still does not has a higher disutility then the ASC's. This indicates that even if another regular bus service or HOV bus service with same travel time is provided, the current bus users will still use their current bus commute. This has to do that commuters prefer to stay with their current commute because they are used to it. However, the attribute for mode has a correlation with the total travel time. A different mode has a different speed and therefore a different travel time. For example, for the bike the utility for the current commute increases however because if the bike is used as the mode for the current commute the travel time increases because a bike travels at lower speed then another mode.

The main mode of the current commute has categorical levels and therefore a maximum utility contribution to the total utility of the current commute. With shorter trips the preference for the current mode determines a larger part of the utility then it does with longer trips.



Conclusions analysis of coefficients

The analysis showed that with certain attributes there are indeed differences in valuation between the regular bus service and the HOV bus service. These differences have been found by comparing the ratios between the attribute of the regular bus service with the HOV bus service. For most attributes it was seen that the attributes for the HOV bus had the largest ratio's. The HOV bus is more negatively valued for "seat with a neighbor" (59% more negative), egress time (44% more negative), access time (31% more negative), ASC (27% more negative) and "standing (20% more negative). The HOV bus and the regular bus are valued equally for frequency and "stand; than sit". The HOV bus is more positively valued for reliability (100% more positive, twice as much). Reliability also has the largest ratio amongst all the attributes, meaning that this attribute is valued differently the most between the regular bus service and the HOV bus service. A negative valuation translates to a positive valuation for improvements. Even though most attributes are more negatively valued for the HOV bus, it does mean that for those attributes improvements are more positively valued with the HOV bus service than with a regular bus service. But for reliability and frequency the opposite is true: deterioration is more negatively valued.

It was also seen that the alternative specific constants which indicate the preference of the alternatives in regards to the current commute are more negative for the HOV bus service than they are for the regular bus service. This was surprising as HOV bus services are promoted as a service to be of a better quality. But the severity of this difference in ASC value between the bus services will become more clear through testing the model in scenario's. It could be that the differences in valuation of the attributes could compensate for this difference in preference. It could also be that since commuters are skeptical towards the regular bus service quality, being told about a bus that is supposed to deliver a higher quality service can receive more skepticism since the regular bus is already not able to deliver the quality the commuter wants.

For the time components of the utility it was seen that for the regular bus service egress time and in-vehicle time were equally valued. For the HOV bus service it was seen that access time, egress time and in-vehicle time were all differently valued.

The analysis showed that from this analysis, the difference in valuation between the regular bus and the HOV bus service depends on the magnitude of the attributes. This is due to the use of continuous variables which do not have specific levels. For shorter trips, the variables with limited levels determine a larger portion of the total utility than for longer trips. For longer trips, the total utility is determined more by the time components. It was also seen that even though most of the attributes of the HOV bus service have a larger disutility's than the attributes of the regular bus service and the ASC's is more negative, that the HOV bus resulted in a larger modal split.

This comparison of the coefficients does not indicate which alternative is more likely to be chosen since it depends on the combination of different levels that determine the total utility as well as the utility difference with the current commute. Therefore, additional analysis is needed to understand how each attribute influences the probability of the alternatives. The comparison of the coefficients has however shown multiple other results. Even though most of the coefficients for the HOV bus are more negative, for reliability it does indicate that improvements are more positively valued if it is an HOV bus, access and egress. Frequency is equally evaluated and seating more negatively. However, it needs to be investigated whether the improvements are enough to compensate for the attributes that are more negative valued than for the regular bus.

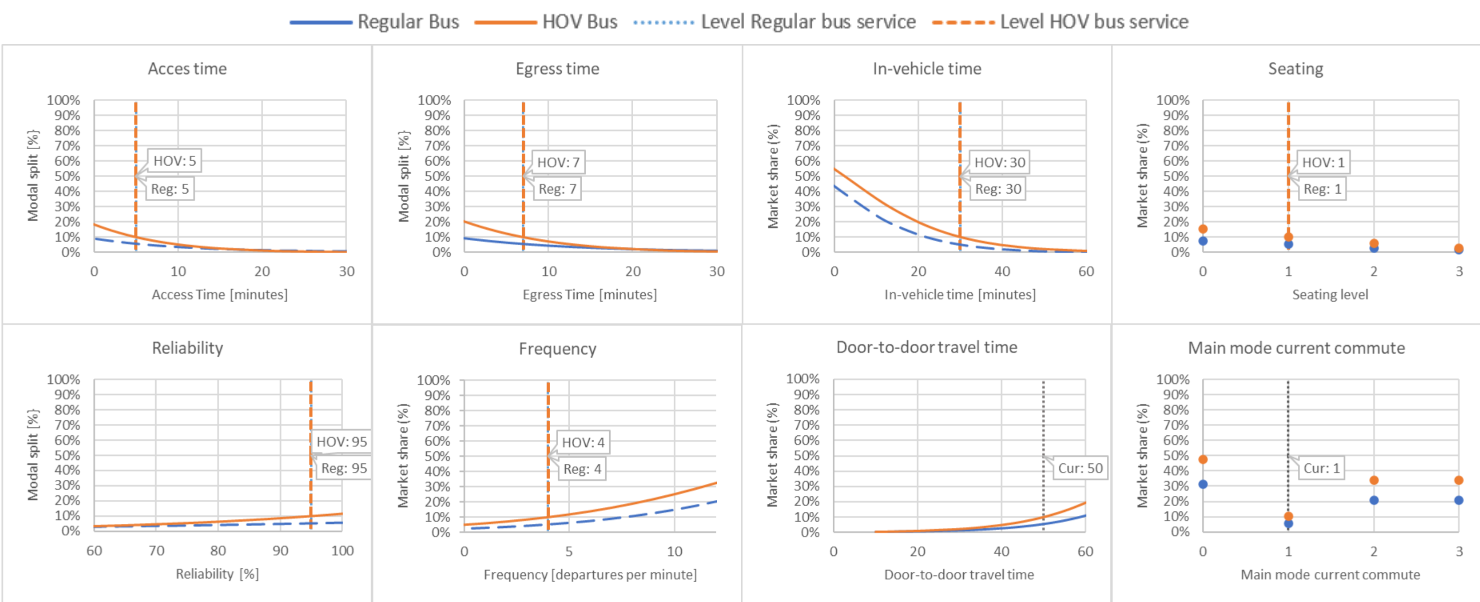
7.2 From utility to modal split

As described in Section 6.1 , the utility function can be used to derive probabilities. These probabilities can be translated to modal splits. The utility is determined by the different attributes and the coefficients explain how much one unit of the attribute contributes to the total utility. The total utility of an attribute is described by the estimated utility function. With the estimated model the utility functions have been determined for the regular bus, the HOV bus and the current commute. The previous analysis showed how the different attributes affect the total utility and what differences exist in valuation between the regular bus service and the HOV bus service. Now it can be further looked into how the total utilities translate into probabilities and modal splits.

As it was explained in 6.1.2 there is a s-curve relation between utility and probability. Utility is always analyzed in the relative sense. There is a direct relation between utility difference and probability. For example, if two alternatives have no difference in utility the probability will be 50% choosing for either one independent of how large the levels are. This probability will be the same when both alternatives have a utility of, for example, -5 or when both alternatives have utility of 10. For both cases the difference in utility is 0 and will therefore result in a 50% probability for each of the alternatives. However, the larger the utility differences the harder it is to increase the probability further. The implication of this is that it can be complicated to interpret direct relations between the attributes and the choice probability.

Since 3 of the 6 attributes are time components a large part of the utility is determined by time attributes. Because of this travel time ratio can be used as an indicator for the expected rate of change in probability when changing the attribute levels. The travel time ratio describes the difference between the total travel time of the bus and the current commute. A ratio of 1 means that the total travel time of the bus and the current commute are equal. A ratio larger than 1 indicates that the current commute has a shorter travel time and a smaller then 1 indicates that bus service has a shorter travel time. Therefore it also describes a difference in utility.

The probability function can be plotted for each attribute. For example how it is done in Figure 28. The attributes are also plotted as S-curves. These plots can be used to evaluate with which attribute additional gain in probability can be achieved. Depending on the utility difference between the alternatives improvements can be achieved easier or harder, because the utility difference determines where the starting point is on the probability curve also for the attribute probability curve. The



parameter value depends the rate of change of the logit function, but the utility difference between the alternatives depends the starting point on this curve. Because of this utility changes of the same magnitude will not have the same magnitude in effect on the probability. The effect of changing an attribute by 1 unit therefor has a different impact on the probability depending on the context.

Figure 28 shows how these probability functions can look like. Note that probability can be related to market share and therefore market share has been specified in the graphs. It also seen what the base case is and what the current levels are of the regular bus service and of the HOV bus service. It can be seen that the market shares now are 10% for the HOV bus service and 6% for the regular bus service. How one can use these graphs is one can look for which attribute a sufficient market gain can be achieved for the lowest cost. The cost depends on the effort that is needed to change the attribute to the new desired level. It is notable that the HOV bus service will have a higher market share then the regular bus despite of most attribute being more negative than the regular bus service. It can be seen that in order for the regular bus service to have a similar market share to the HOV bus attributes need to be adjusted. For example, a market share of 10% would be possible for the regular bus when setting the in-vehicle time to 20 minutes or increasing the frequency to 6 or putting a higher guarantee on that everyone will have seat. Making these changes would make the regular bus service have the same utility as the HOV bus. This is just a short demonstration on how this visualization can be used to determine changes on bus lines. The cases in the next section will give more insight. However, since the impact of the attributes is very context dependent the graphs will change every time one aspect is change since the difference in utility will change.

7.3 Case studies

Through the use of cases it can be better demonstrated how the utility relates to the probability and how this probability can be related to modal splits. The goal of the research was to understand how the characteristic attributes of HOV bus services affect the commuters choice to choose a bus over for their commute. The cases will demonstrate a case in which the commuter has the choice between their current commute and a bus service. This bus service can be a regular bus service or a HOV bus service. What will be done in the cases is that the bus service will be compared with the bus service. By first comparing the current commute to the regular bus service and calculate the corresponding choice probabilities after which the regular bus service can be replaced with the HOV bus service and the probabilities can be determined again. It is expected that one can see difference between the choice probabilities of the bus services. Additionally, since utility relates to probability, a graph can be plotted for each attribute which will show how improving this attribute influence the choice probability further. These graphs can also be used to see with which attribute the most choice probability gain can be achieved and therefore it can be determined with which attribute a higher modal split can be achieved. The plots of the graph change dependent on the situation that is being modelled. The model can be used to calculate the total utilities of each alternative. Filling those utilities into the probability function will then output the choice probability, which corresponds to the modal split.

7.3.1 Case selection

3 cases have been chosen to demonstrate the model and understand the relation between utility and probability. The 3 cases where also chosen to reflect the 3 HOV types that can be found in the Netherlands: city HOV, inter-city short HOV and inter-city HOV. Additionally, each case reflects a different travel time ratio. With each case the travel time ratio becomes lower.

7.5.1 Case 1: Inter-city short HOV

For this case a bus route in the Amsterdam was chosen. More specifically, line 44 on the route Diemen Rietzanger Weg to Bijlmer Arena Station. Figure 29 shows the route and travel time according to Google Maps (Google, 2023) for the bus and the car. According to Google Maps the trip by car takes between 10 to 16 minutes depending on traffic. However, the model is asking for the door-to-door travel time. This includes parking and walking to the destination. Taking 13 minutes as the average trip time and adding 5 minutes for parking and walking results in a door-to-door travel time of 18 minutes.

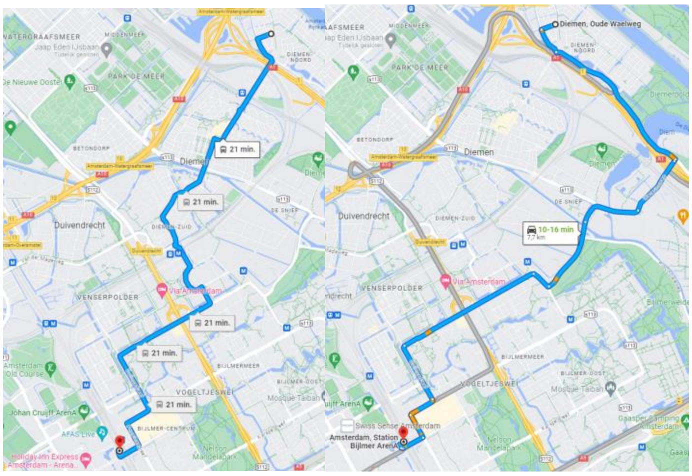


Figure 29 Google Maps Direction of bus (left) and car (right) (Google, 2023)

The attribute levels for this commute can be seen in Table 25 as well as the calculation of the modal split. The initial modal split predicted for this route is 5,5% will choose the bus and 94,5% will choose the current commute with the bus. This is the distribution for people that consider a choice between their car and the bus. The same calculation can be made again, but now the regular bus service can be replaced by the HOV bus service, thus actively promoted as HOV bus. A new calculation will be made but with the utility function to the HOV bus service. These calculations can be seen in

Table 26. The difference in utility with the current commute has decreased by 0,312 utilities with the HOV bus service. The modal split of the bus increased to 7,4%. It increased by 1,9 percent points which is a 34% increase. To put this into perspective: it could be assumed that on line 44, 20 people were travelling who also considered the car as an option. 5,5% reflects these 20 people. Then a 34% increase results in 7 additional passengers. Having 27 passenger using this bus instead of their car. This only reflects the change for the commuters who currently travel by car and consider the bus. This calculation could be done for the other modes as well, which would then reveal a total modal shift from different modes. Despite most attributes resulting in more disutility by switching to an HOV bus, reliability seemed to have overcome this difference, since it has the highest positive utility contribution. The HOV bus has a larger modal split then the regular bus.

Table 25 Attribute levels and modal split of the regular bus service case 1

Diemen, Oude Waelweg → Bijlmer Arena Station	Bus Line 44		Coefficient		Utility	Modal split
Service Type	Regular		-3,45	=	-3,45	
Access	3 minutes	*	-0,106	=	-0,318	
Egress	2 minutes	*	-0,081	=	-0,162	
In-vehicle time	21 minutes	*	-0,087	=	-1,835	5,5%

Frequency	2 departures / hour	*	0,188	=	0,376	
Reliability	90%	*	0,016	=	1,467	
Seating	Seat with neighbor	=	-0,296	=	-0,296	
			Total Utility	=	-4,218	
	Current commute					
Average door-to-door travel time	18 minutes	*	-0,076	=	-1,373	
Mode	Car	=	0	=	0	
			Total Utility	=	-1,373	94,5%
Travel time ratio	(21 + 3 + 2) / 18 = 1,5		Utility difference	=	2,845	

Table 26 Attribute levels and modal split of the HOV bus service case 1

Diemen, Oude Waelweg → Bijlmer Arena Station	Bus Line 44		Coefficient		Utility	Modal split
Service Type	HOV		-4,37	=	-4,37	
Access	3 minutes	*	-0,139	=	-0,417	
Egress	2 minutes	*	-0,117	=	-0,234	
In-vehicle time	21 minutes	*	-0,079	=	1,661	
Frequency	2 departures / hour	*	0,182	=	0,364	
Reliability	90%	*	0,032	=	2,889	
Seating	Seat with neighbor	=	-0,472	=	-0,472	
			Total Utility	=	-3,901	7,4% (+1,9)
	Current commute					
Average door-to-door travel time	18 minutes	*	-0,076	=	-1,373	
Mode	Car	=	0	=	0	
			Total Utility	=	-1,373	92,6% (-1,9)
Travel time ratio	(21 + 3 + 2) / 18 = 1,5		Utility difference	=	2,533	

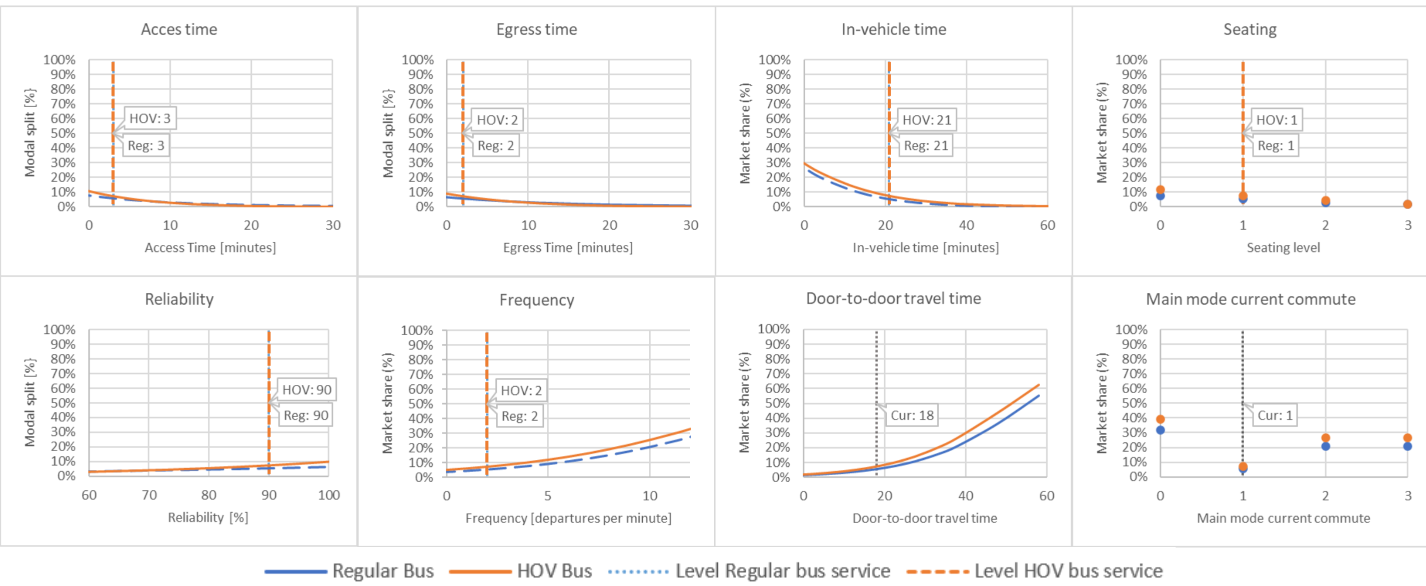


Figure 30 Probability graphs of attributes for case 1

If one wants to achieve additional growth, one can look at the probability graphs of the attributes and look for the attribute that contributes the wanted growth. For most attributes it can be seen that large changes are needed in order to reduce the utility difference and gain in market share. For shorter routes it can be difficult to improve on time aspects. Significantly improving speed or changing the seating configuration could be done. However, giving a guarantee to travelers for having their own seat can be expensive as well improving the speed difficult. Dependent on the cost connected to that improvement one can choose the best improvement. For this route it will be difficult to achieve gains in travel time because it is a short route. Looking at the graphs it can be seen that the modal split of the HOV bus service could be increased to around 10% by increasing the frequency from 2 (0,364) to 4 (0,728) buses an hour. With this a utility gain of 0,364 would be achieved making the difference in utility between the current commute and the HOV bus decrease to 2,169. This results in a new modal split for the HOV bus service of 10,3% and 89,6% for the current commute. That is an additional increase of 2,9% percentage points. Translating this value to passenger gains it results in 38 passengers (5,5% = 20 → 10,3% = 38). That is 18 additional passengers for this line. Ridership gains can be calculated with ridership of a specific line at a specific time or also for an whole hour. Table 27 shows how changing the frequency has different effects in modal split gain dependent on the utility difference between the bus service and the current commute.

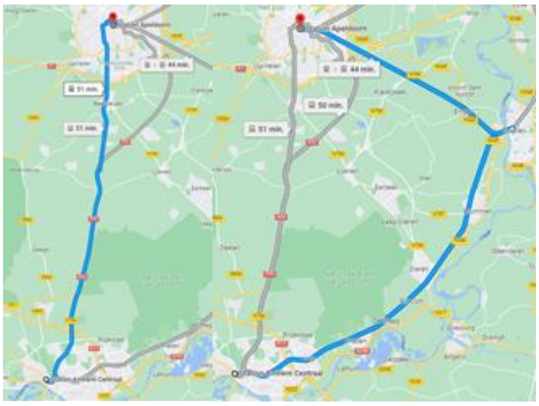
Table 27 Modal split change when improving the frequency from 2 departure per hour to 4 departures per hour

Frequency Change from 2 dep/h to 4 dep/h	Initial utility contribution (Frequency = 2)	Initial utility difference	Initial modal split	New utility contribution (Frequency = 4)	Utility gain	New utility difference (Initial utility – utility	New modal split	Modal split gain (Initial modal split – new modal split)
Regular bus service	0,376	2,845	5,5%	0,752	0,376	2,469	7,8%	2,3
HOV bus service	0,364	2,533	7,4%	0,728	0,364	2,169	10,3%	2,9

In the previous section it was found that the frequency is valued equally for both bus services and therefore the utility contribution is the same. However, because the utility difference with the current commute is larger for the regular bus service then it is for the HOV bus service, it will result in a different modal split gain. This is due to the characteristic of the logistic function and the position on the probability curve. This shows that changes in utility do not have the same impact on the modal split. It depends on the initial utility difference with the current commute. The smaller the utility difference with the current commute, the larger the change in modal split per utility.

7.5.2 Case 2: Inter-city HOV

Buses and HOV buses also travel on longer routes. One type of HOV bus service that was seen was the inter city long HOV bus service. This service connects two bigger cities by bus. The route from Arnhem Station to Apeldoorn Station has been chosen to demonstrate modal split determination and attribute influence on longer routes. Additionally, this case demonstrates the difference in modal split when the current commute is a train and also when the access time is larger. Currently, a bus service is provided by Line 302. This is a regular bus. Alternatively one can choose the train travelling via Zutphen. The travel times have been derived from Google Maps and the commute will take place in the morning peak. Also for the train alternative acces time is included in the total travel time.



First, it will be looked at the difference in modal split when only upgrading the regular bus service to an HOV bus service. The attribute levels for this case as well as the calculation for this case are presented in Table 28. In Table 29 the calucaltion of the modal split when upgrading the line to an HOV bus can be seen. Switching the regular bus to an HOV bus has increased the modal split by 3,4% percentage points. This corresponds to an 46% increase in ridership. The difference in utility with the current commute has decreased by 0,419 utilities. This difference is mainly caused by the difference in the valuation for reliability. The difference in the utility contribution of reliability between the regular bus service and the HOV bus service is 1,488. Part of this positive utility is lost mainly to the larger nagative valuation of the ASC and the access time.

Table 28 Attribute levels and modal split of the regular bus service case 2

Arnhem Station → Apeldoorn	Bus Line 302		Coefficient		Utility	Modal split
Service Type	Regular		-3,45	=	-3,45	
Access	10 minutes	*	-0,106	=	-1,060	
Egress	1 minutes	*	-0,081	=	-0,081	
In-vehicle time	51 minutes	*	-0,087	=	-4,437	
Frequency	2 departures / hour	*	0,188	=	0,376	
Reliability	93%	*	0,016	=	1,488	
Seating	Seat with neighbor	=	-0,296	=	-0,296	
			Total Utility	=	-7,452	7,3%
	Current commute					
Average door-to-door travel time	57 minutes	*	-0,076	=	-4,349	
Mode	Train	=	-0,569	=	-0,569	
			Total Utility	=	-4,918	92,7%
Travel time ratio	(10 + 1 + 51) / 57 = 1,1		Utility difference	=	2,534	

Table 29 Attribute levels and modal split of the HOV bus service case 2

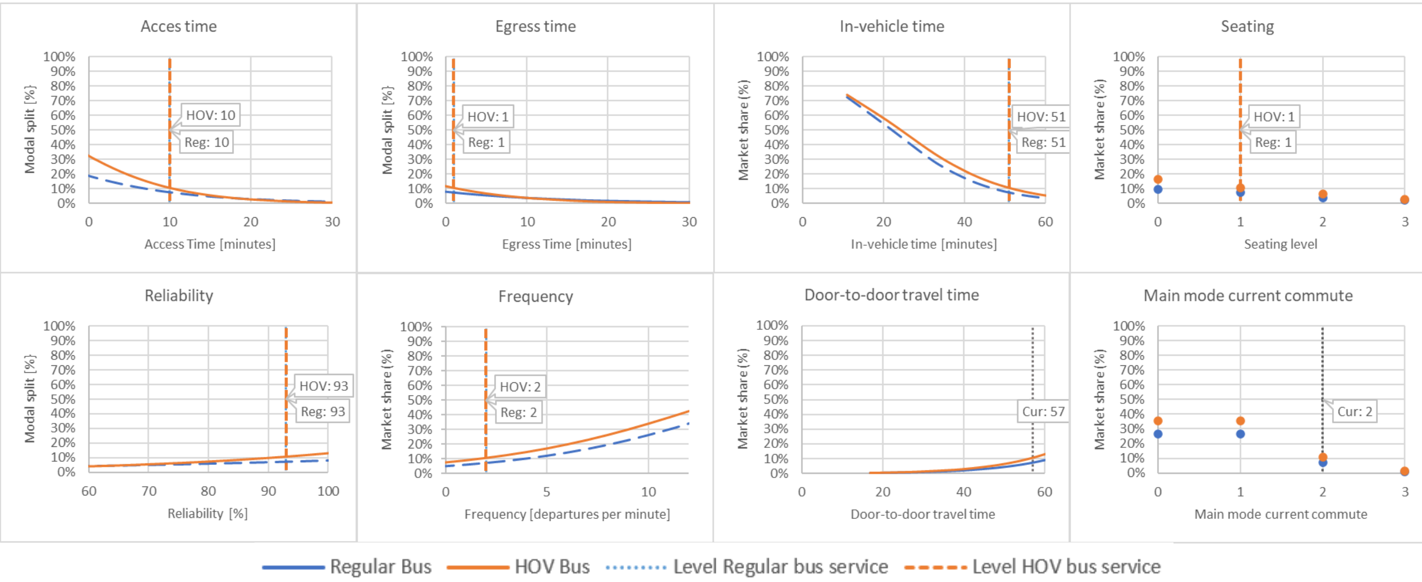


Figure 31 Probability curves for the attributes for case 2

Arnhem Station → Apeldoorn	Bus Line 302		Coefficient		Utility	Modal split
Service Type	HOV		-4,37	=	-4,37	
Access	10 minutes	*	-0,139	=	-1,390	
Egress	1 minutes	*	-0,117	=	-0,117	
In-vehicle time	51 minutes	*	-0,079	=	-4,029	
Frequency	2 departures / hour	*	0,182	=	0,364	
Reliability	93%	*	0,032	=	2,976	
Seating	Seat with neighbor	=	-0,472	=	-0,472	
			Total Utility	=	-7,033	10,7% (+3,4)
	Current commute					
Average door-to-door travel time	57 minutes	*	-0,076	=	-4,349	
Mode	Train	=	-0,596	=	-0,569	
			Total Utility	=	-4,918	89,2% (-3,4)

Travel time ratio	(3 + 1 + 51) / 50 = 1,1	Utility difference	=	2,115

Also for this case the probability curves can be analyzed when wanting to obtain further market share. Since it is a long route there is possibility for reducing the travel time through introducing priority on junctions and removing stops. Looking at in-vehicle time, it can be seen that reducing the in-vehicle time by 5 minutes could lead to a potential market share of 15% for the HOV bus. This could also be achieved by adjusting the frequency to 4. Dependent on the costs, one can choose.

7.5.3 Case 3: Eindhoven Station – Eindhoven Airport HOV assessment

For the last case it will be looked at a situation in which the bus fulfills the demand for people going from their work to a working area within the city without having a station as starting or ending point. This will be evaluated on the route Eindhoven Europalaan to Eindhoven Sciencepark Oost. Line 406 is currently operating here as an HOV line under the HOV formula Bravo Direct. Table 30 shows the calculations of the modal split of the regular bus service. Table 31 shows the calculations of the modal split of the HOV bus. The travel time by bike is 19 minutes according to Google Maps (2023). However, parking time and getting the bike should be included too. Additional 5 minutes will be added resulting in a total travel time of 24 minutes.

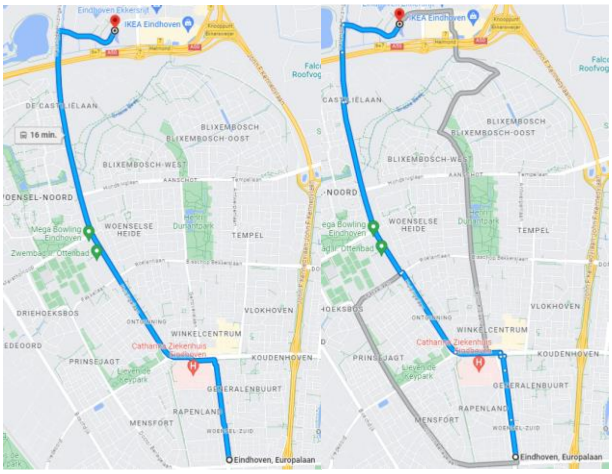


Figure 32 Google Maps Directions case 3 by bus (left) and by bike (middle) (Google, 2023)

It can be assessed whether the branding of the HOV bus has an effect on whether bike users would choose the bus opposed to not actively promoting it and leaving it as a regular bus service. Table 30 shows the modal split for the regular bus service and Table 31 shows the modal split for the HOV bus service. The modal split of the regular bus service amongst commuter who are biking is 3,9%. For the HOV bus service this is 5,2%. A gain of 1,3 percent points can be seen. That is an increase of 33%. If for example 100 travel on this route by bike at 7:00 in the morning, 4 people would choose the regular bus service. If it would be an HOV bus service then 6 people would choose the HOV bus service instead of the bike. The difference is not that significant since bike user have a higher preference for their bike over a bus. Also in this case the reliability has compensated for the negative parameter values.

Table 30 Attribute levels and modal split of the regular bus service case 3

Arnhem Station → Apeldoorn	Bus Line 302		Coefficient		Utility	Modal split
Service Type	Regular		-3,45	=	-3,45	3,9%
Access	3 minutes	*	-0,106	=	-0,318	

Egress	3 minutes	*	-0,081	=	-0,243	
In-vehicle time	13 minutes	*	-0,087	=	-1,136	
Frequency	2 departures / hour	*	0,188	=	0,376	
Reliability	95%	*	0,016	=	1,548	
Seating	Seat with neighbor	=	-0,296	=	-0,296	
			Total Utility	=	-3,519	
	Current commute					96,1%
Average door-to-door travel time	24 minutes	*	-0,076	=	-1,831	
Mode	Bike	=	1,51	=	1,51	
			Total Utility	=	-0,321	
Travel time ratio	(3 + 3 + 13) / 24 = 0,8		Utility difference	=	3,198	

Table 31 Attribute levels and modal split of the HOV bus service case 3

Arnhem Station → Apeldoorn	Bus Line 406		Coefficient		Utility	Modal split
Service Type	HOV		-4,37	=	-4,37	
Access	3 minutes	*	-0,139	=	-0,417	
Egress	3 minutes	*	-0,117	=	-0,351	
In-vehicle time	13 minutes	*	-0,079	=	-1,028	
Frequency	2 departures / hour	*	0,182	=	0,364	
Reliability	95%	*	0,032	=	3,049	
Seating	Seat with neighbor	=	-0,472	=	-0,472	
			Total Utility	=	-3,225	5,2% (+1,3)
	Current commute					
Average door-to-door travel time	24 minutes	*	-0,076	=	-1,831	
Mode	Bike	=	1,55	=	1,55	
			Total Utility	=	-0,321	94,8% (-1,3)
Travel time ratio	(3 + 3 + 13) / 24 = 0,8		Utility difference	=	2,903	

It can also be looked at whether bike users would still consider the bus if the bus got busier and one would need to stand for a while. The seating level will be set to “Standing”. Table 32 present the changes. It can be seen that a crowded bus results in the HOV bus service having almost equal modal split as the regular bus service. This shows when comfort is not up to level, the buses are almost perceived as equal. It also shows that almost no bike users consider a crowded bus for their commute. The probability curves in this case show that utility gain is difficult to be achieved for any of the attributes. Looking at the curve of “Main mode of current commute” it can be seen that adjust will have a larger impact on the market share with other modes. However, this is only an indication since mode and door-to-door travel time are correlated. When adjusting the mode, one also needs to recalculate travel time.

Table 32 Change in modal split by changing seating comfort

Seating comfort Change from Seat with neighbor to Standing	Initial utility contribution (Seat with neighbor)	Initial utility difference	Initial modal split	New utility contribution (Standing)	Utility gain	New utility difference (Initial utility – utility	New modal split	Modal split gain (Initial modal split – new modal split)
Regular bus service	-0,296	3,198	3,9%	-1,65	-1,35	4,877	1,0%	-2,9
HOV bus service	-0,472	2,903	5,2%	-1,98	-1,51	4,733	1,2%	-3,0

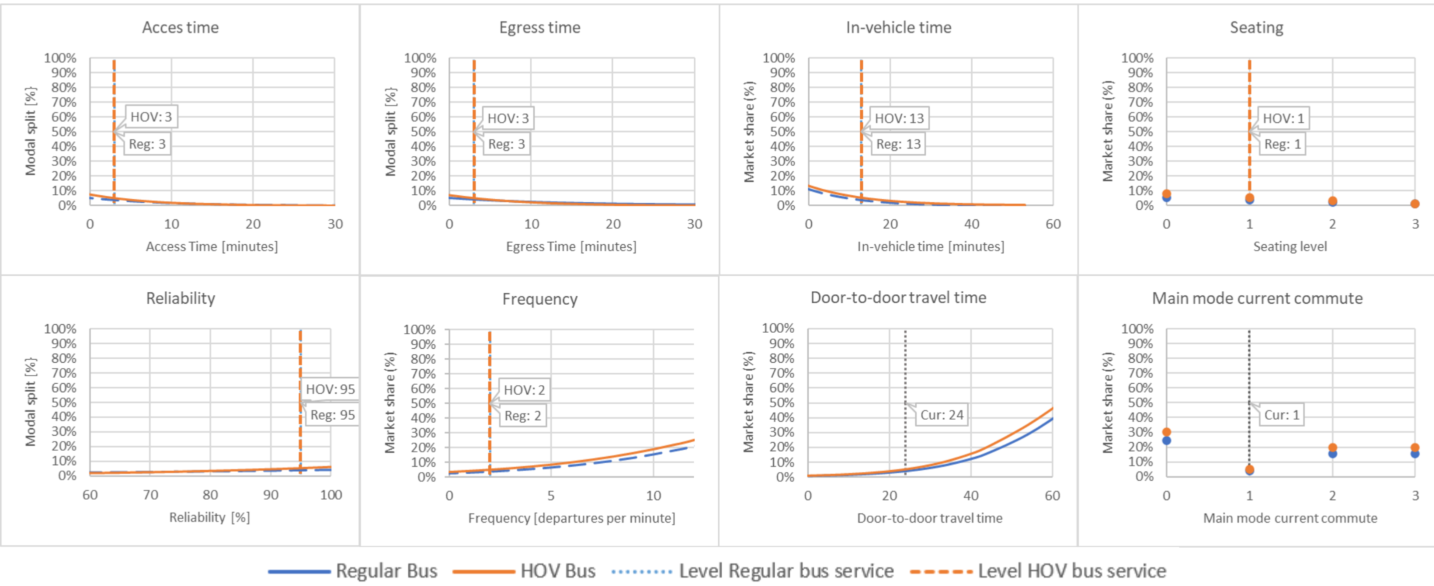


Figure 33 Probability curves for the attributes case 3

7.5.4 Conclusions from cases

The cases demonstrated how utility contribution is not linear with modal split gains. Instead, the change of rate in modal split is dependent on the utility difference between the bus alternative and the current commute. For utility differences larger than 3, it is hard to gain in modal split. For smaller utility differences between the alternatives, the utility of an attribute has more impact on the change in modal split per utility. It was also seen that despite of the HOV bus line having a lower utility contribution for most attributes, it was able to overcome the utility difference with the regular bus due to the 2 times higher valuation for reliability. For situations in which the utility differences are large, the HOV bus would remain to have a higher market share until a reliability of 80% and for trips where the utility difference is smaller this would be at 60%. Under these values the regular bus and the HOV bus would be valued equally. It was also demonstrated how the probability curves of each attribute can be used to determine which attribute should be changed in order to gain modal split. However, the downside with this method was that the curves change depending on the situation of the choice. In general this made it challenging to discover direct relations between the attributes and the modal split. Therefore, this method was created. However, it can be said that the impact per utility on the modal split depends on the utility difference between the bus and current commute. To improve modal split, one should be aware of how the difference in utility can be increased for the preferred alternative. Utility growth can be achieved by adjusting the parameters. Different growth can be achieved dependent on the attribute. However, the costs of making a change depends which change is to be made in the end. There is no go-to solution that can be done in every case since it is dependent on the situation, context and availability of resources.

7.4 Validity of the model

It is notable that the modal split stay at the lower spectrum and in most cases do not take the majority of the model shift. This has to do with the phenomenon that travelers tend to stick to their preferred mode of travel despite of a better option existing. When the bus is being set as the mode of the current commute and the current commute and bus alternative have the same values. The share almost becomes 50/50 however in favor of the current commute, thus verifying the phenomenon explained above. For car, bike and train users this effect will be stronger since as the model showed bike, car and train users have a stronger preference for their current commute. A second point with the percentages stay at the lower spectrum is because for most trips the bus has a lower modal split. The modal split that is calculated with the model also only reflects the people that travel on that specific route and with that specific commute. If for example the modal split would be larger for car commutes, it would be difficult to catch all the demand as the public transport system does not have the capacity.

7.5 Model use cases

When wanting to use this model in practice one can do so for a specific corridor. For this corridor can then be evaluated what the expected model shift is when improving a bus service to an HOV bus service. The model can be used to predict how many people will switch from their current commute to the new or improved option on this specific route. For each available mode the change in modal share can be calculated. From this the expected travelers can be determined.

7.5.1 Model use

The model could be used for different evaluations.

- Evaluating whether to market a regular bus line as an HOV line on existing lines or proposed lines: it can be evaluated whether it is worthwhile to upgrade an existing bus the an HOV line.
- Evaluation of whether HOV quality delivery is justified for a specific line: it can be evaluated whether the difference in market share differs significantly for an existing HOV bus line or whether running a regular bus service would be sufficient too.
- Evaluation of with which aspects most ridership gains can be achieved: the probability curves give insight into which market share can be expected when adjusting a certain attribute to a certain level.
- Evaluate on which aspects can be saved without significant ridership loses: The probability curves can give insight into what adjustments can be made to the attributes without having large losses in ridership.

These are just a few examples of possibles ways of using this model. The usefulness of the model can be further extended. The probabilities outputted by the model can be linked to passenger numbers to output actual ridership gains. Additionally, by linking costs to the attribute levels and profits to the passenger numbers monetary evaluations can be made to evaluate policies or operational improvements.

Additionally, the modal split can be related to ridership numbers. The ridership numbers can be directly calculated from the modal splits. Doing so for every possible combination of current commute and bus alternative will results in the total ridership gain.

7.5.2 Improvement of the attributes

The previous cases demonstrated how the shares are influenced when a regular line service is being delivered as a HOV line service. This can be the starting the point for improvements. Improvements can be achieved through different ways.

Access and egress indicate whether it should be considered to shorten the stop distance or to evaluate the impact on lengthen the stop distance. This will also impact the speed of the line as longer stop distance. Access and egress can be related to stop distance. More stops would decrease the number

Reliability can be used to evaluate whether measurements should be taken to increase the reliability through dedicated infrastructure or priority measures. Reliability can also by improving speed.

In-vehicle time can be used to evaluate whether speed should be improved, speed can be improved through dedicated infrastructure, larger stop distances, upgrading vehicles.

Seating indicates whether the used vehicles should be improved. Buying other busses with more seats or changing the bus configuration to include more seating area or using longer busses.

Model can be used to calculate the passenger gain between stations, by combining the data on multiple stations, it can then be determined what total demand will be. In practice, if you should do it on their busiest corridor as applying to this quality ensures the quality throughout the whole line.

With the case testing it was seen that one needs to consider specific things in order to get as accurate as possible results. The model can be used for very specific trips but also for more generalized trips with averages. It needs to be considered that the model predicts trips for a specific day of the time.

There is always a reference case needed. The HOV bus line cannot be introduced on route as the estimated model is not a demand model.

7.6 Conclusion

This section gave insight into how the mode choice between a regular bus and an HOV bus differs. A model was estimated with which it is possible to predict modal split between a bus in regards to the current commute for a commuter. The parameter values that have been estimated show that the valuation of the characteristic attributes differ between the regular bus service and the HOV bus service. The ratio's indicate by how much the parameter values are larger. The HOV bus is more negatively valued for "seat with a neighbor" (59% more negative), egress time (44% more negative), access time (31% more negative), ASC (27% more negative) and "standing (20% more negative). The HOV bus and the regular bus are valued equally for frequency, in-vehicle time and "stand; than sit". The HOV bus is more positively valued for reliability (100% more positive). The reliability mostly compensates for the difference in utility between the regular bus service and HOV bus service.

It has also be seen that attributes do not contribute equally to the utility of the alternatives, additionally the magnitude in which the alternatives contribute is dependent on the utility difference between the bus and the current commute. Thus, the larger the difference, the lower the modal split and the harder it gets to gain modal split. The cases have demonstrated aspects. For one, the cases showed that the HOV bus service had a larger market share then the regular bus service, despite of having parameter values which are mostly more negative than the parameter values of the regular bus service. It was found that this is due to the reliability which is twice as much valued for the HOV bus service opposed to the regular bus service. Moreover, the cases demonstrated also that when the utility difference between the bus service and the current commute are large, that it is hard for the bus alternative to grow in market share.

Overall, a model has been estimated which can be used for the evaluation of planned and existing HOV lines to predict ridership growth.

With this it can be said that reliability has the largest impact on the modal split when changing a regular bus service to an HOV bus service. And the largest changes in utility can be achieved thorugh the improvement of the seating comfort. However, depending on how much improvement can be made in terms of travel time, the travel components could out perform the contribution. The same can be said about frequency. Altering the reliability further does further improve the modal split significantly.

■

8

Conclusion, discussion and recommendations

In this chapter the answer to the main research will be given. Additionally, the research will be concluded. Limitations and recommendations will be provided to highlight what further research would be of interest and what aspects about this research should be taken into account regarding the validity and interpretation of the result.

8.1 Research questions

In this section the conclusion of the research will be presented. The research started with the following main research question:

How do the characteristic level of service attributes of HOV bus affect the commuter's choice on choosing an HOV service for their commute?

To answer this question, it was necessary to answer the following sub-questions:

1. What is the current situation of HOV buses in the Netherlands?
2. How does the decision maker define HOV Buses in the Netherlands?
3. Which attributes are relevant to the commuter?
4. Which attributes are characteristic for HOV Bus services?
5. Which variations exist in the levels of the characteristic attributes of HOV Buses?
6. Which variations exist in the trip characteristics of the commuters?
7. How do commuters choose between an HOV bus and regular bus for their commute?

Answers to the sub-research questions

The sub-research questions served the purpose of mostly gaining background knowledge into the matter as it was revealed that HOV is undergoing a development in terms of terminology. It was concluded that a distinction still needs to be made between HOV and BRT. They are not seen as equal. BRT is more characterized by dedicated infrastructure, whereas HOV focusses more on service aspects. A wide variation of HOV can be found in the Netherlands as well as in the implementation of it. There is no fixed formula for HOV. Different configurations exist. All HOV services focus on delivering a higher quality then the regular bus however in some cases the HOV busses share operational levels with regular bus service. There is inconsistency in in the definition of higher quality. Not all decision makers think that the promotion of it specifically is a priority. From the analysis in chapter 3 the characteristics attributes of HOV have been revealed and where: frequency, directness, recognizability, speed, reliability and comfort. Since a lot of variation was found in the HOV characteristics as well as in the commuters characteristics a choice experiment had been setup which presented choice profiles adapted to the respondents realistic situation. During the design of the survey the characteristic attributes have been translated to attributes more relatable and relevant to the commuter. Directness has been translated into access and egress time, speed into in-vehicle time, comfort into seating levels. Frequency and reliability remained the same but were differently expressed in the survey. The survey indicated that there could be a slight preference for HOV even though the configuration did not differ from the regular bus. The survey also indicated that there can be a difference in the magnitude of preference dependent on the mode that is being used for the current commute. With these findings in mind a model could be estimated which would give the answer to the final research question. The model estimation resulted in the following utility functions:

$$V_{reg} = 0{,}188 \cdot FR_{reg} + 0{,}016 \cdot RL_{reg} - 0{,}106 \cdot AC_{reg} - 0{,}081 \cdot EG_{reg} - 0{,}087 \cdot VTT_{reg}$$
$$-0{,}296 \cdot ST1_{reg} - 0{,}988 \cdot ST2_{reg} - 1{,}650 \cdot ST3_{reg} - 3{,}450$$

Equation 18 Defined systematic utility of the regular bus alternative

$$V_{hov} = 0{,}182 \cdot FR_{hov} + 0{,}032 \cdot RL_{hov} - 0{,}139 \cdot AC_{hov} - 0{,}117 \cdot EG_{hov} - 0{,}079 \cdot VTT_{hov}$$
$$-0{,}472 \cdot ST1_{hov} - 1{,}070 \cdot ST2_{hov} - 1{,}980 \cdot ST3_{hov} + ASC_{hov}$$

Equation 19 Defined systematic utility of the HOV bus alternative

$$V_{bas} = -0{,}076 \cdot TT_{bas} + 1{,}510 \cdot Bike_{bas} - 0{,}569 \cdot Train_{bas} - 2{,}080 \cdot Bus_{bas}$$

Equation 20 Defined systematic utility of the current commute alternative

How do the characteristic level of service attributes of HOV bus affect the commuter's choice on choosing an HOV service for their commute?

Upon closer examination of the factors it was seen that there is a difference in the valuation between the regular bus service and the HOV bus service. The HOV bus is more negatively valued for “seat with a neighbor” (59% more negative), egress time (44% more negative), access time (31% more negative), ASC (27% more negative) and “standing” (20% more negative). The HOV bus and the regular bus are valued equally for frequency, in-vehicle time and “stand; than sit”. The HOV bus is more positively valued for reliability (100% more positive). For access time and egress time, the lower valuation for these factors become more significant with growing access and egress time. From 15 minutes of access time, utility difference can be more than 0,5 utilities between the bus alternatives in favor of the regular commute for this attribute. From 14 minutes of egress time, utility difference can be more than 0,5 utilities between the bus alternatives in favor of the regular bus service for this attribute.

The relations have been found for how the characteristic attributes of HOV influence the commuters choice for choosing the bus for their commute. The conclusion is that the impact of the characteristic attribute depends on the context of the comparison. If utility difference between the regular bus service and the current commute is large, introducing an HOV bus service with the same attribute will not change the market share by much and thus are the regular bus service and the HOV bus service valued equally. However, when the utility difference is less than improving the bus service can lead to higher modal splits.

Reliability has the largest impact on the market share when changing a regular bus service to an HOV bus service. Then the largest changes in utility can be achieved by improving the seating comfort. However, depending on how much improvement can be made in terms of travel time, the travel components could out perform the contribution. The same can be said about frequency. Changing the reliability further does further improve the modal split significantly.

To conclude, there is a difference in valuation between the regular bus and the HOV bus which mostly stems from the promises that are being made about the HOV bus service and commuters knowing that a bus is a HOV bus serivce. Commuters seem to have more faith in the quality that is being delivered by the HOV bus however still remain sceptical about the bus in general. So the characteristic attributes of HOV bus services influence the users choice for a bus over their current commute in a postive way resulting in higher modal split due to the higher valuation for reliability and more positive valuation of improvements to the service.

8.2 Discussion

The topic of the research was quit broad in the beginning of the research. Literature showed that not much is known about the travelers perspective on HOV busses. The research was conducted in a time where BRT was an upcoming term for HOV. In the beginning of the research it was therefore looked into the right international terminology for HOV. BHLS has been found, but it turned out that BHLS was no longer used that much. Instead a rise in the usage of BRT has been seen but the research does not agree with BRT being a synonym for HOV, rather BRT is a subgroup of HOV bus services.

Choice of model

The model has been estimated with an MNL model. Other models that could have been considered are a nested logit model, ML-model or a Panel ML model. It is likely that these models will results in more accurate results. A nested logit model would make sense because two buses are being compared and the situation reminds of the blue bus red bus problem. Branding can be seen as color and therefore it reminds of this. But HOV branding does not only entail the color of the bus but also the service provision and extend of promotion towards the consumer. The Panel ML model would make sense as panel data has been used and preferences play an important role with this research. On the other side the MNL model is a solid model as well and applicable to many cases. However, whether other models would have resulted in more accurate results is not known. In general, one starts with the simplest model and build their way up from there. Not all parameters were significant at a 95%-significance level, so this could hint at estimating with a different model.

Use of continuous variables

A consideration had to be made between expressing the attributes with continuous variables or categorical variables. The use of continuous variables allows for the testing of scenario's which have not been tested in the stated choice experiment. For time components this makes sense. It could have been considered to express frequency and reliability in categorical attributes, since it could be seen that common levels are chosen for these attributes. It would have also shown more insight into whether one level contributes much more in utility compared with another level. This would have been insightful knowledge. But it could also be that there are no significant difference between the levels and that the parameters of the levels would not be significant. Still the model shows how attributes are differently valued between the busses, but for most attributes it is the case that higher means better. It does allow for the testing of configurations that have not been presented in the choice profiles.

Low percentages in modal split

At first glance the modal split percentages seem low. The model estimates market shares for the situation in which a commuter wants to choose between a bus service and their current commute on a specific route. Depending on the main mode a different modal split will then be estimated. The outputted modal split can seem low since in most cases the commuter has a strong preference for their current commute. However, upon calculating ridership gains from these modal splits, the ridership number result in realistic number. One should also take in mind that if a bus would full fil the need of all the people that consider a car or a bus, the bus is most likely not able to handle the number of people having that demand. But this depends on the route.

Iorder to find the total ridership gain, once can run the estimation multiple times and varying the mode every time. Then from this ridership gains can be calculated per main mode and the gains can be summed up. Now it gives insight into from which segments most new passenger will come from.

Interpretability of ASC

The interpretability of the ASC is not very clear. For now it has been defined as a preference. It indicates that the current commute has a systematic preference over the bus options and that this preference is stronger in regards to the HOV bus service. Yet, the cases demonstrated that despite this difference in preference, the HOV bus service results in higher modal splits than the regular bus service. Originally, the ASC was included to reflect recognizability. However, alternative specific parameters were used which reflect this as well to some extent. The ASC therefore gives more insight into how much of the choice is not decided by the characteristic attributes of HOV busses.

All in all the research demonstrate a way of including the travelers needs more actively in the decision making. A model has been estimated which can have practical use as it links attributes which are used by commuters with operational characteristics used by decision makers. The research emphasize the focus on the commuter when planning and organizing public transport services since in the end the service is designed to fulfill the needs of the commuter.

8.3 Limitations

A first limitation is that the results provided are only relevant for the Netherlands. However, the same methodology can be followed with local data so that models can be estimated for other areas around the world. On the other hand, it is likely that the attributes levels such as frequency, in-vehicle time, access time, egress time and reliability will differ dependent on the current connectivity of the country and the standard of public transport. For the model there was also an assumption made that cost will not play a major role as most commuter trips are paid for. Therefore the model does not say something about the monetary valuation of only the valuation difference of the attributes. This may have introduced the risk that respondents assumed a price during the process of making a choice even though it was said that the trip is being paid for, but the survey data also showed that for 80% of the respondents there commute is being paid for.

In the survey access and egress was set to walking distance. Since many commuters use the bike for access or egress in the Netherlands. It was considered to tell respondents that access will be done by bike and egress by walking. However, this could cause confusion amongst the respondents in how to interpret the access and egress time as well as making the model to complex and leading to inaccurate choices. Also the valuation in travel time could be different between these two modes. Thus, it was decided to only include walking as it was most relatable. There could be a risk that though that this has made the commuter more critical for the access and egress time. It is not known whether access time is differently valued depending on the mode, this could be interesting for future research.

Additionally, the model assumed a trip without change. However when doing a model estimation, one can involve a commute with a change as the changing time will be part of the travel time. The does however not assume different valuations for waiting or transfer time. In case 2, a situation shown in which the choice was between a bus and a train with change. Additionally, It could be considered to add a parameter for change. The model does show how people would choose their mode if they would need to travel on that specific route and have a specific preferred mode.

Another limitation is caused by the estimation model. To estimate the model an MNL was used. Although, it could also be considered to estimate a Nested MNL or a Panel ML model. The data is panel data a panel ML model can lead to more accurate probabilities.

The data that was used to estimate the model was explicitly data from commuters that travel during rush hour as that was the objective of the research. It needs to be verified if the model still holds for trips outside of rush hour. The model does not consider social demographic characteristics. This was not done as the focus was on the characteristic attributes. The data for socio demographics such as age, sex, urbanity and had been collected and also used in the estimation. However, the coefficients where not significant enough which would indicate that there might no significance influence from socio demographics however this has not been further addressed. It is recommended to test the model with real ridership values. These could be retrieved from OV chipcard data. This will give insight into the true validity and predictive power of the model.

The most time consuming part of the research was the setup of the survey and the estimation of the model. The survey was distributed through a third party. Many feedback session were required to make sure that the survey suits the respondents of the survey panel. The type of questioning as it is done in a choice experiment was new to them. Therefore the risks had to be mitigated that the respondents would not be able to finish the survey which resulted in lowering the number of choice sets a respondent would be presented with. The number of choice profiles had to be kept limited in order to adhere to the maximum duration allowed for the survey. The more choice sets one can present the more data can be collected, but nevertheless were the results significant.

Even though different mode users are represented in the sample, most of the commuters in the sample are car users. This led to the high numbers in choosing one's own commute over a bus option. However, it has been accounted for this, by including parameters that explain the choice for different modes and it showed that bike users have an even higher preference for their own commute. It was also seen that bike users had a large preference for their own commute.

With the final model the estimated probabilities seem very low, however the model explains the demand for specific options. The cases have also demonstrated for a situation in which a growth of 50% would have been achieved, the ridership gain that cannot be catched by the bus system. One does not want to achieve 100% in ridership as the bus system would not be able to handle the demand. The bus is the least used mode among the train, the car and the bike. When testing the model in different scenario's reasonable results come forth of the estimations.

8.4 Further Research

During the research many other findings have been made which would result in its own research. During the model estimation, it was already decided to switch to minutes for access and egress. However, it could also be considered to make a distance model. Instead of minutes, distance to stop could be taken but then access mode needs to be considered. Also speed could be directly included in the model. The model could be further developed to be combined with demand models. It was also considered to look more deeply into the difference of different bus. Additionally, to extend the usefulness of the model it can be connected to demand models. These models predict the number of trips that will be made between two points. Linking this model to the estimated model in this research could show how many of those trips would be done with a bus and how the introduction of an HOV bus could increase the share of the bus. A latent class model could be estimated creating clusters based on travel distance. Different effects were already found for different distances. A latent class model could make better conclusions about this. It could also be looked into the effect on HOV with electric buses, as electric buses seem to have an effect on perception as well. There also seems to be a need to clearly define HOV bus categories or higher service of bus categories. An attempt was made with BHLS, but it was without success. BRT seems to be the go to terminology and also the preferred. Yet, it does not fully describe HOV bus in the Netherlands. Instead, BRT is more likely a subgroup of HOV. It should be looked into specifically whether the need for a categorization of HOV bus and BRT is needed and if there is an interest. What could be an interesting way of categorizing bus systems would be based on different service measures one can apply to a bus in order to make it a higher service.

■

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11

Appendix

Appendix 1: Scientific Paper

Understanding the commuters' choice for HOV bus services in regards to regular bus services in the Netherlands

A. S. Eichler
MSc student Transport, Infrastructure and Logistics at Delft University of Technology, Delft, The Netherlands

Abstract – The implementation of a bus system is a attractive alternative for decision makers since it has a short lead time and the service can be easily adapted depending on the demand. Due to the flexible nature it allows for the use of fulfilling different magnitudes of demand. Usually bus service provide a lower level quality service, however busses can be configured in such a way that they also provide higher level of service up until a point where they compete with rail systems. In the Netherlands referred to as HOV ("Hoogwaardig Openbaar Vervoer", *high-level public transport*). This is a large spectrum with many different configurations. One should still consider the need for a HOV bus service as it comes with extra investment costs compared with the regular bus. Therefore, this research was looking into where there is no difference in valuation between a regular bus line and a higher level of service bus line. Through interviews, analysis of current lines and looking into what decision makers promise as a higher level of service attributes could be defined which could be seen as characteristic for a higher level service bus service. Additionally, the commuters perspective played a important role as most literature mostly considered only the decision makers perspective. A method has been demonstrated which shows how commuter needs can be used as and translated to operational characteristics with which decision makers specify, plan and design current and future higher level of service bus lines. The method includes a MNL model which expresses the valuation of the characteristics attributes of high level bus services which allows for the prediction of the modal split between a bus service and the current commute. This gave insight on which attributes a differently valued between a regular bus and a HOV bus and when a HOV bus service is equally valued as a regular bus service, hence not justifying investments in a higher level service. It was found that in most cases the HOV bus service results in a higher modal split despite of having a lower valuation for most of the characteristic attributes. The commuter seems to have more trust in the reliability promoted by higher level bus services.

Keywords: HOV, Commuter, BRT, Mode choice, Multinomial Logit Model

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1. Introduction

In the Netherlands a higher level of public transport exists called HOV (Hoogwaardig Openbaar Vervoer) which is Dutch for High level Public Transport (Heddebaut et al. 2010). This type of public transport distinguishes itself from lower level public transport by delivering a service which may not be realistic in other cases. Higher level of public transport should not be introduced for routes that do not justify the investment in a higher level of service. HOV can be delivered with trains and busses. In the Netherlands most HOV services are delivered by busses. Transport authorities promise with HOV bus services a bus that offers a higher frequency service at higher speeds with better comfort and reliability. With a growing demand for mobility, authorities want to support the use of public transport and make large investments into transportation infrastructure. Most infrastructure projects however take multiple years to complete and there is always a risk that once a project is completed the demand has changed, either negatively or positively. So there are cases for which large investment are not justified because the expected demand is not that high but where the current infrastructure is not sufficient enough. For example a case where the investment for a rail system is not justified but the current bus system in place is not sufficient in quality or catching the demand. For these kind of situations a HOV bus service is often considered as it allows for flexibility, lower investment costs and has a short lead time depending on the measures that are taken. Flexibility therefore because with busses it can be easily adapted to growing demand by increasing or lowering the frequency without the need of adapting existing infrastructure too much and it can be made of existing infrastructure which can be upgraded to further improve the service if necessary. A question this rises is: what does higher level of service mean? And is it beneficial and needed all the time? Is the commuter aware of these higher level of services? In the end authorities want to use investments effectively. This means providing a service which fits the demand. It should not be blindly invested into higher level of service infrastructure but carefully considered what is needed and what is not.

This requires a clear understanding of what a high level of service defines. As mentioned before transport authorities make this promise that HOV bus service will deliver a higher level of service opposed to the regular bus service. But there is a lack of common understanding of what these promises mean in practice. Different carriers and transport authorities have their own interpretation. In general it is known that a higher frequency, higher speed, better comfort and greater reliability contribute to higher satisfaction but lesser is known about what "more & higher" means. And at which point "more & higher" does not contribute anymore.

Amongst transport authorities it can also be seen that HOV is differently emphasized. For some parties the emphasize of HOV is very important towards the traveler, for others it is not. Adding another aspect that is differently interpreted amongst authorities. Since the traveler is the main user of the system and also the one for which these system exist one can involve the users view more closely into the design and evaluation process of public transport systems. This research allows for the opportunity to demonstrate this and at the same time answer the question if and how the promises of HOV buses the users choice for their commute influence.

1.1 Research Objective

The research wants to contribute insights to the ongoing discussion about bus rapid transit in the Netherlands and wants to provide practical output which can be used by transport authorities to evaluate and design existing and new HOV bus services with the needs of the commuter in mind. Additionally, the research shows how traveler related needs can be linked to the operational aspects authorities are designing bus services with. The main question the research wants to answer is:

How do the characteristic level of service attributes of HOV bus affect the commuter's choice on choosing an HOV service for their commute?

The output will be the identification of the characteristic level of service attributes for HOV bus services, understanding the difference in valuation between the regular bus and the HOV bus and knowing which attributes contribute the most to a change in market share and when this is the case.

2. Theory

The notion is that the promises can be linked to attributes. The promises can be seen as characteristics of HOV bus services. There is literature on which aspects play the most important role (Wan et la, 2016; Rojo et al., 2012; Quddus et al. 2019; *Tyrinopoulos et al. 2008;* Sukhov et al. 2021; Sinha et al. 2020; Mouwen, 2015) but there is less literature on how varying these aspects directly influences the mode choice of the commuter. Additionally, this knowledge is not specifically known for higher level of bus service but more in general for public transport.

1.2 Utility theory

As the research question shows the research is about a choice. A choice between a regular bus service and a HOV bus service in regards to a current commute. It is assumed that a commuter has a preferred way of travelling. This way of travelling was chosen based on specific attributes regarding the travelers living environment, demographic, need for mobility and preferences for modes. The assumption that a choice is based on different attributes is derived from the utility theory. Utility theory states that an individual chooses the alternative which provides the highest utility (McFadden, 1975). The utility of an alternative depends on attributes. Each attribute contributes to a different extend to the utility. How much depends on the individual. Each attribute can be linked to a taste parameter which explains how an attribute is contributing to the total utility. The utility function can be described as follows:

$$U_i = V_i + \epsilon_i$$

Where $\boldsymbol{U_i}$ is the utility, $\boldsymbol{V_i}$ is the systematic utility and $\boldsymbol{\epsilon_i}$ the error component of the utility which entails the utility that cannot be explained by the systematic utility. Utility in itself has no meaning only when compared with other utilities of the same choice set. The systematic utility consists of the attributes and a corresponding taste parameter:

$$V_i = \sum_{k=1}^{k} \beta_k \cdot x_{ik}$$

$\boldsymbol{\beta_k}$ is the taste parameter and $\boldsymbol{x_{ik}}$ is the attribute. The systematic utility is the sum of the attribute value multiplied by the taste parameter.

1.3 Logit Model

From the utility one can derive the probability that an alternative is chosen amongst a specific set of alternatives. The probability is specified as follows (Bernasco & Block, 2013):

$$P_i = \frac{e^{V_i}}{\sum_{j=1}^{J} e^{V_j}}$$

The systematic utility of the alternative for which one wants to know the choice probability will be divided by the utilities of the other alternatives that can be chosen. This will result in a probability which can be related to market share in transportation engineering.

It was found that the difference in utility between two alternatives can be related to the probability. The smaller the utility difference between the two alternatives the more equal the probability. For example, for a difference of 0, the probability will be 50% for each alternative. Is the utility difference larger than then the alternative with the higher utility will have a higher probability to be chosen. The relation between utility and probability is not linear. Instead it is described by an s-curve. This has the characteristics that when the utility is very large, further probability grow is more difficult to achieve for when the utility difference is 0. The figure below illustrated how the utility difference is related to the probability.

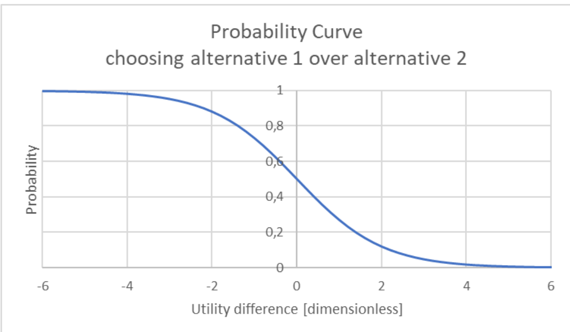

Figure 34 Probability curve related to utility difference

Each attribute that is part of the utility function can be described by such a curve, however the rate of change in probability is dependent on the parameter value.

1.4 Multinomial Logit Model

A utility function of an alternative can be estimated as a model. This can be done with Multinomial Logit Models (MNL) and stated choice experiments. A respondent is presented with 2 or more alternatives which can share the same attributes or have different attributes. For each attribute specific levels are defined. One can create multiple variations in which the alternatives have different levels for the attributes. Varying these attribute levels strategically will allow of the determination of trade-offs and understanding how a respondent chooses an alternative. The choice will be captured for multiple choice sets. Through estimation with for example an MNL model one can then derive the taste parameter of the attribute and create this way a model with which the choice can be predicted. Since it is a prediction the outcomes will always have a certain probability.

1.5 Service quality loop

The choice for this method is also motivated by the theory of the service quality loop. The service quality loop is introduced by the European Committee for Standardization under EN13816. Mohammed et al. (2020) has related this quality loop to public transport services. Delivered, desired, targeted and perceived quality of a public transport service are linked within a loop. This research focuses on starting the loop with the desired quality and how decision makers can translate this to the targeted quality which can be realistically delivered by carriers. It can be seen that desired quality can be determined with stated preference and reflects the perceived quality of commuters.

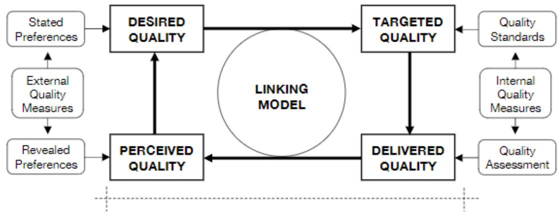

Figure 35 Service quality loop

2. Methods

At the core of the research is the estimation of an MNL model since it will give insight into how attributes influence the choice, a question this research is interested in. A stated choice experiment needs to be setup in order to collect stated preference data. To design the stated choice experiment background information is needed on the current state of HOV busses, configurations of HOV busses, current commuter behaviour and most importantly the characterstic attributes.

1.6 Identification of characteristic attributes

The characteristic attributes were revealed by interviewing decision makers involved with the planning and organization of HOV; by analyzing the current HOV product formulas and by looking into literature which describes which aspects travelers find important. Since decision makers decide on a network level and travelers on an individual level it is expected that the attributes will be different. However, it will be possible to link the attributes and express the attributes in such a way that the commuter can relate to them and that attributes from the commuters perspective can be translated into operational aspects with which decision makers can work.

3. Survey Design

After having revealed the attributes they can be used to design a stated choice experiment. A stated choice experiment has been designed consisting of 36 choice sets, in each choice set included 2 alternatives (a regular bus service and a HOV bus service). Both alternatives had the same attributes and attribute levels, as with this it could be tested whether the label as influence on the choice. Additionally, the choice experiment was setup in such a way that the choice profiles where unique to the respondent. This would ensure that the presented choice task is relatable to the respondent and more accurate answers can be given. For each choice task the respondent was presented with two questions: “Which bus service has your preference?” and “Would you consider this choice over your current commute?”. This is to mitigate that people will not make a choice and escape the choice task which does not allow for the collection of data.

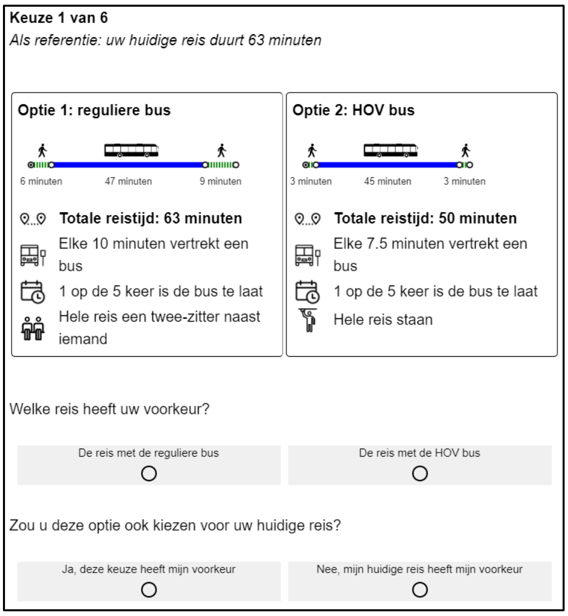

Figure 36 Choice task from survey of research

1.7 MNL model estimation

By distributing the survey data points can be collected. The data will be formatted and mode can be estimated. For this utility functions were defined which included the characteristic attributes. A utility function for the regular bus service, for the HOV bus service and the current commute has been determined and the parameter values of the utility functions have been determined. A alternative specific constant has been included as well to test the existence of a systematic preference for the HOV bus service. Each alternative will have alternative specific parameter values and attributes. However, the bus alternatives will share the same attributes but different parameters will be estimated to get insight into the differences.

1.8 Analysis of parameters

The analysis of the parameter was done by looking at the differences in parameters values between the parameters of the bus alternatives. The parameter value indicates the utility contribution of changing this attribute by 1 unit. Equal attributes were directly compared and other attributes were also compared by looking at the parameter values. However, it should be note that the a comparison of the values also entails the same costs of changing attributes to those levels. Some changes in attribute values could more or less costs despite of having the same utility contribution to the total utility. It was also assessed what the attribute effect would be on the utility difference between a bus alternative and the current commute. The utility difference indicates the probability proportion. At last the impact of attributes was assessed through creating scenario’s and calculating the market share changes when changing a regular bus to a HOV bus service. The results of this analysis were used to answer the main research question.

4. Results

The characteristics attributes were revealed as frequency, directness, reliability, speed, and comfort. These attributes where from a decision makers perspective. They were made more relatable to the commuter in the following way: frequency was expressed in follow-up time between buses instead of departures per hour; directness was related to the access and egress time to the stop; reliability was translated from the probability to which bus in every so many buses would be late; speed was translated to in-vehicle time and comfort has been expressed in terms of the seating situation. Appropriate levels were assigned based on the background information that was collected.

An MNL model has been estimated (Final LL: 1283,75; Rho-square: 0,441) resulting in the parameters presented in Table 1. For the current commute parameters have been estimated too. Door-to-door travel time and main mode of commute have been collected in the survey.

Table 33 Estimated parameter values

Attribute	Parameter	Value	Std err	T-test	P-value	Ratio's	Difference
Regular Bus							
Preference	ASC_{reg}	-3,450	1.120	-3.10	0.002	0,79	0,920
Access to stop	$\beta_{AC,reg}$	-0,106	0.026	-4.15	0.000	0,76	0,033
Egress from stop	$\beta_{EG,reg}$	-0,081	0.026	-3.12	0.002	0,69	0,036
Service frequency	$\beta_{FR,reg}$	0,188	0.032	5.87	0.000	1,03	0,006
Service reliability	$\beta_{RL,reg}$	0,016	0.012	1.32	*0.187	0,50	0,016
Seating level							
Seat with neighbor	$\beta_{ST1,reg}$	-0,296	0.191	-1.55	*0.121	0,63	0,176
Seat with neighbor half way	$\beta_{ST2,reg}$	-0,988	0.218	-4.53	0.000	0,92	0,082
Standing	$\beta_{ST3,reg}$	-1,650	0.244	-6.79	0.000	0,83	0,330
In-vehciel travel time	$\beta_{VTT,reg}$	-0,087	0.013	-6.83	0.000	1,10	0,008
HOV Bus							
Preference	ASC_{hov}	-4,370	1.160	-3.76	0.000	1,27	0,920
Access to stop	$\beta_{AC,hov}$	-0,139	0.027	-5.24	0.000	1,31	0,033
Egress from stop	$\beta_{EG,hov}$	-0,117	0.025	-4.69	0.000	1,44	0,036
Service frequency	$\beta_{FR,hov}$	0,182	0.034	5.35	0.000	0,97	0,006
Service reliability	$\beta_{RL,hov}$	0,032	0.013	2.48	0.013	2,00	0,016
Seating level							
Seat with neighbor	$\beta_{ST1,hov}$	-0,472	0.192	-2.46	0.014	1,59	0,176
Seat with neighbor half way	$\beta_{ST2,hov}$	-1,070	0.221	-4.82	0.000	1,08	0,082
Standing	$\beta_{ST3,hov}$	-1,980	0.260	-7.59	0.000	1,20	0,330
In-vehciel travel time	$\beta_{VTT,hov}$	-0,079	0.013	-5.92	0.000	0,91	0,008
Current commute							
Total trip travel time	$\beta_{TT,current}$	-0,076	0.010	-7.68	0.000		
Main mode of current commute							
Bike	$\beta_{bike,current}$	1,510	0.177	8.54	0.000		
Train	$\beta_{train,current}$	-0,569	0.169	-3.36	0.001		
Bus	$\beta_{bus,current}$	-2,080	0.284	-7.32	0.000		

For each attribute an analysis has been conducted which revealed the difference between the bus services, the utility change per unit and other relations of interest.

Attribute differences

ALTERNATIVE SPECIFIC CONSTANT

The ASC of the regular bus is -3,45 and the ASC of the HOV bus is -4,37. The ASC of the HOV bus is 26% more negative than the ASC of the regular bus. Since these values are non-zero, the ASC's indicate that the current commute has a systematic preference over both bus services. The ASC of HOV differs by -0,92 utilities from the regular bus service and is more negative. This indicates that the regular bus service is

preferred over the HOV bus service. It could be that because commuters are skeptical of the regular bus service it makes them even more skeptical of the quality provided by an HOV bus service which promises higher quality. The ASC is constant. This makes the utility for the bus alternatives by definition lower and introduces a larger utility difference with the current commute from the beginning. In order for the HOV bus service to have a larger market share, it needs to overcome the systematic difference with other positive attributes or performing less negative with other attributes.

ACCESS TIME

The parameter of access time indicates the utility contribution for every minute of access time. Access time is valued negatively. The regular bus service has a parameter value of -0,106 and the HOV bus service has a parameter value of -0,139. There is a difference of 0,033 utilities per minute. The parameter of the access time of the HOV bus is 30% more negative than the regular bus service. This means that access time is 31% more negatively valued for an HOV bus service than it is for a regular bus service. From 20 minutes and onwards a utility difference of 0,5 utilities or larger can be observed.

EGRESS TIME

The parameter of egress time indicates the change in utility for every minute of egress time. An increase in egress time is seen as a disadvantage and negatively influences the utility. The longer the egress time the more disutility. The regular bus has a value of -0,081 and the HOV bus has a value of -0,117. There is a difference in utility of 0,036. This means that every minute spend on egress time has a disutility of -0,081 for a regular bus service Egress time is expressed in minutes. For the HOV bus service egress time is almost 59% more negatively valued than for the regular bus. From 18 minutes and onwards, an utility difference of 0,5 can be observed.

IN-VEHICLE TIME

The parameter of in-vehicle time expresses the change in utility for each minute of in-vehicle time. The regular bus has a value of -0,087 and the HOV bus has a value of -0,079. The sign indicates that in-vehicle time is valued negatively. . The value for the regular bus service is 10% more negative than the value of the HOV bus service. There is a difference of 0,008 utilities. From 62 minutes an onward utility differences of 0,5 can be observed. For most trips the in-vehicle time is almost equally valued between the regular bus service and the HOV bus service.

DOOR-TO-DOOR TRAVEL TIME

The parameter for door-to-door travel time is a parameter part of the utility function of the current commute. This parameter expresses the utility contribution of 1 minute of door-to-door travel time. The parameter value for the travel time of the current commute is -0,076. It can be said that the in-vehicle time of the HOV bus services is valued the same as the door-to-door travel time of the current commute.

FREQUENCY

The parameter for frequency indicates the utility contribution for 1 departure per hour. The higher the frequency, the more positively valued it is. The regular bus has a value of 0,188 and the HOV bus has a value of 0,182. The difference between the values of the busses is 0,006. This difference is very small and indicates that frequency is not significantly different valued for an HOV bus service then it is for the regular bus. On trips longer than 25 minutes, frequency becomes less important than the time components.

RELIABILITY

The parameter of reliability indicates the utility for 1% of reliability. Reliability expresses the chance of a delayed arrival of a bus at a station. A higher reliability is seen as a positive change and increases the utility. The regular bus service has a parameter value of 0,016 and the HOV bus service has a parameter value of 0,032. There is a difference of 0,016 utilities per percent of reliability. The value for the reliability of the HOV bus is 2 times as large as the value for the regular bus. This means that the reliability of a HOV bus service is twice as much valued then the reliability of a regular bus service. When the reliability is 60% or more for the busses, the positive utility can compensate for the systematic difference in preference. The reliability at which can be compensated depends on the negative utility of other factors. For example, for longer trips for which the time components have a more negative utility, this threshold value can go up to 80% at which the HOV bus service is able to overcome the difference in utility between the busses.

SEATING

The seating level has been expressed in 4 levels: a seat without neighbor; a seat with a neighbor; half of trip standing then a seat with neighbor; standing the entire way. “A seat without neighbor” was taken as the base level relative to which the parameters for the seating levels where estimated. This base level was set to 0. The values “seat with neighbor”, “Standing half way then sitting” and “Standing” are as following for the regular bus service -0,296; -0,988; -1,650 respectively and for the HOV bus service the parameter values -0,472; -1,070; -1,980 respectively. . The parameter value for “seat with neighbor” for the HOV bus service is 59% more negative than the parameter of the regular bus service. . The parameter value for “standing then sitting” for the HOV bus service is 10% more negative than the parameter of the regular bus service. This seating level is almost equally valued amongst the two bus services. . For “Standing”, the parameter value of the HOV bus service is 20% more negative than the regular bus service. Adjusting the seating levels can overcome significant utility differences with current commute.

MAIN-MODE OF THE COMMUTE

The main mode of the current commute has been coded with 3 parameters: bike, train and bus. Car has been chosen as base mode. The parameter indicates whether the choice of the main mode of the current commute has influence on the utility and whether there is a difference between the modes in choosing a bus as an alternative for their current commute. The parameter values are 0,000 (car); 1,51 (bike); -0,569 (train); -2,080 (bus). The parameters differ for the different modes, therefore it can be concluded that the mode the commuter is currently using has influence on the likelihood of choosing a bus as alternative. The parameter for the bike has the highest value indicating that bike user have the highest preference for their current commute. After the bike users, car users have the highest preference for their current commute. The parameters for train and bus are negative. They decrease the utility difference between the bus alternatives and the current commute. The parameter for the train has a smaller disutility then bus users. This indicates that there is a difference in preference for the current mode between train and bus users. The bus users have the least preference for their current commute.

The analysis showed that with certain attributes there is indeed a differences in valuation between the regular bus service and the HOV bus service. These differences have been found by comparing the ratio’s between the attribute of the regular bus service with the HOV bus service. For most attributes it was seen that the attributes for the HOV bus had the largest ratio’s. The HOV bus is more negatively valued for “seat with a neighbor” (59% more negative), egress time (44% more negative), access time (31% more negative), ASC (27% more negative) and “standing (20% more negative). The HOV bus and the regular bus are valued equally for frequency and “stand; than sit”. The HOV bus is more positively valued for reliability (100% more negative). Reliability also has the largest ratio among all the attributes, meaning that this attribute is valued differently the most between the regular bus service and the HOV bus service. A negative valuation translates to a positive valuation for improvements.

6. From utility to modal split

A next step is to relate the total utilities of an alternative to modal split. Previously it was explained how utility can be related to probability and that utility difference has a relation with probability. Probability can also be used to determine modal split. This makes it complicated to understand the true effects of the attributes on the modal shift. The change in modal shift is dependent on the utility difference with the current commute. During the research cases were provided to demonstrate this relation. The relation basically describes that if an alternative is already performing very well, it is hard to convince people using another alternative. Also if an alternative is performing very poor, then it is hard for alternative to gain in market share even though large improvements are being made. Most modal split gains can be achieved for situations in which the utilities do not differ by more than 3 utilities. Depending on the context this utility difference can be reduced by changing the levels of the attribute. Attributes with high parameter values will also have cause a larger change to the modal split. For the cases probability graphs were plotted which would show for the specific situation of the case which attribute would cause what gain in modal split at which level.

7. Conclusion

To answer the main research question, it was found that there are differences in the valuation of the aspects between the regular bus service and the HOV bus service. The HOV bus is more negatively valued for “seat with a neighbor” (59% more negative), egress time (44% more negative), access time (31% more negative), ASC (27% more negative) and “standing (20% more negative). The HOV bus and the regular bus are valued equally for frequency, in-vehicle time and “stand; than sit”. The HOV bus is more positively valued for reliability (100% more positive, twice as much). It was notable that most parameters were more negatively valued for the HOV bus then they were for the regulars bus. Yet, the reliability mostly compensates for the difference in utility between the regular bus service and HOV bus service. In addition this means that improvement that are being made to the seating configuration, egress time and access time are more positively valued then doing so for the regular bus line. When relating this to modal split then the conclusion is that the impact of the characteristic attributes on the modal split change depends on the context of the case that is being evaluated. If utility differences between the regular bus service and the current commute are large, introducing an HOV bus service with the same attribute will not change the modal split by much and thus are the regular bus service and the HOV bus service almost valued equally. However, when the utility difference with the current commute is smaller than improving the promoting the bus service as an HOV bus service can lead to higher modal splits. Reliability has the largest impact on the market share when changing a regular bus service to an HOV bus service. Then the largest changes in utility can be achieved by improving the seating comfort. However, depending on how much improvement can be made in terms of travel time, the travel components could out perform the contribution. The same can be said about frequency. Changing the reliability further does not further improve the modal split significantly. Overal, it was seen that promoting the a bus line as an HOV line has a positive impact.

To conclude, there is a difference in valuation between the regular bus and the HOV bus which mostly stems from the promises that are being made about the HOV bus service and commuters knowing that a bus is a HOV bus serivce. So the characteristic attributes of HOV bus services influence the users choice for a bus over their current commute in a postive way resulting in higher modal split due to the higher valuation for reliability and more positive valuation of improvements to the service.

8. Discussion

The model estimates market shares for the situation in which a commuter wants to choose between a bus service and their current commute on a specific route. Depending on the main mode a different modal split will then be estimated. The outputted modal split can seem low since in most cases the commuter has a strong preference for their current commute. However, upon calculating ridership gains from these modal splits, the ridership number result in realistic number. One should also take in mind that if a bus would full fil the need of all the people that consider a car or a bus, the bus is most likely not able to handle the number of people having that demand. But this depends on the route.

On order to find the total ridership gain, once can run the estimation multiple times and varying the mode every time. Then from this ridership gains can be calculated per main mode and the gains can be summed up. Now it gives insight into from which segments most new passenger will come from.

Moreover, the model has been estimated with an MNL model. Other models that could have been considered are a nested logit model, ML-model or a Panel ML model. It is likely that these models will results in more accurate results. A nested logit model would make sense because two buses are being compared and the situation reminds of the blue bus red bus problem. Branding can be seen as color and therefore it reminds of this. But HOV branding does not only entail the color of the bus but also the service provision and extend of promotion towards the consumer. The Panel ML model would make sense as panel data has been used and preferences play an important role with this research. On the other side the MNL model is a solid model as well and applicable to many cases. However, whether other models would have resulted in more accurate results is not known. In general, one starts with the simplest model and build their way up from there. Not all parameters were significant at a 95%-significance level, so this could hint at estimating with a different model.

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Appendix 2: HOV lines in the Netherlands

The currently available HOV lines (State: February 2023) in the Netherlands have been analyzed. In total 130 bus lines have been found by looking on the carriers website, timetables (Hermes, 2023), HOV project websites and PT databases (such as OV Wiki). This dataset has been constructed by the author and can be found via following links:

4TU.Research: https://data.4tu.nl/private_datasets/3Ysi4-QL3U3itUK9tVO7D7AzEoqsLW-mjOG_bAS6NFc (Publication in Progress: 14-11-2013)

GitHub: https://github.com/Aaronstephen/hovlines/tree/af9f983a54bca0832d6c16a95c528f8ac9d70a21

Appendix 3: Travel satisfaction attributes in literature

	Frequency	Travel time	Cleanliness bus	Reliability	Ride comfort	Waiting time	Transfer experience	Affordable fare	General information	Seat availability	Crowdedness	Staff and assistance	Customer interface	Safety against crime	Ticket accessibility	Network	Distance to bus stop	Safety on board	Staff and assistance	Proximity to stations	Response to feedback	Air quality	Comfort bus stop	Noise level	Use of ecological vehicles	Cleanliness busstop	Distance between stops	Path/Directness	Information on planned	Information on unplanned	Lighting on board	Number of stops	Seats busstop	Service time	Station maintenance	Travel speed	Own infrastructure	Information at stop	Accessibility	Waiting conditions	Safety busstop	Busstop satisfaction	Interior bus	Fellow travellers	Vehicle condition	Convenience of service
Swedish PT Barometer	X	X	X	X	X				X	X			X	X	X	X			X	X									X	X					X											
OV-Klantenbarometer	X		X	X	X		X	X	X	X	X	X			X			X	X			X		X					X	X						X		X	X		X	X	X	X		
(Jung, 2015)	X	X	X	X																		X		X																						
(Sinha et al., 2020)		S	X		S	S	S	X	S	S		X					S	X			X					X							X								X					
(Sukhov et al., 2021)	X	X	X	X			X	X	X	X							X	X	X			X		X							X															
(Friman & Fellesson, 2009)	X	X								X																																				
(Eboli & Mazzulla, 2011)	X		X	X	X			X	X		X							X	X	X	X	X	X	X	X		X	X						X												
(Dell'Olio et al., 2011)		X	S		S	S					X				X																															
(Mouwen, 2015)	X		X	X								X																								X										
(Eboli & Mazzulla, 2010)	S		S	S				X	X		X	X		X				X	X	X	X		X		X			X																		
(Eboli & Mazzulla, 2007)	X			X				X	X		X			X				X	X	X	X		X		X	X	X					X														
(Eldeeb & Mohamed, 2020)	S	S					S	S	X																																					
(Abenoza et al., 2019)	X	S			X				X			S	S		S	X													X	X																
(Wan et al., 2016)	X		X	X					X						X		X												X	X		X				X	X									
(Tyrinopoulos & Antoniou, 2008)	S		S	S	X		X	X	X	X					X	S	X						X										X	X			X	X	X	X						
(Quddus et al., 2019)	X			S	S	S		X			S			S	X									X															X						X	X
(Rojo et al., 2012)	X	X						X																				X																		
(Garrido & De Dios Ortuzar, 1994)		X	X		X	X		X		X	X	X						X																												
TOTAL COUNT	15	10	12	11	9	4	5	11	11	7	7	6	2	4	7	3	4	7	6	4	4	4	4	5	3	2	2	3	4	4	1	2	2	2	1	3	2	2	3	1	2	1	1	1	1	1
SIGNIFICANT COUNT	3	3	3	3	3	3	2	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4: Ngene syntax

Following syntax has been used to generate the profiles for the choice experiment

```
design
;alts = bus,hov
;rows = 36
;block = 6
;orth = sim
;model:
U(bus) =
 fr*frequentie[2,4,6,8]
+ rt*reistijd[0.80,0.90,1.0,1.1]              ?Gebaseerd op reisafstand en gem. auto snelheid
+ nb*naarbusstop[0.05,0.10,0.15,0.20]             ?Percentage van deur-tot-deur reistijd
+ vb*vanbusstop[0.05,0.10,0.15,0.20]
+ bh*betrouwbaarheid[0.95,0.9,0.85,0.80]
+ cf*comfort[1,2,3,4]
/
U(hov) =
 fr*frequentie
+ rt*reistijd                                 ?Gebaseerd op reisafstand en gem. auto snelheid
+ bh*betrouwbaarheid
+ cf*comfort
+ nb*naarbusstop                                  ?Percentage van deur-tot-deur reistijd
+ vb*vanbusstop
$
```

Appendix 5: Choice profiles

The Ngene syntax presented in profile

	Regular Bus						HOV Bus					
Scenario	Frequency	Travel time	Access	Egress	Reliability	Comfort	Frequency	Travel time	Access	Egress	Reliability	Comfort
1	2	0.8	0.05	0.05	95	1	2	0.8	0.05	0.05	95	1
2	8	1.1	0.05	0.15	85	3	6	0.8	0.15	0.15	95	3
3	8	0.9	0.2	0.05	95	3	6	1	0.05	0.15	85	2
4	6	1.1	0.15	0.1	90	1	8	1.1	0.2	0.05	85	3
5	4	0.9	0.05	0.2	80	3	4	1.1	0.1	0.05	95	4
6	8	0.8	0.1	0.1	80	1	4	0.9	0.2	0.15	85	2
7	6	0.8	0.15	0.15	90	4	2	0.9	0.1	0.2	85	3
8	4	1	0.2	0.15	80	2	6	1.1	0.1	0.2	95	1
9	2	1.1	0.1	0.05	90	4	6	0.9	0.2	0.1	95	2
10	4	1	0.15	0.05	80	4	4	1	0.15	0.05	80	1
11	6	1	0.1	0.15	80	2	8	0.8	0.05	0.05	80	4
12	2	0.9	0.2	0.15	90	2	4	1	0.15	0.15	90	4
13	4	1	0.15	0.1	95	1	2	1.1	0.15	0.2	90	4
14	6	1	0.1	0.2	85	3	2	1.1	0.15	0.1	80	1
15	2	0.9	0.2	0.2	85	1	6	0.9	0.05	0.1	80	4
16	2	0.8	0.05	0.1	95	4	8	1	0.1	0.2	80	2
17	8	1.1	0.05	0.2	95	2	4	0.8	0.1	0.1	90	1
18	8	0.9	0.2	0.1	85	4	8	0.8	0.2	0.2	90	3
19	6	0.8	0.15	0.2	95	4	8	0.9	0.15	0.05	95	2
20	4	1	0.2	0.2	95	4	4	0.9	0.05	0.15	85	3
21	2	1.1	0.1	0.1	85	2	8	1.1	0.05	0.15	95	1
22	6	1.1	0.15	0.1	80	2	2	0.8	0.15	0.2	85	2
23	4	0.9	0.05	0.2	90	2	6	1	0.15	0.1	85	3
24	8	0.8	0.1	0.1	80	4	2	1	0.05	0.1	95	4
25	4	1	0.15	0.05	85	1	8	0.8	0.1	0.1	85	4
26	6	1	0.1	0.15	95	1	4	1	0.2	0.2	95	4
27	2	0.9	0.2	0.15	85	3	4	1	0.2	0.1	85	1
28	6	0.8	0.15	0.2	80	1	6	1	0.1	0.15	90	1
29	4	1	0.2	0.2	90	3	6	0.8	0.2	0.05	90	2
30	2	1.1	0.1	0.1	90	3	2	0.8	0.1	0.15	80	3
31	6	1.1	0.15	0.05	85	4	2	1.1	0.1	0.05	90	4
32	4	0.9	0.05	0.15	85	2	2	0.9	0.2	0.15	80	2
33	8	0.8	0.1	0.05	95	2	6	1.1	0.2	0.05	80	3
34	2	0.8	0.05	0.05	80	3	8	0.9	0.15	0.2	90	3
35	8	1.1	0.05	0.15	90	3	8	1.1	0.05	0.2	80	2
36	8	0.9	0.2	0.05	90	1	4	0.9	0.05	0.1	90	1

Appendix 6: Survey questions

In this appendix the survey questions can be found as well as the choice options. It has also been highlighted where follow-up questions will be asked and when these follow up questions are appearing.

Daily commute

Question	*Choices*
1. How often do you make this trip?	More than 5 times a week 4 to 5 times per week 2 to 3 times per week 1 to 2 times per week More than 1 time per month, less than 1 timer per week Less than1 time per month
2. What is the purpose of your trip?	School Work Other
3. At what time do you depart?	Before 6:00 o'clock Between 6:00 and 7:00 o'clock Between 7:00 and 9:00 o'clock Between 9:00 and 12:00 o'clock Between 12:00 and 15:00 o'clock Between 15:00 and 16:00 o'clock Between 16:00 and 17:00 o'clock Between 17:00 and 18:00 o'clock After 18:00 o'clock
4. With which mode of transport do you cover the longest distance during your trip?	Car (as driver) Car (as passenger) Bus E-bike Bike Walking Train Tram/Metro Other
5. Which additional modes of transport do you use during your trip?	I only use 1 mode of transport Bike Walking Car (as driver) Car (as passenger) Bus E-bike Tram/metro Train Other
6. How long does your trip take from door-to-door in minutes? With this question we are interested in the actual travel time and not the travel time suggested by travel planners.	[Fill in minutes]
7. What distance do you cover during your trip?	[Fill in kilometers]

8. How long does it take from home to the stop/station? Answer in minutes.* **DISPLAY WHEN RESPONDENT SELECTED BUS, TRAIN OR TRAM/METRO IN QUESTION 4*	[Answer in Minutes]
*9. How long does it take from the exit stop/station to your destination?** **DISPLAY WHEN RESPONDENT SELECTED BUS, TRAIN OR TRAM/METRO IN QUESTION 4*	[Fill in minutes]
*10. How often do you need to change to another bus/train/tram/metro during your trip?** **WHEN RESPONDENT SELECTED BUS, TRAIN OR TRAM/METRO IN QUESTION 4*	I do not need to change mode I need to change 1 time I need to change 2 times I need to change more than 2 times
*11. Would it be possible for you to use a car during your trip?** **WHEN RESPONDENT SELECTED BUS, TRAIN OR TRAM/METRO IN QUESTION 4*	Yes, whenever I want Yes, but it depends on members of my household Yes, but it depends on parties outside of my household No, I cannot use a car for this trips, but I can for other trips No, never (ex. no car, no drivers license, etc.)
12. Do you receive any travel allowance? (Examples: kilometer allowance, public transport subscription from work, student travel card, etc.)	Yes, I do No, I need to pay for my own travel expenses
13. How would you rate your current commute on a scale of 1 to 10?	[Rating input]

Familiarity with HOV

Question	*Choices*
13. Were you familiar with the term "HOV" before this survey?	No, I was not familiar with term HOV Yes, I have heard of it
14. Do you know the following or other HOV lines? - *Bravo Direct* - *Brabantliner* - *Other HOV lines*	Yes No
15. Have you used one of the following or other HOV lines? - *Bravo Direct* - *Brabantliner* - *Other HOV lines*	Yes No I do not know
IF THE RESPONDENT ANSWERS "OTHER HOV LINES"WITH "YES" IN QUESTION 14	
*16. With which other HOV lines are you familiar?** **IF THE RESPONDENT ANSWERS "OTHER HOV LINES"WITH "YES" IN QUESTION 14*	[Text answer]
17. Which other HOV lines have you used in the past?	[Text answer]
IF THE RESPONDENT ANSWERED "BUS" IN QUESTION 4 OR QUESTION 5 AND IF THEY	

ANSWERED "YES" FOR ANY OF THE OPTIONS IN QUESTION 14	
18. Do you use one of the following buses for your daily commute?	Bravo Direct Brabantliner Other HOV line

Social demographics

Demographic	*Choices*
What is your year of birth	[Year input] I rather not say
What is your gender?	Female Male Other No answer
Yearly income	I rather not say No own income Less than 10 000 euro 10 000 to 20 000 euro 20 000 to 30 000 euro 40 000 to 50 000 euro 50 000 to 60 000 euro 60 000 to 70 000 euro 70 000 to 80 000 euro 80 000 to 90 000 euro 90 000 to 100 000 euro 100 000 euro or more
What is your main occupation	I rather not say Employed: less than 32 hours per week Employed: more than 32 hours per week Pupil/student Unemployed Retired Other
What are the 4 digits of your postal code?	[Fill in 4 digits of postal code] I rather not say
What is the population of your town?	I rather not say Less than 5 000 inhabitants 5 000 to 25 000 inhabitants 25 000 to 50 000 inhabitants 50 000 to 75 000 inhabitants 75 000 to 150 000 inhabitants More than 150 000 inhabitants

Appendix 7: Final model configuration

In this document it will be explained what the reasoning is behind selecting the final mode: model 5. First the different models will be explained that have been estimated. The utility functions can be seen on the last page of this appendix. After explaining the models, it will be explained why model 4 was estimated, why it was decided to estimate model 5 and why model 5 has been chosen.

4 models were estimated. There are 3 alternatives: the current commute, the regular bus service and the HOV bus service. In model 1 and model 2 only the choice between the bus alternatives was taken fort he estimation. So only 2 utility functions were specified. In model 1 generic parameters were used and only the HOV bus service had a ASC_HOV. In model 3 alternative specific parameters were estimated, with again an ASC for the HOV bus service. In model 1 and model 4 the choice between the regular bus, the HOV bus and the current commute was estimated. The current commute has the attributes travel time and a coding scheme fort o specify the main mode of transport. In model 2 and model 4 has the current commute no ASC. In model 2 and model 4 for bus alternatives have an ASC

	Model 1	Model 2	Model 3	Model 4
Alternatives	BUS, HOV	BUS, HOV, BAS	BUS, HOV	BUS, HOV, BAS
Parameters	Generic	Generic	Alternative Specific	Alternative Specific
Final LL	-1057,28	-1301,87	-1030,32	-1299,29
Adjusted Rho Square	0,544	0,438	0,552	0,435

When one only looks at model 1 and 3 and compares the descriptive statistics it can be seen that model 3 (the model with alternative specific parameters) results in a better model than model 1 (the model with generic parameters). When looking at the models that included the current commute it can be seen that the change from generic parameters to alternative specific parameters not significantly better is (LRS = 5.16 -> 8 extra parameters -> 0.75). From these models model 2 and 4 have the preference, even though the rho-squares are equal. However, models 1 and 3 have been estimated with different choice data then model 2 and 4, therefor this comparison cannot be made anyway. Model 4 and 2 give more useful insight into the potential traveler, so people that do not travel with the bus.

Model 4

Model 4 is the preferred model since it provides more useful insight such as which differences there are between the mode choice for a regular bus service or the HOV bus service. With model 4 one could also see at which travel times or maximum values the regular bus service is equally valued to the HOV bus service. However, extending this model leads to significant improvements

Name	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_H*	-4.29	1.16	-3.7	0.000
ASC_R*	-3.46	1.1	-3.14	0.002
B_ACM	-0.1	0.0257	-3.89	0.000
B_ACM_H	-0.138	0.0269	-5.13	0.000
B_EGM	-0.079	0.0252	-3.13	0.002
B_EGM_H	-0.111	0.0254	-4.38	0.000
B_Mode1_B (Bike)	1.51	0.177	8.5	0.000
B_Mode2_B (PT)	-0.901	0.155	-5.8	0.000
B_FR	0.188	0.0319	5.89	0.000

B_FR_H	0.178	0.0339	5.25	0.000
B_R	0.0161	0.0122	1.32	0.188
B_R_H	0.0313	0.0129	2.42	0.015
B_S1	-0.292	0.189	-1.54	0.122
B_S1_H	-0.463	0.193	-2.39	0.017
B_S2	-0.98	0.217	-4.51	0.000
B_S2_H	-1.06	0.223	-4.75	0.000
B_S3	-1.65	0.24	-6.88	0.000
B_S3_H	-1.95	0.261	-7.49	0.000
B_TT_B	-0.076	0.00974	-7.81	0.000
B_VTT	-0.0871	0.0127	-6.88	0.000
B_VTT_H	-0.0794	0.0134	-5.94	0.000

*The current commute was set as the base case fort he estimation

Model 5

In model 4 the coding scheme for the main mode only included bike and PT as modes. In model 5 the mode has been expressed in 3 coded parameters. The car is the reference mode and set to 0. PT has been split into bus and train. The log-likelihood improves by 16 points, which is a significant change over model 4.

$$V_{reg} = \beta_{FR} \cdot FR_{reg} + \beta_{VTT} \cdot VTT_{reg} + \beta_{AC} \cdot AC_{reg} + \beta_{EG} \cdot EG_{reg} + \beta_{RL} \cdot RL_{reg} + \beta_{ST1} \cdot ST1_{reg} + \beta_{ST2} \cdot ST2_{reg} + \beta_{ST3} \cdot ST3_{reg} + ASC_{reg}$$

$$V_{hov} = \beta_{FR} \cdot FR_{hov} + \beta_{TT} \cdot VTT_{hov} + \beta_{AC} \cdot AC_{hov} + \beta_{EG} \cdot EG_{hov} + \beta_{RL} \cdot RL_{hov} + \beta_{ST1} \cdot ST1_{hov} + \beta_{ST2} \cdot ST2_{hov} + \beta_{ST3} \cdot ST3_{hov} + ASC_{hov}$$

$$V_{bas} = \beta_{TT,bas} \cdot TT_{bas} + \beta_{Mode1,bas} \cdot Mode1_{bas} + \beta_{Mode2,bas} \cdot Mode2_{bas} + \beta_{Mode3,bas} \cdot Mode3_{bas}$$

The only implication is that the sample bus travelers is 18 for the main mode and 22 take the bus a secondary mode. The parameters values are significant. Looking at the percentage it can be however concluded that this reflects realistic proportions. In the survey data 9% of the commuters is bus users and according to the data of the Dutch government 8% of commuters use the bus. This reflects the preference for the bus and train in a better way. Most parameters value did not change looking at model 4, but the LL and rho-square has been improved. The parameter of the bus as main mode was compared with the bus alternatives and it was seen that this resulted in modal splits that are almost 50/50. The current commute always has a slight preference.

Name	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_H*	-4.37	1.16	-3.76	0.000
ASC_R*	-3.45	1.12	-3.1	0.002
B_ACM	-0.106	0.0256	-4.15	0.000
B_ACM_H	-0.139	0.0265	-5.24	0.000
B_EGM	-0.0812	0.026	-3.12	0.002
B_EGM_H	-0.117	0.0251	-4.69	0.000
B_Mode1_B (Bike)	1.51	0.177	8.54	0.000
B_Mode2_B (Train)	-0.569	0.169	-3.36	0.001
B_Mode3_B (Bus)	-2.08	0.284	-7.32	0.000
B_FR	0.188	0.0321	5.87	0.000
B_FR_H	0.182	0.034	5.35	0.000
B_R	0.0163	0.0123	1.32	0.187
B_R_H	0.0321	0.013	2.48	0.013

B_S1	-0.296	0.191	-1.55	0.121
B_S1_H	-0.472	0.192	-2.46	0.014
B_S2	-0.988	0.218	-4.53	0.000
B_S2_H	-1.07	0.221	-4.82	0.000
B_S3	-1.65	0.244	-6.79	0.000
B_S3_H	-1.98	0.26	-7.59	0.000
B_TT_B	-0.0763	0.00994	-7.68	0.000
B_VTT	-0.0874	0.012 8	-6.83	0.000
B_VTT_H	-0.0791	0.0134	-5.92	0.000

Final log likelihood: -1283.752 (LRS met model 2 and 4 = 31.538; 1 extra parameter; <0.01)
Rho bar square (null): 0.441 (+0.006)

As a verification the model was estimated with generic parameters for the busses as variation of model 2 and model 3 but with coded parameters for mode.

Final log likelihood: -1286.88
Rho bar square (null): 0.444

Both are significantly better then the previous model with small difference between them. There is not much difference between model 5 with generic parameters or with alternative specific parameters (LRS = 6.256, 8 extra parameters, 0.75). Based on the usefulness it can be said that model 5 with alternative specific parameters is more useful and has the preference therefore.

Model Choice

The preference goes towards model 5 with alternative specific constants. It has the preference because all considerations are taken into account and also because of the representativeness, significance, insightfulness and usefulness.

Utility functions

Generic parameters

Model 1

$$V_{reg} = \beta_{FR} \cdot FR + \beta_{VTT} \cdot VTT + \beta_{AC} \cdot AC + \beta_{EG} \cdot EG + \beta_{RL} \cdot RL + \beta_{ST1} \cdot ST1 + \beta_{ST2} \cdot ST2 + \beta_{ST3} \cdot ST3$$

$$V_{hov} = \beta_{FR} \cdot FR + \beta_{VTT} \cdot VTT + \beta_{AC} \cdot AC + \beta_{EG} \cdot EG + \beta_{RL} \cdot RL + \beta_{ST1} \cdot ST1 + \beta_{ST2} \cdot ST2 + \beta_{ST3} \cdot ST3 + ASC_{hov}$$

Model 2

$$V_{reg} = \beta_{FR} \cdot FR + \beta_{VTT} \cdot VTT + \beta_{AC} \cdot AC + \beta_{EG} \cdot EG + \beta_{RL} \cdot RL + \beta_{ST1} \cdot ST1 + \beta_{ST2} \cdot ST2 + \beta_{ST3} \cdot ST3 + ASC_{reg}$$

$$V_{hov} = \beta_{FR} \cdot FR + \beta_{VTT} \cdot VTT + \beta_{AC} \cdot AC + \beta_{EG} \cdot EG + \beta_{RL} \cdot RL + \beta_{ST1} \cdot ST1 + \beta_{ST2} \cdot ST2 + \beta_{ST3} \cdot ST3 + ASC_{hov}$$

$$V_{bas} = \beta_{TT,bas} \cdot TT_{bas} + \beta_{Mode1,bas} \cdot Mode1_{bas} + \beta_{Mode2,bas} \cdot Mode2_{bas}$$

Alternative specific parameters

Model 3

$$V_{reg} = \beta_{FR} \cdot FR_{reg} + \beta_{VTT} \cdot VTT_{reg} + \beta_{AC} \cdot AC_{reg} + \beta_{EG} \cdot EG_{reg} + \beta_{RL} \cdot RL_{reg} + \beta_{ST1} \cdot ST1_{reg} + \beta_{ST2} \cdot ST2_{reg} + \beta_{ST3} \cdot ST3_{reg}$$

$$V_{hov} = \beta_{FR} \cdot FR_{hov} + \beta_{TT} \cdot VTT_{hov} + \beta_{AC} \cdot AC_{hov} + \beta_{EG} \cdot EG_{hov} + \beta_{RL} \cdot RL_{hov} + \beta_{ST1} \cdot ST1_{hov} + \beta_{ST2} \cdot ST2_{hov} + \beta_{ST3} \cdot ST3_{hov} + ASC_{hov}$$

Model 4

$$V_{reg} = \beta_{FR} \cdot FR_{reg} + \beta_{VTT} \cdot VTT_{reg} + \beta_{AC} \cdot AC_{reg} + \beta_{EG} \cdot EG_{reg} + \beta_{RL} \cdot RL_{reg} + \beta_{ST1} \cdot ST1_{reg} + \beta_{ST2} \cdot ST2_{reg} + \beta_{ST3} \cdot ST3_{reg} + ASC_{reg}$$

Model 5

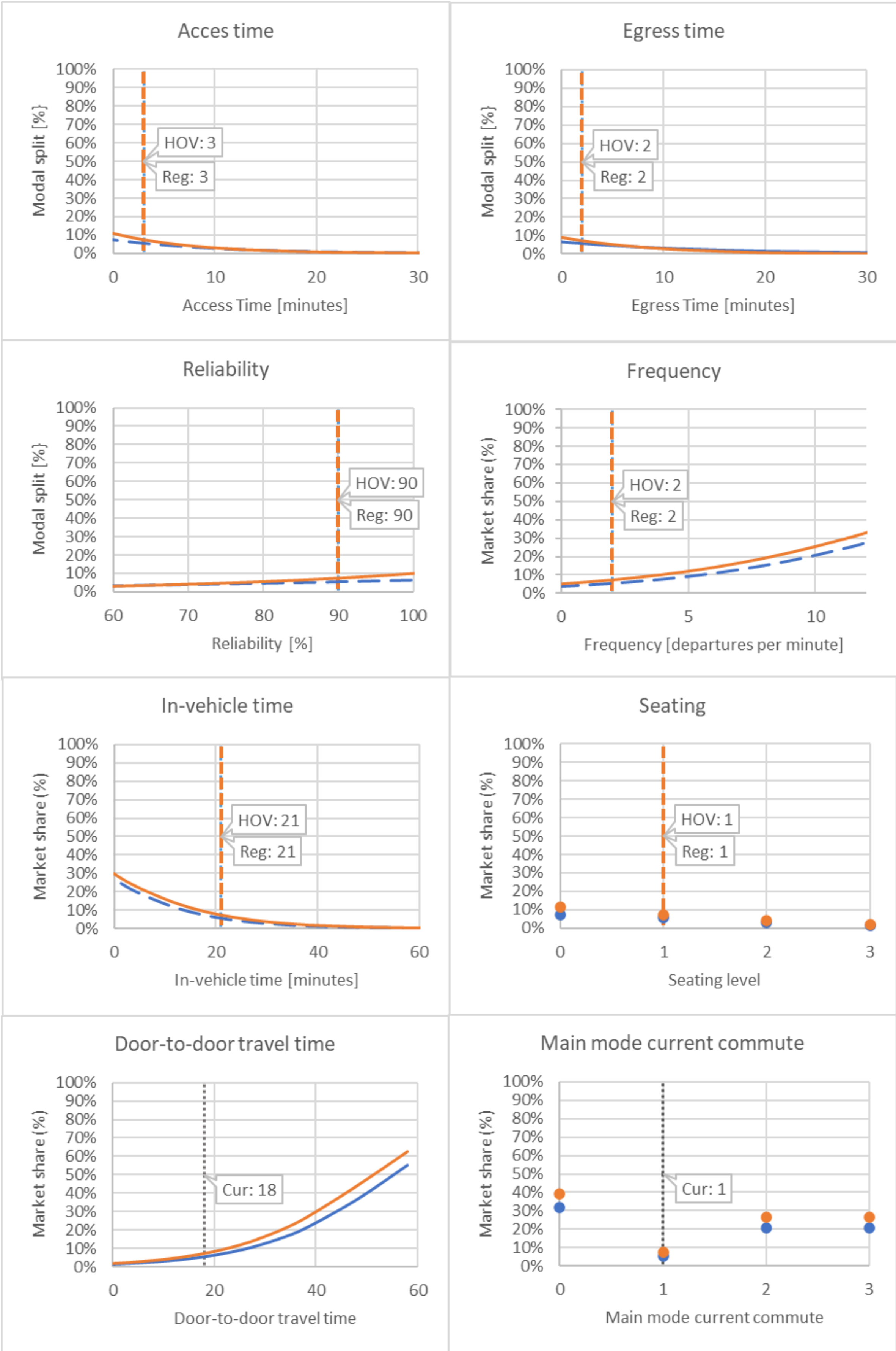
$$V_{reg} = \beta_{FR} \cdot FR_{reg} + \beta_{VTT} \cdot VTT_{reg} + \beta_{AC} \cdot AC_{reg} + \beta_{EG} \cdot EG_{reg} + \beta_{RL} \cdot RL_{reg} + \beta_{ST1} \cdot ST1_{reg} + \beta_{ST2} \cdot ST2_{reg} + \beta_{ST3} \cdot ST3_{reg} + ASC_{reg}$$

$$V_{hov} = \beta_{FR} \cdot FR_{hov} + \beta_{TT} \cdot VTT_{hov} + \beta_{AC} \cdot AC_{hov} + \beta_{EG} \cdot EG_{hov} + \beta_{RL} \cdot RL_{hov} + \beta_{ST1} \cdot ST1_{hov} + \beta_{ST2} \cdot ST2_{hov} + \beta_{ST3} \cdot ST3_{hov} + ASC_{hov}$$

$$V_{bas} = \beta_{TT,bas} \cdot TT_{bas} + \beta_{Mode1,bas} \cdot Mode1_{bas} + \beta_{Mode2,bas} \cdot Mode2_{bas} + \beta_{Mode3,bas} \cdot Mode3_{bas}$$

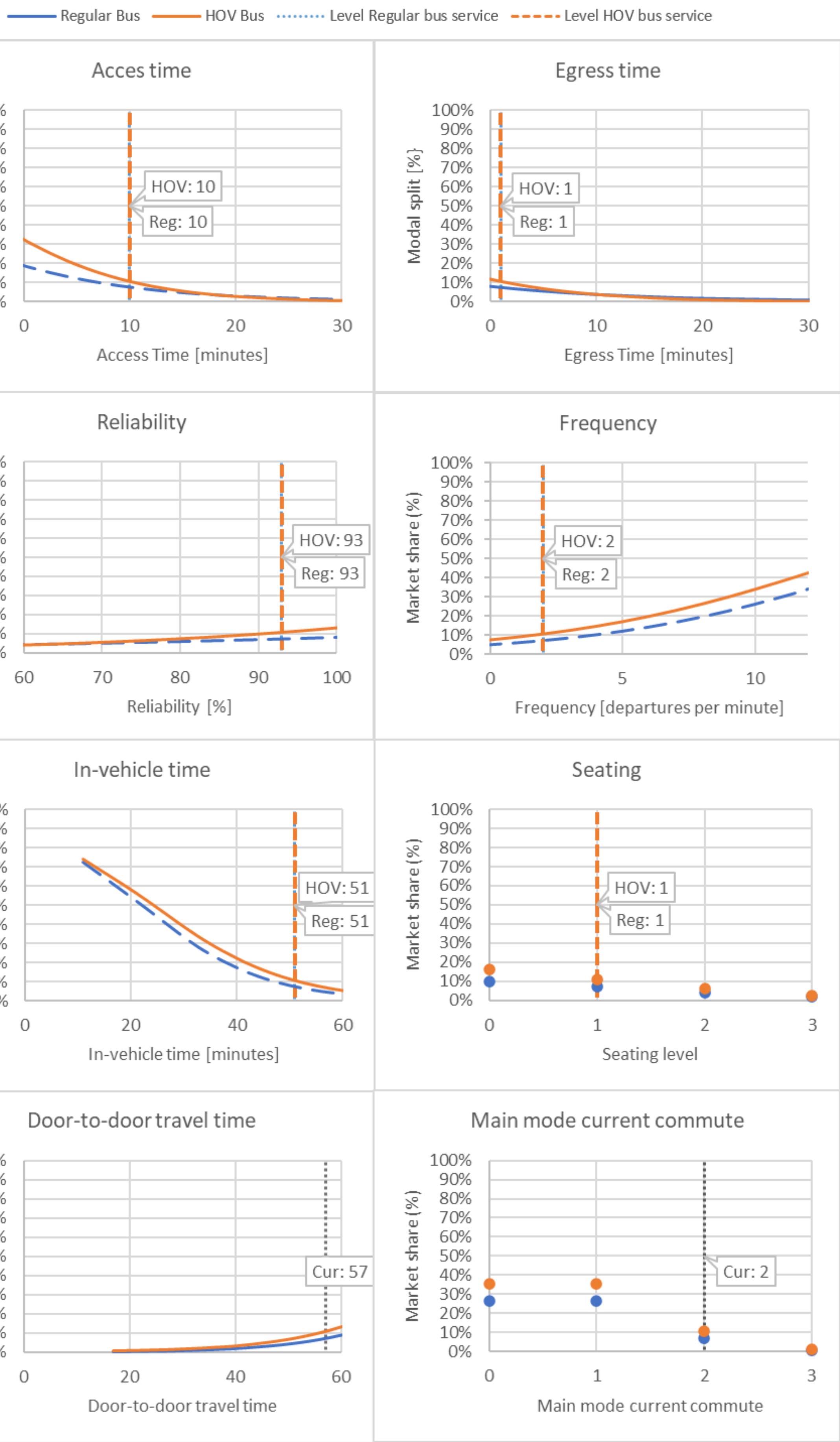
Appendix 9: Probability functions for cases

Case 1:

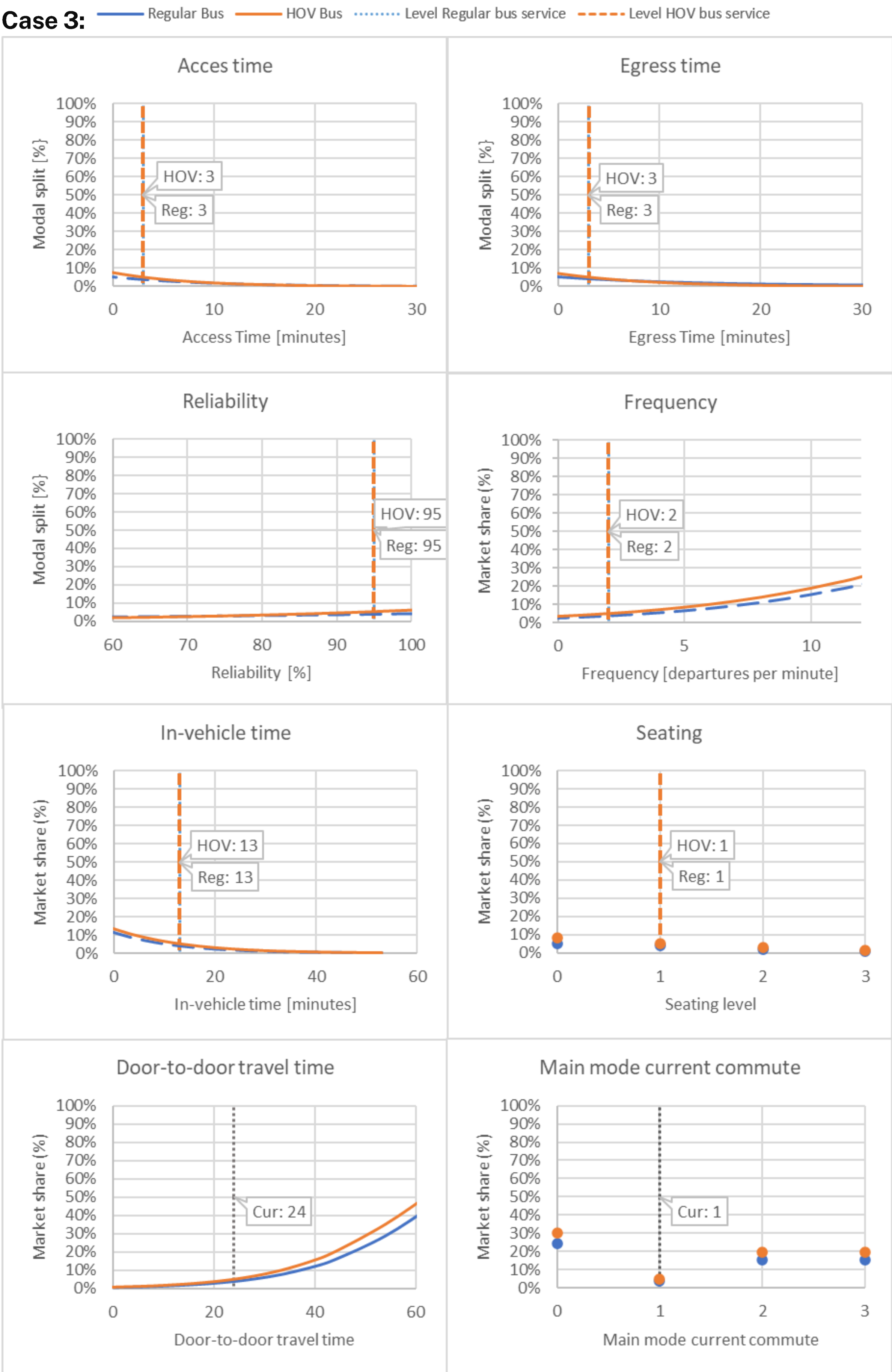


Acces time
Modal split [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
HOV: 3
Reg: 3
0
10
20
30
Access Time [minutes]
Egress time
Modal split [%]
HOV: 2
Reg: 2
Egress Time [minutes]
Reliability
Modal split [%]
HOV: 90
Reg: 90
60
70
80
90
100
Reliability [%]
Frequency
Market share (%)
HOV: 2
Reg: 2
5
Frequency [departures per minute]
In-vehicle time
Market share (%)
HOV: 21
Reg: 21
40
60
In-vehicle time [minutes]
Seating
Market share (%)
HOV: 1
Reg: 1
1
2
3
Seating level
Door-to-door travel time
Market share (%)
Cur: 18
Door-to-door travel time
Main mode current commute
Market share (%)
Cur: 1
Main mode current commute

Case 2:


Regular Bus
HOV Bus
Level Regular bus service
Level HOV bus service
Acces time
Modal split [%]
HOV: 10
Reg: 10
Access Time [minutes]
Egress time
Modal split [%]
HOV: 1
Reg: 1
Egress Time [minutes]
Reliability
Modal split [%]
HOV: 93
Reg: 93
Reliability [%]
Frequency
Market share (%)
HOV: 2
Reg: 2
Frequency [departures per minute]
In-vehicle time
Market share (%)
HOV: 51
Reg: 51
In-vehicle time [minutes]
Seating
Market share (%)
HOV: 1
Reg: 1
Seating level
Door-to-door travel time
Market share (%)
Cur: 57
Door-to-door travel time
Main mode current commute
Market share (%)
Cur: 2
Main mode current commute

Case 3:


Regular Bus
HOV Bus
Level Regular bus service
Level HOV bus service
Acces time
Modal split [%]
HOV: 3
Reg: 3
Access Time [minutes]
Egress time
Modal split [%]
HOV: 3
Reg: 3
Egress Time [minutes]
Reliability
Modal split [%]
HOV: 95
Reg: 95
Reliability [%]
Frequency
Market share (%)
HOV: 2
Reg: 2
Frequency [departures per minute]
In-vehicle time
Market share (%)
HOV: 13
Reg: 13
In-vehicle time [minutes]
Seating
Market share (%)
HOV: 1
Reg: 1
Seating level
Door-to-door travel time
Market share (%)
Cur: 24
Door-to-door travel time
Main mode current commute
Market share (%)
Cur: 1
Main mode current commute

Understanding the commuters' choice for HOV bus services in regards to regular bus services in the Netherlands

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for high-level of service buses in the Netherlands

Aaron S. Eichler

14th of November 2023

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