Predicting bus ridership

Development of a framework

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Predicting bus ridership

Development of a framework

MSc Thesis

by

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"Als dit pas het begin is, waar eindigt het dan?"

-Unknown

Executive summary

Keywords: Bus ridership, ridership prediction, public transport modelling, level-of-service, elasticity

Problem introduction

Since the introduction of 'Wet personenvervoer 2000', public transport in The Netherlands became subject to tendering (Veeneman, 2016). In the tendering process, which is a short but intensive period, the network and level-of-service (LOS) supplied is reconsidered. Substantiation of predicted growth/decline in ridership is required; both for the public transport authority as for the business case of the public transport operator.

EBS, as a public transport operator, is in need of a model which can help them in understanding behavior of (potential) passengers after LOS changes and therewith predict future ridership. Bus transit ridership is subject to numerous factors with mutual interaction, such that predicting ridership is far from straightforward (Van Wee and Banister, 2016). During tenders, time and input data is limited and at the same time sufficiently substantiated predictions are requested. Current models are not suitable for efficient and accurate ridership prediction. Models are either too extensive and time consuming, requiring huge amounts of input data, or the models are too simplistic and inaccurate. Currently available models for prediction during tenders have a large variety of outcomes under the same input. Furthermore, these available models are based on ancient data and often not based on empirical studies. There is an absence of recent, empirical elasticity studies in The Netherlands (MuConsult B.V., 2015), such that accurate model parameters are unavailable. The lack of recent, Dutch-context predictors, and by extension a model that integrates these into a framework, inspires the following main research question:

> Which relations between level-of-service and ridership can be derived from Dutch bus transportation, being both recent and data based and how can they be translated into a model suitable for tendering?

This thesis adds to current knowledge by providing an empirical data analysis on elasticities of recent, Dutch cases and the development of a ridership prediction model at a different scale and with different boundary conditions than current models. It is hypothesized that an improvement in LOS leads to an increase in ridership; a deterioration in LOS to a decrease in ridership. The research is focused on bus ridership in The Netherlands and recent data (2012-2019). In order to develop the most suitable methodology, a literature review is presented. The literature review focuses on finding the variables which should be included in the data analysis and model, and the type of model that should be developed.

Literature review

The magnitude of bus ridership growth/decline is determined by numerous factors, which can for the purpose of this research be subdivided into two categories: Level-of-Service (LOS) related factors and Non-Level-of-Service related factors (table 1). The focus is on those factors leading to a short-term change in ridership.

Table 1: Overview of level-of-service and non-level-of-service factors of influence on bus ridership.

LOS factors	non-LOS factors
Travel time	Economy & demography
Frequency	Urban development
Transfers	Fares
Access/egress	Competing modes
Crowding	Weather
Reliability	One-time events
Comfort of the buses	
Bus type	
Demand responsive alternative	

Different models are currently present for predicting bus ridership. A distinction can be made into four conceptual model categories (adjusted based on Van Oort et al., 2015):

- Multimodal transport models, such as the 4-step model. This is an extensive model including production and attraction of trips, distribution of those trips over zones, mode choice and assignment of those trips over the network (Ortuzar and Willumsen, 2011).
- Elasticity models. Models based on elasticities, i.e. the relative change in an independent variable leading to a relative change in a dependent variable.
- Quick-scan models. Simple calculation rules or rules of thumb, often based on assumptions (Expert interview F. van der Blij).
- Non-transportational models. Models that are not based on transport engineering principles, but predict ridership based on external data, e.g. usage of travel planners (Van Roosmalen, 2019).

Table 2: A comparison of the four different model types with the requirements transparent, easy-to-use and accurate.

	Multimodal (4-step)	**Elasticity**	**Quick-scan**	**Non-transportational**
Transparent	**-**	**0**	**0**	**0**
Easy-to-use	**-**	**+**	**+**	**-**
Accurate	**+**	**0**	**-**	**-**

For tender suitability, the models should be transparent, easy-to-use and accurate. Each of the model types are scored based on these requirements (table 2). The large scale transport models are elaborate, requiring extensive amounts of inputs and computation time and are therefore unsuitable. Elasticity models can be developed in different forms and different inputs, dependent on the level of detail required. They often suffice with a single input and provide instant computation. A growth factor for each variable can be applied to current ridership numbers. Quick-scan models, which are often simple calculation spreadsheets or rules of thumb, do not provide the required amount of detail. They are mostly based on very rough assumptions and are often not accepted as substantiation during a tender. Non-transportational models are still underdeveloped and therefore score negatively on the requirements easy-to-use and accurate. Based on the set of requirements, the elasticity model is deemed most suitable.

Continuing from these conceptual model categories, there are three known, existing models, which are possibly suitable for ridership prediction during tenders: Waaier van Brogt (Goudappel Coffeng, 2013), Effov tables and the VF model by Van Goeverden and Van den Heuvel (1993). They provide a (very) large range of outcomes and the origin of the models is sometimes unknown. They do not seem to meet the accuracy requirement. This indicates that empirical analysis of recent data is necessary to find out which elasticities are really present in bus public transportation nowadays.

Methodology & data description

The empirical analysis to derive relations between ridership and level-of-service is performed based on a before-after study. In this before-after study, the change in ridership after a level-of-service change is determined and translated into a growth factor and elasticity. These elasticities can then later be used to calibrate a model. The before-after study and the development of the model consist out of 8 steps (figure 1).

The cases and variables that can be included in the model are dependent on the availability of data. Detailed data of concessions Waterland (2012-2019) and Voorne-Putten & Rozenburg (2019 only) is available. From concession Groningen-Drenthe, less detailed data (OD-tables per month) for a small selection of lines is available. Availability of data from three concessions makes comparison over regions possible. The LOS changes that can be analyzed in the data are mostly in-vehicle time and frequency. An expert meeting is used to put the results of the data analysis into context. The second-last step is to translate the results of the before-after study into a model. Since the model is unable to provide a ridership prediction in certain specific cases, a selection of those specific cases are analyzed to provide tools for ridership prediction. Those cases include the effect of urban development and implementation of new stops, the influence of schools on ridership, the duration of an implementation period and the expansion of operating hours.

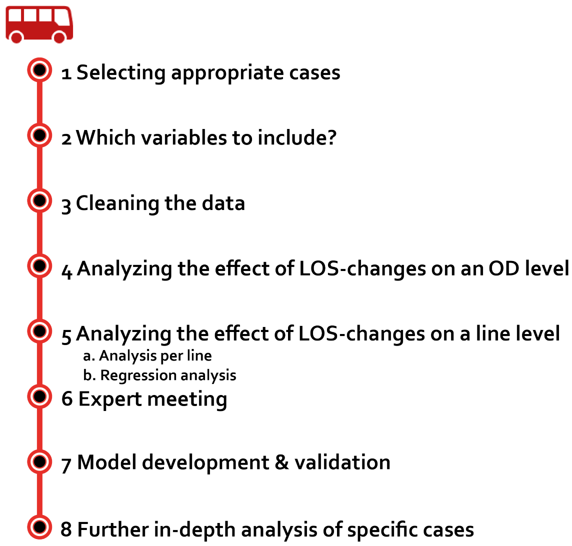

Figure 1: Methodology overview.

Data analysis result highlights
For the data analysis, data from three concessions is used (figure 2). Two approaches are used to analyze the effect of LOS changes. In the OD-pair based analysis, two issues are observed: (1) The spread of the results is large; the fit is bad ($R^2 < 0.23$ in all variants). (2) There is abundant a-typical behavior. I.e., OD-pairs with an improved level-of-service showing a decrease in ridership and vice versa. These results from the OD-based analysis are not sufficient to lead to a model. The distortions found include interaction between bus stops in each other's vicinity, influence of the network, stochastic variation and importance of context. In the line-based analysis, the effect of these issues diminishes or can be compensated, since the data analysis is more aggregated. 31 lines are analyzed. The results of the analysis based on lines show trends which are in line with the hypothesis and literature, but still a large range of growth factors and elasticities is shown (figures 3, 4).

Figure 2: Summary of the case studies.

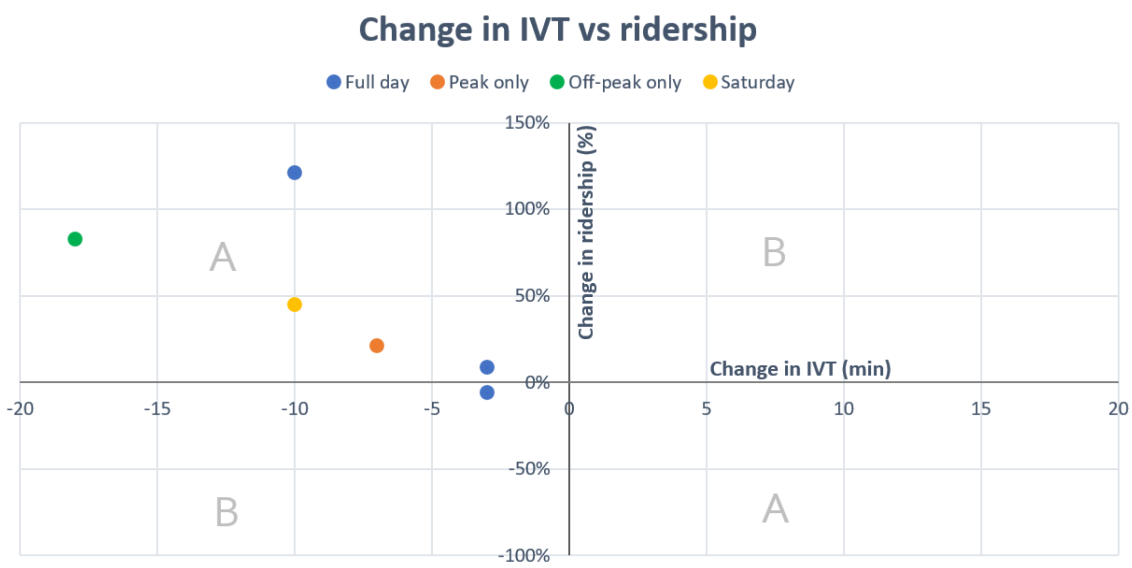

Figure 3: The change in in-vehicle time versus the change in ridership of the line-based analysis. Note that the growth factors refer to the growth over the full day, regardless of the hours in which the measure has been implemented.

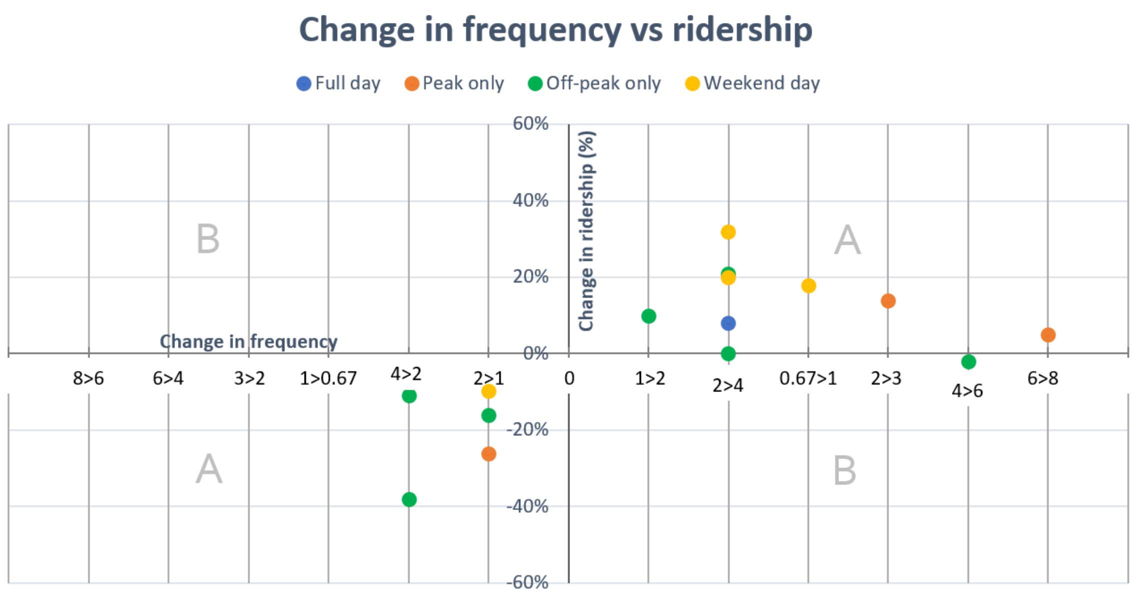

Figure 4: The change in frequency versus the change in ridership of the line-based analysis. Note that the x-axis is not continuous, but bin-based.

The ranges of values are large and no converging model parameters can be found. Opposed to the OD-based analysis, no in-explainable a-typical behavior is present. When comparing the results with literature and the three known models (Waaier van Brogt, Effov tables and the VF-model), IVT results found in this thesis appear to have much larger elasticities. For frequency elasticities, the effect seems to be overestimated by literature and the known models. The range of elasticities is much larger than acknowledged by literature, for both IVT and frequency (figures 5 and 6). Also, again the relevance of context arises. Product usage shows that infrequent travelers and students are the most sensitive user groups. To further analyze the results and a possible relation, a regression analysis is performed.

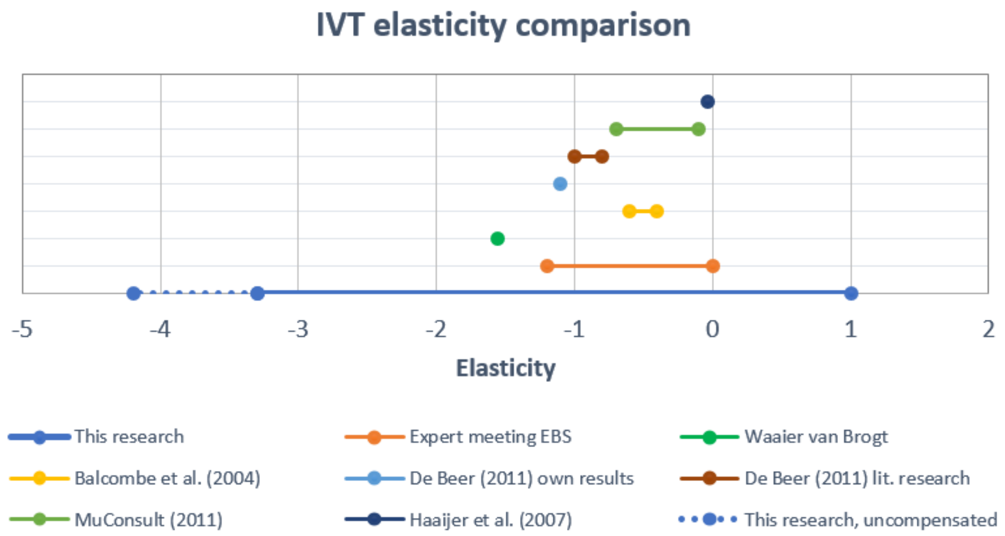

Figure 5: IVT elasticties compared to literature. The dotted line illustrates the larger range if the WL103b elasticity would not be compensated for the fare decrease.

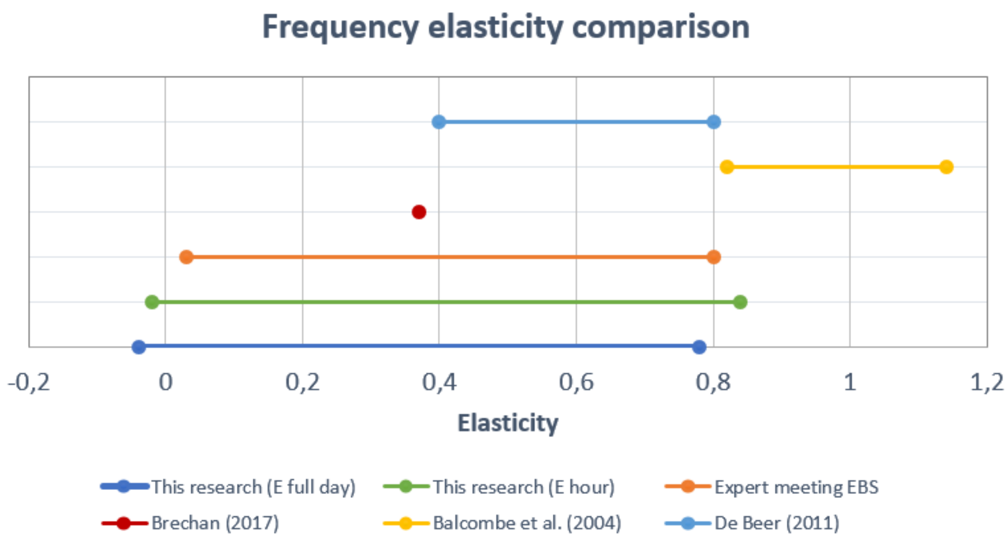

Figure 6: Frequency elasticties compared to literature. Note that Expert meeting EBS is comparable to This research (E full day) and all literature values are comparable to This research (E hour).

The regression analysis is limited by the low number of data points: 27 suitable for regression; of which 6 for IVT, 16 for frequency, 1 for both IVT and frequency and 4 for additional LOS factors. The relation between ridership change and IVT is only significant in half of the regression model designs; the relation between ridership change and relative frequency change is significant. Other factors, such as type of line, urbanity, price change and main user group are significant, dependent on how the regression is designed. Due to the low amount of cases and the inconclusive outcomes, the results of the regression should be only interpreted as indicative results, rather than conclusive results.

The data analysis show that the line-based approach shows much more promising results than the OD-based approach, but that a converging, continuous model is not possible based on the data set present. At the same time, the importance of context is shown multiple times. To lead to a usable model, all cases are presented individually in a so-called comparison model. Within each case, not only the growth factors are presented, but also the context.

The model

The model that is developed in this thesis needs to meet a selection of criteria, mainly meant for suitability for tender usage. All criteria are met either by the data that forms the input of the model, the conceptual design and the user interface design. The model that is created is a comparison model in Excel: the Case Study Search Engine (CSSE). A comparison model refers to the model matching case characteristics assigned by the user (the request) with cases in a data base. Cases with comparable characteristics are presented to the user, who can then open a data sheet with all information necessary for ridership prediction (figure 7). The request includes the LOS change, e.g. a frequency increase, but also further selection criteria can be used. These selection criteria, such as type of line, main user group and region are optional and can be used to further filter the data set (figure 8). The selection criteria are all easily obtainable, making the model fast and simple in usage. After the user has found one or multiple lines with comparable characteristics, the data sheets of those lines provide a large quantity of information. This data includes the growth factors (also per hour blocks if possible), the general characteristics of the line (bus type, IVT, frequency, VF, competing modes), 5 graphs indicating the usage of the line and the product types used, characteristics of the area (inhabitants, density, important destinations etc.) and important remarks about either the data analysis or the context of the line. The range of the growth factor after compensation for non-LOS factors is also shown. It is then up to the user to decide whether the case is sufficiently equivalent to the request and whether the growth factors can be used for ridership prediction. The growth factor is the outcome which the user can use for a numerical prediction of ridership change.

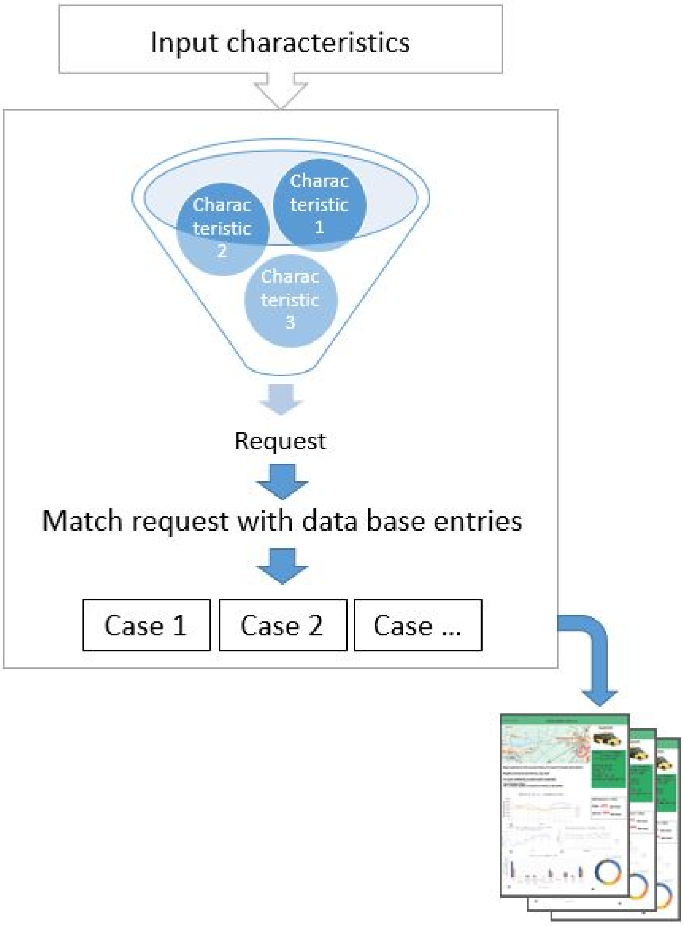

Figure 7: A schematic overview of the concept of the model: Finding a match between cases in the data base and input characteristics and presenting data sheets of those matches.

The model is validated in two steps. The tool is validated by testing the amount of measures it can give a ridership prediction for in a recent tender. Whereas the originally used model could provide a prediction for 67% of the measures, the CSSE can do this for 75% of the measures. For those categories of measures the CSSE cannot provide a ridership prediction at this stage, in-depth analysis of specific cases is performed. These lead to a set of tools EBS can use when the model does not provide ridership predictions. Examples of this are expansion of operating hours and the effect of urban development. The second step of validation is to compare the ridership prediction with real-world cases. In some cases the prediction matches rather well with the real-world ridership change, in some other cases there is still quite some variation. This variation will likely be more limited once more cases are added to the CSSE. The flow chart of the data analysis and model development is now completed (figure 9).

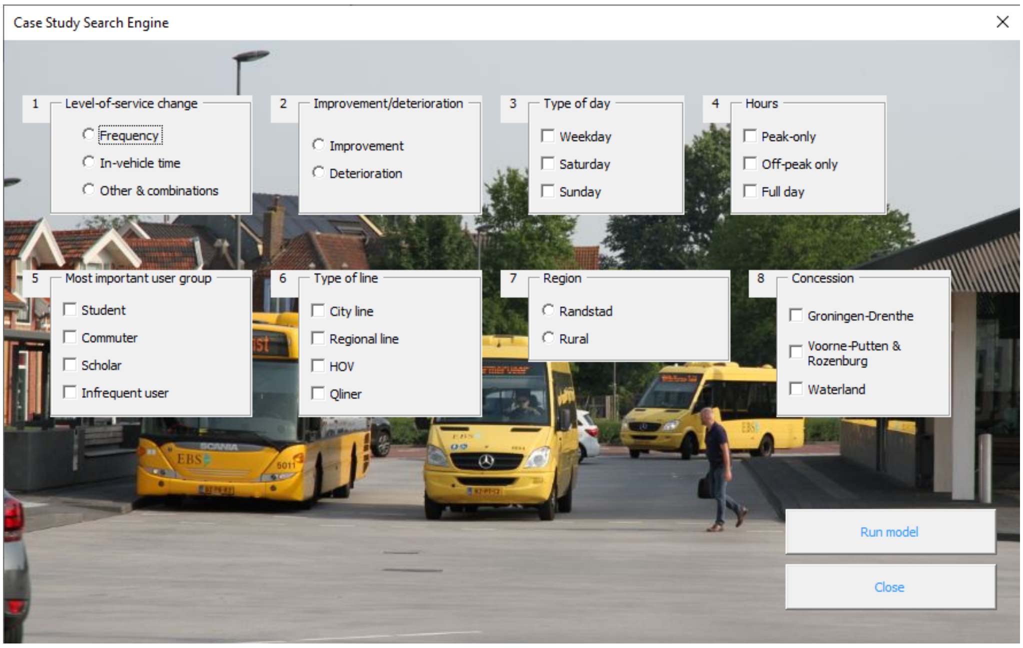

Figure 8: Search engine interface

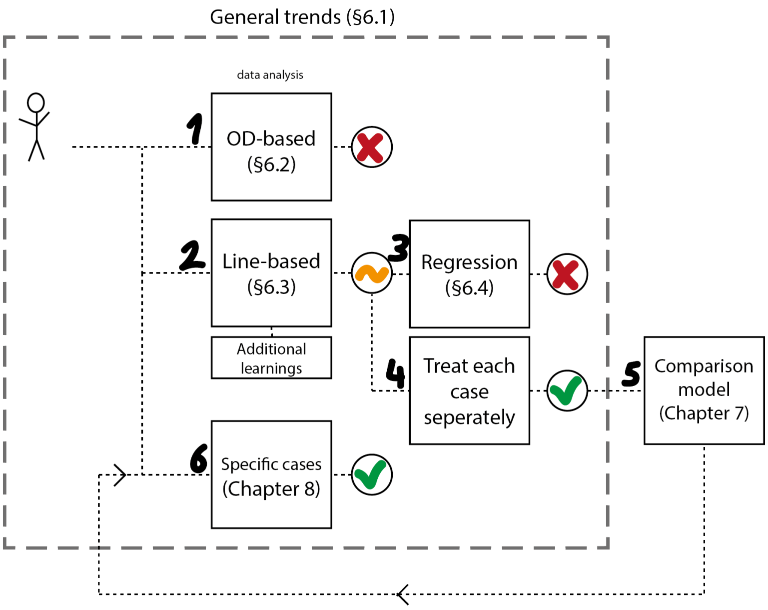

Figure 9: Flow chart of how the data analysis results lead to the model design.

Discussion & recommendations highlights

The analyses have shown that an analysis per OD-pair (stop-to-stop) leads to too much variation in the results to find satisfying relationships. This stresses that current models using an OD-basis should be reconsidered. Furthermore, one should be aware of network effects, since people might change origin, destination and routing. This thesis emphasizes that elasticities occur in ranges and should be presented and used as such. Integrating them into a model is complex. Context is vital to determine where in the range of elasticities the effect of a measure falls. The importance of context is acknowledged by experts, but at the same time barely applied in elasticities in literature.

In the data, transfers cannot be identified. The consequence is that it is more difficult to analyze changes in behavior in the before-after study, since their full trip is invisible. Furthermore, it results in the effect of transfers on ridership cannot be predicted with the developed model. The content of the model's database is limited and should be extended to fill current gaps in LOS changes. All in all, the model provides a suitable tool for the user to predict ridership, although part of the responsibility still lies with the user.

The most important recommendations for future research and the scientific world are the following: Elasticities occur in ranges and should be presented as such. Furthermore, context should be added to the elasticities presented to help the user select an applicable elasticity. For further research, elasticities should be reviewed in data sets with disaggregate data and visible transfers, such that the effect over the full network can be determined. Also, the interaction between peak and off-peak ridership should be researched.

The most important recommendations to EBS and the public transport world are the following: More cases should be included in the CSSE. When more cases have been added, it must be re-analyzed whether converging modelling parameters can be found or regression provides conclusive results. Furthermore, not only the effect of level-of-service changes on a single line should be analyzed, but the full network effect.

Conclusions
Elasticities occur in much larger ranges than previously acknowledged by literature, with context being essential in determining the magnitude of the elasticity. With the development of the CSSE, a new, empirical based model for substantiation of ridership prediction exists. It meets all the requirements set. The line-based analysis is a suitable approach for answering the main research question, as long as context is taken into consideration. The hypothesis that an increase in level-of-service leads to an increase in ridership can be accepted, when considering lines/clusters. Despite, a much wider range is seen then what is expected based on literature. A regression analysis might lead to valuable results, however, with the few data points available in this thesis no inconclusive results are produced. Development of a model is possible and performed, but context should be included. The main research question can be answered as follows:

> *Which relations between level-of-service and ridership can be derived from Dutch bus transportation, being both recent and data based and how can they be translated into a model suitable for tendering?* The before-after study on line basis shows that there is a large variability in ridership growth with level-of-service changes, based on 31 cases. On an aggregated scale, an increase in level-of-service leads to an increase in ridership; on an OD-based level of detail there is more variation. Elasticities have a large range; context and network effects play a vital role and influence the magnitude of the elasticity and resulting ridership growth. Graphs, tables and/or single elasticity values can be misleading, since they lack context. Integrating elasticities into a model is complex. The Case Study Search Engine, a comparison model, enables inclusion of the context and honoring of the results, while still the requirements for tender suitability are met.

Empirical data analysis has been performed, providing recent, Dutch elasticity values for bus transportation, which was a lack of in literature. The CSSE enables a better substantiation of measures applied by the public transport operator and ridership predictions; e.g. during tenders. The model requires further development, but the framework developed in this thesis is scalable and future proof. At the moment, the user input is crucial to enable a transparent, easy-to-use and accurate tool to enable suitability for the tender environment within EBS. The insights obtained and the framework developed in this thesis enables transport engineers to make a better prediction of what the effects of proposed LOS changes are. Improved predictions of the effect of LOS changes on ridership can improve the quality of bus services for (potential) passengers. Improved predictions can thus lead to LOS better meeting the demands of the (potential) users and a more optimized network.

Contents

Preface

If anyone would ask me what the place is I am most comfortable in, I would answer the bus. The bus is a beautiful product which gives you the opportunity to enjoy the landscape, the presence of many inspiring individuals, a warm and cozy environment, the peaceful humming of the engine and enables you to spend your time as you wish. Despite, most people see the bus as a necessary evil they'd rather avoid. A job for the transport engineers to optimize the bus system to better fit to the needs and wishes of (potential) passengers. Not just for the sake of sustaining their own profession, but also because public transport might be the key to creating a sustainable world. We can no longer afford to drive our individual car and even if we could, do we still want to? Why spend time driving a car, if we can spend our time working or relaxing in a bus?

Starting my Transport & Planning master has never been an obvious choice for me as a former Applied Earth Sciences student. Luckily I decided to step into the office of my student advisor with my weird plan and he told me 'why not, go for it' and started making phone calls to master coordinators and professors. Without this support I might have never dared to make this choice. A choice I never regretted, because I found a field of studies and work where I feel at home and passionate about. A field that is not only has a future in itself, but (hopefully) also a future for me.

Over the past months I got the chance to set my first steps in the public transportation world. I was happy to find out that actually sitting in the bus is already part of the job and, in my opinion, an essential one. We can analyze life with numbers from behind a computer, but passengers are more than numbers. Apart from the fact that numbers are not always as straightforward and correct as we would like to think.

This thesis would not have been formed without the help of many people. I would like to express my gratitude towards everyone involved in this project. In special my daily supervisor Niels van Oort, my company supervisor Marc Stikvoort, my unofficial company supervisor Marcel Fledderus and my valuable source of inside knowledge Joost Rienderhoff. Also my gratitude towards Bart van Arem and Jan Anne Annema, for their participation in my thesis committee and their input in this project and my personal development. Furthermore, my gratitude towards everyone I have spoken with, to increase my knowledge, in special all the field experts. Also thanks to OV Bureau Groningen-Drenthe, for their willingness to share vital data and knowledge on bus transportation in their region and their expert view on the subject. I would also like to express my gratitude towards Nederlandse Spoorwegen (NS), Metropool Regio Den Haag Rotterdam (MRDH), Gemeente Hoorn, Gemeente Alkmaar and Tom Schilder from Gemeente Edam-Volendam for providing additional data. And lastly, thanks to everyone at EBS for welcoming me into the company, making me feel part of the team and giving me all the chances to get a taste of the industry. And I am very happy to conclude that the job of a transport engineer is an essential one.

For now, it is time to depart from my student life. But I sincerely hope that everyone hops on my bus and continues being around during the rest of my journey.

Jasper de Lanoy
Zwolle, 28 November 2019

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List of Abbreviations

Amsterdam CS	Amsterdam Centraal Station (Amsterdam Central Station)
ASC	Alternative Specific Constant
BRT	Bus Rapid Transit
BTM	Bus, tram, metro
CBS	Centraal Bureau voor de Statistiek (Bureau for statistics of the Netherlands)
CSSE	Case Study Search Engine, the model developed in this thesis
DRT	Demand Responsive Transit
DUO	Dienst Uitvoering Onderwijs (Education authority)
EBS	EBS Public Transportation BV
GD	(Concession) Groningen-Drenthe
GDP	Gross Domestic Product
HBO	Hoger Beroeps Onderwijs (secondary higher education)
HOV	Hoogwaardig Openbaar Vervoer (high-quality Public Transport, BRT)
IVT	In-vehicle time
LOS	Level-of-service
MBO	Middelbaar Beroeps Onderwijs (community college)
MIPOV	Model Informatieprofiel Openbaar Vervoer (standardized data format)
MON	Mobiliteitsonderzoek Nederland (predecessor of OViN)
MRDH	Metropoolregio Rotterdam Den Haag
NS	Nederlandse Spoorwegen (National railway operator)
OD	Origin-Destination
ODiN	Onderweg in Nederland (National mobility survey from CBS)
OVG	Onderzoek Verplaatsings Gedrag (predecessor of MON)
OViN	Onderzoek Verplaatsingen in Nederland (predecessor of ODiN)
PT	Public Transport
PTA	Public Transport Authority
PTO	Public Transport Operator
SOV	Student OV (travel product for students)
VF	Verplaatsingstijd Factor (ratio between PT travel time and car travel time)
VPR	(Concession) Voorne-Putten & Rozenburg
WL	(Concession) Waterland

1
Introduction

Have you ever wondered why every year the public transport network and schedule is being changed and you have to adapt your (daily) travel routine? The changes are meant to improve the public transport network, but how can be predicted how (potential) passengers will respond? And therefore, which changes to implement and which not?

This is one of the fundamental questions public transportation operators (PTOs) need to answer when competing in a tender. In 2001 the new regulation 'Wet personenvervoer 2000' was implemented, making the public transportation system in The Netherlands subject to tendering (Veeneman, 2016). A competition system was introduced in which the bus operators need to win concessions, allowing them to operate in a certain geographic area for a certain period. In the tendering process, which lasts ca. 4 months from opening to closing (Vigren, 2018), the bus operator needs to develop and present their plans for the concession, as well as a vision for the future duration of the concession. One needs to be able to predict the consequences of network changes, such that an optimal network can be developed and which results in a financially viable plan. Since the tendering process is limited to a small amount of time, the tendering process is intense. Therefore, fast-to-use tools (models) are needed, which can help the bus operator to predict the consequences when changing line characteristics, bus type and/or the network. The amount of concessions is low: 39 in 2015 (Veeneman, 2016) and decreasing (due to merging of regions), with concession durations increasing to 10-15 years (Veeneman, 2016). There is a lot at stake and the tendering process becomes more and more important for the continuity of the company. Predicting the behavior of people after a change in level of service is not only relevant for tendering, but is also required to substantiate decisions made in the yearly transport plans and schedule updates.

Mode choice is dependent on the characteristics of the modes of transportation (Peek and Van Hagen, 2002), but also on the characteristics of the users. A distinction is often made between choice travelers and captives, who do not have alternatives (Van Goeverden and Van den Heuvel, 1993). It is often assumed that a change in characteristics of one mode, can change the modal split and therefore result in a change in use of all modes; i.e. better quality of the public transport network can attract car-users (Van Goeverden and Van den Heuvel, 1993). As Fujii and Kitamura (2003) states, travel behavior is generally assumed to be dependent on the service levels of the transport system.

One of the main difficulties in transport science is the fact that there are many variables influencing an independent variable in a complex manner (Van Wee and Banister, 2016). Isolating individual variables can therefore be difficult and have multiple interpretations (Van Wee and Banister, 2016). Currently there are several types of demand models. In public transport modelling, traditionally the 4-step model is used. A disadvantage of the 4-step model is that the model is time intensive and requires large amounts of input (Van Oort et al., 2015). Therefore, the OV-lite model has been developed by Goudappel-Coffeng (Van Oort et al., 2015). However, in the tendering process, even the OV-lite model is too extensive and time consuming, a more hands-on approach is needed (personal communication with M. Fledderus (EBS)). In addition, there are rules of thumb (e.g. Waaier van Brogt) and elasticities. The rules of thumb and elasticities show large variation in outcome. The rules of thumb are often too simplistic and based on assumptions (Expert interview F. van der Blij). Elasticities are often foreign based and decades old (Balcombe et al., 2004), making their use for the current Dutch public transport system unknown. Over time there is a change in organization of the passenger transport industry, legislative framework, technology and characteristics such as income, life-style, car ownership and attitudes of the policy maker (Paulley et al., 2006). This means that there are differences between regions and that data and research from the past is not necessarily relevant today. Furthermore, no empirical studies have been done in The Netherlands for the past 30 years (MuConsult B.V., 2015). Empirical studies are essential, since the prediction accuracy of current models is poor and consistently overestimating future travel demand (Kerkman et al., 2018). After smart card data became available (due to the introduction of automated fare collection), such empirical studies are easier to do (Van Oort et al., 2015).

All in all, the consequences of network changes (e.g. frequency, directness, travel-time, transfers) on ridership and development of those lines in the network cannot be determined in a time effective way and/or is not based on recent data. A new approach is explored, aiming at better ridership prediction and improved substantiation of ridership prediction. This thesis aims at developing such an estimation tool in the form of a model.

This leads to the following research question:

> Which relations between level-of-service and ridership can be derived in Dutch bus transportation, being both recent and data based and how can they be translated into a model suitable for tendering?

Shortly, the goal of the thesis is to develop a bus ridership prediction model suitable for tender usage, based on empirical data analysis of recent, Dutch cases. To reach the goal of this research, enabling the development of a model, the following sub-research questions provide guidance:

(A) Which level-of-service variables have significant elasticities in literature and should be included in the model?

(B) Which non-level-of-service variables are of influence on ridership according to literature and how can these effects be quantified or compensated for?

(C) What relations can be derived between ridership and level-of-service changes?

(D) How can ridership prediction be modelled, based on the outcomes of the preceding sub-questions, such that it is transparent, easy-to-use and accurate?

A model is developed that is suitable for tendering, which means it should be transparent, easy-to-use and accurate. Easy-to-use refers to the model being intuitive, operable by someone without specific knowledge of the software, fast (calculating within minutes) and limited in the input data required (i.e. not time consuming to gather the input data). The new model is relevant for the tendering process, but also for development in concessions in which a bus company is currently operating.

It is hypothesized that an increase in level-of-service results in an increase in ridership. I.e., increasing frequency increases the ridership, decreasing the travel time increases the ridership, decreasing the number of transfers increases the ridership, etc. Testing the hypotheses and the development of the model is done by performing a before-after study. The focus is on elasticities, since those models are relatively simple, but still make good use of the data (Van Oort et al., 2015). Using elasticities holds under the assumption that future ridership can be predicted by past ridership. The before-after study will be used to test existing models and/or to develop a new model forecasting the consequences of the network changes proposed by the bus operator. The scope of the research is limited to recent changes (up to the past 5 to 10 years) and within The Netherlands, such that the model is directly applicable to tendering processes in The Netherlands.

This thesis is performed in cooperation with one of the bus operators in The Netherlands: EBS Public Transportation BV; from now on referred to as EBS. Data of the concessions Waterland and Voorne-Putten & Rozenburg are available through EBS. Furthermore, OV-bureau Groningen Drenthe provides additional data from the concession Groningen-Drenthe. Whether the changes in ridership are caused by the level-of-service (LOS) changes or by other non-level-of-service changes has to be determined. For each of the non-LOS factors, their relation to bus ridership and how the relation is quantified must be determined. The before-after study is performed on different levels of aggregation. Data allows for three approaches, each with a different value of results. The first approach consists of an analysis per Origin-Destination (OD) pair (i.e. from origin bus stop to destination bus stop); which provide the most disaggregate results. The second approach is an analysis per line (segment), aggregating the results over the line which the LOS change has been implemented. The last approach provides more in-depth insight into specific cases, which provide further insight into the behavior of (potential) passengers after LOS changes.

Before describing the methodology, literature study is performed which provides a basis for methodological choices. In Chapter 2, the characteristics of the current Dutch public transport usage is described and the variables relevant for bus ridership are discussed. In Chapter 3 public transport models are described, such that the context in which the newly developed model will operate is known. Chapter 4 describes the methodology and approach used in this thesis. The case studies and a description of the data used are shown in Chapter 5 and is meant to familiarize the reader with the context of the cases in the before-after study. The results of the before-after study are shown in Chapter 6. The resulting model is described in Chapter 7. Additional data analysis of specific cases supplement the model and are described in Chapter 8. The data analysis results and the model are discussed in Chapter 9, with corresponding recommendations. The thesis is finalized with conclusions in Chapter 10.

2
Forecasting bus public transport demand

Summary: First of all, the current bus public transport in The Netherlands is described; what are the characteristics, who are the users and what are their options? Then the factors which determine the choice whether or not to use the bus. These variables relevant for bus ridership are divided into two categories: those related to level-of-service and those not related to level-of-service. Each of the variables and the existing literature are discussed and when possible, the effect is quantified.

This chapter answers the question: 'How is the current bus usage in The Netherlands, which factors determine the bus usage and to which extent, and how can these factors be quantified and included in a model?' Inclusion into a model is necessary such that a convergent framework is available which can be used in a variety of cases. First, the current state of the Dutch transportation network is elaborated upon, since context is considered to be essential for ridership prediction (Expert meeting EBS, Appendix A.2) and an impression can be formed in which conditions the bus operates and to which modes (e.g. car, train, bike) and on which characteristics it competes. The context also provides input to which variables should be considered. How is the supply and demand for bus usage? Who is in the bus and which alternatives are available? The second section describes which variables are relevant for (not) choosing to use the bus as mode of transport and how they are quantified in models.

2.1. Characteristics of bus public transport

In order to obtain insight in the current usage of bus public transport in The Netherlands and how it is subject to level-of-service (LOS) changes, it should be known who are the (potential) users and how the current situation is.

In The Netherlands, the public transport network covers a large part of the country. 92.4% (2016) of all inhabitants have nearby access to public transport (defined as within 500m of a bus or tram stop, 1km of a metro or lightrail stop, 2km of train station or 3km of an intercity train station). (CROW, 2017). Therefore, in many cases using public transport is an option (though not necessarily an attractive one). A selection of key characteristics of the Dutch public transport system, according to Van de Velde et al. (2010), are:

- Commitment to integrated public transport (PT) networks including integrated fares.
- High level of bicycle usage.
- Free public transport for students.
- Local rail and bus sometimes within a single contract.
- Experimentation in combining health care, social, educational and public transport services and budgets.
- Experience with franchising of local public transport networks.
- Land use planning that promotes inclusion of transport planning.

Statistics over the past decade show a market share of ca. 2.5% to 3% of bus-tram-metro (BTM) in respect of number of trips per 1000 persons per day (figure 2.1). Similar market shares for BTM are shown in total passenger kilometers (Centraal Bureau voor de Statistiek (CBS), 2018). Both the total number of passenger kilometers and the total number of trips per 1000 persons per day peaked in 2014 (table 2.1). In section 6.3 this data will be used for de-trending the ridership data in this research.

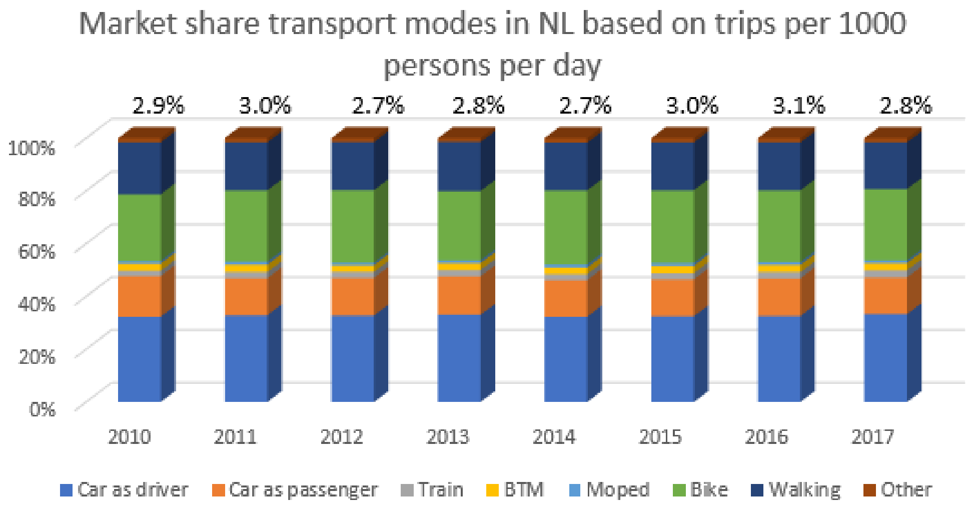


Figure 2.1: Market share modes in terms of number of trips per 1000 persons per day (based on: Centraal Bureau voor de Statistiek (CBS), 2018). Market share of BTM is shown in numbers on top of the bars.

Table 2.1: Mobility in The Netherlands according to OVIN 2017 (Centraal Bureau voor de Statistiek (CBS), 2018)

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Total passenger kms (billion km)	193.6	198.5	193	199.5	201	192.5	194.9	194.2
BTM passenger kms (billion km)	5.7	5.9	5.3	5.5	5.4	5.8	5.9	5.5
Bike passenger kms (billion km)	13.7	14.9	14.7	14.5	16.3	15.0	14.7	14.5
Total trips per 1000 persons per day	2771	2669	2682	2680	2693	2601	2548	2497
BTM trips per 1000 persons per day	74	75	68	70	67	72	70	68
Bike trips per 1000 persons per day	700	720	737	703	755	716	692	675

Within the study period (ca. 2012-2019), there have been developments from a mode choice perspective, increasing the amount of options. For example, Graehler et al. (2019) shows that in American cities, the introduction of bike sharing facilities and transportation network companies like Uber and Lyft decreased the amount of bus ridership. Uber's limited availability in The Netherlands has to be considered (Uber, 2018). Secondly, electric bikes become increasingly more popular, albeit mostly by 55+ aged people (Lee et al., 2015). Most e-bike trips are replacing a trip by car or bike; only 7% is replacing a public transport trip (Lee et al., 2015). Since Lee et al. (2015) has data from a relative old group and only 4 respondents using the e-bike for school trips, the question rises whether the results are comparable for both. Students and scholars are a potential group in using the e-bike for e.g. their trips to school (Plazier et al., 2018); distance is considered to be an essential barrier in using active modes to school (Nelson et al., 2008) and the e-bike can shift this barrier. Nelson et al. (2008) finds the distance barrier in Ireland to be at 2.5 miles (= 4km), though in The Netherlands the barrier is possibly higher due to better infrastructure and long-standing cycling culture. In areas with larger distances to school, such as rural areas, the impact of e-bikes is therefore likely larger.

Which of the modes is chosen, is dependent on both the characteristics of the mode and the characteristics of the user. In The Netherlands, higher income groups relatively travel more by car than lower income groups, men relatively more than women, couples and families with children more than singles (Steg, 2003). Younger people more often use other modes next to the car than older people (Steg, 2003). The car is appreciated more in almost every aspect when compared to public transport (Steg, 2003) (figure 2.2). Public transport has thus difficulty competing with the car. This is also partly due to a negative image, not necessarily the actual characteristics (Berveling et al., 2009). Furthermore, cycling is an alternative to public transport, certainly in The Netherlands (table 2.1).

The mode choice a traveler makes is dependent on the options he/she has. Captives are those travelers who do not have a reasonable alternative and are therefore stuck with a certain mode. E.g., choosing public transport is only possible if both your origin and destination are reachable with public transport; choosing to travel by car (as a driver) is only possible if you have a driver's license. Yet, even a captive has a choice: choosing whether or not to make the trip at all (Van Goeverden and Van den Heuvel, 1993).

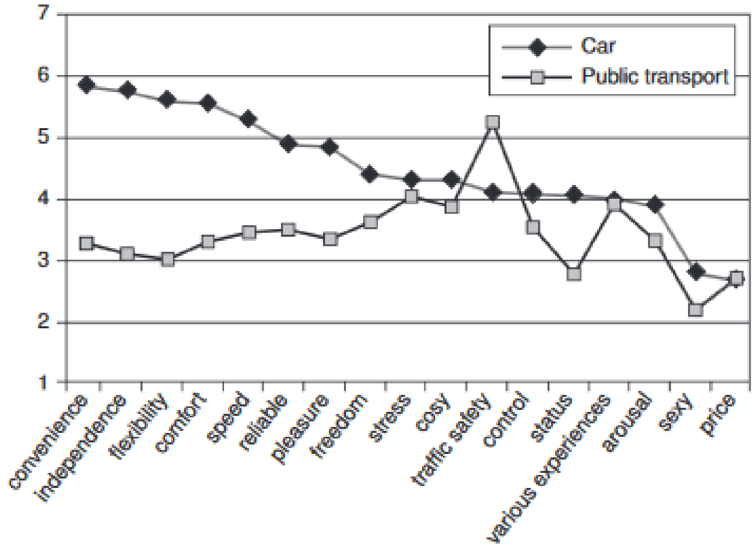


Figure 2.2: User appreciation of the car versus public transport (Steg, 2003).

Whether a traveler is classified as a captive, depends on the definition/cut-off that is chosen (Van Goeverden and Van den Heuvel, 1993). The car captives provide an upper limit for public transport share; the public transport captives provide a lower limit for public transport share, unless quality decreases such that the trip is no longer made (figure 2.3). This implies there is always a minimum and a maximum usage (as long as there is demand for trips between the serviced destinations and the quality is above the bare minimum) and that ridership can be increased by targeting the choice travelers.

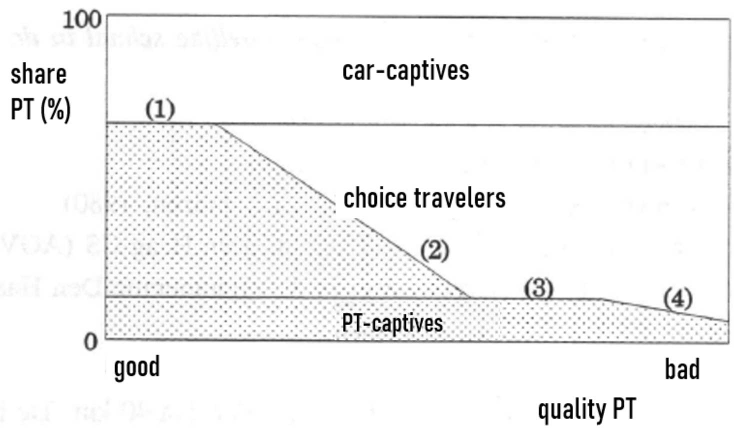


Figure 2.3: Captives in transport (Van Goeverden and Van den Heuvel, 1993; translated). (1) Refers to the upper limit of public transport market share. (2) Shows the choice of choice-travelers is very sensitive to the quality of the public transport (PT). (3) Refers to the case where only captives are left, no one chooses voluntarily for PT. (4) Refers to the case when the quality is below the minimum base level.

If a traveler has the option to choose between multiple alternatives, their choice is dependent on the characteristics of each of the modes. The Maslow Pyramid describes which variables are essential in public transportation by describing satisfiers and dissatisfiers (figure 2.4). The must-haves are dissatisfiers with safety & reliability being a prerequisite; while the satisfiers can improve experience when the dissatisfiers are met (Peek and Van Hagen, 2002). There is thus a certain order in which variables should be improved, i.e. a bare minimum must be met for certain variables.

But what are actually the variables of influence on bus public transport? A literature overview is presented in the next section.

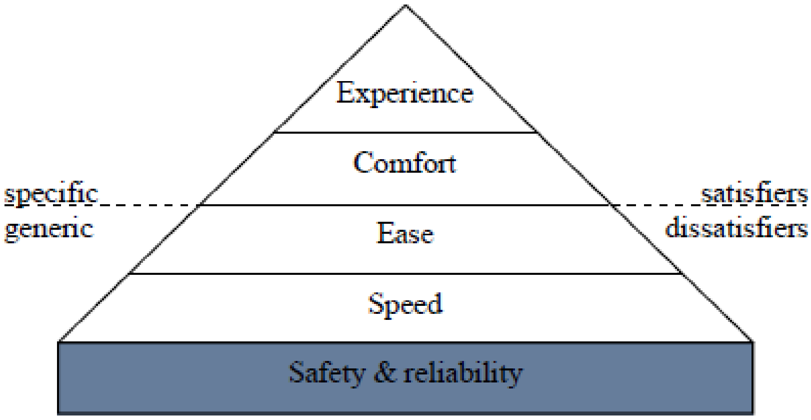


Figure 2.4: The Maslow Pyramid describing satisfiers and dissatisfiers (Peek and Van Hagen, 2002).

2.2. Factors of influence on bus ridership

For the factors of influence on bus ridership, a distinction is made between level-of-service (LOS) related factors and non-level-of-service (non-LOS) factors. Non-LOS factors refer those factors which are not linked to the supply of transport by the public transport operator (PTO), but are nonetheless relevant for the usage. Examples of non-LOS factors are fares and weather conditions.

2.2.1. Level-of-service related factors

In literature, many factors are included which are relevant and significant for public transport ridership. Quantifications of those factors can differ significantly. Known explanations for different results are location dependent characteristics, short-term vs long-term effects, changing behavior over time and research methodology (Balcombe et al., 2004). The following LOS factors are prevalent in literature and expert consultation and/or most relevant to tendering:

- Travel time
- Frequency
- Transfers
- Access & egress time
- Crowding
- Reliability
- Comfort of the buses
- Bus type/capacity
- Demand responsive

A summary of the level-of-service variables and how they are quantified is listed below. Variables are not necessarily mutually exclusive. Crowding is for example related to frequency and capacity of the buses.

Travel time

Different definitions for travel time exist. In-vehicle time (IVT) refers to the time within the vehicle. Total travel time refers to the total time of the trip, so including access, egress and a possible transfer. The 'verplaatsingstijd factor' VF has been introduced by the TU Delft in 1989 and refers to the ratio between travel time by car and travel time by public transport (Van Goeverden and Van den Heuvel, 1993). As opposed to all other variables described, the ratio determines a value which is equal to a relative comparison with alternatives, instead of relying on the supply of a single mode. Since in reality not only the characteristics of a single mode are determining the effect, but more likely the difference with the best alternative of all other options.

In-vehicle time elasticities in the UK are in the range of -0.4 to -0.6 for urban bus transport (Balcombe et al., 2004). MuConsult B.V. (2015) finds in its literature study a range of -0.4 to -0.7 for IVT with respect to trips and -0.6 to -0.9 for generalized journey time (total travel time) with respect to trips, both for long-term situations. For short-term, values are lower with ranges from -0.10 to -0.70 with respect to IVT (MuConsult B.V., 2015). Goudappel Coffeng (2013) assumes a long-term IVT elasticity for BTM of -1.56. In-vehicle time can be translated to costs (e.g. for a generalized costs or utility model) by using value of time (VoT), i.e. the amount one is willing to pay to save an hour of time. The VoT for travel time for all travel purposes combined is €9/h for car and €6.75/h for BTM (Kennisinstituut voor Mobiliteit, 2013); i.e. time savings in car traffic are more valuable than time savings in BTM.

De Beer et al. (2011) finds elasticities in the region Amsterdam, based on a traffic model. An average IVT reduction of 5 minutes (-10%) leads to 11% more ridership, i.e. an elasticity of -1.1. They also note that the improvements lead to more ridership, i.e. bus stops are busier and the IVT reduction becomes smaller. De Beer (2011) finds the elasticities in Dutch literature to be higher than the elasticities in international literature.

A small change in travel time will not change behavior significantly, at least on short-term (Expert interview Fred van der Blij / Expert meeting EBS, Appendix A). By contrast, expert experience does suggest that a difference in IVT of ca. 3 minutes already provides a shift in usage from the slower to the faster line (Expert meeting EBS). However, these are likely current users shifting to a faster option, instead of new users to the bus system.

Furthermore, Haaijer et al. (2007) (via MuConsult B.V., 2015) finds that when bus is used as an access or egress mode to the train, the bus travel time elasticities are much lower: -0.035. I.e., the users are less sensitive to change, possibly also because their relative change in travel time for the total trip is much less than the change in bus travel time.

Frequency

Increasing the frequency of bus services has multiple advantages: both waiting time and crowding reduces (Borjesson et al., 2017) and in some cases it can reduce the need to plan ahead for a specific trip. Due to the crowding effect, the optimal frequency is lower when using larger buses (Borjesson et al., 2017). The average waiting time in case of random arrivals is defined as $\frac{1}{2} headway$. Though people often do not randomly arrive at a stop, but always only a few minutes in advance, it is argued that waiting time at home can also count as waiting time. How waiting time is perceived can be dependent on the conditions at the bus stop. The perceived waiting time is not necessarily equal to the real waiting time (Mishalani et al., 2006).

An average elasticity for frequency of 0.37 was found after a revealed preference study in Norway (Brechan, 2017). The study also indicated that frequency elasticity is larger than price elasticity. The elasticity that is seen when increasing frequency is influenced by the size of the increase (Brechan, 2017). Balcombe et al. (2004) finds most literature elasticities for frequency increase in the range of 0.82 to 1.14, but are based on service hours instead of frequency. De Beer (2011) finds in a literature study a lack of elasticities for the Dutch context. In this thesis, also no recent, Dutch frequency elasticities have been found in literature. However, De Beer (2011) concludes a short-term elasticity of 0.4 to 0.8 and a long-term elasticity of 0.6 to 1.0 for the Amsterdam region; again recognizing a larger elasticity on the long-term scale.

Transfers

Transfers consist out of three components: additional travel time, additional costs and additional dis-utility (the discomfort of the transfer itself) (Ortuzar and Willumsen, 2011). In the London Subway system, a transfer was found to be perceived equal to 4.9 minutes of in-vehicle time (Guo and Wilson, 2011). Garcia-Martinez et al. (2018) developed a SP survey, finding that a transfer in itself is equivalent to 15.2-17.7 in-vehicle minutes. Curry (2005) performed a literature study, finding a range of 5 to 50 minutes of IVT (average 22) in case of a bus-bus transfer; 6 to 23 minutes of IVT (average 13) in case of a bus-urban rail transfer. The impact of the added transfer is likely related to the frequencies of the buses.

Inclusion of the effect of transfers in data analysis and development of networks is often underdeveloped, since often multiple modes and therefore multiple operators are included (Guo and Wilson, 2011). A similar issue exists in PT data analysis in The Netherlands: ridership data is owned by the operators, so transfers to another operator are often lost in the data.

Reliability of a transfer is dependent on 5 factors: (1) scheduled transfer time; (2) distribution of actual arrivals of the first and second line; (3) headways, i.e. the time between two buses of the same bus service; (4) transfer walking time; (5) transfer demand (Lee et al., 2014). Furthermore, Lee et al. (2014) concludes that changing a particular transfer at a node also has effect on other transfers at that node.

Access & egress time

In public transport, access and egress are essential links in the system. Often used access and egress modes in The Netherlands are walking and cycling (Ton et al., 2019; Stam, 2019). Access refers to the part of the trip from origin to access point to the public transport system (e.g. a bus stop) and egress refers to the part of the trip from exit point of the public transport system (e.g. a bus stop) to the final destination. Lengths that passengers are willing to travel are dependent on the level of service provided by the public transport system (Transtec adviseurs B.V., 2010). For regular bus services, the catchment area is approximately a radius of 450m, while for high-quality public transport (HOV) like R-net, the radius is 800m with walking as access mode and 2350m with cycling as access mode (Transtec adviseurs B.V., 2010). Stam (2019) finds that for Almere (The Netherlands) the largest share (67%) of activity end trips are walking based, only 18% uses the bus. Home-end trips are mostly made by bus (43%) and bike (41%). The share of each mode is dependent on the availability of services (Stam, 2019).

Access and egress times weigh 1.3 to 2.1 times the in-vehicle time (Paulley et al., 2006), regardless of the access/egress mode. If only walking is considered as access/egress mode, the weights are 1.4 to 2.0 times the in-vehicle time. Moreover, they found no clear relation with trip type or main mode. MuConsult B.V. (2015) finds literature values to vary between 1.3 and 2.18 times the IVT; a single elasticity value of -0.93 regarding the access/egress time for train usage is found.

Crowding

The amount of crowding in a bus determines the customer experience and comfort perceived by the traveler. A crowded vehicle can mean not being able to sit and/or not being able to perform an activity while traveling (such as working). Yap et al. (2018) concluded after a revealed preference study that crowding has a significant influence on route choice in public transport and is mainly relevant for frequent travelers. On average, a crowding multiplier of 1.16 has been found when all seats are occupied; for frequent travelers the multiplier is 1.31 (Yap et al., 2018). These multipliers imply that upgrading the capacity and/or the frequency and therewith decreasing crowding can in fact increase bus ridership.

Crowding can start to be an issue from an occupancy rate of 50% to 60% and higher (MuConsult B.V., 2015). Multipliers go up to 1.5 for seated passengers and 2.5 for standing passengers and are significantly higher for standing passengers compared to seated passengers and higher the longer the duration (MuConsult B.V., 2015). For train users even higher values are found. Peak travelers are less sensitive to crowding, possible due to expectations and habituation (MuConsult B.V., 2015).

Reliability

Reliability requirements can be different per person, trip purpose and frequency. The reliability needs to be above a bare minimum, but when that minimum is met, further improvement is unlikely to change ridership (Expert interview F. van der Blij). Reliability influences the journey of the passengers by increasing waiting times and/or increasing in-vehicle times (Paulley et al., 2006). Van Oort (2011) and Van Oort (2014) describe three effects of unreliability on passengers: average travel time extension, increased travel time variability and a lower probability of finding a seat in the vehicle. These effects can affect mode choice and/or the decision to make the trip at all (Van Oort, 2011). Improving the reliability can lead to 5% to 15% increase in ridership (Van Oort, 2011).

MuConsult B.V. (2015) finds a large variety of literature values, but are hardly comparable due to different definitions and measurement methodology. A time saving due to early arrival is experienced as 0.81 of IVT and a late arrival is experienced as 1.80 of IVT. A reliability ratio is often used, being the ratio between value of reliability and value of time, which is found to be ca. 0.6-0.69 for BTM/short trips (MuConsult B.V., 2015), though outliers exist.

When (long-term) disturbances are in place, replacement public transport is perceived more negatively compared to the original (Yap et al., 2018). A tram replaced by a more frequent bus has been researched in The Hague. The higher frequency of the replacing bus service of a tram line is not appreciated as expected (Yap et al., 2018), since vehicle capacity is lower.

Comfort of the buses

Comfort is difficult to define and to quantify and can be experienced differently per traveler. Comfort of the buses is found most important by older people (65+) and by infrequent travelers (dell'Ollio et al., 2011). Operation with low-floor buses has caused an increase in ridership of 5% (Paulley et al., 2006). Comfort can also be related to crowding and thus to frequency.

It depends on the already provided level of comfort to what amount improving comfort contributes to ridership increase. As long as comfort is above a certain minimum, elasticities are expected to be low and only relevant on long distances (Expert interview Fred van der Blij).

Bus type/capacity

Bus type is partially related to comfort and crowding, but since during a tender the bus type is one of the main choices the public transport operator has to make, it is presented separately. Usage of a minivan instead of a standard bus, can increase the amount of crowding and is often regarded as less comfortable. Furthermore, the bus type can result in better recognizability and image. Whereas comfort and crowding are difficult to measure and quantify based on revealed preference studies, bus type is easier to analyze. Literature on bus type and bus characteristics are mainly referring to comfort (discussed above) and low floor versus high floor buses (Balcombe et al., 2004), however the latter characteristic is outdated for this research.

The choice for a smaller bus can be made to better match capacity, or since it has a better maneuverability (Hemily and King, 2002). Hemily and King (2002) also found that only 15% of their respondents classified the experience with the small vehicle as poor; with the lowest level of satisfaction found in the companies having the lowest share of small vehicles. It is also suggested that the perception towards smaller vehicles is negative (Workfloor experience check EBS, Appendix A.3), such that a large group will not consider using the small vehicles and thus not be part of the group of respondents in Hemily and King (2002).

Demand responsive

Another recent development is the introduction of flexible public transport. Of the surveyed bus users, 68% is considering a flexible option if offered; 15% is not willing to switch to a demand responsive option or to a combination with shared bikes (Bronsvoort, 2019). The largest negative effect for a flexible option, as well as an alternative with shared bikes, is costs, followed by access and egress times (Bronsvoort, 2019). How often a demand responsive tranit (DRT) service is used is rather unknown. De Jonge (2014) suggests literature (Pelsma, 2014) which finds that only 10% of the offered journeys is used. Van Westerop (2015) suggests literature (VCC-Oost, 2014) which finds a twice as large use of DRT in areas with regular bus service compared to areas with no regular bus service; and an average occupancy of 1.2 (however it is unknown whether the occupancy is of all rides offered or only the ones operated).

The introduction of Nachtvlinder in Zutphen, a DRT service at night, caused an increase of 20% in ridership after doubling frequency with smaller vehicles (Provincie Gelderland, 2016). In the Nachtvlinder service, the vehicle waits at the station and is always accessible; however the other stops are only serviced on request with a flexible routing. Sultana et al. (2018) finds that the main trip purpose of a DRT system in Tennessee is 'medical' (>50%); work related trips follow second (ca. 15%).

Conclusions

All in all, of most variables literature values are present (being elasticities, IVT-weights or growth factors), of others the knowledge is still limited (table 2.2). In rural, less dense areas, car usage and ownership tends to be higher than in urban areas; therefore rural areas show larger elasticities (Paulley et al., 2006). Also, elasticities can differ per country/location (Balcombe et al., 2004; MuConsult B.V., 2015). A before-after study to find elasticity values applicable to recent, Dutch cases is justified. The variables to include can be any of the described LOS variables. However, most relevant to the model are the most prominent, important and significant LOS variables: travel time, frequency and transfers.

Table 2.2: An overview of the LOS elasticities as found in literature.

Variable	Elasticity	IVT-weight	Remark	Source
In-vehicle time	-0.1 to -1.56	-	Short-term: lower elasticities	Balcombe et al. (2004); MuConsult B.V. (2015); De Beer (2011); Goudappel Coffeng (2013)
Frequency	0.37 to 1.2	-	-	Brechan (2017); De Beer (2011); Balcombe et al. (2004)
Transfers	-	4.9 - 50 minutes	bus-bus transfer is heavier penalized than bus-train	Guo and Wilson (2011); Curry (2005)
Access & egress	-0.93	1.3 to 2.18	-	Paulley et al. (2006); MuConsult B.V. (2015)
Crowding	-	1.0 to 2.5	Dependent on user, time, standing vs seated and occupancy	Yap et al. (2018); MuConsult B.V. (2015)
Reliability	-	-	5% to 15% increase possible	Van Oort (2011)
Comfort of the buses	-	-	unknown	-
Bus type	-	-	unknown	-
Demand responsive	-	-	unknown	-

2.2.2. Non level-of-service related factors

Demand for public transport is not exclusively generated by the supply of it. Changes in the context and environment in which the buses are operating are captured under the term non level-of-service related factors and are described below. This subsection describes those non-LOS related factors which are likely to explain a *change* in ridership on a *short-term* basis. Short term refers to the time span of 1 to 2 years, which is the time span for which the to be developed model must provide a ridership prediction. The following non-LOS related factors are prevalent in literature and will be discussed in more detail:

- Demography and economy
- Fares
- Urban development
- Competing modes
- Weather
- One time events

Each factor is explained further and the influence on ridership is quantified if possible.

Demography and economy

Economic and demographic development can trigger changes in both trip generation and mode choice. Demographic development is more likely to be relevant on a longer scale, with an exception of urban development (which is treated separately). However, economic growth often has its effect on bus ridership. An increase in welfare can lead to a higher share of car ownership and decreasing bus usage (Bass et al., 2011), but at the same time there can be a growth in number of trips made, e.g. due to larger employment rates (Chen, 2010). Mitrani et al. (2002) (via Balcombe et al., 2004) estimates that a 10% increase in car ownership per capita would lead to -8.5% bus ridership, for the area of greater London.

For train usage, the growth in ridership is explained not in terms of economic growth, but by a combination of a.o. jobs, population growth, income and car ownership (Kennisinstituut voor Mobiliteitsbeleid, 2017). Li et al. (2015) provides literature research with employment, car ownership and the economic geographic framework found as relevant factors. Including all these factors requires a very extensive methodology. A more hands on approach is found in Ecola and Wachs (2012): The total number of vehicle miles can directly be related to the Gross Domestic Product (GDP) (figure 2.5).

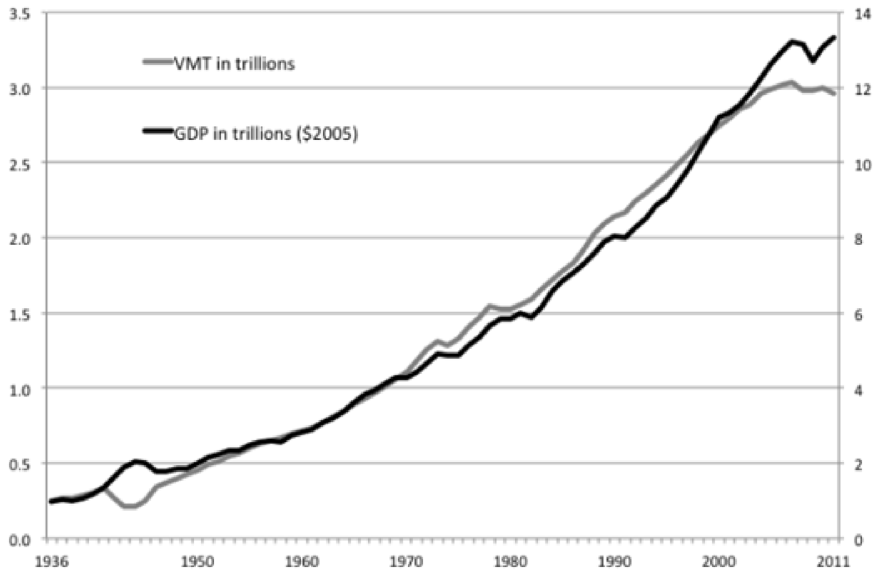


Figure 2.5: The GDP and Vehicle miles of the past decades (Ecola and Wachs, 2012). The GDP growth is roughly equal to the growth in vehicle miles.

The relation between vehicle miles and GDP does not mean that the number of bus miles/kms and GDP has the same growth factor as GDP, since modal split can change. Table 2.1 shows that trends can differ between total trips/passenger kms and BTM trips/passenger kms. Therefore, compensating economic growth by a national change in BTM trips seems best.

Nonetheless, it takes time for e.g. GDP changes to be of influence on behavior and choices made by people; i.e. there is a delay (Li et al., 2015). Li et al. (2014) (via Van Roosmalen, 2019) keeps the data set within a year to prevent large influence of socioeconomic factors.

Fares

Research on fare elasticity is abundantly present (Goodwin and Williams, 1985; Balcombe et al., 2004). Fare elasticity in the Dutch public transportation network can be relevant in two ways. First of all, the height of the fare per kilometer. The km-fare can be slightly different per region. Second of all, since the smart card fares are determined by the number of kilometers travelled, a change in route results in a change in fare.

Fares of the public transport system in The Netherlands can vary over different concessions; occasionally even within concessions (BRT might cost more than regular bus transport). A base fare (access fee) is paid when entering the public transport system; after which an additional fee for each kilometer travelled is added. Fares for public transport have relatively increased more than inflation in the period 2011-2019 (figure 2.6). Note that price indexation between 2011-2019 is a factor 1.13 for the full time period; the base fare 1.22; km fare Groningen-Drenthe 1.32, km fare Voorne Putten & Rozenburg 1.21 and km fare Waterland 1.58.

Fare elasticity values show a large variation, dependent on the mode, time of analysis and specific environment in which the mode is operating (Paulley et al., 2006). In the UK, the bus fare elasticity is on average -0.4 (short-term)

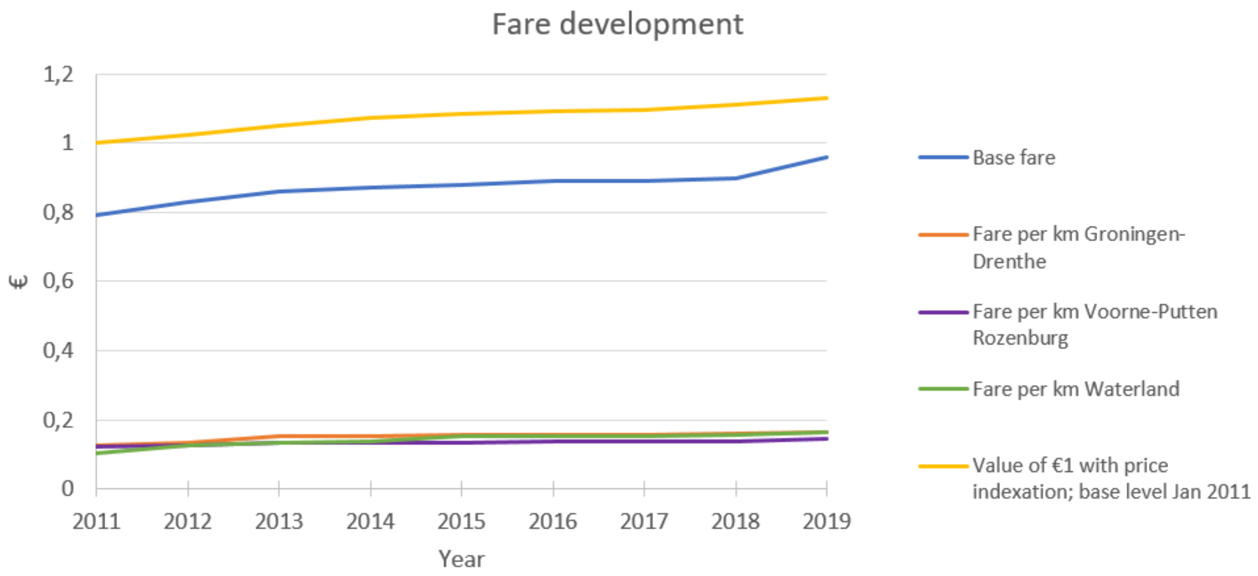


Figure 2.6: Fare development in different concessions (Raw data from OV in Nederland, 2019; Centraal Bureau voor de Statistiek - Statline, 2019).

to -1.0 (long-term) (Paulley et al., 2006). Around the 1980's, a bus fare elasticity of -0.3 was most used (Goodwin and Williams, 1985). Larger fare changes are expected to have a larger elasticity than smaller fare changes (Paulley et al., 2006). Furthermore, price elasticities are larger during off-peak periods compared to peak periods (Paulley et al., 2006). Litman (2007) provides a literature study on parking price elasticities: Cross-elasticities (i.e. the increase in PT ridership) ranges from 0.2 to 2.9. Fare elasticity in The Netherlands is less comparable to fare elasticity abroad, since the bicycle plays an important role and (often) offers an alternative for bus transport, which is often not available abroad (Nijkamp and Pepping, 1998). De Beer et al. (2011) finds a price elasticity of -0.3 in a traffic model for the region Amsterdam.

Another way in which fares have influenced the public transport system is by implementing the free Student OV card (SOV) for MBO-students under the age of 18. For all other students (>18 years of age) this was already available. This measure, implemented on 1 January 2017, meant that thousands of students could now travel with public transport for free during a part of the week. Beforehand, KiM expected an increase in BTM of 17% of the number of free travel kilometers (Kennisinstituut voor Mobiliteitsbeleid, 2014). However, a large part of these travel kilometers were likely made in the past as well, but not for free. Kennisinstituut voor Mobiliteitsbeleid (2014) estimates that 80% of these kilometers is for the home-education trip. Public transport operators stated not to expect a significant increase in ridership, since most students already travelled with public transport (OVPro, 2017). Arriva Brabant states that in Tilburg, no large effect of the implementation or effect of implementation of SOV for MBO students has been seen on the lines to the HBO and MBO schools (Arriva, 2019). OV-bureau Groningen Drenthe has experienced an increase in ridership and did take measures to account for ridership growth (Personal communication OV-bureau Groningen Drenthe). No further research has been found that has analyzed the effect after implementation of the measure.

Urban development

When a new housing area or a new shopping center is completed, it likely has an effect on the ridership as well, do to an increased production and/or attraction in the zone. Rules of thumb for trip generation in The Netherlands are available in 'Kencijfers parkeren en verkeersgeneratie (CROW, 2012), however they provide a too disaggregate level of detail for this study and do not distinct trip generation by mode.

In general, the larger the city, the larger the PT ridership per capita; due to congestion, parking prices and better PT service due to economies of scale (Litman, 2019). Not only the size of the population matters for public transport ridership development, also the number of public transport users per 100 inhabitants (Expert interview Fred van der Blij), since it offers insight in the current saturation and potential.

A sufficiently urbanized catchment area is indispensable for the success of public transport (Cervero and Guerra, 2011). Cervero and Guerra (2011) also recognizes that sufficient jobs must be available along the public transport corridor for it to be attractive. No relation between bus usage and urban development has been found in literature. However, Cervero and Guerra (2011) finds that a 1% increase in population leads to a 0.37% increase in passenger miles in light rail systems in the USA. Fehr Peers (2004) (via Litman, 2019) implies a ridership elasticity of 0.23 with population and employment within 800m of a transit station, but only a 0.02 ridership elasticity with population growth within the catchment area of a station. Again it emphasizes the importance of not only housing, but also jobs being accessible by the transit system.

Pratt (1999) (via Litman, 2019) finds new bus service in a community with no prior bus service to generate 0.8 to 1.2 passengers per bus mile / annually 3 to 5 trips per inhabitant, taking 1 to 3 years to reach its equilibrium. For routes into new neighborhoods in an already serviced community, ridership elasticity is ca. 0.6 to 1.0 with each PT mile/hour added, though ranges even exceed to 0.3 and above 1.0 (Pratt, 1999 (via Litman, 2019)). Further insights can be gained from case studies within this thesis and are presented in the results.

Competing modes

Changes in characteristics of competing modes can lead to a mode choice shift. Influence of (characteristics of) competing modes is best described by cross-elasticities; i.e. how an elasticity that describes the effect on one mode when another mode is changed (further explained in Chapter 3).

In making a mode choice, the availability and quality of options are of influence on the choices made. Van Goeverden and Van den Heuvel (1993) introduced a mode choice estimation model including the VF, a factor between travel time by car and by PT. Balcombe et al. (2004) finds in its literature study a large variety of elasticities, again stating that a higher bus fare and/or an increased bus travel time leads to a higher car use. Bus travel time show a cross elasticities of 0.06 towards car usage (Balcombe et al., 2004). Bus fare cross elasticity ranges from ca. 0.05 to 0.21 towards car usage (Balcombe et al., 2004). Vice versa, an increase in car time leads to an increase in PT trips (elasticity of 0.27 short-term and 0.15 long-term) (Balcombe et al., 2004). Bus IVT cross elasticity with respect to car use ranges from ca. 0.05 to 0.5 (MuConsult B.V., 2015).

Mainly in The Netherlands, active modes such as walking and cycling are relevant (Ton et al., 2019). Ton et al. (2019) provides a literature study on the use of active modes and finds a.o. distance, road infrastructure and weather conditions to be of influence. Despite, no cross-elasticities are found in literature. Furthermore, additional usage of the e-bike can lead to public transport trips being replaced (Lee et al., 2015). A cross elasticity of bicycle usage with respect to PT supply and travel time is known (table 2.3), however, reversely it is not (MuConsult B.V., 2015).

The usage of the train might have a double role: 1. An alternative to the bus and car; 2. The bus being used as an access and/or egress mode for the train. Generally, increasing bus costs lead to increased train usage and increased train costs lead to increased bus usage (Balcombe et al., 2004), suggesting more of a competition. The Dutch network is more designed for the bus and train network to complement each other; implying that bus and train might be more complementing each other instead of competing. MuConsult B.V. (2015) argues, based on data from Haaijer et al. (2007), that a 10% increase in bus travel time indeed leads to a decrease of 3.5% of train ridership when the bus is used as access and egress mode. In Centraal Bureau voor de Statistiek (CBS) (2018), no clear relation between changes in train trips and BTM trips can be distinguished. Possibly this is very location dependent, sometimes the bus being an important access/egress mode for the train, while in other regions the bus is more competing.

De Beer et al. (2011) (together with Gemeente Amsterdam: Dienst Infrastructuur Verkeer en Vervoer, 2011) provides cross elasticities for Amsterdam (table 2.3).

Table 2.3: Cross elasticities in the Amsterdam region as found by De Beer et al. (2011) in cooperation with Gemeente Amsterdam: Dienst Infrastructuur Verkeer en Vervoer (2011).

Change	**Cross elasticity car**	**Cross elasticity bike**
Price of PT	0.04	0.13
Supply of PT	0.2	0.8
Travel time PT	0.5	0.4

Weather

During a survey in Geneva, about 40% of the travelers mentioned that weather is significantly influencing their travel decision; this mainly entails departure time decisions and much less mode or route choices (De Palma and Rochat, 1999). A stated preference survey in Brussels revealed 58% of travelers changing their mode, departure time and/or route (Khattak and De Palma, 1997). Of those 58% of the travelers, 27% classified mode choice (which can also be changing from car driver to car passenger) as either important or very important. However, there is no consistent effect on ridership found in literature. Some researches show an increase in ridership during rain, others a decrease (Zhou et al., 2017). Most research is based on stated preference (SP) methods, i.e. surveys (Zhou et al., 2017). Smart card data analysis has shown that for both regular as occasional travelers, an increase in rain and wind has a negative effect on the number of trips made, while warm temperatures have a positive effect on the number of trips made (Arana et al., 2014). Based on revealed preference data in The Netherlands, Creemers et al. (2015), concluded that temperature, rainfall and aesthetics (e.g. clouds) are significant in mode choice and that snow is not. Ton et al. (2019) finds no relationship with extreme weather conditions and the choice for active modes. For cycling, no significant relation with the weather is found (Ton et al., 2019). Also Centraal Bureau voor de Statistiek (CBS) (2018) finds no clear relation between the weather conditions and number of trips with car, bike or train; possibly due to the fact that location and time of weather conditions are essential, while historical weather data is aggregated (Centraal Bureau voor de Statistiek (CBS), 2018). Van Roosmalen (2019) finds that rainfall is one of the least essential parameters to include in a model when estimating ridership based on travel planner usage. Zhou et al. (2017) finds weather to have a larger impact on ridership during weekends than weekdays and more during off-peak hours than during peak hours.

Since weather conditions are highly variable, the summary of the KNMI indicates the average weather during each November, the month mostly used in the analysis (table 2.4).

Table 2.4: Weather conditions in Novembers according to KNMI (Royal Netherlands Metereological Institute, 2019).

Month	**Classification**
Nov 2012	Dry, regular temperature and amount of sun
Nov 2013	Regular temperatures, relatively wet, gloomy
Nov 2014	Mild weather, very sunny and dry
Nov 2015	Exceptionally mild, wet and regular amount of sun
Nov 2016	Cold, very sunny, regular amount of precipitation
Nov 2017	Quite mild, quite sunny, regular amount of precipitation
Nov 2018	Very dry, very sunny, regular temperatures

Apart from the disagreements in literature regarding the effect on bus ridership, it is also suggested that mode choice is made on predetermined expectations; i.e. children getting a bus subscription for the winter months, regardless of the daily variation (Workfloor experience check EBS, Appendix A3).

One-time events

One time events can, depending on the size, be of potentially significant effect on monthly passenger numbers. On a national level, strikes are significant. Over the years, several strikes have taken place (mainly in 2018), both for bus and for train.

Correcting for medium size events (with large size events being football games and large concerts and huge size events Olympic games, World Championship etc.), is difficult due to a lack of information about such events and even if there is, a lack of estimate of demand (Pereira et al., 2013). In Groningen-Drenthe, the planning for large events is based on trial-and-error and historical data (Van Roosmalen, 2019), but for medium size events and many large events, often no measures are taken by the PTO (Pereira et al., 2013). Most events are small or medium scale, which individually have a negligible effect, but can become relevant when aggregated (Pereira et al., 2013). However no literature on the effect has been found by either Pereira et al. (2013) or this author. Pereira et al. (2013) develops a model based on online event calendar and PT usage in Singapore, however the used events exceeds the size of events relevant to this research' case studies.

Conclusions

As also recognized by Van Roosmalen (2019), the non-LOS factors of relevance in literature vary largely. Dependent on the aggregation level, required level of detail and the time scale, the factors to include are varied. Table 2.5 summarizes for each of the factors how their impact can be compensated for. For this research, one time events will not be compensated for. Striking months will be avoided when possible. If impossible, it can be compensated by the average of that month's unaffected days (of that specific day). Weather can also be used as qualitative context information, but due to the lack of a clear relation in literature and the large variability, no quantitative compensation over the results is performed. The effect of economic and demographic growth can be kept limited by using shorter time spans and can be compensated for with the relation between GDP and passenger kilometers. Urban development and competing modes are region specific and are discussed in Chapter 5. Fares are compensated for by using a literature value.

Table 2.5: An overview of the effect of non-LOS factors

Factor	**Impact compensation**	**Source**
Demography & economy	GDP growth proportional to vehicle miles growth	Ecola and Wachs (2012)
Fares	Literature fare elasticity -0.3	De Beer (2011)
Urban development	Avoidance or local compensation (see Chapter 5)	-
Competing modes	Qualitative statements (see Chapter 5)	-
Weather	Inconclusive effect, no compensation	Zhou et al. (2017); Ton et al. (2019); Creemers et al. (2015); Van Roosmalen (2019); Khattak and De Palma (1997)
One-time events	Avoidance or replacement by averages	Pereira et al. (2013)

2.3. Literature study conclusions

All factors described above, both LOS- and non-LOS related, can be used for predicting bus ridership (figure 2.7). Most prevalent in literature for large, short-term changes are price, frequency, travel time and transfers. Traffic and/or public transport models use these factors as input for prediction. With this, sub-research questions (A) and (B) have been answered. How these factors can be included in different types of models is described in the next chapter.

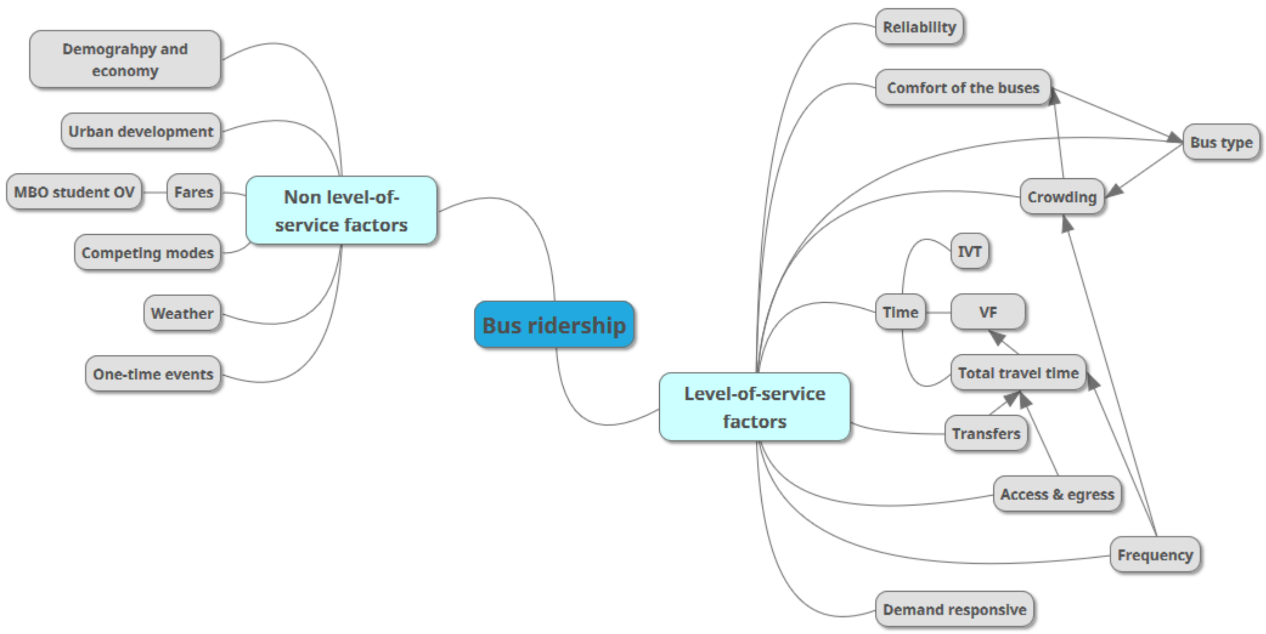


Figure 2.7: Overview of all variables of effect op bus ridership. Made with mindmup.com.

3
Public transport modelling

Summary: Public transport models are classified in four categories: Multimodal (4-step) models, elasticity models, quick-scan models and non-transportational models. Main differences are in the level of detail of both input and output and the model complexity. The elasticity model is most suitable for this research. Currently only three models from practice are known which might be suitable for tendering: Waaier van Brogt, Effov tables and a VF-model. However, they are based on untraceable and/or (out)dated data and their outcomes differ significantly.

This chapter describes the types of models that are used in transport modelling, such that the environment is described in which the to be developed model is operating and such that a suitable model can be developed. This leads to a decision on the most suitable modelling type, which is necessary input for the methodology. In line with the research question, the focus is on demand modelling. First, an introduction into transport models is presented, which characteristics they have and what their purpose is (section 3.1). Section 3.2 describes the different categories of models, such that a better understanding of the conceptual background is achieved. This extends into section 3.3, where the models from practice which are possibly suitable for tendering are discussed. The chapter is concluded with the bus transport modelling conclusions, in which the most suitable modelling type is determined.

3.1. Characteristics of public transport models

The factors of relevance for bus transport ridership have been discussed in Chapter 2. Incorporating these factors into a model can be done in a various ways. This mainly refers to how to present resolution/detail, uncertainty and time (Flügel et al., 2014). Generally, the following choices have to be made, or are made due to data constraints (based on Ben-Akiva et al., 2007):

(1) Aggregated vs disaggregated
The scale at which the model operates can be either on an individual traveler/car basis (disaggregate; microscopic) or at the behavior of a more generalized group (aggregate; macroscopic) (Ortuzar and Willumsen, 2011). Aggregate models can be criticized for being inflexible, inaccurate and expensive (Ortuzar and Willumsen, 2011). Disaggregate models have as disadvantage that they require high statistical and economical knowledge of the analyst (Ortuzar and Willumsen, 2011). Choosing between a disaggregate versus a aggregate model is furthermore dependent on the data availability.

(2) Deterministic vs stochastic
Deterministic models always have the same output under the same input; while stochastic models always have a randomly drawn value from a statistical distribution included. A stochastic model can be chosen if one works with distributions, to better represent uncertainty in reality, or for computational reasons (Ben-Akiva et al., 2007).

(3) Static vs dynamic
Static models do not have a time element included. That is to say, static models are averages for a certain time period, while dynamic models allow variation over time (Pel, 2018). Static models are more simple; dynamic models have as advantage that it is more realistic, dynamic control measures can be taken and output is in the form of dynamic performance indicators (Pel, 2018).

(4) Trip vs tour/activity based
A trip based model considers travel behavior in units of trips from one location to the other (Ben-Akiva et al., 2007). A tour based model acknowledges the fact that (public) transport users can make intermediate stops, e.g. shopping

while on your way home after work. Activity based models refer from the viewpoint that traveling is only a by-product from activities and that understanding of these activities is necessary (Ben-Akiva et al., 2007). Trips are thus only the result of activities. The inclusion of intermediate stops (tour based) or activities (activity based) can for example lead to different preferences regarding mode choice.

(5) Analytic vs simulation
In analytical models, generalized mathematical relations are applied on a non-individual level (Ben-Akiva et al., 2007). In simulation models, each user is identified and the response is predicted individually. Results can still be aggregate, but as cumulative of the individual responses (Ben-Akiva et al., 2007). Simulations are more complex and a large variety of characteristics and relations can be combined.

Ben-Akiva et al. (2007) describes a trend from aggregated, static, trip-based analytic models towards more disaggregated, dynamic, tour-based simulations, due to continual research and development. Pel (2018) summarizes reasons to choose for either a more advanced or a more simpler model:
Advanced model

- Required functionality (ability to answer)
- Required accuracy (correctness of the answer)

Simpler model

- Easier to build
- Lower running time/effort
- Scalability
- Constraints in data
- Model stability
- Convergence

Which characteristics a model should have is also dependent on the time span, intended use and modes to include. Furthermore, Ortuzar and Willumsen (2011) emphasizes that a model is only possibly realistic from the perspective or point of view it was intended for.

Whereas the characteristics as described by Ben-Akiva et al. (2007) are very conceptual, Van Oort et al. (2015) proposes a much more practical classification of models, specifically focusing on public transport models. Van Oort et al. (2015) classifies public transport models into three categories: multimodal models, elasticity models and quick-scan models (figure 3.1). Based on these categories described by Van Oort et al. (2015), as well as a fourth category describing non-transportational models, the different modelling strategies are discussed.

Characteristic	Multimodal Model	Elasticity Model	Quick-Scan Model
Modes	Car, public transport, bike	Public transport	Public transport
Scale	National, regional, urban	Regional, urban	Urban
Time horizon	10–20 years	<10 years	<5 years
Project type	Strategic, policies, infrastructure changes	Tactical, changing lines, frequencies, stops	Tactical, changing lines, frequencies
Usage	Modal split, cost–benefit analysis	Network effect	Route choice effects

Figure 3.1: Classification of public transport models (Van Oort et al., 2015).

3.2. Model concepts

3.2.1. Multimodal (4-step) models

Multimodal models are large scale traffic models, such as the LMS (Landelijk Model Systeem) and NRM (Nederlands Regionaal Model) used in The Netherlands, and useful for strategic studies (Rijkswaterstaat, 2017). They are often based on the 4-step model. The 4-step model consist of the subsequent set of trip generation, trip distribution, mode choice and trip assignment (Ortuzar and Willumsen, 2011; Garber and Hoel, 2015) and provides a multimodal transport model between OD zones (figure 3.2). In addition, time of day can be added as additional (sub)step.

The four steps are described shortly. Mode choice is the most essential to this research and is described more extensively.

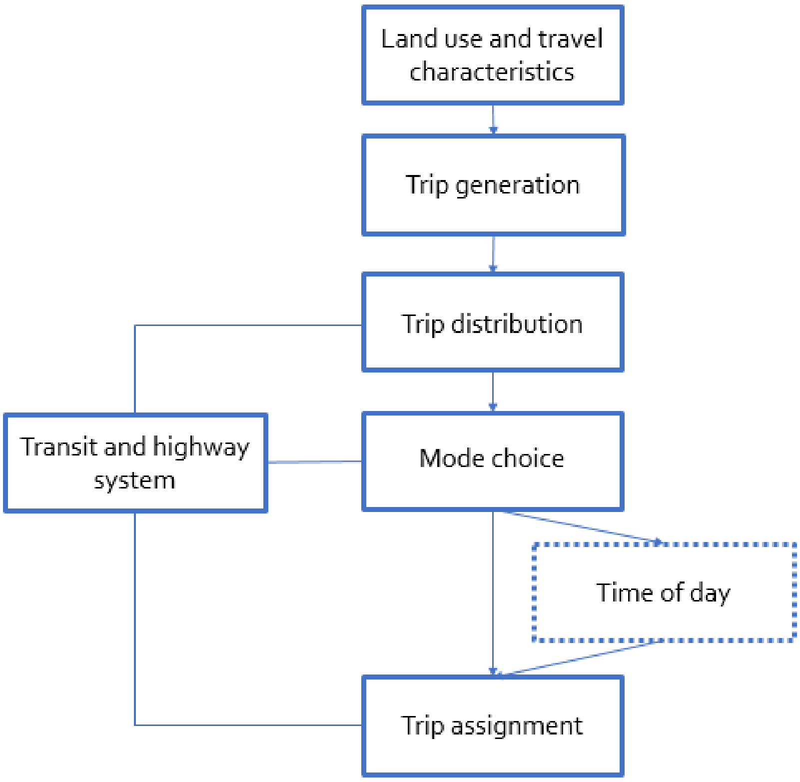


Figure 3.2: The 4-step model as used in transportation modelling. Adjusted from and based on Garber and Hoel (2015).

Trip generation

In the trip generation phase, the number of trips generated and attracted per zone are determined; the demand is modelled. The demand for transport in urban areas is determined by three factors: 1. The land-use of a zone, both location and intensity; 2. The socio-economic characteristics of the inhabitants and 3. The extent, quality and costs of the transportation options (Garber and Hoel, 2015). The first two factors are linked to the non-LOS related variables as described in Chapter 2, although described on a different level of detail. The third factor relates to both level-of-service (quality) and non-LOS (price). These factors determine among others the amount of trips that are undertaken, their distribution and their mode choice.

Trip distribution

In the trip distribution step, the generated trips per zone are allocated to other zones, i.e. destinations (Garber and Hoel, 2015). The gravity model is the best known distribution model, stating that the number of trips between two zones is proportional to the trip attractions by the destination zone and inversely proportional to the travel time between the zones (Garber and Hoel, 2015).

The gravity model (Garber and Hoel, 2015):

$$T_{i,j} = P_i \frac{A_j F_{i,j} K_{i,j}}{\sum_j A_j F_{i,j} K_{i,j}}$$

With $T_{i,j}$ being the number of trips produced in zone i and attracted to zone j, P_i the total number of trips produced in zone i, A_j the number of trips attracted by zone j, $F_{i,j}$ an inverse function of travel time and $K_{i,j}$ a socioeconomic adjustment factor.

Mode choice

Factors which are essential for mode choice are summarized by Stam (2019): 4 categories proposed by Zhao et al. (2002): Transit level-of-service, land use, socioeconomic/demographic characteristics of the population, regional accessibility and a fifth factor proposed by Racca and Ratledge (2004): Characteristics of the trip. The level of service factors have extensively been discussed in the previous chapter, as well as non-LOS factors which could impose a change in ridership. However a category such as ‘characteristics of the trip’ and ‘land use’ can be of influence on the amount of effect a LOS change has.

Regarding mode choice modelling, several approaches can be used, one of which is discrete choice modelling. Discrete choice modelling consists out of 4 elements: (1) a decision rule, often utility maximization; (2) a decision maker; (3) alternatives, the different modes; (4) attributes of alternatives, such as travel time and comfort (Ton, 2019). Which alternatives are suitable is dependent on the duration of the trip (figure 3.3) (Ton et al., 2019).

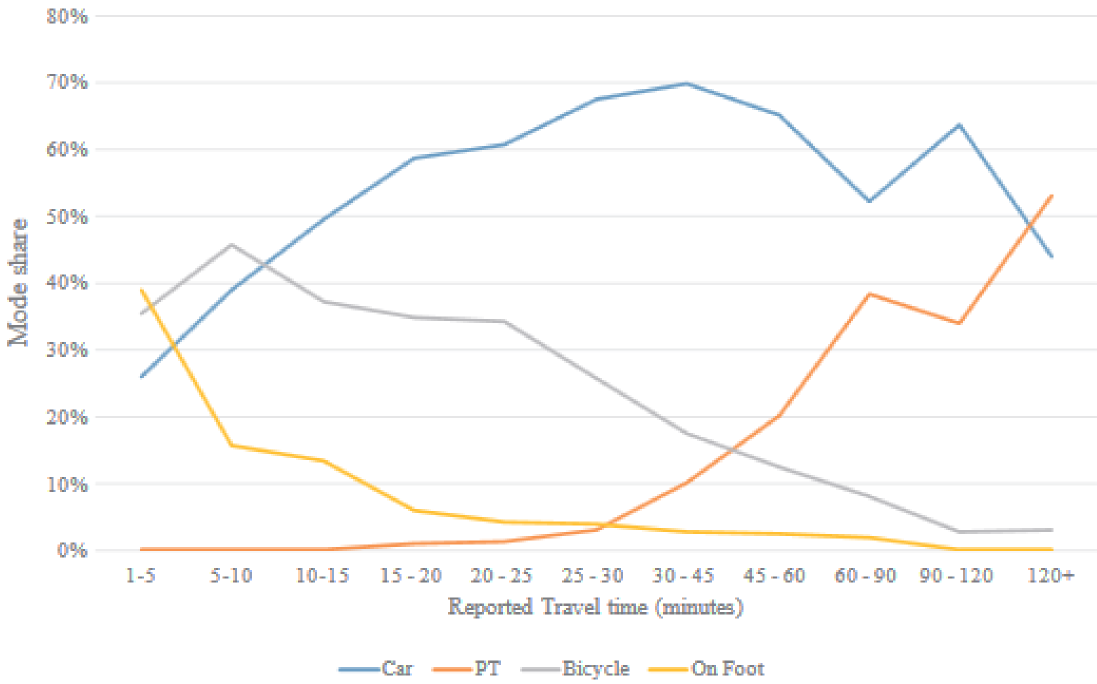


Figure 3.3: Use of modes per travel time class (Ton et al., 2019).

Mode choice is often modelled by means of a generalized costs model or a utility model. An example of such a generalized costs model is provided in Van Oort et al. (2015):

$$c_{i,j} = a_1 T_{i,j} + a_2 WT_{i,j} + a_3 NT_{i,j} + a_4 F_{i,j}$$

in which c presents the generalized costs, T the in vehicle time per OD pair i-j, WT the waiting time, NT the number of transfers and F the fare. Coefficient a_1 to a_4 present weight coefficients. The mode with the lowest generalized costs is then chosen.

A utility model translate the mode choice preferences into a modal share. The option with the smallest dis-utility (or largest utility) has the largest market share, based its relative weight to all other utilities. It can be generalized as:

$$A_{PT} = \frac{exp(U_{PT})}{exp(U_{PT}) + exp(U_{car})}$$

With A_{PT} being the market share of public transport, U_{PT} the utility of the public transport option, U_{car} the utility of the car option. As such, it can be extended using numerous modes. If modes are not mutually exclusive, nested logit functions can be used. The utility of each of the options is determined similarly to a generalized costs function. The option with the highest generalized costs has the largest dis-utility and will lead to the smallest market share.

Trip assignment

Trip assignment refers to the route choice. In bus transportation, trip assignment can be relevant if multiple routes can be taken within the bus network. Furthermore, since active modes are often used as access and egress to public transport, taking active modes into account results in more realistic route choice models (Brands et al., 2014). Trip assignment is the last step of the 4-step model.

The pros and cons of the multimodal 4-step models are summarized in table 3.1.

Table 3.1: Pros and cons of the 4-step model (lecture Van Oort, 2018; Van Oort et al., 2015; Ortuzar and Willumsen, 2011; own).

Pros	**Cons**
Extensive	Time consuming
Multimodal	Focused on road traffic
New scenarios can be modelled	Expensive*
Multi-purpose	Non-intuitive
Suitable for long-term estimations	Rigid separation of modes
-	A lot of input information is required
-	Feedback loops necessary, rarely leading to stability

*Price ranges ca. €5000 to €25000 for a single license for governmental use (Personal communication DAT Mobility).

3.2.2. Elasticity models

Elasticity models mean to predict future ridership by applying an elasticity value to historic ridership. Elasticities of many variables exist, as has been described in Chapter 2. Elasticity is defined as the change on a dependent variable after changing the independent variable (Holmgren, 2007). In case of demand elasticity, as is evaluated in this thesis, it is defined as (Holmgren, 2007; Garber and Hoel, 2015):

$$E = \frac{\Delta Q}{\Delta x_i} \frac{x_i}{Q}$$

With E being the elasticity, Q the demand and x the variable of which the elasticity is tested. Shortly, a fare elasticity of e.g. -0.4 implies that if a fare is increased by 1%, the demand reduces by 0.4%. Elasticities are often based on stated preference studies (Balcombe et al., 2004). Often point elasticities are used, which can be defined as (Holmgren, 2007):

$$E_{point} = \frac{\delta Q}{\delta x_i} \frac{x_i}{Q}$$

Whereas point elasticity determines the elasticity at a single moment in time (Holmgren, 2007; Oostra, 2004), (midpoint) arc elasticity determines the elasticity over a time period and is therefore more useful in a before-after study (Oostra, 2004). Midpoint arc elasticity is defined as (Garber and Hoel, 2015):

$$E_{arc} = \frac{\delta Q}{\delta x_i} \frac{x_{average}}{Q_{average}}$$

When in a before-after study, the midpoint arc elasticity after an change is evaluated, the equation can be rearranged to:

$$E_{arc} = \frac{(Q_0 - Q_n)/[(Q_0 + Q_n)/2]}{(x_0 - x_n)/[(x_0 + x_n)/2]}$$

With 0 being the initial situation and n being the situation after the change. The future demand (or ridership) can then be calculated as follows:

$$Q_n = \frac{(E_{arc} - 1)(x_0 Q_0) - (E_{arc} + 1)(x_0 Q_0)}{(E_{arc} - 1)(x_0) - (E_{arc} + 1)(x_0)}$$

Besides the distinction between point and arc elasticities, a distinction can be made between input and output elasticities and invariable and variable elasticities (MuConsult B.V., 2015): Input elasticities refer to elasticities from literature which are included in a model, output elasticities refer to outcomes from models after specific changes in variables. Variable elasticities depend on the original size of the quantity it describes (e.g. IVT elasticity being dependent on the original IVT), while invariable elasticities are independent.

Apart from regular elasticities, cross-elasticities exist. Cross-elasticities describe the effect of a change in property of mode X on the use of mode Y (MuConsult B.V., 2015), e.g. the effect of changing IVT of the car on bus ridership. Cross-elasticities are sensitive to market share of each of the modes and therefore very location and time sensitive (MuConsult B.V., 2015).

How elasticities can be obtained is summarized by De Beer (2011) (table 3.2).

Table 3.2: Classification of studies that lead to elasticities. Adjusted from De Beer (2011) (based on Balcombe et al., 2004).

Type of study	**Method**	**Description**
Revealed preference (RP)	Cross-section studies Time series Before-after studies	Surveys or sales at a certain time period Statistical relations from long-term data (5-15 years) Measuring change in total volume
Stated preference (SP)	Surveys	Surveys about hypothetical situations
RP and SP	Meta-analysis	Combining and integrating multiple empirical studies
Modelling	Econometric model	Elasticity calculation based on models with recent data

Elasticities are relevant for variables that are continuous in nature where proportionate changes can be specified, such as costs and time (Balcombe et al., 2004). The magnitude of the elasticities are subject to three factors: the availability of alternatives, the time span of analysis and the part of the (time) budget which is requested from the user (MuConsult B.V., 2015). There can be large differences between outcomes of a revealed preference (RP) study and a stated preference (SP) study, up to a factor 2 (MuConsult B.V., 2015). Stated preference studies tend to overestimate elasticities (Bourgeat, 2015). Revealed preference studies can have difficulty showing sufficient variability and to show the relative importance of each of the variables (Ortuzar and Willumsen, 2011).

The step from an elasticity into an integrated model is often not taken. Van Oort et al. (2015) does take this step with the OV-lite model; combining elasticities with OD-data and the network in OmniTrans. This step can be taken since numerous data has become available since the introduction of the smart card (Van Oort et al., 2015). The smart card data provides an OD-matrix, which can be implemented in OmniTrans for combination with the infrastructure. Based on demand elasticity, network effects of changes in the public transport system can be analyzed (Van Oort et al., 2015). The elasticity values used are existing values from literature. However it does illustrate that elasticities can be used in a more dynamic environment such as OmniTrans.

The advantages and disadvantages of using an elasticity model are summarized in table 3.3.

Table 3.3: Pros and cons of elasticity models (lecture Van Oort, 2018; Van Oort et al., 2015; Balcombe et al., 2004; MuConsult B.V., 2015; own)

Pros	**Cons**
Easy and intuitive concept	Loss of detail
Can be as extensive as one wants	Aggregated and generalized
Cross elasticities can combine multiple modes	Only suitable for proportionate changes
-	Very sensitive to underlying data and context

3.2.3. Quick-scan models

Public transport operators sometimes turn to one-step models which are more simple, fast and spatially disaggregated (Upchurch and Kuby, 2014). Such quick-scan models are often developed by/for the bus operators themselves. For confidentiality reasons, they are often not public (Expert interview F. van der Blij). Their time horizon is often small and not on a network basis (Van Oort et al., 2015). An example of a quick-scan model is Waaier van Brogt (Goudappel Coffeng, 2013), where the effect of frequency changes can be predicted based on rules of thumb from experts experience.

The advantages and disadvantages of quick-scan models/rules of thumb are summarized in table 3.4.

Table 3.4: Pros and cons of quick-scan models (lecture Van Oort, 2018; Upchurch and Kuby, 2014; Van Oort et al., 2015; Expert interview F. van der Blij; own).

Pros	**Cons**
Very easy to use	Low level of detail
Fast	Inaccurate
-	Too much relying on assumptions and unknown origin
-	Unimodal

3.2.4. Non-transportational models

All previously described models estimate ridership from a transport engineering point of view. Recently new ways of predicting public transport ridership are being developed. Van Roosmalen (2019) tries to predict ridership with travel planner data. However, the prediction is very short-term and not suitable for predicting ridership after LOS changes. Pereira et al. (2013) uses web data to predict public transport usage during special events, linking event characteristics to historic ridership. Again, the methodology is not suitable for predicting ridership after LOS changes.

The pros and cons of the other models are difficult to describe, since these are very case specific. The general pros and cons are presented in table 3.5.

Table 3.5: Pros and cons of non-transportational models.

Pros	**Cons**
Makes use of big data, new insights can be gained	No transport engineering origin
-	Underdeveloped

The conceptual model types as described above have been applied in practice. Of those models, a small selection has the suitable characteristics for tender usage. The known models are described in the next section.

3.3. Known models and their results

In The Netherlands, several types of models are used. A national disaggregate traffic model exists, mainly focused on road travel; on a city level there are models with more detailed modelling of the public transport network, being often multimodal gravity models and thus more simplified (Van Oort et al., 2015). Public transport operators barely use models for ridership prediction, often simple rules and spreadsheets are used (Van Oort et al., 2015). Van Oort et al. (2015) therefore developed the OV-lite model, but this is still a too extensive model for use during tenders. Currently, only three simple rules / spreadsheet like models are known and possibly suitable for the tendering process:

- Waaier van Brogt
- Effov tables
- VF model by Van Goeverden and Van den Heuvel (1993)

Those current models and their outcomes are discussed further.

Waaier van Brogt

Waaier van Brogt provides a set of rules of thumb, based on both literature and expert opinions (Goudappel Coffeng, 2013). For LOS-related variables, it provides elasticities and cross-elasticities. For example, for the LOS variable frequency, it provides four frequency growth factors (dependent on the frequency change) and they mention a frequency decrease to lead to a decrease in ridership 20% larger than the increase in ridership in case of an equivalent frequency increase. An example of data in the Waaier van Brogt is shown in table 3.6.

Table 3.6: Example of data in the Waaier van Brogt, in this case the frequency change growth factors (Goudappel Coffeng, 2013)

Frequency change	**Ridership change**
1x/2h >1x/h	+60%
1x/h >2x/h	+40%
2x/h >4x/h	+25%
4x/h >8x/h	+15%

Effov tables

Effov (Effecten openbaar vervoer) tables originate from empirical research by Adviesgroep voor Verkeer en Vervoer (AGV) (Bakker, 1979) and it is over 50 years old. Yet, they have still been in use decades later (e.g. Provincie Noord Brabant, 2009). The tables provide growth factors for frequency changes, IVT changes for both bus and train and access/egress time changes. The relationships behind the tables are as follows:

$$Growth\,factor\,access/egress\,time = \frac{e^{-1.972ln((time_{new}+26.62)/26.62)-2.231)}}{e^{-1.972ln((time_{old}+26.62)/26.62)-2.231}}$$

$$Growth\,factor\,IVT\,bus = \frac{e^{-3.192ln((IVT_{new}+69.7)/69.7)-2.231)}}{e^{-3.192ln((IVT_{old}+69.7)/69.7)-2.231}}$$

$$Growth\,factor\,frequency = \frac{e^{2.165(1-exp(-0.0503numberoftrips_{new}))}}{e^{2.165(1-exp(-0.0503numberoftrips_{old}))}}$$

With the access/egress time and in-vehicle time (IVT) in minutes and for the frequency growth factor the number of trips referring to the number of daily trips in both directions combined.

VF model

The VF-model by Van Goeverden and Van den Heuvel (1993) is a model based on revealed behavior from the OVG (nowadays ODiN) surveys. *VF* is a factor used to express the ratio of public transport travel time over car travel time. A model including *VF*, number of transfers and frequency has been estimated by hand, leading to the relation predicting the market share of public transport:

$$A_{PT} = exp(-0.36VF^2 - 0.17N_T - 1.35F^{-1} + 0.23) + 0.03$$

With A_{PT} being the market share of public transport, VF the ratio of public transport travel time over car travel time, N_T the number of transfers, F the frequency. The model has been fitted manually, based on OVG data (a survey) (Personal communication C. van Goeverden). The model is calibrated and verified based on revealed preference choices of both car and public transport users (Van Goeverden and Van den Heuvel, 1993). Advantages of this model are its simple and fast results under limited input and inclusion of interdependent relations. Besides, a distinction between car ownership versus no car ownership can be made. Disadvantages are that journeys<10km have not been included, eliminating walking and cycling as a competing mode. Furthermore, no distinction has been made between bus and train transport, not in the calibration nor in the model itself. Lastly, it is (out)dated, since the data originates from 1981.

Outcomes

Comparing the three known models shows that their prediction when changing e.g. frequency has an enormous variation in predicted ridership increase (table 3.7). Furthermore, they are too much relying on assumptions (Expert interview F. van der Blij).

Table 3.7: A comparison of the ridership increase predicted by three known models when changing the frequency.

Frequency per hour (before->after)	Waaier van Brogt	Effov*	van Goeverden**
0.5->1	+60%	+70%	+178%
1->2	+40%	+45%	+83%
2->4	+25%	+11%	+37%
4->8	+15%	+0%	+17%

*Assuming 15 operating hours per day.
** Based on Vf=1.5 (on a 30 minute car trip) and number of transfers=0.

3.4. Public transport modelling conclusions

Of the different model types, the level of detail and aggregation is the main differentiating factor, as well as ease of use. Overall, the three types of models provide a tool for predicting bus ridership in a different manner and with different level of details. What type of model is suitable for this thesis can be considered by discussing the advantages and disadvantages and by comparing the characteristics of the models to sub-research question D: 'How can ridership prediction be modelled, based on the outcomes of the preceding sub-questions, such that it is transparent, easy-to-use and accurate?' (table 3.8).

Table 3.8: A comparison of the four different model types with the requirements set in sub-research question D.

	Multimodal (4-step)	Elasticity	Quick-scan	Non-transportational
Transparent	-	0	0	0
Easy-to-use	-	+	+	-
Accurate	+	0	-	-

A 4-step like model immediately seems unsuitable, it is not easy-to-use (time consuming and requires a lot of input information). Furthermore, due to the feedback loops, large quantity of input information and being non-intuitively, the use of the model not transparent. Quick-scan models are on one hand fast and easy-to-use, but their lack of accuracy and detail makes them unsuitable. Their low level of detail, unknown origin and reliance on assumptions also makes the outcome of the model non-transparent, despite the tool possible being transparent due to its simplicity. A non-transportational type of model seems unsuitable for the goal of the thesis, since non-transportational models are underdeveloped and it is uncertain whether they are easy-to-use and have accurate predictive value. An elasticity model has the best balance of properties and most importantly, no characteristic that would make it immediately unsuitable (table 3.8). It has an easy and intuitive concept and can be easily extended and/or scaled. The model being aggregated is not an issue, since the effect on ridership during tenders is requested on an aggregated level. However, its sensitivity to underlying data and context should be kept in mind in the research design and discussion of the results.

Existing models such as Waaier van Brogt and Effov tables, which might be suitable for the tendering process, are based on ancient data and provide a large variety of outcomes. A suitable, accurate model is not available. This leaves a gap, which this thesis means to fill. How this problem is approached is described in the next chapter; the methodology and data description.

4 Methodology

Summary: A before-after study is performed. After selection of appropriate cases and variables to be included, two variants of data analysis are proposed: analysis per OD-pair and analysis per line. Further insights are gained with a regression analysis of the line-based results and an expert meeting. In the end this leads to a model, which is developed and validated. Further in-depth analysis of specific cases is performed to supplement the model.

Chapter 2 and 3 provide input for the methodology, such that substantiated choices can be made. This chapter describes the methodology used in the research, such that the research is understandable and reproducible.

4.1. Methodology

To obtain the goal of this thesis; the development of a tender suitable model for predicting bus ridership, different approaches can be used. As described in table 3.2, elasticities can be obtained with a variety of studies. Referring back to the research question of this thesis is necessary to select the most suitable type of study. The research question refers to level-of-service variables being both recent and data based; those elasticities which are actually shown in reality. Data based immediately points towards a revealed preference study. Ortuzar and Willumsen (2011) describes a before-after study as the only objective method to measure the success of a forecast. Since current, known models have a large variety in outcome, such an objective method is preferred. A before-after study is thus most suitable for answering the research question. The before-after study will be used to develop parameters for the model. Data of the month November is used; November is an industry standard for comparison (Personal communication M. Fledderus, EBS). It lacks holidays and peaks or troughs in student usage and has average weather conditions. Furthermore, November is in most cases the last full month before a schedule change. If for any reason November is not suitable or available, March or April is used as alternative. Due to large seasonal trends, comparing to a preceding month is not as valuable. There are large differences in monthly trends per line, per region and per year, which makes de-trending the data difficult and unreliable.

The methodology, from data gathering and analysis for the before-after study to the final result consists of 8 steps (figure 4.1). Each step is elaborated upon.

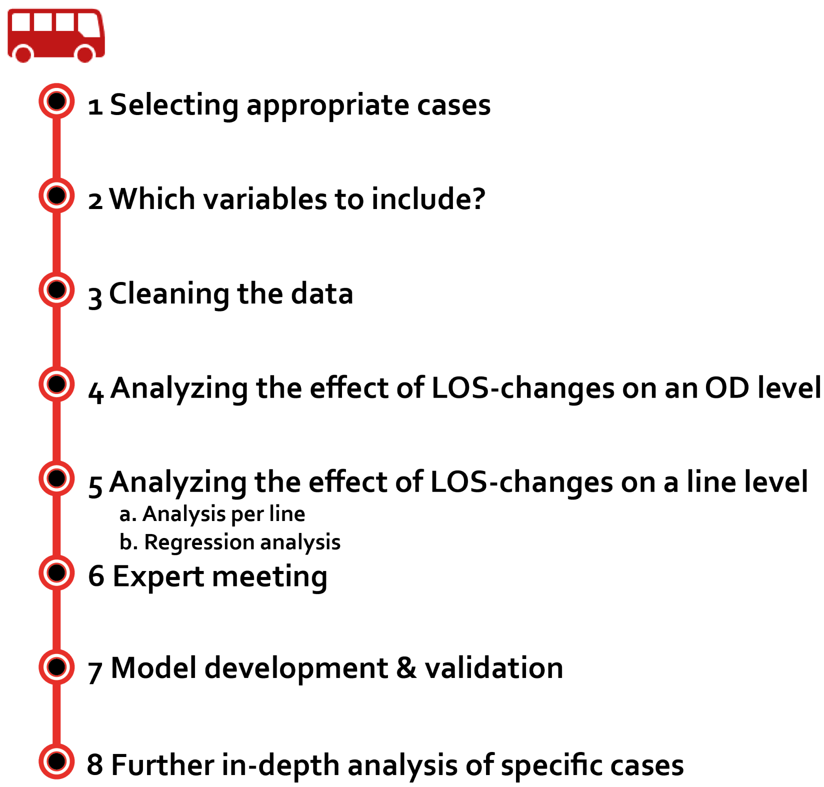


Figure 4.1: Methodology overview.

Step 1. Selecting appropriate cases

Data from three concessions is available. The amount of detail and level of aggregation is different for each data set. Data for concession Waterland ranges from 2012 to 2019; Groningen-Drenthe (2015-2019) and Voorne-Putten & Rozenburg (2016-2019) also fall within the 2012-2019 period. The period of interest for this research is therefore defined as 2012-2019. These data sets all fit the recent data requirement.

Within the available data, appropriate cases which can be used for a before-after study must be selected. The data map describes the data in the Waterland, Voorne-Putten & Rozenburg and Groningen-Drenthe concessions (figure 4.2).

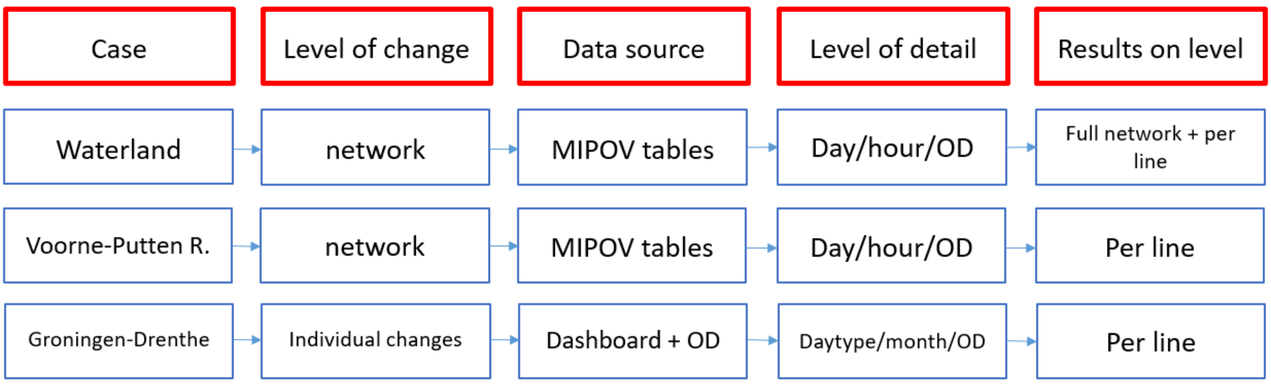


Figure 4.2: Data availability for this thesis and their level of detail. MIPOV tables refer to a standardized data format. Dashboard refers to the online data dashboard of OV-bureau Groningen Drenthe.

For Waterland, raw smart card data is available for a two year time period. With the raw smart card data, transfers within the EBS bus network could be followed. However, using this more detailed data would mean that there is only a small selection of LOS changes that can be analyzed and that there is a mismatch between the different concessions, since for Groningen-Drenthe ans VPR this more detailed raw smart card data is unavailable. Furthermore, the amount of data would be limited. Therefore the choice is made to analyze more aggregated data as described in figure 4.2.

Step 2. Which variables to include?

As described in Chapter 2, various factors influence bus ridership. To determine which variables will be included in the analysis, the goal of the research is reflected upon. A simple and fast tool for predicting ridership when changing LOS, which can help in the tender process, is to be developed. Implementing numerous variables limits this goal. Price, travel time, frequency and transfers are most prevalent (see Chapter 2). Price is not a level-of-service change and falls outside the scope of this research. The influence of number of transfers can only be analyzed when using raw smart card data. In the previous step, the choice is made to use more aggregated data: MIPOV format data (figure 4.2). As a consequence, the influence of number of transfers cannot fully be evaluated. This leaves two focus points: frequency and travel time. However, if possible in the data, further factors will be described. As described in chapter 2, non-LOS related factors are also of influence on bus ridership. In order to analyze the effect of a LOS change, the non-LOS related factors must be accounted for (as described in Chapter 2) or their effect must be diminished.

Step 3. Cleaning the data

Two types of data are used in the analysis. Most results are based on OD-matrices. Firstly, all OD's with a [0] entry are removed, since they include a missed or unknown check-out. Their actual trip is therefore unknown. In the case of Groningen-Drenthe, also all 'zone grens' (zonal boundary) entries are removed. The zonal boundary is a fictional check-out for subscription holders when they travel beyond their allowed zone. Since their actual trip is unknown, data is removed. Lastly, all origins and destinations that are not and have not been part of the bus route are removed. Incorrect origins and destinations are often present; possibly due to passengers staying put when the bus continues as another line after reaching its final destination or by an erroneous configuration of the smart card system.

In some cases, additional results are gathered by analysis of the number of check-ins per stop. For the check-ins, no additional cleaning is applied; the issues described above are not applicable to this data.

Step 4. Analyzing the effect of LOS changes on an OD-basis

Based on the network changes in Waterland in August 2014, the difference in ridership between November 2013 and November 2014 for all OD-pairs on weekdays is determined. Waterland is the only concession of which a complete data set is available, which enables this analysis. Since an elasticity model is to be developed (Chapter 3), growth factors are needed to be able to calculate elasticities. A division is made between frequency and in-vehicle time. Results are generated for all OD-pairs and for a selection of OD-pairs which are meant to be representative for the LOS change.

Two variants of the analysis are to be presented: a relative change in ridership and an absolute change in ridership. The first shows the relative increase/decrease in ridership for each OD-pair. The latter shows the increase/decrease in passenger numbers for each OD-pair. A distinction is made, since OD-pairs can have a large range of usage. E.g.: An increase of 10 passengers has a relative large effect on an OD-pair with low usage, while the absolute increase is small. This effect is partly obviated by eliminating all OD-pairs which have a usage below a certain cut-off. The cut-off is varied within the results, e.g. a cut-off of 30 implies all OD-pairs which have a usage below 30 passengers a month (in either November 2013 or November 2014) are removed in both years. These cut-offs are chosen in a range such that sufficient data points remain and such that stops with very low usage are cut off. Furthermore, some filtering measures are applied to the data set and varied; these include a.o. removal of transfer ODs (meaning stops known for transfers within the bus network, not being popular destinations such as Amsterdam CS), compensating for economic growth and removal of statistical outliers.

For the in-vehicle time, results are analyzed by adding a trend line to the results. For frequency, no trend line can be added. Frequency results are added per bin. The frequency change from 1x/h to 2x/h is a doubling in frequency, but the effect is likely to be different from an increase from 2x/h to 4x/h (also a doubling in frequency) (as shown in Chapter 2). Therefore bins are defined by hand, in such a way that the expected effect (based on the literature in Chapter 2) is highest to lowest.

Step 5. Analyzing the effect of LOS changes on a line-basis

Step 5.a. In-depth analysis per line

The analysis on a line basis is not limited to a specific time period or concession, all three concessions are included. Changes in LOS are analyzed for all time periods available. For every LOS change, the growth factor is ridership is determined; which can then be translated into an elasticity.

Two approaches are used: an analysis based on a full line (section) and a cluster analysis. The distinction is made for data reasons. If possible, an analysis of a full line is made. Full line analysis is possible whenever a line is largely isolated, or when the effect from a parallel line can easily be compensated for. When full line analysis is not possible, for example in a dense network as in Purmerend, a cluster analysis is applied. Cluster analysis means that only the ridership from an isolated end to a major destination is analyzed. For example, the village De Rijp to Amsterdam Central Station. Here the cluster around De Rijp (i.e. all stops in De Rijp) and the cluster around Amsterdam CS (i.e. all stops near Amsterdam CS) are used. All passengers from cluster De Rijp to cluster Amsterdam CS and vice versa are accounted for. The rest of the ODs along the line are excluded.

The cases are chosen such that the effect of non-LOS related factors is diminished as far as possible. This means that the change in ridership after 1 year is analyzed (when possible), such that the effect of demography and economy is small. According to expert opinion, within the first year the largest part of the growth/decline is already obtained (Expert interview F. van der Blij, Appendix A.1). Since the months of analysis are always the same, the difference in weather conditions is minimal.

From the data, three categories of LOS changes can be defined: change in frequency, change in in-vehicle time and other LOS changes, such as vehicle type or branding. The relative change in ridership after 1 year is calculated (a growth factor). Similarly to the analysis per OD-pair, all data is first scaled to the same number of days. E.g., November 2014 has 20 weekdays, while November 2013 has 21 days, leading to a ratio of 21/20. To obtain a comparable result, data is scaled according to this ratio. From the growth factor, also elasticities can be determined (as defined in Chapter 3).

For each of the categories, the change in ridership for the full day is determined. Level-of-service changes are in several cases only implemented in a selection of hours. If possible, the ridership change is also calculated for the peak and/or off-peak hours only, for better comparison to the hours in which the LOS change has been implemented. The ridership change for peak/off-peak hours only also enables insight in the interaction of ridership changes in different hour blocks. Figure 4.3 illustrates which hours are referred to. No definition to peak and off-peak hours are given, since these differ per line. Since selection of data is limited to blocks of a full hour, peak hours are always fully captured in the blocks for the peak; i.e. for a peak from 06.30 am to 08.30 am, hour blocks 06.00 am to 09.00 am are used, despite the last half hour belonging to off-peak LOS. When results are presented as full day, ridership of all hours are included. When results are presented as peak only or off-peak only, only those respective hours are included. The full day effect is not equal to the combined effect of peak only and off-peak only effect, since the latter lacks (late) evening and early morning ridership.

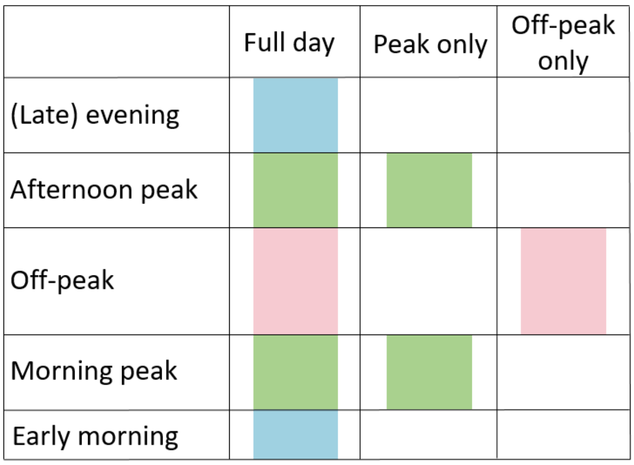


Figure 4.3: Time of day terminology. Note that the effect of off-peak + peak hours is not equal to the full day ridership.

For those lines of which detailed data about the used product type is available, product type can be translated into user groups. These product types are first sorted into one of 12 categories:

- No product - adult
- No product - anonymous
- No product - child
- No product - senior
- No product - teenager
- Subscription adult

- Subscription anonymous
- Subscription child
- Subscription senior
- Subscription teenager
- Students
- Other

These categories are then translated into user groups:

- Infrequent travelers (all 'No product' product types except teenagers)
- Commuters (Subscription adult)
- Scholars (No product - teenagers and Subscription teenagers)
- Students

Note that product types 'other', 'child' and 'subscription senior' are not in any user group; those products are barely used and do not fit the categorization. However, some qualitative statements about those groups will be given when applicable.

All lines in the region Waterland and Voorne-Putten & Rozenburg and a selection of lines in Groningen-Drenthe have been visited during the course of this research. This enables a better qualification of the type of line, the main OD's along the line and the urban development along the line, which is also referred to when compensating for non-LOS factors. Compensation for non-LOS factors results in a range of ridership growth, referring to the approximate change that is expected when is compensated for non-LOS effects, such as economic growth and paper ticket sales. A compensation for economic growth is performed by accounting for the national difference in vehicle kms for BTM, as discussed in Chapter 2. Compensation of paper ticket sales is performed for the concession Waterland by using trends in revenue data from EBS. Groningen-Drenthe and VPR data is compensated by the national trends, as shown in Chapter 2. Fare elasticity is compensated for by subtracting of the trends described in Chapter 2.

The search for model parameters continuous by using a linear regression analysis on the IVT and frequency cases.

Step 5.b. Regression analysis
The lines described in **step 5.a.** can be used in a linear regression analysis to determine which variables have a significant effect on ridership. The regression analysis is performed with SPSS software. The data set has been is discussed during the expert meeting (Expert meeting EBS (Appendix A.2), see also step 7), in which a plausibility check is performed. Implausible entries are removed from the data set.

Multiple regression is used, meaning a linear regression with multiple independent variables (Twisk, 2016). The variables used in the regression analysis are not all independent of one another (e.g. concession and region), which must be taken into account. For prediction models, inclusion of all variables thinkable might lead to a better estimation, but also to a larger standard deviation and inclusion of (largely) superfluous variables (Twisk, 2016).

A first limitation is the small amount of data points available. A rule of thumb is a minimum of 10 data points per variable tested for in the regression analysis (Twisk, 2016), though sometimes more are requested as minimum. 10 is an arbitrarily chosen (but often used) rule of thumb (Twisk, 2016), but it clarifies that sufficient data must be available to enable a reliable regression analysis.

A variable is classified as significant if a p-value lower than 0.05 is reached, however often a more lenient cut off of 0.10 can be used (Twisk, 2016). The larger the data set, the smaller the cut off is often chosen (Twisk, 2016). Therefore, the significance will be tested on the $p < 0.10$ cut-off, i.e. significance in the 90% confidence interval. However, it will be mentioned if variables are significant in the 95% confidence interval ($p < 0.05$) as well.

Initially, the relations between ridership and LOS-factors IVT and frequency are determined. In a second step, more possible predictors are added to the model. Due to the limited number of data points, each additional predictor is added one at a time and tested for significance. The predictor is removed before adding the next predictor, regardless of it being significant or not. The reasoning for each predictor is described below.

According to the Expert meeting EBS (Appendix A.2; see also step 7), most relevant for difference in elasticity are the region and the main users. Also, it is described that elasticities might be different if more alternatives exist within the public transport network, such that it is not necessarily a mode shift that is made. This leads to the predictors:

- Region - either Randstad or Rural.
- Concession
- Main user
- Number of alternatives
- Network density - ordinal variable, either ‘dense’, ‘average’ or ‘not-dense’.

In the Expert meeting F. van der Blij (Appendix A.1) it was discussed that number of public transport users per 100 inhabitants is a relevant measure for future ridership prediction. This data is available, but related to that, these predictors can be added:

- Catchment area - number of inhabitants for which the line is relevant
- Urbanity - the dominant urbanity of the cities/villages serviced by the bus line. Scale from 1 (urban) to 5 (rural), based on ‘Stedelijkheid’ classification from CBS.

Furthermore, from literature in Chapter 2, several more predictors can be added. Van Goeverden and Van den Heuvel (1993) provides a predictor model based on VF (also related to the already added ‘number of alternatives’ predictor). Balcombe et al. (2004) finds different elasticities for peak versus off-peak hours, but also for user groups (already added). Related to both is the predictor for type of day. Furthermore, the relevance of price changes has been shown (Chapter 2). The following predictors are added:

- VF factor
- Hour of relevance - the time of day in which the changes occurred (peak only, off-peak only or full day).
- Daytype 1 - i.e. a distinction between weekdays, Saturdays and Sundays.
- Daytype 2 - i.e. a distinction between weekdays and weekends.
- Price change - the price change in case of a significant change in price.

Some predictors are data inflicted, i.e. changes that occurred with cases within the period of analysis:

- Branding - i.e. a change to a new HOV brand or no change.
- MBO student OV

Finally, an additional predictor is suggested by the author:

- Line type - the type of line, being either ‘city’, ‘regional’, ‘HOV’ (BRT) or ‘Qliner’.

Step 6. Expert meeting

As a further check of the results, an expert meeting (Expert meeting EBS, Appendix A.2) and a workfloor experience check (Workfloor experience check EBS, Appendix A.3) are organized. The workfloor experience check is a meeting with a bus driver and team leader in Voorne-Putten & Rozenburg, to discuss the outcomes and to test the outcome from a more practical oriented point of view. In the expert meeting, at first the expert opinion about the magnitude of elasticities is gathered. All LOS changes which are analyzed in this thesis are introduced to the experts and their predictions of ridership change are documented. Furthermore, the results from this thesis are discussed. All cases analyzed in the line-based analysis are subject to a plausibility test, in order to identify and remove erroneous cases and to provide further context to the cases. This results in a data set, suitable for implementation into the model.

Step 7. Model making and validation

Based on the results and its interpretation, a model is made. As described in Chapter 3, an elasticity model is most suitable. The model means to provide predictive insights in the effect of changing the LOS. The requirements of the model are first further specified. This leads to the development of the conceptual model design. An Excel based tool is made, such that both the front-end as the back-end are easily adaptable for future expansion. Next, the user interface is designed.

The data sheets are the main source of data for the model and are based on the results of step 5, the analysis per line. To obtain an as complete as possible understanding of the effect of the LOS change, the three categories of data/results are added to the data sheet:

- Description of the characteristics of the line
- A quantitative analysis of the line
- A qualitative analysis of the line

A more detailed list of all data included in the model and the assumptions can be found in Appendix C.
Two aspects of the model are validated: the tool itself and the outcome. The tool is validated by analyzing the number of measures in a recent tender for which a ridership prediction can be given. The outcome is validated by comparing the outcome of the model to ridership growths as seen throughout cases of LOS-changes in The Netherlands.

Step 8. Further in-depth analysis of specific cases

In the validation of the model, ridership prediction for a selection of specific cases is found to be impossible. This holds for both existing models, as the newly developed model. Other tools beside the model are necessary to predict ridership in these cases, which could not be part of the before-after study and cannot be included in the model. The data also allows for this further insights into the response of (potential) passengers to changes. Which cases can be evaluated, depends fully on what is available in the data. The data available to this research allows for evaluation of the following questions:

- What is the effect of new urban development on ridership? This is done by analyzing the number of check-ins and check-outs of (new) bus stops near urban development and combining this with the number of households and inhabitants in that neighborhood. Since household and inhabitant statistics are only present on a yearly scale, a linear interpolation over the months is assumed.
- What is the effect of longer operating hours? Which ratios of use can be seen in each hour block and what are the characteristics of the main traveler in each hour block?
- How long does it take for passengers to respond to a change in level of service? Based on data analysis of a number of cases, the duration of behavioral changes is determined. Since it is suggested that a decrease in LOS has a quicker effect than an increase in LOS (Expert interview F. van der Blij), both situations are analyzed.
- What is the effect of schools on ridership? The usage of the bus stops near the schools are monitored and compared to the number of students based on data from DUO.
- What is the effect of operating a dedicated airport bus and how is the bus usage related to airport usage?
- Who are the early users when a new community service bus line is implemented and how much ridership can be expected on Saturdays?

Cases are analyzed by evaluating the ridership based on OD-matrices and/or the amount of check-ins. A variety of approaches is applied; all are data based and provide empirical relations. This step concludes the methodology.

5
Case study description

Summary: Data from three concessions is used. Concession Waterland is a concession with large passenger flows to/from Amsterdam. Most lines are frequent R-net lines and the network is well covering. It is rather well known what the developments in the area have been. Concession Voorne-Putten & Rozenburg is an area with no connection to the rail network, only one city is linked by metro to Rotterdam, which is also where the network is focused on. Groningen-Drenthe is a much larger area, but more rural. Lines are less frequent and the network less dense. The developments in Groningen-Drenthe are not well known and not described extensively, due to the large area it covers. Together, these three cases provide sufficient data and variability in data to base a model on.

5.1. Data description

The data available to this research includes OD-matrices based on smart card data. Since transaction data (and therefore ridership data) is often owned by the public transport operator (PTO) (Van Oort et al., 2015), it is not publicly available. The data used for this thesis is selected based on availability. Data from three different concessions is used: concession Waterland, operated by EBS, concession Voorne-Putten & Rozenburg, operated by EBS and concession Groningen-Drenthe, operated by Qbuzz (figure 5.1). Sufficient data from other concessions is not available.

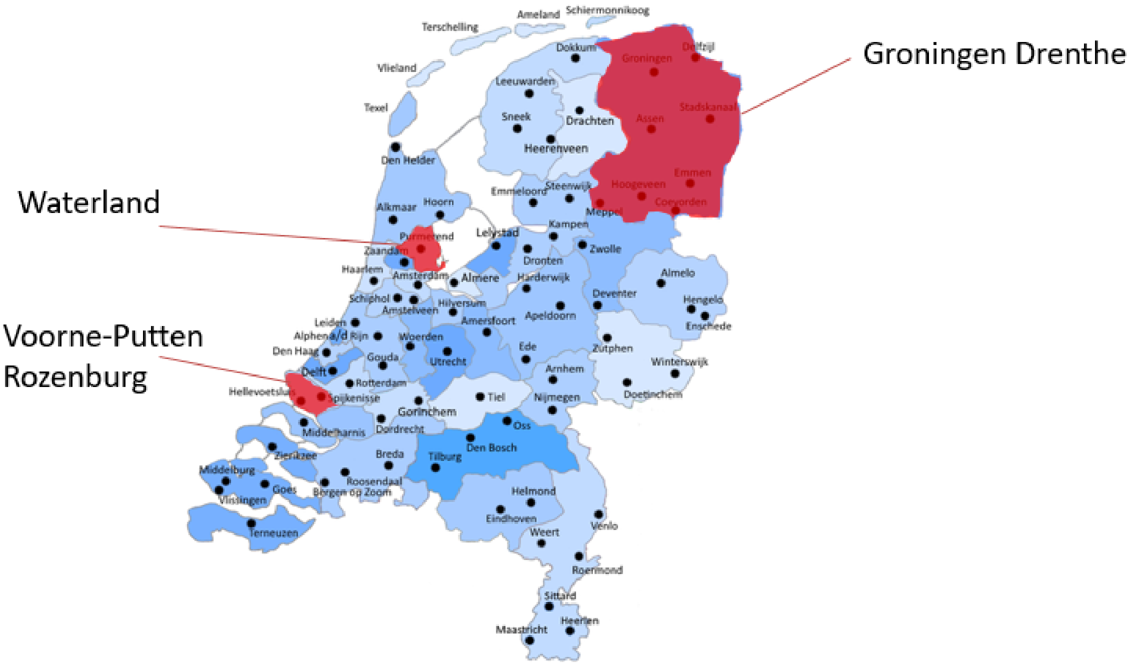


Figure 5.1: Geographic locations of the case study areas (Adjusted from: OV in Nederland, 2019).

Figure 5.2: Summary of the case studies.

Since public transport ridership is very context dependent, this chapter describes the areas from which the data originates and introduces vital context information for the analysis and the results, of which a short overview is presented in figure 5.2. The description of the concessions also provides input to the data sheets in the final model and enables proper comparison of the results in the discussion. For all three concessions, both the area and the bus network are described, as well as possible non-LOS factors of influence on ridership. Waterland is described most extensively, since the most and most detailed data is from Waterland, most results originate from the Waterland concession and the area is rather homogeneous. Since data is available from three different sources, the available data is described per concession. The chapter is partly descriptive of nature, providing context for interpretation and discussion. Furthermore, the case study description provides input for data analysis: the compensation for non-LOS factors (section 6.3) and regression analysis (e.g. number of competing modes) (section 6.4).

5.2. Case study I - Waterland

The first concession that is used for data analysis is the concession Waterland, near the cities of Purmerend, Volendam and Amsterdam. The PTO of the concession is EBS. The time period of interest is 2012-2019.

5.2.1. Description of the area

The concession Waterland is focused around the Waterland area near Amsterdam, largely focused on transport between Purmerend (ca. 80.000 inhabitants (Centraal Bureau voor de Statistiek - Statline, 2018), Edam-Volendam (ca. 35.000 inhabitants), Hoorn (ca. 70.000 inhabitants) and Amsterdam (ca. 850.000 inhabitants). The area is characterized by rural areas and small villages in between those few larger cities. A train line runs from Hoorn in the north towards Amsterdam Sloterdijk via Purmerend Overwhere, Purmerend and Purmerend Weidevenne. Only Hoorn has a direct connection to Amsterdam CS, the stations in Purmerend do not have this direct connection.

Roughly two corridors exist: a western one between Purmerend and Amsterdam and an eastern one between Edam/Volendam and Amsterdam. Both are connected with provincial roads (N235 vs N247), which have 2x1 lanes and are very sensitive to delays and traffic jams. The N247 between Amsterdam and Volendam was the most heavily congested (length congestion x duration congestion) provincial road (N-road) in The Netherlands in 2017; number 4 in 2018 (ANWB, 2018). Both roads have a single or tidal flow bus lane for large sections of the road, such that the bus is less sensitive to traffic jams. The region Waterland is mainly seen as an origin (home bound) with Amsterdam as a main destination (work bound) (Survey EBS, 2016) and therefore the transport tends to be very peak sensitive.

Tourism is also of essence in Waterland. The large amounts of international tourists in Amsterdam, or domestic tourists from all over the country travel to known hot spots as Volendam, Edam and Marken. Traveling can be done by guided tour in tour buses, by car of by public transport.

5.2.2. Description of the bus network

The Waterland network is subject to several product brands. R-net lines provide fast (direct) and frequent services for the longer distances. R-net is a product brand used in the larger Randstad area and used in more concessions. The R-net lines are complemented by an underlying network of regular buses, often meaning to provide a more local transport function. Three 'Buurtbus' (Community bus service) lines provide a regular service by minivan to the rural areas. Bizzliners (part of the R-net brand) are luxury touringcars with a higher fee, meant to attract business travelers. Lastly, there are a few lines especially for high school students, only available a few times a day (but accessible to all). Equipment used consists of luxurious touringcars as Bizzliner; 12.7m buses with comfortable seating for R-net lines; 12.0m citybuses for the underlying network and school lines; 21-persons Mercedes Sprinters for smaller liners in the underlying network; Volkswagen/Mercedes minivans for the community bus services (figure 5.3).

Figure 5.3: Equipment used in concession Waterland. From left to right: 8-person community service bus, 21-person midibus, 12m standard bus (both in regular and R-net branding (12.7m)), 18m articulated bus, Bizzliner touringcar.

The network map per July 2018 is shown on the next page to give an impression. The internal network has varied significantly over the years. The network is mainly focused on transport to/from Amsterdam Central Station (some by changing at Amsterdam North metro station). It is estimated that ca. 1/3th travelers from Purmerend have Amsterdam Center as destination, 1/3th the south of Amsterdam (center) and 1/3th transfers to the train (Quee, J. (SWECO), 2016). The Bizzliners focus on business travelers to Amsterdam South-East and until August 2014 also Amsterdam West (after which the Bizzliners have been replaced by a peak-only R-net service). It provides fast services from almost every neighborhood. Within the PTA of Waterland, Vervoerregio Amsterdam, 98.0% of the inhabitants have nearby access to public transport (CROW, 2017).

Due to the existence of dedicated bus lanes and difficult accessibility of Amsterdam city center by car, the bus is competitive to the car regarding travel time. A local train (Sprinter) runs from Hoorn via Purmerend Overwhere, Purmerend and Purmerend Weidevenne to Amsterdam Sloterdijk. Amsterdam Central Station can only be reached after transferring at Amsterdam Sloterdijk. An intercity service between Hoorn and Amsterdam Central Station is available as well. Wormerveer Station is connected directly by local train to both Amsterdam Sloterdijk and Amsterdam Central Station.

Survey EBS

In 2016, EBS performed a survey as part of a network redesign exercise (aggregated results are also published in EBS Public Transportation B.V. (2016)). Results of the survey (>2500 respondents) provide further insight in the characteristics of the travelers in Waterland. Hardly any of the respondents start their PT journey from outside the region. Also, only 7% of respondents continues their journey by transferring to the train. The main final destination by public transport is Amsterdam Center (65%). The number of respondents having Waterland as destination is insignificant (all zones have individually 0% share). This implies that Waterland is a region where people live and the bus is used to travel out of the region; and is only used to return home. However, Volendam, Edam and Marken are known touristic destinations and this means there are likely to be activity end trips going into the region Waterland; possibly these groups were not part of the survey since they are not familiar in the region and unaware of/not bothered by the survey. Over 60% of the respondents use the bus for work. The survey was meant for optimizing the network after implementation of the new metro line in Amsterdam. For transport within the region, the survey was less relevant and therefore possibly a non-representative group of respondents is present in the sample population. Furthermore, the survey was placed on the website; participating was voluntary.

Network map Waterland (EBS Public Transportation BV 2018)

5.2.3. Non-level-of-service factors

As described in Chapter 2, several non-LOS factors are of influence on ridership. Those being region specific are discussed here, separately per concession. The non-LOS factors which are region specific are competing modes, tourism and urban development.

Competing modes

The train stations in Waterland are Hoorn, Purmerend Overwhere, Purmerend and Purmerend Weidevenne. Only Hoorn is an IC-station and has a direction connection to Amsterdam CS. The Sprinter-stations Purmerend Overwhere, Purmerend and Purmerend Weidevenne are only connected to stations in the west of Amsterdam (Sloterdijk, Lelylaan and further). In the west of Waterland, busline 121 connects to station Wormerveer, a Sprinter-station with a direct connection to both Amsterdam CS and Amsterdam Sloterdijk. The situation in/near Purmerend is unique, since the bus network is the base of the public transport network instead of the train (Quee, J. (SWECO), 2016). The train stations are barely serviced by the buses.

The usage of all stations in Purmerend has been decreasing between 2013 and 2017 (figure 5.5). It is unknown whether the decrease in usage implies that less trips are made or that a mode shift has taken place. In case of the latter, it is possible that buses have become more popular as mode. Remarkably, station Wormerveer has seen an increase in usage by 7% in the same time period (figure 5.5). Station Amsterdam Holendrecht, located near the business park to which most Bizzliners are routed, has an increase in usage by 36%. Usage of the IC-stations in Amsterdam has seen a significant growth over the years 2013-2017 (figure 5.4), but due to their importance in the national network they are difficult to link with the region Waterland.

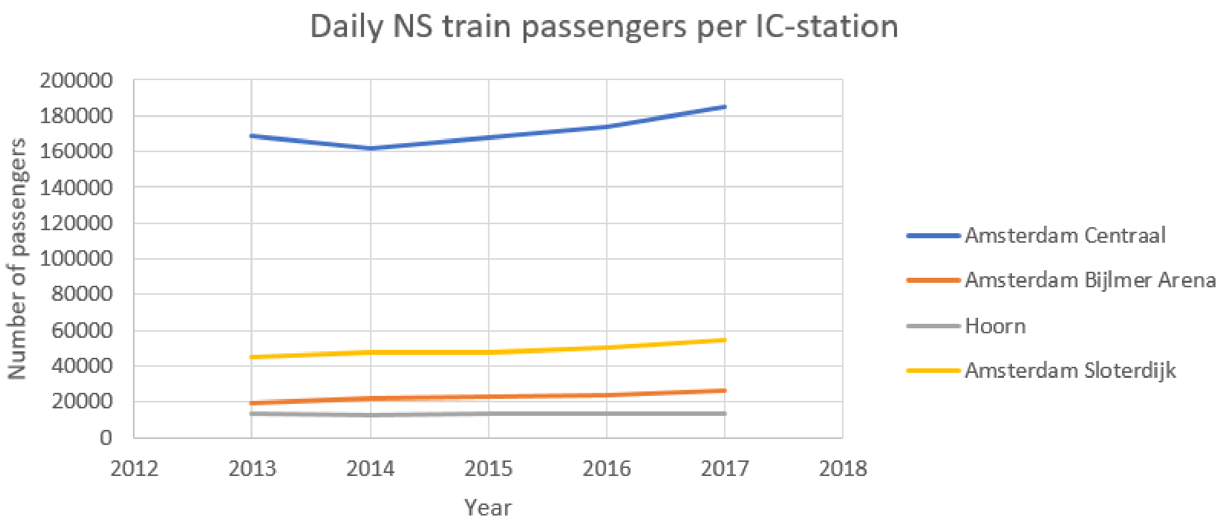


Figure 5.4: The development of the number of NS train passengers on IC-stations from 2013 to 2017 (data based on internal documents provided by Nederlandse Spoorwegen). Note that Amsterdam Bijlmer Arena is not classified as IC-stations, but has regular and scheduled IC-services.

Apart from the trains, bike and car are competitive with the bus. The bike can mainly be used internally in the cities, for example in Purmerend or in Edam/Volendam the bike is a very efficient alternative, competing with the regular buses. From the region Waterland to Amsterdam is too far, such that the R-net lines are often not competed by the bike. With the increased usage of the e-bike, this might have changed, since travel time/distance has become within a reasonable range. Though parking an expensive e-bike easily and safely in Amsterdam center might be a point of concern.

Due to the very high frequent bus services and dense network, combined with dedicated bus lanes and a congestion sensitive car road, the bus is able to compete with the car. In addition, parking in Amsterdam is difficult and expensive, making public transport favorable. This leads to a large modal share of the bus, with likely a large selection of choice travelers. This can have effect on the magnitude of elasticities and is further discussed in Chapter 9.

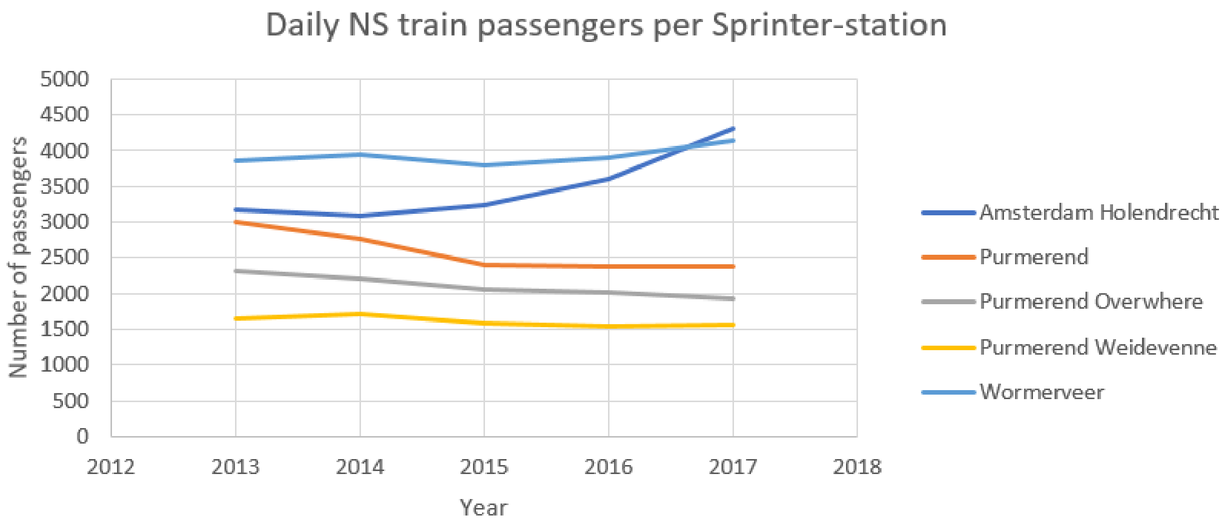


Figure 5.5: The development of the number of NS train passengers at Sprinter-stations in the region from 2013 to 2017 (data based on internal documents provided by Nederlandse Spoorwegen)

Tourism
In the region Waterland, significant tourism is present in Volendam, Edam and Marken. For the lines to/from Edam, Volendam and Marken, one must account for changes in tourism. Though guided tours with touringcars are present, tourists also travel with public transport. Tourists include both domestic and international tourists (Personal communication Gemeente Edam-Volendam).

No data on tourism in Edam, Volendam and Marken is available, however, national trends of overnight guests show an increase of a few percent a year (figure 5.6). Of the multi-day visiting tourists, 14% uses bus/tram/metro as mode of transport (NBTC Holland Marketing, 2014). For Edam-Volendam (single municipality), it is estimated that 39% of the foreign tourists and 11% of the domestic tourists travel by public transport (bus) (Amsterdam Marketing, 2016). The yearly trends (figure 5.6) show that there has been a yearly growth in tourists since 2010 and thus that lines servicing tourist destinations have been subject to a passenger increase not related to level-of-service. Figure 5.6 can be used to compensate for additional tourism. In Waterland, this is relevant for the relations Amsterdam-Marken, Amsterdam-Volendam Center and Amsterdam-Edam (direct).

Urban development
Data regarding urban development has been requested at all municipalities in the concession. The limited and negative responses are complemented with online documentation that could be traced. Development of houses in Purmerend between 2009-2016 has mainly taken place in Weidevenne and Overwhere, while most other neighborhoods did not see large developments (figure 5.1). No specific additions to the bus network have been implemented as a reaction to the urban development. Weidevenne has been a neighborhood in development, and still is. Its effect on bus ridership is discussed in the in-depth analysis of specific cases in Chapter 8. For the data analysis this means that if a line is chosen servicing Weidevenne and/or Overwhere; the growth in households must be accounted for.

Table 5.1: Number of houses in Purmerend over the years; per neighborhood (Purmerend in cijfers, 2019).

	2001	2006	2011	2016
Centrum	2127	2228	2322	2512
Overwhere	6391	6392	6612	6853
Wheermolen	3729	3727	3317	3527
Gors	3800	3856	4003	4089
Purmer-Noord	6243	6242	6356	6313
Purmer-Zuid	5050	5047	5075	5101
Weidevenne	2616	4961	6279	7183
Total	29 956	32 453	33 964	35 578

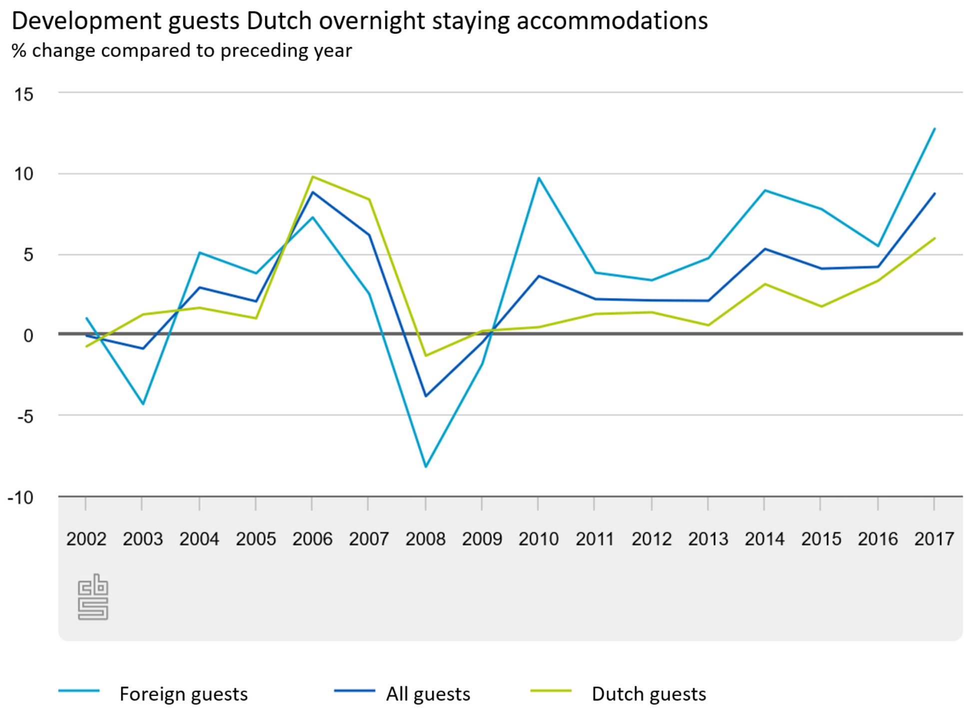


Figure 5.6: The growth in overnight guests in The Netherlands, as compared to the preceding year (Centraal Bureau voor de Statistiek - Statline, 2018; translated).

In municipality Edam-Volendam, the areas Broeckgouw in Volendam (800 houses) and Keergat in Edam (80 houses) have been developed, while in Oosthuizen an additional 49 houses have been added (Personal communication municipality Edam-Volendam). Broeckgouw received new bus service of line 110, which is also discussed in the in-depth analysis of specific cases in Chapter 8. In Hoorn and De Rijp no sizeable projects near the bus lines from concession Waterland were developed (Personal communication municipality Hoorn and municipality Alkmaar) in the relevant time period. Monnickendam has seen no significant urban developments in the relevant time period (Personal communication municipality Edam-Volendam). Middenbeemster is building a new residential area in the south. Project De Keyser has ca. 240 houses, of which ca. 110 have already been completed in 2016/2017/2018 (BPD, 2019). Besides some smaller projects in Landsmeer, Luijendijk-Zuid is a newly developed neighborhood in Landsmeer, with at least 154 households added between 2012 and 2016 (Gemeente Landsmeer, 2016), of which most have been constructed in 2015. At the beginning of 2019, a total of 368 households must be added (Noord-Hollands Dagblad, 2018).

All in all, lines servicing Purmerend Weidevenne and Overwhere, Broeckgouw and Keergat (Edam-Volendam), Middenbeemster and Landsmeer have to be compensated for the urban development when using data from the mentioned time periods. Apart from additional housing, there have been other construction works. From the end of 2013, the main bus station of Purmerend (Purmerend Tramplein) was reconstructed, causing diversions in bus routes between December 2013 and December 2014. A replacing bus stop (Melkwegbrug) was located nearby (walking distance of) the original station. This means that in the data analysis this replacement must be adjusted for.

5.2.4. Data from Waterland

Data is obtained from the Zight database. Before smart card data is entered into the Zight database, several adjustment steps have already been performed. A selection of steps that are essential for this research are:

(i) Cleaning; common data errors are removed; i.e. extreme transaction values, data without correct concession ID, erroneous product codes.

(ii) Marking of duplicates, such that they can be removed.

(iii) Handling unsuccessful check-ins. In case the smart card is removed from the reader before the transaction is complete, the unsuccessful transaction is still registered by the reader. The card needs to be presented again, leading to a second transaction. In passenger related data, this is counted as a single passenger, despite being two transactions in the system.

(iv) Bus stop name from timetable is linked to the bus stop ID from the smart card system. Duplicates are removed.

(v) Non-smart card related products are not included in the passenger data; passenger data only includes smart card data.

(vi) All data is anonymous and therefore limited to an OD-estimation per vehicle. Transferring to another vehicle (often another line) cannot be tracked.

The Zight database then provides among others the OD-matrices which can be split out per line, per year, per month, per type of day, per hour and more. For Waterland, in some cases the LOS change is implemented in August, opposed to the regularly used December month. The data analysis is then still based by comparing Novembers, since August is a holiday month in which different elasticities can be expected. By using Novembers, the change is initially only 3 months after the LOS change. Therefore, in addition the change after 15 months is analyzed.

With the analysis of the data, it must be taken into account that data from 2011 and 2012 on lines (the Bizzliners) is unreliable; due to water damage not all smart card readers were in operation (Personal communication EBS).

5.3. Case study II - Voorne-Putten & Rozenburg

The concession Voorne-Putten & Rozenburg (VPR) includes all public bus transport on the island Voorne-Putten and the city of Rozenburg. It includes the city services in Spijkenisse and numerous regional lines. The concession has been operated by Connexxion until December 2018, after which EBS took over. The time period of interest is 2016-2019.

5.3.1. Description of the area

The area, to the south of Rotterdam, is focused largely on Spijkenisse, which has a metro connection to Schiedam and Rotterdam. The larger cities in the area are Spijkenisse (ca. 80.000 inhabitants (Centraal Bureau voor de Statistiek - Statline, 2018)), Brielle (ca. 13.000 inhabitants), Hellevoetsluis (ca. 39.000 inhabitants) and Rozenburg (ca. 12.000 inhabitants). Furthermore, it is the gateway to the Botlek harbour area.

Rozenburg and the Botlek are connected to Rotterdam by A15 Freeway. On the island Voorne-Putten, several provincial roads are present. Driving into/out of Spijkennisse, a dedicated bus lane is present. The bus is (significantly) slower than the car during off-peak hours, but during peak hours the dedicated bus lane proves to be a huge advantage.

The Botlek harbour area likely attracts workers from outside the concession; there are no other main attractions. Brielle has a historic center, which attracts tourists and Rockanje has the beach, with regular service in the summer. Near Spijkenisse Metro Centrum, the hospital is located.

5.3.2. Description of the bus network

The current concession consists of 2 R-net lines, 4 city lines in Spijkenisse and a few regional lines. The R-net lines provide highly frequent connections between Hellevoetsluis and Brielle to Spijkenisse. A selection of the trips continue to Rockanje and Oostvoorne. The most important travel relations are to/from Spijkenisse Metro Centrum.

The network map of Voorne-Putten & Rozenburg of the year 2019 is shown on the next page. I.e., the map shown is the new network after EBS took over from Connexxion. The introduction of R-net was the most significant change in the new concession, with higher frequencies, higher comfort and less bus stops.

The equipment used is a mix of different size of vehicles (figure 5.7).

Figure 5.7: Equipment used in concession Voorne-Putten & Rozenburg. From left to right: 8-person minibus, 12m standard bus (both in regular and R-net branding), 15m R-net bus (also available in regular branding).

Network map Voorne-Putten & Rozenburg 2019 (EBS Public Transportation B.V., 2019)

5.3.3. Non-LOS factors

Competing modes

There is no train service in the Voorne-Putten & Rozenburg concession, only three metro stations, linking Spijkenisse to Schiedam and Rotterdam. Internally, the bike can be an alternative. However, between the villages and towards Spijkenisse, distances are rather long: biking is possible, but probably not very popular.

Tourism

Over the years 2011-2016, the tourism sector has grown faster on Voorne-Putten than the nations average and of which the sector transport has shown the largest growth (I&O Research, 2017). However, the tourism statistics include bars and restaurants etc. as well. Most hotels are in Brielle and Westvoorne (Rockanje) (I&O Research, 2015). The historic center of Brielle is a tourist attraction, but mainly visited during summer and April 1st (Brielle.nu, 2019); thus less relevant for March. Rockanje is well known for its beaches. Since only a before-after study for March can be performed, the beach is excluded as factor of influence and will not be further discussed. No data is available for the period of interest (2016 to 2019) and tourism is limited in the month March. Therefore no compensation for tourism will be applied in the data analysis.

Urban development

In Rozenburg, Westvoorne and Hellevoetsluis only small scale urban development has been identified. Spijkenisse has a large new urban area in development: De Elementen. It is a long-term project, which has been under development for over 10 years (Kadaster, 2019) and consists of over 1000 households (Centraal Bureau voor de Statistiek (CBS), 2019). Currently, it is serviced by EBS bus line 81. Brielle has seen the development of Nieuwland-Oost, however only a small selection of houses has been constructed between 2016 and 2019. All in all, only quantitative compensation is needed for De Elementen.

5.3.4. Data from Voorne-Putten & Rozenburg

In December 2018, EBS took over the bus operations in the concession from Connexxion. The data available to this research is limited to the OD-matrices of the month March 2016 (Connexxion) and the full database from the Zight database from December 2018 onwards (EBS). As a result, only a comparison between March 2016 and March 2019 can be made. Due to failing smart card systems, no reliable data is available for line 81; for line 85 only reliable data is available for a selection of weeks.

The OD-matrices are available for all lines, all ODs and can be sorted per hour block and type of day. For privacy reasons, for all OD-pairs with less than 5 passengers per hour, per type of day, per line, per month, the number of passengers has been removed and replaced by '*'. This means that no data is available for these entries; those will be estimated using random numbers. The uncertainty of the growth factors and elasticities is thus larger compared to data from Waterland.

For March 2016, no information about product type is available. Analyzing sensitivity per user group is thus not possible.

5.4. Case study III - Groningen-Drenthe

The concession Groningen-Drenthe entails all public bus transport within the provinces of Groningen and Drenthe and is operated by Qbuzz. Trains and private (bus) transport are not included in the concession. The concession entails two entire provinces including many cities and lines; only an aggregate description is given. The time period of interest is 2015-2019.

5.4.1. Description of the area

The area is a rural area, mainly focused on one larger city, Groningen (ca. 200.000 inhabitants (Centraal Bureau voor de Statistiek - Statline, 2018)), and a few mid-size cities such as Assen (ca. 70.000 inhabitants), Emmen (ca. 100.000 inhabitants) and Hoogeveen (ca. 50.000 inhabitants). Groningen houses a university and several public institutions (UWV, DUO, Belastingdienst); Assen houses the NAM and Emmen has the Zoo 'Wildlands Adventure Zoo Emmen'.

Table 5.2: Locations of higher education in Groningen-Drenthe. Based on Dienst Uitvoering Onderwijs (DUO) (2019) and MBO Raad (2019).

University Groningen	HBO Meppel	MBO Stadskanaal	MBO Eelde
HBO Groningen	MBO Delfzijl	MBO Emmen	MBO Veendam
HBO Assen	MBO Appingedam	MBO Meppel	MBO Assen
HBO Emmen	MBO Groningen	MBO Hoogeveen	MBO Leek

Since the introduction of the free public transport card (Student OV) for MBO students in 2017 was expected to have a large effect in this concession (Personal communication OV-bureau Groningen Drenthe), the locations of all higher education institutions are listed in table 5.2. These locations can and should be taken into account in the data analysis.

5.4.2. Description of the network

The network in Groningen-Drenthe is not only centered around the city of Groningen, but provides a connecting network for most of the cities and is complementary to train services. Within the province Groningen, 92.4%, and Drenthe, 83.7% of the inhabitants has nearby access to public transport (2016) (CROW, 2017).

Also in Groningen-Drenthe, multiple product formulae are present. Qliners provide touringcar services for the longer distances. A Q-link network centered around the city of Groningen, providing high capacity, fast (direct), high frequency services from large cities in the surrounding area towards P+R locations around Groningen and important destinations within the city. Since 2018, Emmen also has a Q-link line. Complementary to the Q-link and Qliner lines, there are regular city services and regional services. Together with the network of national and regional trains, they cover the most important destinations within the two provinces. For the more rural areas, an on-demand bus ('belbus') or community bus service ('buurtbus') is present. In smaller cities, such as Hoogeveen, Meppel and even Assen, separate city bus lines (driven with minivans) are present which are organized by private institutions or local government, since public transport was no longer viable.

The equipment used is a mix of different size of vehicles (figure 5.8). The Qliners are driven with touringcars (15m bus, double deck bus) providing more comfort. The regional lines and regular city bus lines are driven with 12m buses or 18m articulated buses. Smaller regional lines are sometimes operated with midi- or minibuses. The Q-link city services are operated with articulated 18m or 21m buses.

Figure 5.8: Equipment used in concession Groningen-Drenthe. From left to right: 8-person minibus, 12m standard bus, 18m articulated bus (both in regular and Q-link branding), Qliner touringcars (12m, 15m or double deck).

The network map of Groningen-Drenthe of the year 2018 is shown on the next page. No major network changes have been implemented in the period of interest.

The concession Groningen-Drenthe is a different network as compared to Waterland. Waterland has a major demand to/from a particular destination (Amsterdam). Groningen-Drenthe consists of an extensive city network in the city of Groningen and a rural network in the provinces.

Network map Groningen-Drenthe 2018 (Qbuzz, 2018)

5.4.3. Non-LOS factors

Competing modes

For the concession Groningen-Drenthe, only very limited data is available on trains. The regional trains in Groningen and some regional trains in Drenthe are operated by Arriva instead of NS and despite requested, they do not publish nor provide data. Therefore, only a limited analysis of the train usage in Groningen-Drenthe can be provided (figure 5.9). All train lines in the province Groningen are directed towards the city of Groningen, not servicing transverse routes. The sudden growth of Hoogeveen is remarkable. Furthermore, the decrease in usage of Groningen HS can imply that passengers use Groningen HS less as transfer stop to the train and instead access the train network at other stations in the network. The growth/decline of the train passengers provide a qualitative impression and can be linked to possible growth in the line-based analysis (section 6.3).

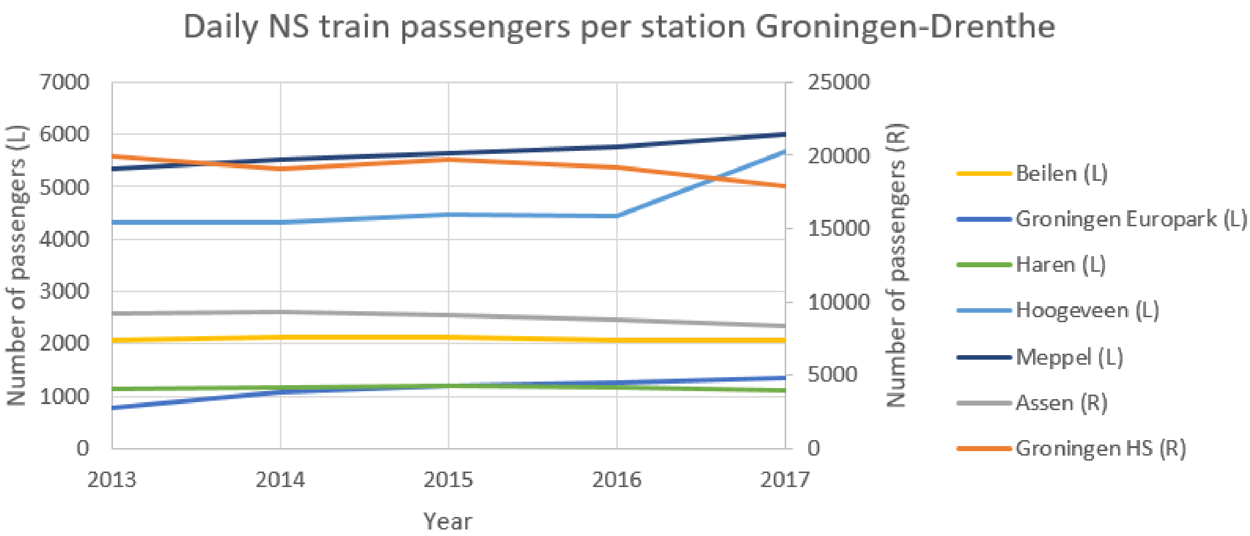


Figure 5.9: NS train users per day at stations serviced by NS. Note that Arriva (regional train) passengers are not included in the data.

Within the cities, the bike is an alternative. However, between cities, distances are large and the bike will no longer be an option. The region is very car focused, also substantiated by the high car ownership. Drenthe has the highest relative private car ownership in The Netherlands, with 512 per 1000 inhabitants, while Groningen is just above average 438 to 436 on average (Centraal Bureau voor de Statistiek - Statline, 2019). Two freeways are present: the A7 (east-west) and the A28 (north-south). Provincial roads build up the largest part of the car network.

Tourism

Within the concession, Drenthe is known for its nature and dolmens. Since Drenthe is more prone to long-stay tourism in the summer, the effect of tourism on data in April and November is assumed to be limited. The city of Groningen is ideal for a city trip or a day visit. Tourism in the province of Groningen shows an upward trend in the period of interest (figure 5.10). Dependent on the line, it is considered whether compensation for tourism is necessary. Trends from figure 5.10 can be used for the compensation.

Urban development

Due to the size of the concession and the limited use for analysis, no information has been requested. For those lines that are in the analysis, a separate overview is provided. In Groningen, Meerstad has been developed, which will be further discussed in an in-depth analysis in Chapter 6. In Assen, the station has been renovated; construction works on the rails was necessary in 2016 and 2017 (ProRail B.V., 2019). The city center in Emmen has undergone development since 2008, with a.o. moving the zoo, adding a parking garage and housing and many of construction works (Gemeente Emmen, 2019). Further urban development will only be discussed when relevant in a specific case studied.

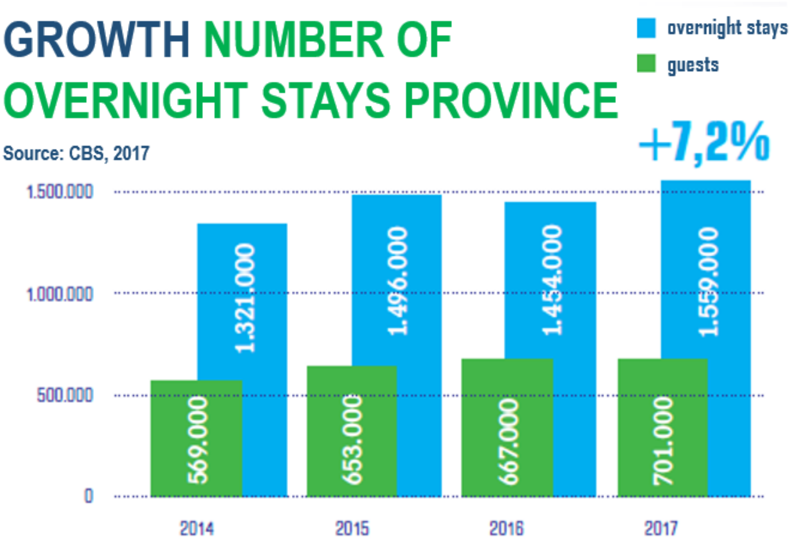


Figure 5.10: Tourism in Groningen (Marketing Groningen (2019) based on CBS data; translated).

5.4.4. Data from Groningen-Drenthe

The data from Groningen-Drenthe consists of a combination of two sources. Data that is provided by OV-bureau Groningen Drenthe are OD-matrices for a limited selection of lines, per year, per month, per type of day. A further distinction per hour is not possible. All OD-matrices are based on smart card data, use of other products is not included.

For Groningen-Drenthe, also publicly available data is provided by the dashboard of OV-bureau Groningen Drenthe. This data includes total number of passengers and total number of passenger kilometers per line, per type of day, per product type, per month, per year. However, no insight into disaggregate data such as OD-matrices or number of check-ins per stop is available. Data is available from January 2015 to present. The dashboard data contains some issues:

- For the full year 2015, the data during the weekends (Saturday + Sunday) is unreliable and therefore disregarded.
- For the months February 2015, March 2015, August 2015 and November 2015, data from the weekdays is written on weekend days. These months will be disregarded as well. The remaining data of 2015 will only be used if necessary for specific cases.

5.5. Case study conclusions

The three concessions all have different characteristics and differences in level of detail of the data. This chapter provides context to the future user of the model and provides further input for the data analysis. Compensation for urban development is needed for several areas in Waterland, Voorne-Putten & Rozenburg and Groningen-Drenthe when they are used in the data analysis; or the areas should be excluded from the analysis. Tourism is of limited relevance since months that are analyzed are outside the tourism season. However, in some cases as e.g. Marken and Volendam center, compensation is possible and applied in the next chapter. The competing modes provide a qualitative impression of the environment in which the lines operate. This cannot be adjusted for in a quantitative manner, but provides input for the regression analysis and to the information provided by the model (see also Chapter 7). The same holds for the type of network and types of line present, which are included in the regression analysis and final model as well. The differences in data provide input for the discussion (Chapter 9), since it can be a factor in differences in results of the three concessions. To conclude, data from these concessions are the basis for this research. This chapter provides the essential context of all cases presented in the next chapter, and input for compensation for non-LOS factors, the regression analysis and the final model.

6
Data analysis results

Summary: Data is analyzed in a before-after study, such that model parameters can be derived. An analysis per OD-pair and an analysis per line is performed, to find the best approach for analysis. Results from the analysis per OD-pair shows a large spread of results with poor fit of a trend line and are therefore classified as unsuitable for translation into a model. Analysis per line show behavior in line with the hypothesis; however, the behavior does not converge towards elasticities. A regression is performed on the line-based results. Regression analysis shows an improvement in LOS increases ridership, as hypothesized. However, which context factors play a role in ridership prediction is very dependent on the regression design and likely limited by the small amount of data points. The best way to create a model with the results is to maintain each of the cases and present them separately, including context.

This chapter presents the results of the before-after study of the three case studies from Chapter 5. Methodology wise, these are the results from step 4 to 6 (figure 4.1). The analysis results in this chapter are presented in four sections. First the general trends in Waterland, Voorne-Putten & Rozenburg and Groningen-Drenthe are presented. This section sets the scene and provides context for all other results. The analysis based on all OD-pairs is presented in section 6.2; the analysis based on lines in section 6.3. Within the line-based analysis, a subsection presents additional learnings. This includes interaction between peak and off-peak ridership and sensitivity of user groups. The results from the expert meeting are incorporated in the line-based analysis. The line-based analysis results form the input of the regression analysis in section 6.4. The data analysis results are meant to answer sub-research question (C): What relations can be derived between ridership and level-of-service changes?

6.1. General trends

The general ridership trends in the concessions provide insight into the context in which the cases operate. These general trends provide an estimation of what autonomous growth can be expected in the concessions. The number of check-ins in the concessions Waterland, Voorne-Putten & Rozenburg and Groningen-Drenthe (table 6.1) over the years show an upward trend of a few percent. For Groningen-Drenthe, the growth of all passengers (i.e. inclusive paper tickets) is calculated. VPR growths are estimates as found in the transportation plans of Connexxion.

Table 6.1: The growth of check-ins in the concessions, compared to the preceding year, averaged over the months.

Year	Change in Waterland	Change in Groningen-Drenthe	Change in Voorne-Putten & R.
2013	+4%	-	-
2014	-1%	-	-
2015	+2%	-	+ 3%**
2016	+2%	+3%*	+1%***
2017	+4%	+6%	-
2018	+1%	-2%	-

*Months with unreliable data removed from average.
**(Connexxion, 2015)
***(Connexxion, 2016)

The share of paper tickets, which do not show up in the OD-data, varies over the years and over the regions (table 6.2). The shares from Waterland are based on revenues; while the shares of Groningen-Drenthe are based on passenger numbers. From VPR, no data is available. Calculation of the share of paper ticket sales is essential for compensation for non-LOS factors in section 6.3. VPR results will therefore be compensated by using national trends.

Table 6.2: Share of paper ticket sales over the years.

Year	Share in Waterland	Share in Groningen-Drenthe
2012	7%	-
2013	5%	-
2014	5%	-
2015	4%	15%*
2016	4%	14%*
2017	5%	11%*
2018	3%**	7%

*Months with unreliable data removed from average.
**Fares and therefore revenues have changed, so not comparable to preceding years.

There is often a small increase in number of check-ins (table 6.1), although this is not yet compensated for a smaller share of ticket sales (table 6.2). There are no clear differences over the concessions. The year 2014 stands out as a sudden decrease in Waterland, possible caused by the redesigned network with service cuts. The year 2017 stands out as a high growth in check-ins, possibly caused by the free student OV (SOV) for MBO, mainly in Groningen-Drenthe.

With these general trends in mind, the next step is to perform before-after studies of LOS changes in the concessions. The first approach is to analyze the effect of LOS changes based on OD-pairs.

6.2. Analysis based on all OD-pairs

The analysis based on OD-pairs describes the change in ridership and change in level-of-service (LOS) on a stop-to-stop basis. OD-pairs thus refer to bus stops. An analysis is made for the time period November 2013 versus November 2014 for the concession Waterland, for weekdays only. Based on the available data, the effect of two LOS factors can be tested: travel time and frequency.

6.2.1. Travel time elasticity

Travel time elasticity relates the change in ridership to change in travel time. Different definitions of travel time can be used: in-vehicle time (IVT), total travel time or VF. The latter two include the in-vehicle time in their definition. Since only IVT is available in the data, travel time elasticity is further referred to as IVT elasticity.

The change in ridership is plotted versus the change in IVT (figure 6.1). For the IVT analysis, scheduled IVT is used and a cut-off for minimum number of monthly users is applied, which is varied. Each data point represents an OD-pair per line. All known outliers are removed. Plots are made showing the change in IVT versus the change in ridership. Results of the IVT show a large scatter of elasticity with numerous data in all four quadrants (figure 6.1). According to the hypothesis, data should fall in the quadrants marked with 'A', but numerous data points fall in the quadrants marked with 'B'. A linear trend line (yellow) finds a relation y=-6x + 10. The trend is as hypothesized, increasing ridership with decreasing in-vehicle time; however the fit is unsatisfying. R^2 is used as a measure for the fit, being a value between 0 (no fit) and 1 (perfect fit). The R^2 is low: 0.097. A fit of 1 is not realistic, since there is not yet compensated for non-LOS factors and literature values for IVT elasticity already show a degree of variability. Despite, the R^2 of 0.097 is far from sufficient.

If ridership change is presented in absolute numbers, instead of relative change, a linear trend line finds a relation y=-39x + 62 (figure 6.2). R^2 is 0.033. Again, numerous data points are found in the'B' quadrants, contradicting the hypothesis. For OD-pairs with very low monthly usage, high relative growths can be obtained easily. Therefore variations in the data analysis have been performed in order to optimize results. Larger cut-offs of minimum monthly users per OD-pair are used (table 6.3), though with the limitation that a larger cut-off means a lower number of data points.

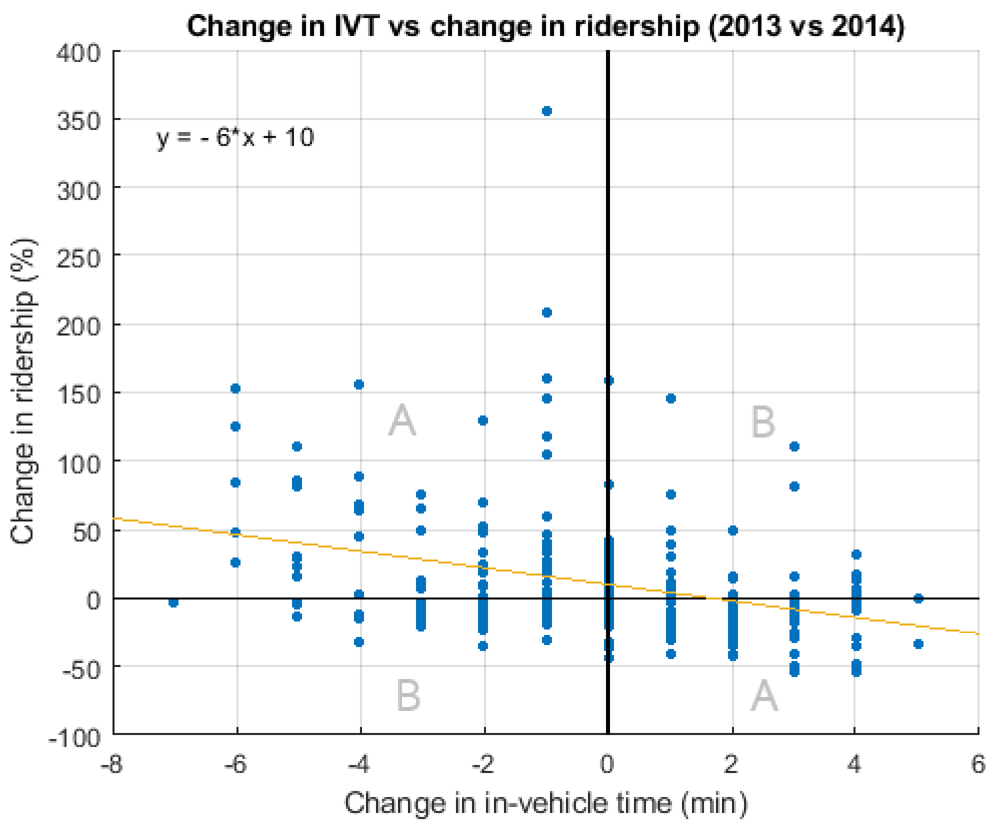


Figure 6.1: Travel time elasticity November 2013 versus November 2014 for all day usage when using relative ridership. Only OD-pairs with > 100 monthly passengers are shown. The quadrants representing the hypothesized relation are marked with 'A'. Quadrants with a-typical (contradicting hypothesis) are marked with 'B'.

Table 6.3: Variation in R^2 in IVT analysis when the minimum number of monthly users is changed. R^2 absolute refers to the R^2 when ridership change is defined in absolute sense; R^2 relative refers to the R^2 when ridership is defined as a relative change (i.e. %).

Variation	**R^2 absolute**	**R^2 relative**
>10 users	0.016	0.015
>30 users	0.023	0.022
>100 users	0.033	0.097
>500 users	0.058	0.028

Elasticities are based on a relative change, the relative change in ridership approach is thus preferred. Since the fit is best when a cut-off of 100 monthly users is used (table 6.3), further variation is performed with a minimum of monthly users per OD pair. In the further variation, the data set is filtered/compensated and the effect on the fit is analyzed (table 6.4). Filtering and compensation operations account for non-LOS changes, other LOS changes, outliers, etc. Small values removed refers to IVT changes smaller than |3| min being removed. Outliers which are removed are outliers as identified by a box plot. OD cleaning refers to removal of prominent transfer stops, i.e. Het Schouw, Ilpendam Dorp, Broek in Waterland Dorp, Tramplein/Melkwegburg and removal of stops with nearby urban development or tourism (as identified in Chapter 5). Line cleaning refers to removal of all lines with frequency changes and removal of Bizzliners and scholar lines. Regardless of which cleaning operation is performed, the hypothesized relation holds for the trend line: a larger IVT leads to a smaller ridership. However, per OD, there is a large variety with many occurrences of unhypothesized (a-typical) relations (those data points in the quadrants marked with 'B') and the fit never exceeding a R^2 of 0.22.

Three features of the results are emphasized:

- The trendline is as hypothesized, i.e. generally an increase in LOS leads to an increase in ridership.
- The fit (R^2)of the trendline is insufficient.
- Many OD-pairs show a-typical behavior, i.e. a decrease in ridership when LOS is improved and an increase in ridership when LOS is decreased.

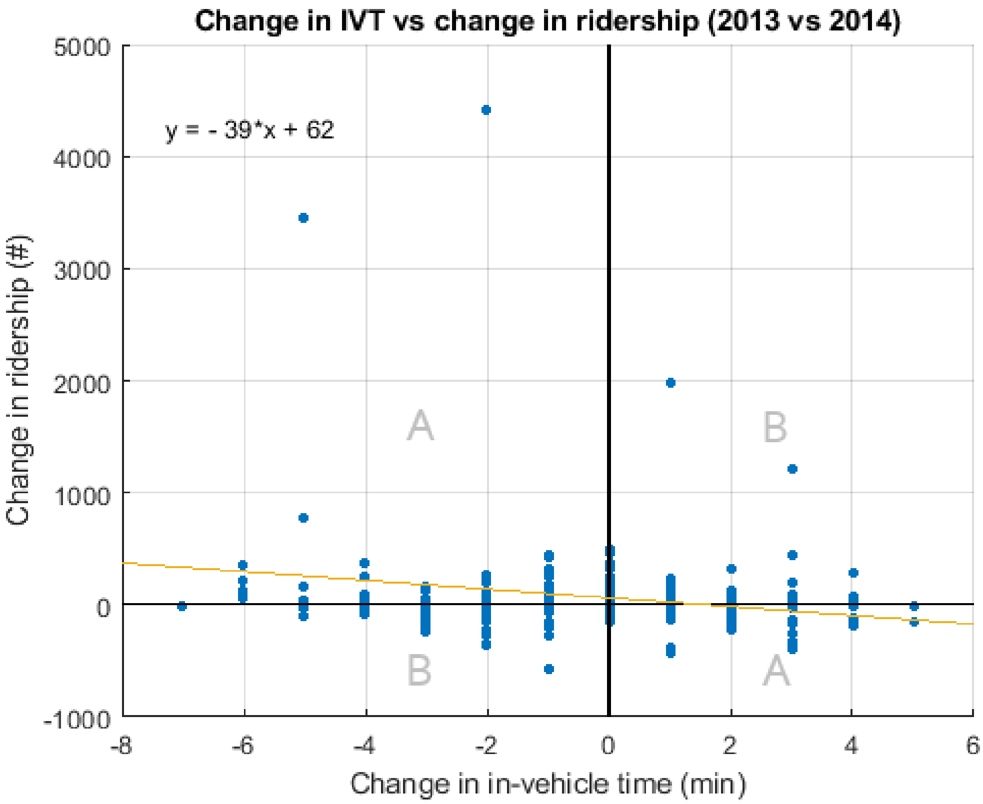


Figure 6.2: Travel time elasticity November 2013 versus November 2014 for all day usage when using absolute ridership. Only OD-pairs with > 100 monthly passengers are shown.

Table 6.4: Variation in R^2 in IVT analysis. Note that the effect of certain cleaning operations is small, since the conditions >100 monthly users per OD pair has already cut-out a large selection of ODs.

Variation	R^2 absolute	R^2 relative
small values removed	0.055	0.217
outliers removed	0.041	0.135
only hours 7 and 8 (>30 users)	0.07	0.04
OD cleaning	0.056	0.215
Line cleaning	0.007	0.027
Growth compensation	0.033	0.097

These results suggests that the analysis per OD-pair for IVT is not going to lead to model parameters due to the last two features mentioned. The question arises if the same features are shown in the frequency elasticity per OD-pair.

6.2.2. Frequency elasticity

An integrated analysis such as for IVT is not possible for frequency. First of all, frequencies stored in the systems showed a deviation with reality when checked. Correct frequencies can only be assigned by hand, which makes bulk analysis very time consuming. Furthermore, in Waterland the frequencies and the frequency changes differ largely between the hours. Therefore only a selection of lines and hour blocks is analyzed. The emphasis of this section is on analyzing whether frequency elasticity per OD-pair shows the same features as IVT elasticity.

Frequency elasticity is determined based on a selection of lines. First, frequency changes on line 304 and 307 are analyzed. Since frequency changes occurred only in a selection of hours, the ridership per OD-pair for each hour is treated as an individual data point and only the relevant hour blocks are included. Since working with hourly data (monthly travelers within an hour block), all OD-pairs with ridership > 3 have been selected, a much smaller cut-off than for IVT. The change in ridership is spread between both negative and positive changes, for both increasing and decreasing ridership (figure 6.3). Whereas it is hypothesized that data would be in the quadrants 'A' (frequency increase = ridership increase and frequency decrease = ridership decrease), numerous data points in the a-typical 'B' quadrants are observed.

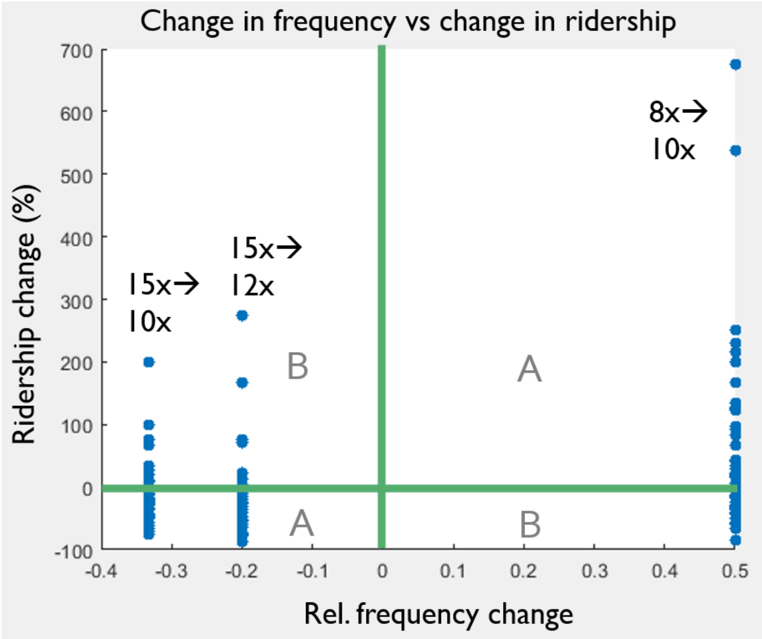


Figure 6.3: Frequency elasticity of the OD-pairs of three lines (November 2012 vs November 2013). All OD-pairs with ridership > 3 have been selected, weekdays only. Note that regardless of the change being a frequency increase or decrease, data points are spread in both negative and positive changes in ridership.

The distribution of the OD-pairs is difficult to observe in the scatter plot. Histograms of two frequency changes show the distribution of ridership change (figure 6.4, figure 6.5). Since the change is limited to a selection of hours, ridership change is measured only for these respective hour blocks. Outliers are removed. Again, side 'B' marks the data points with a-typical behavior compared to the hypothesis.

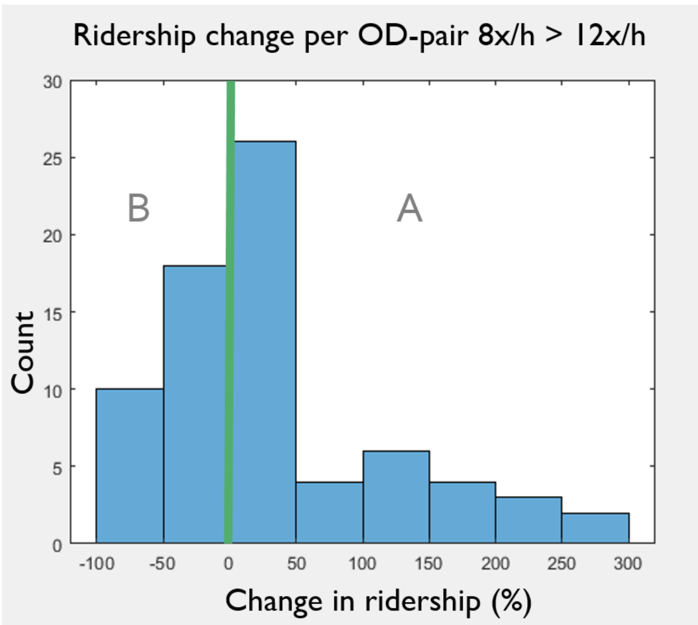


Figure 6.4: Frequency elasticity histogram of the OD-pairs of a single line (November 2012 vs November 2013), which is subject to a frequency increase from 8x/h to 12x/h. All OD-pairs with ridership > 3 have been selected, weekdays only. Note the large amount of a-typical data points (half 'B').

In the network change in August 2014, lines 121, 103 and 306 are decreased in frequency from 2x/h to 1x/h in a selection of hour blocks and type of days. When analyzing the effect on ridership, when each of the hour blocks and lines are treated as individual data points, a large spread in ridership changes is seen (figure 6.5). Since the data is per hour block, no cut-off in minimum number of users is applied.

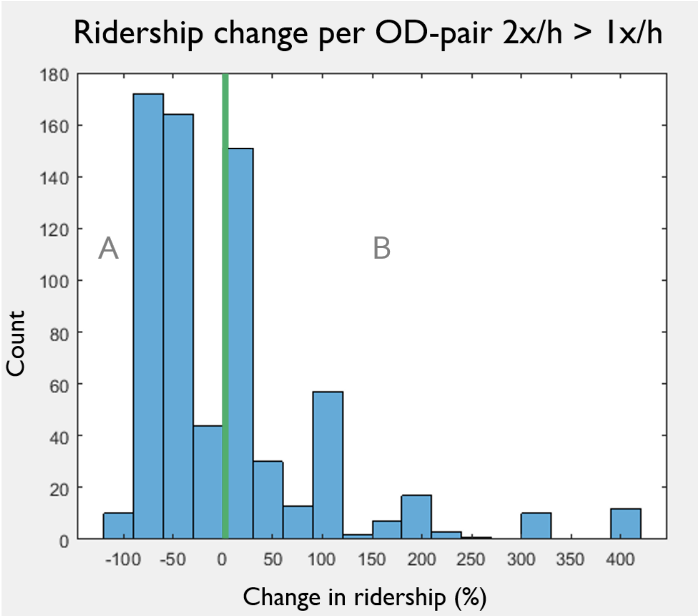


Figure 6.5: Frequency elasticity histogram of the OD-pairs of multiple lines (November 2013 vs November 2014), weekdays only, with a frequency decrease from 2x/h to 1x/h. Note the large amount of a-typical data points (half 'B').

When analyzing the effect on a full day basis, instead of having a new data point each hour block, the daily effect is measured (figure 6.6). Note that not in all hour blocks a frequency change has occurred. A cut-off of minimum 50 users per month is applied. The cut-off is lower than the cut-off used in the IVT analysis, since 2 of the 4 lines in the analysis have relatively low usage and would otherwise be largely absent.

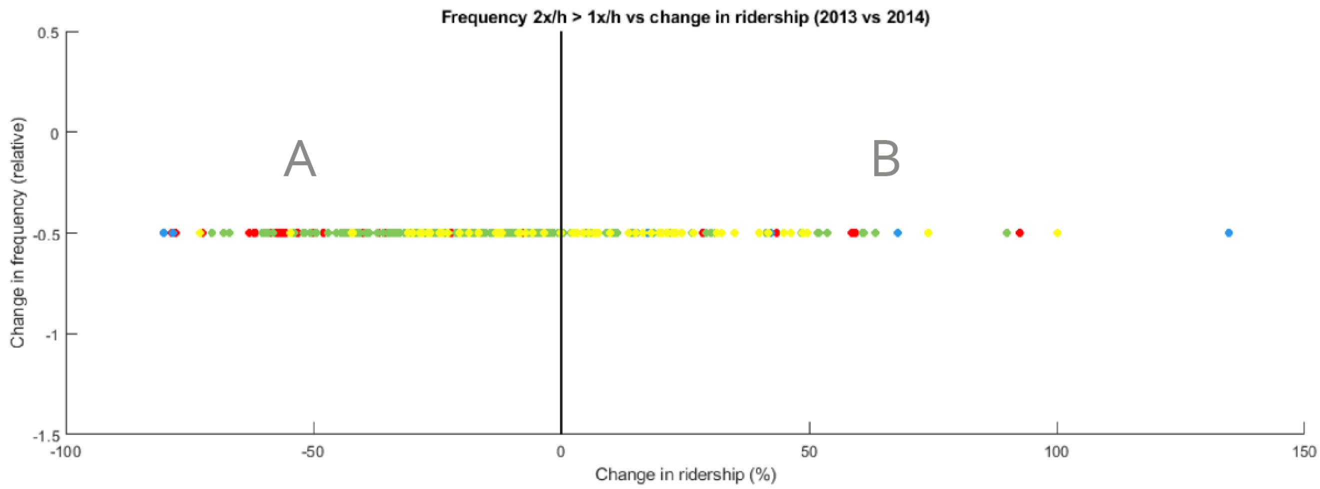


Figure 6.6: Frequency elasticity scatter plot of line 103, 121 and 306 (November 2013 vs November 2014); which all have been downgraded from 2x/h to 1x/h in a selection of hours. A color is applied per line (red for line 103 (off-peak frequency 2x/h > 1x/h); blue for line 121 (peak frequency 2x/h > 1x/h); green for line 306 (off-peak frequency 2x/h > 1x/h); yellow for line 306 (weekend frequency 2x/h > 1x/h)). Note that some points are overlapping and therefore hardly visible.

The results show that for all lines and changes, ridership changes varies both to the negative as to the positive side.

Interpretation
The frequency elasticity per OD-pair shows the same effect as IVT elasticity. Further analysis of frequency is not necessary, i.e. per OD-pair the variety is too large and the methodology appears unsuitable.

The data analysis results show a large variety in ridership growths, even a decline when an increase is hypothesized. The trends are in the hypothesized direction. Therefore, the hypothesis that an increase in LOS leads to an increase in ridership is not declined based on these results, but a cause for the large spread is further researched. A reflection on the use of an OD-based analysis is performed in Appendix B. In the reflection, an example (Waterland line 121) is analyzed in detail, a GIS-analysis is performed and a comparison with other concessions is made. The reflection leads to identification of five reasons that the analysis per OD-pair doesn't lead to converging results:

1. Stochastic variation, i.e. there are infrequent trips that are made in one year but not in the other, which leads to (limited) natural variation. This has a larger effect on smaller numbers, which occur when working per OD-pair.

2. Interchanging between nearby stops, i.e. one stop decreasing and the other increasing, while they are in each other's zone of influence.

3. Network effects, i.e. passengers do not only experience individual lines or OD-pairs. Mainly when they have to transfer anyway, different options can be attractive and preference can change even if only one of them is subject to a LOS change. An example is seen in line 121 (Waterland), where transfer are likely. The line connects to a railway station on one side and a bus station on the other side. When the frequency decreased, at certain stops a change in main used direction could be seen, i.e. people traveling to the train station instead of bus station, possibly because on the larger journey that option became more attractive.

4. Non-LOS related factors playing a role.

5. Other, not analyzed LOS factors playing a role.

To tackle these five issues, combined with what is possible with the data and is suitable to the research question, a new approach is proposed: analysis on a line basis. Line-based analysis means larger passenger numbers, suppressing stochastic variation; it is not subject to interchanging of nearby stops; it partly compensates for network effects and more attention to individual cases can be given, such that a better understanding of non-LOS factors can be included.

6.3. Line-based analysis

In the OD-based analysis, all lines of the concession Waterland have been included. The line-based analysis is performed only when there have been level-of-service changes and the line or line section services a unique relation. Data from all three concessions is used. Again a distinction is made between IVT changes and frequency changes. In this analysis, also 'other' changes, such as change in operating vehicle and combinations of LOS-factors are discussed. A single, full overview of the analysis results is included in Appendix D. The data is initially only compensated for the difference in number of days per month. However, there are more factors which should be compensated for, as described in Chapter 2, such as economic growth and decreasing shares of paper ticket sales. Instead of a full compensation for the non-LOS factors, a bandwidth for each case is described. Since compensation for non-LOS factors can be difficult, debatable and not always quantifiable, ranges for each of the cases are developed. After presenting of the three categories of results, additional learnings are presented. These are findings in the line-based analysis which add value with regard to ridership prediction after LOS changes.

As described in the methodology (Chapter 4), not always the full line is analyzed. For isolated lines, the full line is analyzed; for lines with partly overlapping sections, only the isolated section is analyzed. This is to isolate the effect of LOS changes and prevents interference with other lines in the network. For lines which are largely part of a dense network of lines, a cluster analysis is used, only analyzing the effect between two (major) isolated clusters. All results are shown in tables. When possible, the results are summarized in a graph, comparable to the ones used in the OD-pair based analyses. Not all cases analyzed are shown in the graphs. All cases which do not classify as a frequency change or an IVT change are not shown. Combinations of the two and cases which cannot be captured under the used definitions are also not shown in the graphs, since they can be misleading without context.

6.3.1. IVT-changes

First, the lines with changing in-vehicle times are described. In the data set, only lowering IVTs are present (table 6.5). When plotting the results in a scatter plot, similar to what has been done in section 6.2, all but one cases fall within the quadrant as hypothesized (quadrants marked with 'A') (figure 6.7). The growth factors refer to the growth over the full day, regardless of the hours in which the measure has been implemented. A distinction is made between a frequency change in peak only, off-peak only, a full day (all week days) and Saturdays. All values are of the first November after the change, i.e. for the Waterland cases the first value in table 6.5 (after 3 months). This is chosen since VPR data is limited to March, which is 3 months after the change in LOS; making the data more comparable. The only exception is WL110, of which only the change after 15 months is known.

Table 6.5: Results IVT changes per line, showing the ridership growth over the full day. In case of two growth factors, the first represents when the growth factor after 3 months, the second after 15 months (both Novembers).

Case	IVT change	Day	Ridership growth	Comment
WL110	-3 min	Weekdays	* | 9%	-
GD119	-3 min	Weekdays	-6%	hospital no longer serviced
WL315	peak -7, off-peak -3 min	Weekdays	21% | 33%	peak growth 32%, off-peak growth 7%
WL103b	-10 min (-€1.50)	Weekdays	121%	same route with transfer was possible
WL312	-10 min	Saturdays	45% | 57%	except afternoon peak
GD39	-18 min (off-peak)	Weekdays	83%	-

*Not available

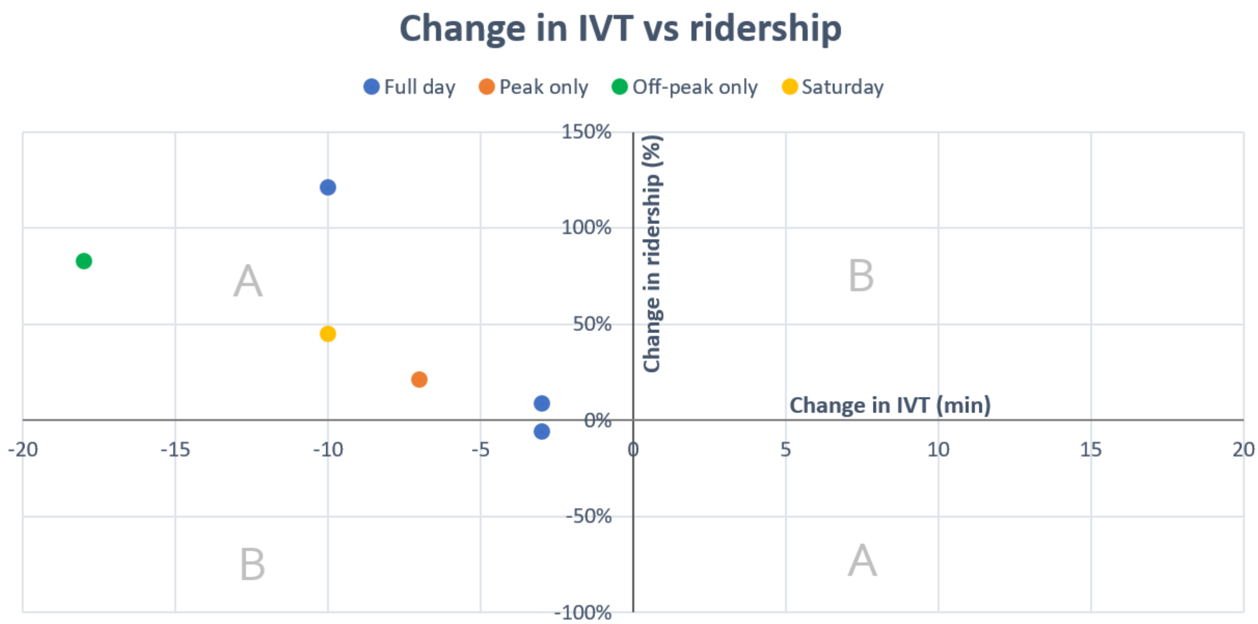


Figure 6.7: The change in in-vehicle time versus the change in ridership of the line-based analysis. Note that the growth factors refer to the growth over the full day, regardless of the hours in which the measure has been implemented.

Table 6.5 presents growth factors; i.e. the original travel time is not taken into account. Elasticities can be calculated, in which the original travel time is taken into account (table 6.6). Elasticities as estimated during the expert meeting (Expert meeting EBS, Appendix A.2) are included in table 6.6 as well. Elasticities are calculated for the full day change, as well as for the hour blocks of relevance only. That is to say, *E full day* describes the change in ridership, regardless of the LOS change being full day, peak only or off-peak only. *E hour* on the other hand, describes the change in ridership in the same hour blocks as the change; e.g. the change in off-peak ridership when a LOS change during off-peak hours is implemented. For LOS changes implemented full day, *E full day* and *E hour* are equal. The expert opinion elasticities should be compared with the full day elasticities (*E full day*); literature elasticities with *E hour*.

An example is given for case GD119. The IVT decreases by 3 minutes. This is, if the most likely average IVT for line 119 is used, a decrease of 6% in IVT. The ridership over the full day decreases by 6%. The elasticity is then:

$$Efullday = \frac{-0.06}{-0.06} = 1.0$$

In this case, *E full day* is equivalent to *E hour*, since the change is applied full day and the ridership decrease is thus the same.

Table 6.6: Elasticities IVT changes per line. Expert av. refers to the average growth as estimated during the expert meeting, while expert range refers to the range of estimations provided by the experts.

Case	IVT change	Day	E full day	E hour	E expert av	E expert range
WL110	-3 min	Weekdays	-0.3 to -0.6	-0.3 to -0.6	0.00	0.00 - -0.03
GD119	-3 min	Weekdays	1.0	1.0	-0.66	0.00 - -0.83
WL315	peak -7, off-peak -3 min	Weekdays	-1.2*	-1.9* vs -1.0**	-0.71	-0.24 - -1.18
WL103b	-10 min (-€1.50)	Weekdays	-4.2	-4.2	-0.48	-0.21 - -0.69
WL312	-10 min (except PM peak)	Saturdays	-1.6	-1.6	-0.38	-0.17 - -0.69
GD39	-18 min (off-peak)	Weekdays	-2.1 to -3.3	-	-0.48	-0.20 - -1.20

*Based on the peak IVT decrease
**Based on the off-peak IVT decrease

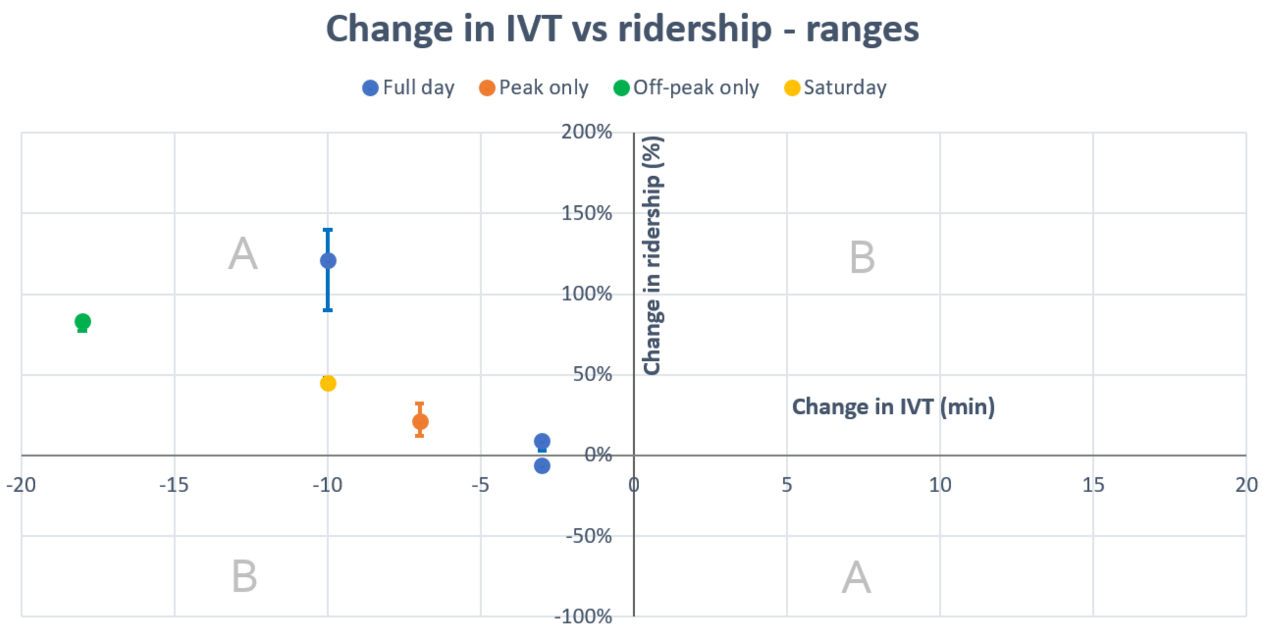


Figure 6.8: Ranges for IVT growth factors when compensating for non-LOS factors.

As described in Chapter 2, compensation for non-LOS factors is necessary. Waterland line 121 is used as example and described extensively in Appendix E. All cases are compensated for economic & demographic growth and share of paper ticket sales. Compensation for indexation of fares has a negligible effect. An exception are those lines with a deliberate route and fare change, for which compensation is applied. Tourism and urban development is compensated for only for cases as identified in Chapter 5. This leads to the ranges as presented in figure 6.8. This is the quantitative range that can be calculated based on the factor described above, it is not necessarily the full range in reality since not for all factors a quantitative compensation can be determined. Note that the maximum ranges are calculated; ranges can expand fast due to accumulation of effects. An overview of the ranges is also provided in Appendix E, including which non-LOS factors have been compensated for per case.

Interpretation
The results of the change of IVT versus ridership provide more promising results than the analysis per OD-pair. Though only cases with a decrease in IVT are present, all but one are in the quadrant as hypothesized; i.e. a decrease in IVT leading to an increase in ridership (figure 6.7). A larger decrease leads to a larger increase in ridership. It is hypothesized that measures only applied during off-peak hours would have a relative lower effect than measures applied in peak hours, which would be again relatively lower than measures applied full day. Unexpectedly, no clear distinction between off-peak, peak and full-day factors can be identified. The absence of a clear distinction might be partly caused by the relative deficit in data points.

There is only a single case which shows a-typical behavior (and thus present in a quadrant marked with 'B'): GD119, which shows a positive elasticity. Both the IVT change as the ridership change are small. Also, the faster route means that the hospital is no longer serviced. The loss of this important destination might be the cause of the ridership decrease (Personal communication OV-bureau Groningen Drenthe). This is an important acknowledgement, i.e. by changing IVT and route, the destinations change; which has additional effect on the ridership. Of the full day 121% growth (WL103b) it can be argued that the ridership increase should be lower, since before the LOS change additional travel options with transfers were an alternative. Applying a price elasticity of -0.3 as described in Chapter 2 to WL103 to compensate for the lower price, a growth of 97% would be obtained. As a consequence, the range for this data point after compensation for non-LOS factors is largest (figure 6.8). The addition of ranges for all other data points, to show the effect of non-LOS changes, has only very limited effect on the growth factors. Lastly, the large ridership increase caused by WL315 should be placed in context. There is a significant amount of people using the car for a small section of the route, then transferring to the bus in Monnickendam (Personal communication transport engineer concession Waterland). The decreased travel time might have attracted more people to already start their journey in Marken (and showing up in the data); but likely not all passengers have changed mode. The context is thus essential in interpreting the data.

Distinguishing elasticities per concession would not make sense, since VPR is completely absent and GD only has a single (a-typical) value for elasticity in the relevant hours. Despite, it is observed that the cases in Waterland have much higher elasticities than estimated in literature and by experts.

When models from literature (Chapter 3) are added to the figure, comparison with literature is possible (figure 6.9). To obtain the literature values, the characteristics of the cases (such as original IVT) are taken into account. For the literature values, it is assumed that the LOS change is implemented full day; this is thus not directly comparable to the peak and off-peak only data points. In general, literature seems to underestimate the growth factors of the cases. However, for example for the WL103 case with 121% growth, the combinations of the price elasticity and the previously available alternatives implies that the growth factor might be more in line with literature and the other growth factors.

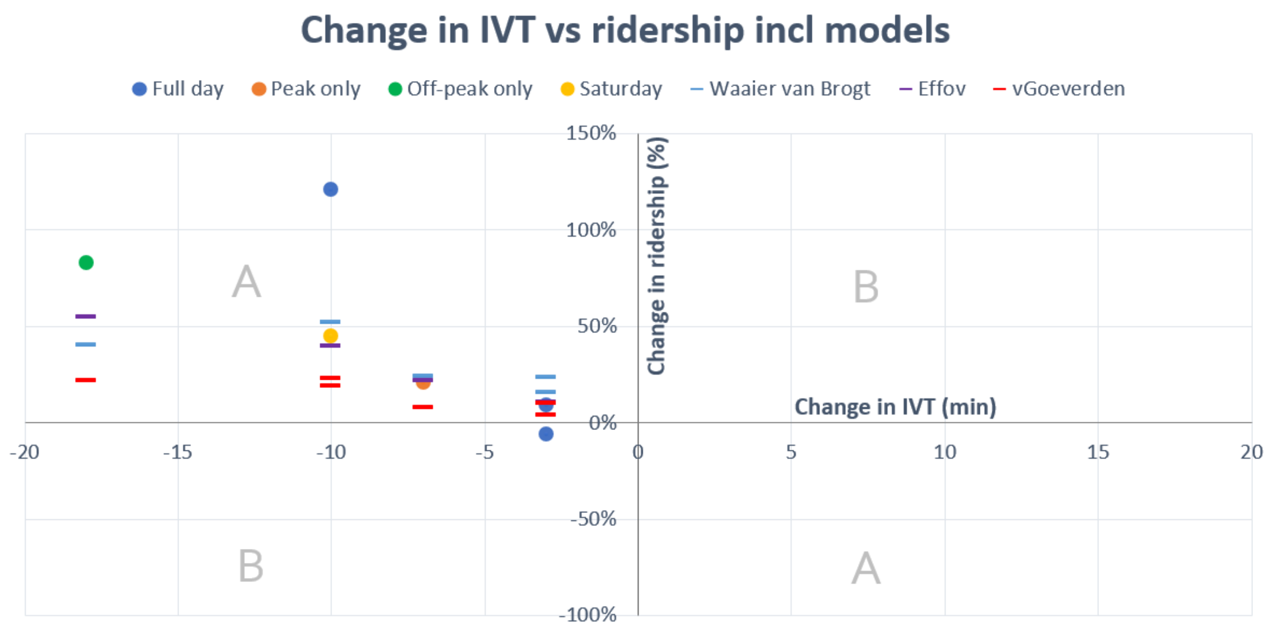


Figure 6.9: The change in in-vehicle time versus the change in ridership of the line-based analysis, with estimations from literature models added. Note that for literature models the ridership change is estimated as if the measure would be applied full day.

IVT elasticity in literature has been estimated within the range of -0.1 to -1.56 (Balcombe et al., 2004; MuConsult B.V., 2015; De Beer, 2011; Goudappel Coffeng, 2013; see also Chapter 2). Elasticities found in this thesis (table 6.6) show a range of 1.0 to -4.2; a much wider range. This is visualized in figure 6.10. No distinction is made between *E full day* and *E hour*, since both ranges are equal. The two extreme values can be explained, the elasticity of 1.0 (counter intuitive behavior) can be caused by the cut of an important destination; the -4.2 elasticity is partly caused by price elasticity and by the inability to see transfers. Even if the two extreme values would be discarded, the range is much larger than current literature shows. The experts estimate an elasticity of 0.0 to -1.20, which on the first hand seems very well in line with literature. However, the expert estimation includes the period of day (such as off-peak only), while literature estimates are full day elasticities. Accounting for this would mean that the expert opinion range is larger than literature estimates, but still significantly lower than the results found.

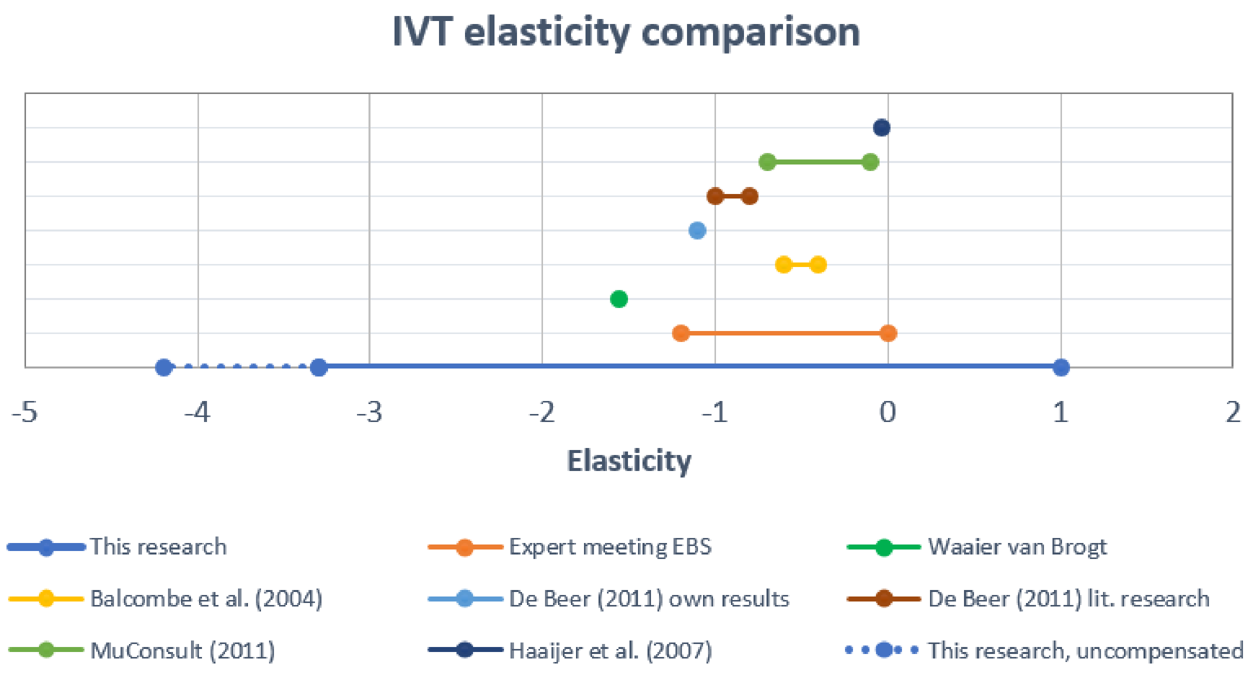


Figure 6.10: IVT elasticties compared to literature. The dotted line illustrates the larger range if the WL103b elasticity would not be compensated for the fare decrease.

6.3.2. Frequency changes

Lines with a frequency change uphold a larger share of data points with more variation in LOS change. The growth factors (table 6.7) are generally smaller than seen in the IVT analysis.

Table 6.7: Results frequency changes per line, showing the ridership growth over the full day. In case of two growth factors, the first represents when the growth factor after 3 months, the second after 15 months (both Novembers).

Case	Frequency change	Day	Ridership growth	Comment
GD65	off-peak 1x >2x	Weekdays	10%	-
WL103a	off-peak 2x >1x	Weekdays	-16% | -17%	-
WL121	peak 2x >1x	Weekdays	-26% | -22%	-
WL301	2x >1x	Sundays	-9%	-
WL305*	peak 2x >4x	Weekdays	78%	Connexxion line 129 (1x/h)
WL314	off-peak 2x >4x	Weekdays	0% | 8%	-
GD309a	off-peak 2x >4x	Weekdays	21%	-
GD300	2x >4x	Saturdays	20%	-
VPR403a	2x >4x	Saturdays	32%	R-net introduction
VPR85	2x 12m >4x 8p bus	Weekdays	> 8%	Minimum estimate due to data issues
VPR403b	off-peak 4x >2x	Weekdays	-11%	R-net introduction
VPR102	off-peak 4x >2x	Weekdays	-38%	part of larger network change
GD26	0,67x >1x	Saturdays	18%	-
GD61	peak direction 2x >3x	Weekdays	14%	-
VPR84	off-peak 4x >6x	Weekdays	-2%	-
GD309b	afternoon peak 5/6x >8x	Weekdays	5%	-

*Since Connexxion line 129 (1x/h) also services this section, it might actually be seen as an increase from 3x/h to 5x/h. The growth is only based on EBS lines, such that the growth in ridership might not be all new passengers, but also passengers previously traveling with Connexxion. Therefore this data point not used in the scatter plot.

Plotting them in a scatter plot shows that all but two values fall within the quadrants as hypothesized: an increase in frequency leads to an increase in ridership (figure 6.11). Frequency change is shown in bins. Bins are in such an order that the relative change decreases the further one moves from the origin. If the relative change is equal, the one with the lowest frequency is presented first. If behavior is as hypothesized, this would mean that the change in ridership would become smaller moving away from the origin. The results show that this trend can roughly be seen in the quadrant of increasing frequency (figure 6.11). For the quadrant with decreasing frequency, insufficient data is present to observe a trend. A distinction is made between a frequency change in peak only, off-peak only, full day (all week days) or weekend days. The change in ridership is the change in ridership for the full day, regardless of the frequency change being limited to peak/off-peak.

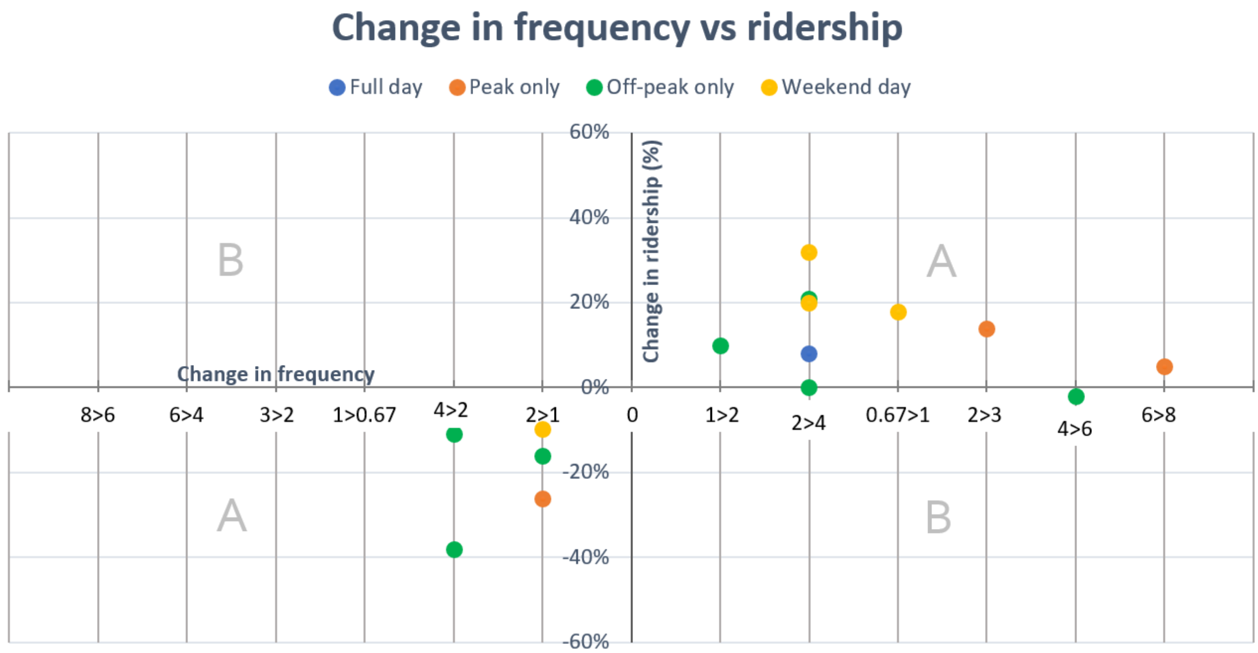


Figure 6.11: The change in frequency versus the change in ridership of the line-based analysis. Note that the x-axis is not continuous, but bin-based.

Translating the growth factors to elasticities, based on the relative change in frequency, shows that the elasticities as found in the results are often in the range as estimated in the Expert meeting EBS (table 6.8). Though there are exceptions. It is hypothesized that the increase in frequency leads to a higher elasticity when frequencies are low; however this is not directly observed in the results.

Table 6.8: Elasticities frequency changes per line. For elasticity calculation, cases with multiple growth factors receive an elasticity based on their first growth factor (after 3 months). Expert av. refers to the average growth as estimated during the expert meeting, while expert range refers to the range of estimations provided by the experts.

Case	Frequency change	Day	E full day	E hour	E expert av	E expert range
GD65	off-peak 1x >2x	Weekdays	0.10	-	0.08	0.03-0.20
WL103a	off-peak 2x >1x	Weekdays	0.32	0.40	0.18	0.10-0.40
WL121	peak 2x >1x	Weekdays	0.52	0.76	0.28	0.14-0.40
WL301	2x >1x	Sundays	0.18	0.18	0.46	0.02-0.80
WL305	peak 2x >4x	Weekdays	0.78	0.84	0.18	0.10-0.20
WL314	off-peak 2x >4x	Weekdays	0.00	-0.02	0.08	0.02-0.20
GD309a	off-peak 2x >4x	Weekdays	0.21	-	0.08	0.02-0.20
GD300	2x >4x	Saturdays	0.20	0.20	0.16	0.05-0.30
VPR403a	2x >4x (+ R-net)	Saturdays	0.32	0.32	0.16	0.05-0.30
VPR85	2x 12m >4x 8p bus	Weekdays	0.08	0.08	0.31	0.20-0.40
VPR403b	off-peak 4x >2x	Weekdays	0.24	0.26	0.16	0.06-0.40
VPR102	off-peak 4x >2x	Weekdays	0.76	0.68	0.16	0.06-0.40
GD26	0,67x >1x	Saturdays	0.36	0.36	0.38	0.02-0.80
GD61	peak direction 2x >3x	Weekdays	0.28	-	0.10	0.04-0.20
VPR84	off-peak 4x >6x	Weekdays	-0.04	0.14	0.10	0.00-0.20
GD309b	afternoon peak 5/6x >8x	Weekdays	0.20	-	0.20	0.08-0.40

The compensation of non-LOS factors for frequency growth factors is done in a similar way as for IVT. An example can be found in Appendix E. Compensation for non-LOS factors leads to the ranges as presented in figure 6.12. An overview of the ranges for each data point is also provided in Appendix E.

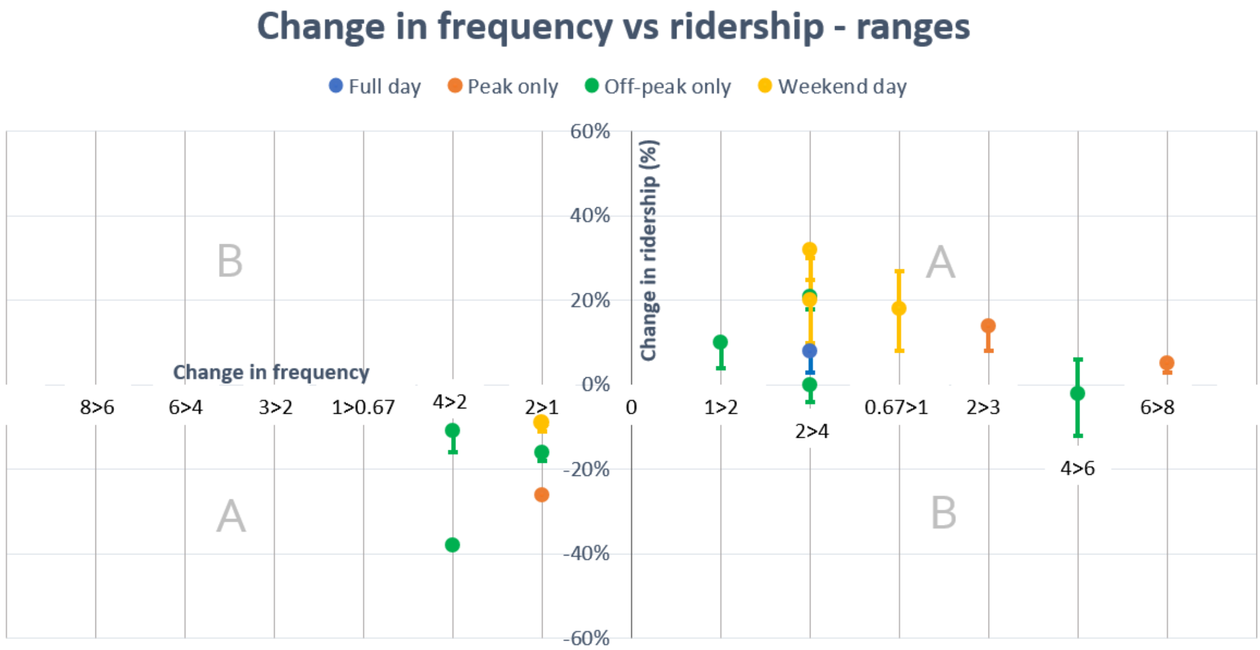


Figure 6.12: Ranges for frequency growth factors when compensating for non-LOS factors.

For lines from the concession VPR, there is an additional uncertainty. This is caused by the data from MRDH lacking ridership numbers on OD-pairs with very low usage. The (possible) effect this has is dependent on the total ridership of the line, as well as the number of OD-pairs with missing values. On a busy line with a relative low amount of OD-pairs with missing values, the deviation is ca. 5%point. For a line with low ridership and a large amount of OD-pairs with missing values, the deviation can be around 20%point, even though it is unrealistic that the full range is applicable. This is classified as uncertainty and not as a non-LOS factor and is thus not included in the range.

Interpretation
The results of the frequency change vs ridership (figure 6.11) show that all but two cases fall within the quadrant as hypothesized (quadrants 'A'). Based on these 15 data points it can be said that generally an increase in frequency leads to an increase in ridership and a decrease in frequency to a decrease in ridership. Despite, a clear relation cannot be seen. Three indicators are used for to come to this interpretation:

1. The range of values within a single bin (e.g. 4>2 or 2>4) is large.
2. There is no clear difference or distinction between the time of day (full day/peak only/off-peak only/weekend), while this would be expected since the change in ridership on full days is shown.
3. Between bins there is no clear trend visible; e.g. the off-peak only frequency change from 1x/h to 2x/h is in between the growth factors for off-peak change from 2x/h to 4x/h.

There are two points which show a-typical behavior (not in quadrants marked with 'A'): WL314 and VPR84, which show no change (WL314) or a decrease in ridership (VPR84) while frequency is increased. The ranges in figure 6.12 show that compensation for non-LOS factors could lead the data points to quadrant 'A', but could also lead the data points further into quadrant 'B'. Further analysis is needed. First of all, both changes are only applied off-peak, such that the effect on full day ridership is expected to be lower. WL314 does grow in the second year (after 15 months) to 8% ridership growth over the full day (see also Appendix D), so it appears that it takes longer for the effect to set in. Despite it must be said that the ridership in off-peak hours only actually declined (-2%) in the first three months, but this is reverted to growth (7%) in the next 12 months. VPR84 declines 2% over the full day, but when only the off-peak hours are included, there is a 7% increase, so the measure seems to have effect. The overall lower ridership can possibly be explained by the fact that the reference year (2016) had seen a significant increase in ridership (Connexxion, 2016) which could have been an irregularity which had a short duration. It seems that for both a-typical data points, the a-typical behavior can be explained. At the same time it does imply that presenting the data in a graph or a table can be misleading, since details are lost.

More data points than just the a-typical ones require context. As already mentioned, WL305 is not shown in the scatter plot. A bus line of another operator services the same line section 1x/h; and no data is available. The frequency increase is therefore not from 2x/h to 4x/h, but from 3x/h to 5x/h while the ridership cannot fully be quantified. The large growth which is shown is likely to be caused by a shift in passengers and not fully by new passengers. The large decline of VPR102 seems remarkable, because the frequency is only decreased during off-peak hours, but the decline during peak hours is relatively larger. Context is able to explain this: a new R-net line has been implemented, which might be a (far) better alternative for this line, mainly during peak hours. Furthermore, VPR102 used to continue as VPR101; however this linkage was terminated. This meant that a transfer was needed to access the city center, making the line less attractive. Again, the importance of context is shown.

The average elasticity (Ehour) per concession shows larger elasticities for Waterland: 0.43 for Waterland; 0.27 for Groningen-Drenthe; 0.29 for VPR. However, one should handle these results carefully, because they are very sensitive to outliers due to a low number of cases. If e.g. WL305 would be removed, the average elasticity for Waterland decreases to 0.33 and is already more in line with the others.

Models from literature (Chapter 3) are added to the figure, such that an easy comparison with existing models is enabled (figure 6.13). Note that the literature values predict the change in ridership when the change in frequency is applied full day. This explains why the literature often estimates larger growth factors than shown in figure 6.13, since they are often peak or off-peak only frequency changes.

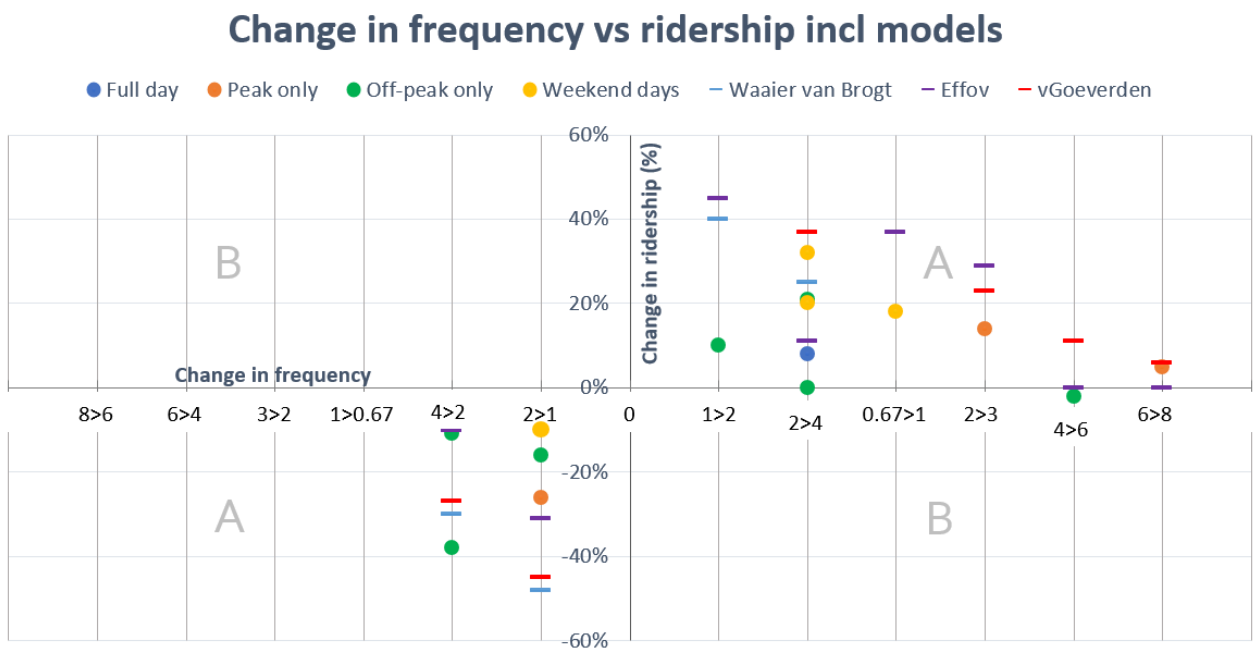


Figure 6.13: The change in frequency versus the change in ridership of the line-based analysis, with estimations from literature models added. Note that for literature models the ridership change is estimated as if the measure would be applied full day.

Frequency elasticity has been estimated to be 0.37 to 1.2 by literature (Brechan, 2017; De Beer, 2011; Balcombe et al., 2004; see also Chapter 2). The results in table 6.8 show that full day elasticities range between -0.04 and 0.78 (figure 6.14). For this research, both the elasticity for full day, as the elasticity in the relevant hour blocks only is shown. The first is comparable to the estimation from the Expert meeting EBS, while the latter is comparable to all literature values. Considering that some changes have only been applied during off-peak hours, they are in some cases lower than the range from literature. Despite, there are still values of full day measures which have a lower elasticity than the literature range. The experts underestimate a few of the elasticities found in the results. This can often be explained by the context, such as WL305 and VPR102. However, even if those cases are removed which have a known issue causing higher/lower elasticity, the elasticities show significant variation.

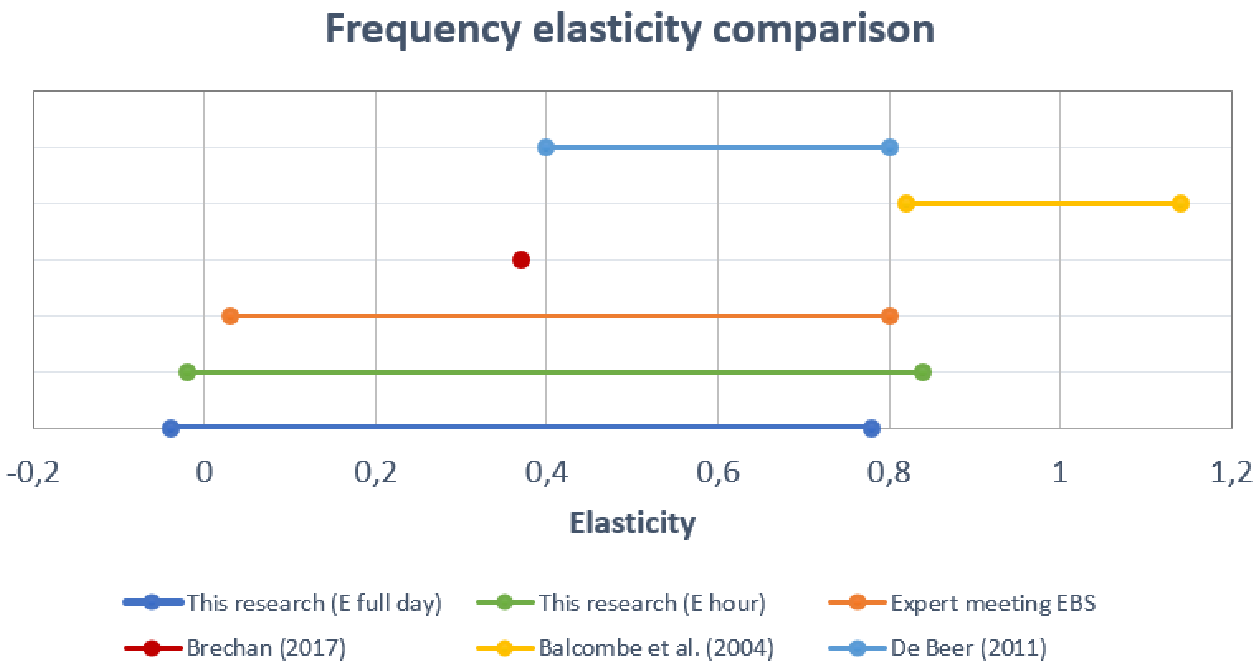


Figure 6.14: Frequency elasticties compared to literature. Note that Expert meeting EBS is comparable to This research (E full day) and all literature values are comparable to This research (E hour).

6.3.3. Other LOS changes

In the cases studied, 9 LOS changes cannot be classified as an IVT change or frequency change; either because it is a combination of the two, or it is another LOS change. Table 6.9 shows the growth factors related to those cases.

Table 6.9: Results other LOS changes per line, showing the ridership growth over the full day. Expert av. refers to the average growth as estimated during the expert meeting, while expert range refers to the range of estimations provided by the experts.

Case	LOS change	Day	Ridership growth	Expert av.	Expert range
WL122	-7 min and peak 2x >1x	WE	-19% | -12%	-5%	0 - -10%
WL312	4x fast iso 2x fast + 2x slow + peak 4x >6x	WE	0% | 4%	-	-
GD6	Q-link, PM peak 2x >4x on a line section	WE	13%	-	-
GD12	Q-link (branding + higher capacity buses)	WE	16%	13%	5 - 20%
VPR404	R-net, network redesign	WE	12%*	-	-
GD32	1 additional trip (+ SOV MBO)	WE	23%	-	-
GD14	1 additional trip (+ SOV MBO)	WE	26%	-	-
GD13	off-peak with 12m iso 8p bus	WE	3%	6%**	0 - 10%**
VPR87	peak only to full day	WE	43%	21%	2 - 50%

*Estimation due to interference of Connexxion line 104.
**Full day estimation i.s.o. off-peak only

In all cases, an improvement in LOS leads to an increase in ridership. For the first data entry (table 6.9) it is observed that the decrease in frequency weighs more than the decrease in IVT.

Compensation for non-LOS factors is applied, similar to IVT and frequency growth factors. Table 6.10 shows the ranges calculated.

Interpretation
There is one case which is a combination of IVT change and frequency change (WL122). Although the frequency decrease is only applicable to the peak hours, the line decreases significantly in ridership. This can be attributed to the fact that most users travel in the peak hours (departing, arriving or both). Furthermore, a changed route means a loss of destinations which might also have an effect.

Table 6.10: Ranges of growth factors for other LOS changes.

Case	LOS change	Compensated	MIN growth	Original growth	MAX growth
WL122	-7 min and peak 2x >1x	EC,TS	-17%	-19%	-19%
WL312	more express buses	EC,TS	0%	0%	1%
GD6	Q-link, PM peak partly 2x >4x	EC,TS	3%	13%	22%
GD12	Q-link (new branding + buses)	EC,TS	10%	16%	16%
VPR404*	R-net, network change	EC,TS	-	12%	-
GD32	1 add. trip (+ SOV MBO)	EC,TS	12%	23%	32%
GD14	1 add. trip (+ SOV MBO)	EC,TS	15%	26%	36%
GD13	off-peak with 12m iso 8p bus	EC,TS	-6%	3%	10%
VPR87	peak only to full day	EC,TS	36%	43%	43%

*Since this is an estimation, no range can be calculated.

The results show two relatively little used lines with only one additional trip, but a significant growth in ridership (GD32 and GD14). This is partly caused by low total ridership, such that a high growth factor is easily obtained. Furthermore, as already stated in the table, in both cases the free SOV for MBO students was implemented. With only a very small increase in frequency (one additional trip), it is likely that a significant part of the growth can be attributed to the free SOV for MBO students.

The growth factors for Q-link branding seem in line with expert opinion and previous experience. That VPR87 grows more than expected by experts when going to full day operation can possibly be attributed by the presence of a nearby bus stop, which is serviced frequently by other lines. The growth in ridership could partly be a shift in ridership and not purely new travelers. The analysis of the full network change in Hellevoetsluis (VPR404), with implementation of R-net, shows a significant growth as well. However, due to the integration with Connexxion line 104, only an estimation of the total growth can be provided.

The growth factors are generally in line with expert estimation. Most cases analyzed have a unique LOS change. Only the Q-link branding and the additional trip (+ free SOV MBO) occur twice and have shown very similar growth factors. Due to the low amount of data points, no model parameters could or should be developed out of these results; apart from the fact that they are difficult/impossible to translate into elasticities. Despite, they offer valuable insights.

The data offers more insight in passenger behavior after LOS changes than only growth factors and/or elasticities. Therefore, additional learnings are extracted for the line-based analyses.

6.3.4. Additional learnings

From above results it becomes clear that no single elasticities can be developed from the bulk data; there is no clear convergence to elasticity values or any other relation. What more can be learned from the results? From the data analysis per line, more information can be gathered than solely the changes in ridership. The data allows, in certain regions, to include product type used. This can be translated into user groups, such that it can be determined which user group uses certain bus lines and which groups are the most sensitive to changes. Furthermore, it allows to check for cross-elasticities when changing only (off-)peak LOS and thus to evaluate the interaction between peak and off-peak hours.

User groups

Data availability allows insight in user groups and also which user group is the most sensitive to the LOS changes as presented before. Since Groningen-Drenthe data does not allow for user group identification with the exception of students, this data is left out. For Voorne-Putten & Rozenburg, only user group data from after the LOS change is known, such that the sensitivity cannot be determined. Furthermore, a minimum usage is required, such that the analysis is not too sensitive for small numbers (e.g. from 5 to 1 user would lead to a very large relative decline, but does not hold much information about user sensitivity). The user group should at least provide 5% of the total usage both before and after the change in LOS. Applying these requirements to the suitable data (i.e. Waterland only), the relative most sensitive user group are students (table 6.11). 11 LOS changes from Waterland have been analyzed, in which 6 times students were the most sensitive in changing ridership. When the absolute change in ridership per user group is counted, infrequent travellers are the most sensitive user group in 5 of the 11 LOS changes.

Table 6.11: The count of the most sensitive user group, by absolute change and by relative change. Note that the results are based solely on the concession Waterland.

Most sensitive user group	absolute change	relative change
Infrequent traveler	5	2
Commuter	0	2
Scholar	2	1
Student	4	6

Note that also in Groningen-Drenthe, data analysis shows that students are often the most sensitive. In the analysis, two weekend days are included: one Saturday on which infrequent users are the most sensitive (both absolute as relative), one Sunday with students being the absolute most sensitive and commuters the relative most sensitive. Remarkably, in all cases of a decrease in IVT, the absolute most sensitive group is infrequent travelers.

Interpretation
As discussed during the expert meeting and as known from literature (Chapter 2), captives are expected to be the least sensitive to LOS changes. These are mostly students, scholars and people without a car. People with a car are expected to be most sensitive to changes. The results show that the sensitivity is dependent whether it is measured in absolute or relative numbers and that infrequent users and students are the most sensitive (table 6.11). For infrequent users this is in line with theory, they are often interpreted as flexible in behavior. However, also students seem very sensitive, what has been unrecognized before (e.g. Expert meeting EBS). This has possibly to do with them being less resistance to changes (Murtagh et al., 2012; Workfloor experience check EBS, Appendix A.3). The question is however whether they changed mode or they changed their trip within the PT network. Commuters seem not that sensitive, at least not in Waterland.

Peak vs Off-peak

In the data from concessions Voorne-Putten & Rozenburg and Waterland, a distinction between operating hours can be made. This enables an analysis of the effect during peak hours vs off-peak hours and their interaction. This section focuses on their interaction or cross-elasticity: i.e. if the LOS is changed during peak hours, how does this affect ridership during off-peak hours and vice versa. The LOS changes during peak/off-peak hours and their respective growths in those hours show a large interaction (table 6.12).

Table 6.12: Peak vs off-peak cross elasticities. When two values are present, one represents the ridership change after 3 months, the second the change after 15 months.

LOS change	Time of day	Ridership peak hours	Ridership off-peak hours
4x/h >6x/h	Off-peak	-2%	7%
4x/h >2x/h	Off-peak	-45%*	-34%*
4x/h >2x/h	Off-peak	-12%	-13%
2x/h >1x/h (IVT -7 min all day)	Peak	-19% | -12%	-9% | 7%
-7 min (peak) and -3 min (off-peak)	Both	32% | 49%	7% | 11%
2x/h >1x/h	Off-peak	-14% | -13%	-20% | -26%
2x/h >1x/h	Peak	-38%	-5%
2x/h >4x/h	Peak	+84%**	+66%**
2x/h >4x/h	Off-peak	2% | 9%	-2% | 7%

*Large network changes, another line has become a (far) better alternative, possibly explaining the large decline.
**travelers have another option (1x/h) with another bus company, probably not all new passengers.

The correlation of all values is calculated and distinguished between peak LOS changes and off-peak LOS changes. This is done based on the correlation coefficient, a value between -1 and 1. I.e., the correlation coefficient off-peak LOS changes is the correlation coefficient between ridership changes in peak hours and off-peak hours, when a LOS change is applied off-peak. The correlation coefficient peak LOS changes is the correlation coefficient between ridership changes in peak hours and off-peak hours, when a LOS change is applied during peak hours.

Correlation coefficient off-peak LOS changes = 0.91
Correlation coefficient peak LOS changes = 0.98

Interpretation
Large cross-elasticities are seen; there is clearly an interaction between off-peak and peak ridership while in only one of the two a LOS change is implemented. The correlation coefficients are very high (>0.9 on a scale from -1 to 1), showing that they are strong, positively correlated. According to expert judgement, changes during off-peak hours have more effect on peak hour ridership than vice versa. However, this is in absolute numbers. If relatively more people travel in peak hours than off-peak hours, the relative change in ridership is suppressed in the peak hours. This taken in mind, it is in line with expectation that the correlations are roughly equal.

These learnings provide additional insights, but they are not able to explain the variation in elasticities and results for each of the cases. The next step is to apply a regression analysis on all cases in search for a relation between LOS changes and ridership.

6.4. Regression analysis

Based on the lines described in this section, a regression analysis is performed with SPSS. The data set is as follows:

- 31 cases, of which 26 are suitable for the regression analysis.
- Of those 26: 9 are off-peak only measures, 6 are peak only measures and 11 are full day measures.
- And of those 27 are 6 only IVT related and 16 only frequency related and 1 both IVT and frequency related; 4 related to other changes.

Assumptions
For the regression, simplifications have to be made, such that a numerical model is possible. For the catchment, the number of inhabitants serviced by the line are included. In case of a regional line providing service from a set of villages towards a large city, the line is mainly providing service for the villages and thus the inhabitants of the main city is not included. If the line has a function within the city or is likely to provide two way traffic, the main city is included. For the urbanity factor, the factor which seems most representative is chosen in case of conflicting factors. The VF factor presented is the VF factor before the change in LOS. Only a single IVT change can be entered in the regression. This despite the change in IVT being dependent on where along the route the passenger is located. Therefore a best guess for the average is entered. For WL315, both a peak and off-peak IVT is present. Since most passengers experience the peak change, this one is entered in the regression data base.

6.4.1. Step 1: clean sheet

In the first step, a linear regression is performed between the ridership change as dependent variable and the level-of-service change as independent variable. Three variants are made:

- IVT only (table 6.5)
- Frequency only (table 6.7)
- IVT and frequency combined

In all models, a constant (ASC) is added. Conceptually, an ASC has value, since 0 change in level-of-service does not necessarily mean that there can be no change in ridership.

In both cases, the change can be defined as a relative or as an absolute change. Conceptually, both have their value. For IVT, an absolute change of 3 minutes has more value if the total journey is only 10 minutes than if the journey is 60 minutes. At the same time, a relative change of -30% has much more value if the total journey is 60 minutes than if the journey is 10 minutes. A passenger experiences both absolute and relative change. For frequency holds the same; the relative change in frequency can be used, or a more absolute measure. From passenger experiences point of view, they are conceptually different. Since it is not known beforehand which definition is most suitable and conceptually they can be interpreted differently, both the absolute and relative variants are used in the regression analysis.

In-vehicle time

IVT change can be defined in two ways: In the absolute case, the change in ridership is defined in minutes. In the relative case, the change in ridership is defined as a growth percentage.

For IVT, only a small selection of data points is available: 6 (table 6.5). Dependent on the definition and design of the regression model, IVT can be significant in the 90% confidence interval (table 6.13). In the first model, with the IVT absolute definition, the p-value is exactly on the cut-off for significance and is therefore discarded. The relative IVT is significant if referred to the full day ridership change. The second set (relevant hour blocks only) consists of fewer data points, since this data is not always available. In these models (3 and 4), it is the absolute IVT which is significant and IVT relative is just above the cut-off value of $p<0.100$. All predictors (β) have a negative sign; i.e. an increase in IVT leads to a decrease in ridership; a decrease to an increase.

Table 6.13: Regression IVT results

Model	Dependent var.	Independent var.	β	std.dev.	p-value	R^2	R^2adj	n
1	Ridership full day	IVT absolute Constant	-0.063 -0.079	0.029 0.293	0.100 0.800	0.532	0.415	6
2	Ridership full day	IVT relative Constant	-3.699 -3.383	1.378 0.339	0.055 0.321	0.643	0.554	6
3	Ridership hours of relevance	IVT absolute Constant	-0.115 -0.358	0.047 0.341	0.090 0.371	0.670	0.560	5
4	Ridership hours of relevance	IVT relative Constant	-3.931 -0.392	1.921 0.421	0.133 0.421	0.583	0.444	5

Frequency

Frequency is harder to define. Two variants are used: growth factor and new frequency. In the first case, the growth factor relative to the old frequency is used. A change from 1x/h to 2x/h and from 2x/h to 4x/h have the same growth factor (+100%) and are therefore indistinguishable. The second case refers to the new frequency. In all cases the new frequency is unique for the case (a new frequency of 4x/h is always an increase from 2x/h to 4x/h), as long as the data set is split between improvement (+) and deterioration (-). This split of the data set leads to less data points per regression. The regression models show that only the relative frequency is significant (even in the 95% confidence interval), for both full day ridership as for relevant hours only (table 6.14). The absolute frequency predictor is insignificant in all cases. The data set with relevant hour blocks only consists of fewer data points. All significant predictors have a positive sign, i.e. an increase in frequency leads to an increase in ridership; a decrease to a decrease.

Table 6.14: Regression frequency results.

Model	Dependent var.	Independent var.	β	std.dev.	p-value	R^2	R^2adj	n
1	Ridership full day	Frequency abs (+) Constant	-0.021 0.270	0.039 0.172	0.603 0.150	0.031	-0.076	11
2	Ridership full day	Frequency abs (-) Constant	-0.080 -0.090	0.116 0.172	0.540 0.637	0.137	-0.151	5
3	Ridership full day	Frequency relative Constant	0.296 -0.053	0.072 0.054	0.001 0.350	0.545	0.513	16
4	Ridership hours of relevance	Frequency abs (+) Constant	0.092 -0.028	0.089 0.365	0.348 0.942	0.177	0.012	7
5	Ridership hours of relevance	Frequency abs (-) Constant	-0.012 0.212	0.134 0.199	0.936 0.366	0.003	-0.033	5
6	Ridership hours of relevance	Frequency relative Constant	0.365 -0.010	0.120 0.090	0.012 0.915	0.480	0.428	12

IVT+frequency

In the previous two variants, IVT and frequency have been tested independently from one another. In this variant, IVT and frequency are combined into a single model. An additional data point, the one with both a frequency as an IVT change, can be included in the regression data set. Since frequency is best described in relative terms and IVT has inconclusive results, the choice is made to present the combination based on relative changes only; i.e. the relative IVT change and the relative frequency change. For both the full day ridership change, as the ridership in relevant hours only, IVT and frequency prove to be significant (table 6.15). The second model consist of less data points; for Groningen-Drenthe data points not always the ridership in relevant hours could be determined. In both cases, the IVT predictor has a negative sign and the frequency predictor a positive sign.

Table 6.15: Regression combination IVT + frequency results.

Model	Dependent var.	Independent var.	β	std.dev.	p-value	R^2	R^2adj	n
1	Ridership full day	IVT relative	-2.536	0.431	<0.001	0.671	0.638	23
		Frequency relative	0.308	0.082	0.001			
		Constant	-0.073	0.059	0.232			
2	Ridership hours of relevance	IVT relative	-2.424	0.704	0.004	0.558	0.499	18
		Frequency relative	0.375	0.119	0.006			
		Constant	-0.033	0.085	0.702			

6.4.2. Step 2: additional predictors

In this second step, additional predictors are added. Due to the low number of data points, each time only one additional independent variable (although it can consist out of multiple dummies) is added to check for significance. Listwise exclusion is used. For all IVT analyses, the number of data points was already below the minimum rule of thumb of 10 data points. Adding an additional predictor is statistically incorrect and invaluable. Therefore, the IVT analyses are not included in this step. For frequency, the relative frequency predicted proved to be the only significant predictor and is therefore used in this analysis. The predictors that are significant in the 90% confidence interval are urbanity, main user group, type of line and price change (table 6.16).

Table 6.16: Significant additional predictors for regression.

Dependent variable	Frequency relative	IVT relative + Frequency relative
Ridership full day	Urbanity	User group, Type of line, Price change
Ridership hours of relevance	None	Price change

For those models with additional significant predictors, the models are shown in table 6.17.

Table 6.17: Regression models with additional predictors.

Model	Dependent var.	Independent var.	β	std.dev.	p-value	R^2	R^2adj	n
1	Ridership full day	Frequency relative	0.337	0.071	<0.001	0.695	0.619	16
		Urbanity 2	-0.208	0.100	0.06			
		Urbanity 3	-0.204	0.110	0.09			
		Constant	0.034	0.060	0.058			
2	Ridership full day	IVT relative	-2.357	0.394	<0.001	0.747	0.708	23
		Frequency relative	0.348	0.075	<0.001			
		User scholar	0.375	0.157	0.027			
		Constant	-0.105	0.055	0.070			
3	Ridership full day	IVT relative	-2.504	0.402	<0.001	0.728	0.685	23
		Frequency relative	0.306	0.076	0.001			
		Line type city	-0.229	0.114	0.060			
		Constant	-0.031	0.059	0.609			
4	Ridership full day	IVT relative	-1.950	0.383	<0.001	0.800	0.769	23
		Frequency relative	0.305	0.065	<0.001			
		Price change	-0.475	0.136	0.002			
		Constant	-0.068	0.047	0.163			
5	Ridership hours of relevance	IVT relative	-1.357	0.716	0.079	0.707	0.644	18
		Frequency relative	0.369	0.100	0.002			
		Price change	-0.557	0.209	0.018			
		Constant	-0.018	0.071	0.800			

Interpretation of the regression
The regression analysis of step 1 shows that the level-of-service changes IVT and frequency can be significantly related to ridership change. For IVT (table 6.13) it holds that the significance varies between the two definitions for IVT and the definitions of ridership change. The p-values of the insignificant variants are just slightly above cut-off. However, the fact that the design of the regression is relevant for whether the predictor is significant implies that the relation is weak. This is possibly caused by the low number of data points. The sign of the β is negative in all cases, i.e. a decrease in IVT leads to an increase in ridership. This is in line with the hypothesis and literature. The R^2s of the models are reasonable, but due to the low number of data points, the value of this is limited.

For frequency (table 6.14), the independent variable 'relative frequency change' proves to be significantly related to both dependent variables. The sign of β depends on the model design, but all βs which are significant have a positive sign. This means the relation is as hypothesized: An increase in frequency leading to an increase in ridership. The negative sign of some of the predictors (those which are insignificant) all fall within the standard deviation. The R^2s of the two models with significant predictors are reasonable of magnitude. The frequency defined in absolute sense (new frequency) does not lead to significant predictors, which can possibly (partly) be explained by the decrease in data points.

The regression sets with the combination of IVT and frequency (table 6.15) show that both IVT and frequency are significant in the 95% confidence interval. The signs of the βs are as hypothesized. In magnitude of β, more weight seems to be put on frequency and less on IVT compared to the individual regression.

In the second step it is shown that certain additional predictors are significant (table 6.16) and contribute to a better fit of the model (table 6.17). Which of those context factors are significant changes per analysis and is based on a small data set. The dependency of the regression design implies that the relation between the additional variable and the dependent variable might not be strong. Results are therefore interpreted as indicative. The variable price change is significant in the models with IVT as variable. This is obvious, since there is only one data point with a price change and this is related to an IVT decrease. Since price change is only related to a single data point, its significance should be reconsidered.

Remarkably, the time of day is insignificant in all models. This implies that for those models with dependent variable 'Ridership full day', it does not matter whether the change is implemented peak only / off-peak only or full day. This contradicts the hypothesis. The fact that this is insignificant, also implies that the spread around equal LOS changes is large, making distinction between time of day insignificant. Splitting the data base, such that a separate data set is formed for peak only, a separate data set for off-peak only and a separate data set for full day would be preferable. However, this decreases the number of data points too far.

For the regression, no unambiguous conclusions can be made. The results of the regression analysis will not lead to a converging, unambiguous result suitable for a model, but suggest that context can be essential. The results of the regression are classified as insufficient to lead to the model as intended, for the following reasons:

1. IVT has an insufficient amount of data points (max. 6).
2. The different regression designs have too much variation in outcome.
3. Time of day is insignificant and contradicts the hypothesis, but can be explained by a (too) large spread in the data.
4. Separating the data bases would conceptually be the best methodology; however this leads to an insufficient amount of data points.

The results should therefore be interpreted as indicative; they do provide valuable insights, but are insufficient for unambiguous conclusions. Based on this insight, the most suitable data for the model as meant in the research question are the results from the line-based analysis while maintaining the characteristics of each individual case. This is applied in Chapter 7, where the model is developed. The search for model parameters and form ends here.

6.5. Result conclusions

Section 6.1 described the general trends in concessions, such that further results can be placed in the context of these trends. The analysis per OD-pair does not lead to results that can be translated into a model, for which five issues are identified. However, it does show trends as hypothesized. A second approach is applied to overcome the issues identified in the OD-based analysis: line-based analysis. The results are more promising, but not leading to converging model parameters. The elasticities calculated in the results show a much larger range than acknowledged in literature. Due to this large range and possibly due to the limited amount of data points, no converging model parameters can be determined. Additional learnings from the data analysis are gathered. A strong correlation between peak and off-peak ridership is present. Furthermore, students can often be marked as the most sensitive user group. Also a regression analysis (section 6.4) does not enable finding converging model parameters, although this can largely be assigned to the insufficient amount of data. The regression analysis does however indicate that additional predictors (e.g. type of line and main user group) can be significant for ridership prediction. The line-based analysis provides the best basis for a model. The to be developed model should be scalable and easy to expand, such that in the future data can be added. Moreover, it has been shown that context is essential and cannot be excluded. The future model should account for this.

7
Model development

Summary: First the requirements of the model are further specified. The requirements and the results of the research are then translated into a conceptual model. The model that suits the requirements and the results of this research is a database of data sheets with a search engine, such that a case comparable to the request can be found: the Case Study Search Engine. The user interface is designed in Excel, which enables easy future expansion. The model is explained and an example of usage is given. Validation of the model is performed in two steps: validation of the tool itself and validation of the outcome.

This chapter describes the development of the model and its result and therewith answering sub-research question D: How can ridership prediction be modelled, based on the outcomes of the preceding sub-questions, such that it is transparent, easy-to-use and accurate? First, the model requirements are described and discussed. Secondly, the conceptual design is described. These two sections lead to preferred modelling software, which meets the requirements and is suitable for the model design. Thirdly, the user interface is described. Finally, an example and the validation is described. In this chapter, the following terminology is used: 'Request' refers to the level-of-service change, with corresponding characteristics, of which the user wants to know the effect on ridership. 'Model' refers to the combination of search engine and the data sheets. 'Search engine' refers to the Excel model which helps configure the request and matches the request with data base entries. 'Data base' refers to the list of cases which have been analyzed, with their relevant characteristics. The data base links to 'Data sheets', each sheet contains all information necessary and available for a single case.

7.1. Model requirements

In sub-research question D it is defined that the model should be transparent, easy-to-use and accurate to make it suitable for tendering. The requirements are now made more detailed, further specified and extended to optimize suitability. Requirements for the model are based on consultation within EBS, as well as De Keizer et al. (2009). Ultimately, the model should be suitable for (but not necessarily limited to) use in a tender. De Keizer et al. (2009) describes the following requirements for forecasting models in public transport:

- Input must be sufficiently available.
- Output must be understandable and traceable.
- Level of detail must be adjustable in time and space for each individual request.
- The model must be transparent.
- The model must be consistent.
- The model must be flexible with a short running time.
- The model must be easy to control and maintain.

The time limitations in a tender requires the model to be easy-to-use. This means that the amount of input requested from the user must be limited and easily and fast available. For every requested run, an outcome must be provided within several minutes. In addition, the model should be recent in order to be accurate, since the mode choice of people can change over time, due to e.g. new modes and increases welfare. Also, the model is meant to predict short-term behavior. Short-term is defined as 1 to 2 years, similarly to what is often used in literature (Paulley et al., 2006). This is the most suitable time period for the purpose of the model; using it in tenders. This leads to the addition of two more requirements, apart from those proposed by De Keizer et al. (2009):

- The model must provide a prediction of ridership on short-term level.
- The model must contain present-day data.

As concluded in the data analysis results:

- The model must be scalable and easy to expand.

Finally, the most essential requirement is to meet the goal of the model:

- Reliable and accurate prediction of ridership.

Meeting these requirements has to be assured. Certain requirements have been met in the data analysis: containing present day data and a prediction on short-term level. All other requirements are met in the conceptual design of the model and choice of software.

7.2. Model design - conceptual

7.2.1. Type of model

Based on the literature study in Chapter 3, the methodological choice has been made to aim for an elasticity model. The data analysis results form the input of the model. As described in Chapter 6, not all analyses lead directly to model parameters. In section 9.5 it will be discussed whether this initial choice and design for elasticities is still valid, or that another model type should have been aimed for. Despite, a model is designed based on the results from the data analysis in Chapter 6.

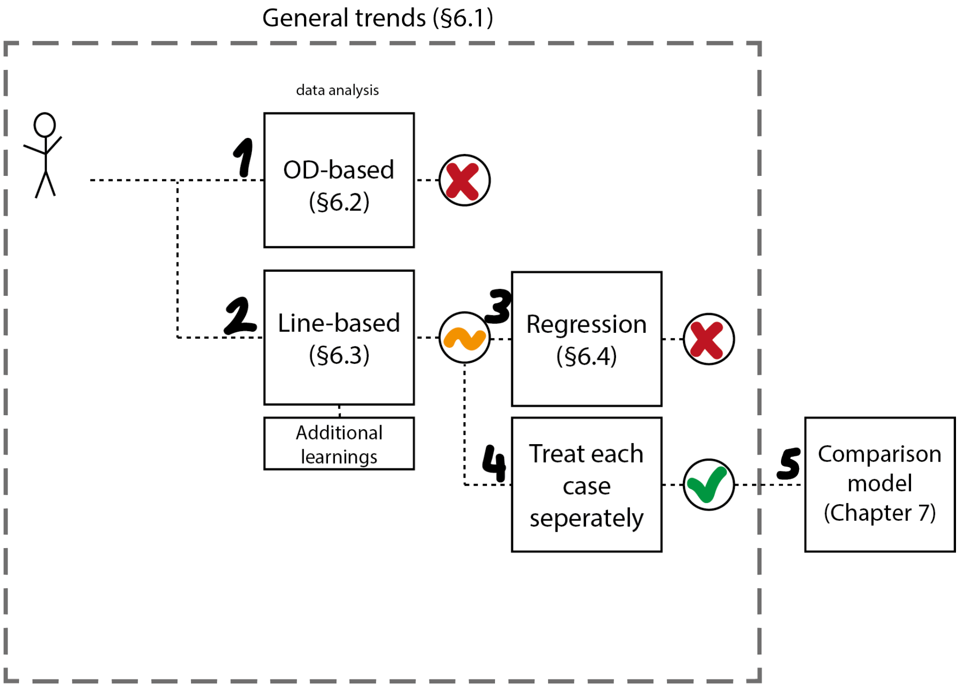


Figure 7.1: Flow chart of how the data analysis results lead to the model design.

As concluded from the data analysis results (section 6.5), neither of the approaches lead directly to converging model parameters. The line-based results lead to the most promising results. Combining the line-based results into elasticities also proved impossible. Context proves to be essential for predicting ridership, which is recognized during the expert meeting (Expert meeting EBS) and is also shown in Chapter 6. A model is thus needed that can honor this large variation in outcome and should be able to include context factors. The goal of this thesis is to develop a model. In order to reach to this goal, despite the lack of converging model parameters, an explorative model concept is proposed. The model is developed as far as the current data analysis results allow and can be developed further in the future.

Since the results of each case is not only dependent on the LOS change, but also largely influenced by the context, each case is valuable in itself. Generalizing the results would mean essential loss of information and value. All cases are therefore included individually into the model (figure 7.1). The model enables the user to find a case which is comparable to the situation the user requests (figure 7.2), by entering input characteristics. The input characteristics are translated into a request, which the search engine matches to entries in the data base. The model then provides the cases which match the request. As Chapter 6 has shown, elasticities occur on a large range. The model intends to find a case with similar conditions, such that it can be determined where in this range of elasticities an applicable elasticity can be found for the request of the user. Of these cases, a data sheet is available, providing all information available and necessary to the user. On the data sheet, context factors are be described. Furthermore, it is able to present growth factors for multiple time periods (e.g. full day, peak and off-peak) and describes the effect on the user groups. Therewith, it provides much more information to the user than a simple elasticity value would give. Shortly, it is a stack of cases which the user can search through with a search engine. The main advantage of such a model concept is that it honors both the large variation in data points and it is able to include contextual information.

This model concept has consequences for the requirement 'Reliable and accurate prediction of ridership'. The model itself, unlike a regression, best-fit or trend line, does not add any uncertainty (unless interpolation/extrapolation from the cases is used). In that sense it is reliable and accurate. The inaccuracy lies in the interpretation of the user, who can interpret a line as fully comparable, while it might not be. The search criteria of the model mean to help the user in judging comparability (subsection 7.2.2). Furthermore, the reliability and accuracy is linked to the data base of cases. The reliability of the cases is tested and assured in the plausibility check during the expert meeting (Expert meeting EBS, Appendix A.2). The reliability and accuracy of the model will also be subject to the amount of cases available. Adding cases in the future can help the user with finding better comparable cases and finding a more suitable ridership prediction.

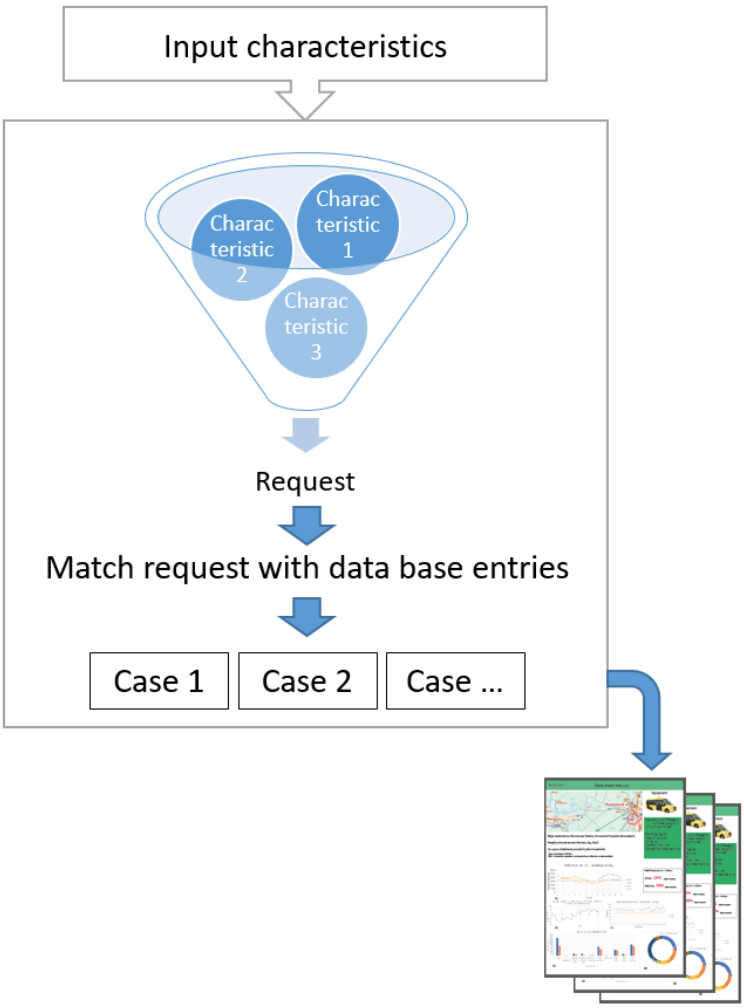


Figure 7.2: A schematic overview of the concept of the model. The input characteristics can be entered in a user interface and are translated into a request. The search engine then matches the request with entries in the data base. The outcome is a list of comparable cases, linked to corresponding data sheets.

7.2.2. Model design - defining in- and outputs
The search engine which enables the user to find a case requires input. This input, the search criteria, are defined in the user interface. Which characteristics the user can search is predefined. They are chosen based on which characteristics are available and necessary with respect to the data, which are found to be important in literature, the regression analysis and during the expert meeting (Expert meeting EBS).

The user is allowed to make the following choices:

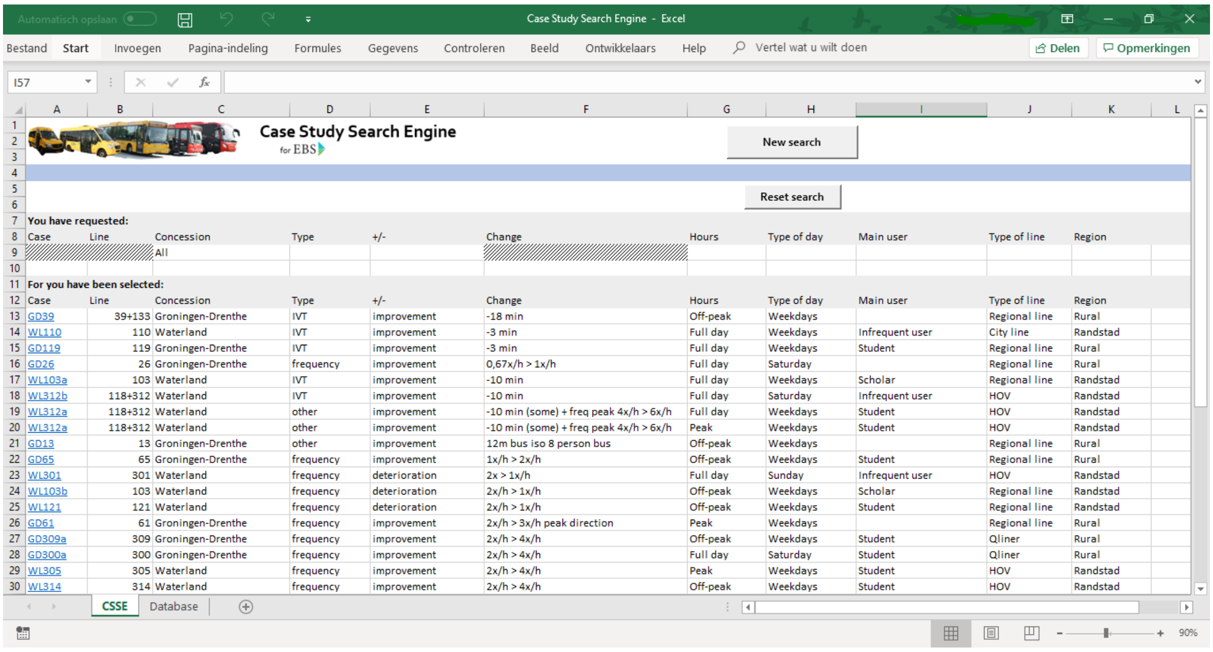
- level-of-service change
- improvement or deterioration in LOS
- type of day
- peak vs non-peak vs full day
- main user group
- type of line
- region
- concession

The search engine first enables the user to choose between the type of level-of-service change, i.e. change in travel time, change in frequency and 'other'. 'Other' refers to e.g. a change in equipment, change in branding, or a combination of changes. In the future these can be classified in individual categories; at this moment there is an insufficient amount of cases for this. Furthermore, the user is able to choose between an improvement and a deterioration of this level-of-service change. In a later stage the exact LOS change could be added to the model (e.g. frequency increase from 2x/h to 4x/h), however at this moment there is not a sufficient amount of cases available for this to be useful. The column for this is already added to the model, in partial fulfillment of the requirement for a scalable and easy to expand model. A choice per type of day (weekday, Saturday or Sunday) can be made. Furthermore a distinction in measures during peak-only, off-peak-only and full day can be made. The exact definition of peak and off-peak times are case specific. The main user group is based on the product types used in each of the cases and enables distinction based on user group. 'Type of line' refers to the line being a city line, a regional line, a HOV line or a long distance line. Region refers to the case originating from an urban region (Randstad) or from a rural region. This classification is based on the concession it originates from. However, the user can also select based on concession, if one believes one concession to be more comparable to its request than the other. These inputs are easily available, since they represent the request of the user. If the request does not specify certain variables, they can left open and all cases are selected for that variable. With this property, the model meets the requirements of the inputs being sufficiently available and of an adjustable level of detail. Adding more search criteria at this stage would possibly increase reliability and accuracy, since it enables the user to better judge which of the cases are comparable to its request. However, at this stage this conflicts with the requirement of sufficiently available inputs and the deficit of number of cases.

7.2.3. Preferred modelling software
Taking into account all requirements from the previous section and the proposed model characteristics, the model software can be chosen. Since use-ability, transparency and accessibility are essential, a software package which is widely used/available in industry is preferred. In addition, it must be easily adaptable for future improvements to meet the requirement of a scalable and easy to expand model. Microsoft Excel is very suitable for this requirement. It is easy to control and maintain, since it is widely used in industry. Furthermore, in Excel a model as proposed can be build. The next section describes how the model is designed in Excel.

7.3. Model design - user interface
The model means to enable the user to find a comparable case to its request. The search engine helps with this. By entering the characteristics of the request, it provides a list of cases having the same characteristics. When the Excel file is opened, the user first sees the data base and selection criteria (figure 7.3).

To help the user to deliver all characteristics to the search engine in a 'translatable' request, in the search engine the model one can push the new request ('New search') button (figure 7.4).



Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
		All								
GD39	39+133	Groningen-Drenthe	IVT	improvement	-18 min	Off-peak	Weekdays		Regional line	Rural
WL110	110	Waterland	IVT	improvement	-3 min	Full day	Weekdays	Infrequent user	City line	Randstad
GD119	119	Groningen-Drenthe	IVT	improvement	-3 min	Full day	Weekdays	Student	Regional line	Rural
GD26	26	Groningen-Drenthe	frequency	improvement	0,67x/h > 1x/h	Full day	Saturday		Regional line	Rural
WL103a	103	Waterland	IVT	improvement	-10 min	Full day	Weekdays	Scholar	Regional line	Randstad
WL312b	118+312	Waterland	IVT	improvement	-10 min	Full day	Saturday	Infrequent user	HOV	Randstad
WL312a	118+312	Waterland	other	improvement	-10 min (some) + freq peak 4x/h > 6x/h	Full day	Weekdays	Student	HOV	Randstad
WL312a	118+312	Waterland	other	improvement	-10 min (some) + freq peak 4x/h > 6x/h	Peak	Weekdays	Student	HOV	Randstad
GD13	13	Groningen-Drenthe	other	improvement	12m bus iso 8 person bus	Off-peak	Weekdays		Regional line	Rural
GD65	65	Groningen-Drenthe	frequency	improvement	1x/h > 2x/h	Off-peak	Weekdays	Student	Regional line	Rural
WL301	301	Waterland	frequency	deterioration	2x > 1x/h	Full day	Sunday	Infrequent user	HOV	Randstad
WL103b	103	Waterland	frequency	deterioration	2x/h > 1x/h	Off-peak	Weekdays	Scholar	Regional line	Randstad
WL121	121	Waterland	frequency	deterioration	2x/h > 1x/h	Off-peak	Weekdays	Student	Regional line	Randstad
GD61	61	Groningen-Drenthe	frequency	improvement	2x/h > 3x/h peak direction	Peak	Weekdays		Regional line	Rural
GD309a	309	Groningen-Drenthe	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays	Student	Qliner	Rural
GD300a	300	Groningen-Drenthe	frequency	improvement	2x/h > 4x/h	Full day	Saturday	Student	Qliner	Rural
WL305	305	Waterland	frequency	improvement	2x/h > 4x/h	Peak	Weekdays	Student	HOV	Randstad
WL314	314	Waterland	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays	Student	HOV	Randstad

Figure 7.3: The user interface of the model.

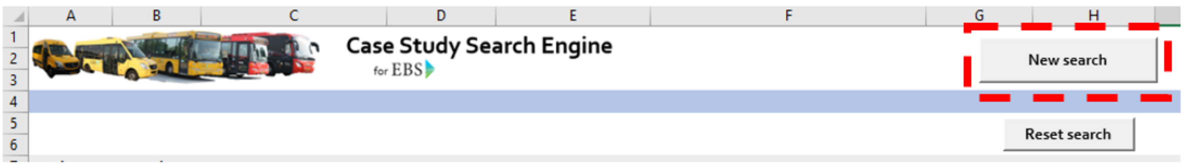


Figure 7.4: Entering a new request into the search engine. ‘New search’ opens a pop-up interface.

The ‘New request’ button opens a pop-up interface, which helps the user with the input of his request (figure 7.5). In this interface, all 8 input characteristics (as determined in the previous section) can be entered. In the user interface, two variants of questions are present. One being a unique choice, e.g. it being a improvement or a deterioration; the second allows multiple choices, e.g. which concessions should be included (figure 7.6).

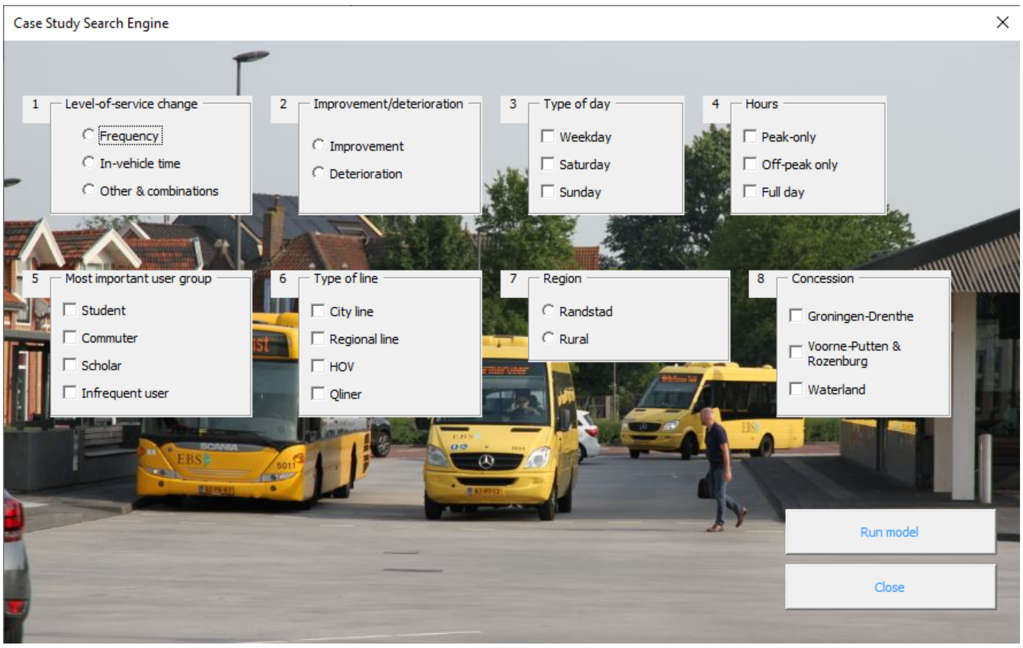


Figure 7.5: Search engine interface

Figure 7.6: The two types of questions present in the interface. Left: a unique choice, one selects either it being an improvement or it being a deterioration. Right: allowing for multiple choices, e.g. one or multiple concessions can be selected.

After all necessary inputs have been entered, the model can be run. At the top of the Excel sheet, the request is shown, such that the user knows what has been entered. Below, the user finds the cases that are comparable with the request (figure 7.7). The user can also click the 'Reset search' button, such that the full data base is shown. The full data base is also available on the second worksheet, such that the user can always scan the full data base to find additional cases. This enables the users to find any of the cases and their characteristics without limiting themselves by the search engine, in case they enter any wrong characteristics or they want to use a case even though it is not fully compatible with their characteristics (e.g. when a case with the requested characteristics is not available in the database). These characteristics fulfill the requirement of the model being transparent.

	A	B	C	D	E	F	G	H
7	You have requested:							
8	Case	Line	Concession	Type	+/-	Change	Hours	Type of day
9			Waterland	frequency	improvement			Weekdays
10								
11	For you have been selected:							
12	Case	Line	Concession	Type	+/-	Change	Hours	Type of day
29	WL305	305	Waterland	frequency	improvement	2x/h > 4x/h	Peak	Weekdays
30	WL314	314	Waterland	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays
49								
50								
51								

Figure 7.7: Results of the search engine. For this request, two comparable cases have been found.

The user can find the data sheet manually by opening the data sheet with the corresponding code (which is always the initials of the concession + the line number) from the CSSE folder, or by clicking on the code. This links directly to the file (figure 7.8). However, the hyperlink only works when linked to the correct folder, which must be kept in mind. To enable easy future expansion with more data sheets, templates for data sheets are included in the model folder.

11	For you have been selected:		
12	Case	Line	Concession
13	GD39	39+133	Groningen-Drenthe
14	WL110	110	Waterland
15	GD119	119	Groningen-Drenthe
16	GD26	26	Groningen-Drenthe
17	WL103a	103	Waterland
18	WL312b	118+312	Waterland

Figure 7.8: Results linking directly to the data sheets.

To illustrate the usage of the model, an example is given: increasing the frequency of the city bus lines in Delft from 2x/h to 4x/h (on a Weekday for full day).

It is possible to select only the frequency change and not provide any context factors. The user opens the Case Study Search Engine, clicks the 'New request' button and answers criteria 1 with 'Frequency' and criteria 2 with 'Improvement'. All other criteria can be left empty. The result is a list with all 11 cases with a frequency increase (figure 7.9). Since the changes are sorted by change, it is immediately clear that there are 6 cases with a frequency increase from 2x/h to 4x/h.

You have requested:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
			frequency	improvement						

For you have been selected:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
GD26	26	Groningen-Drenthe	frequency	improvement	0,67x/h > 1x/h	Full day	Saturday		Regional line	Rural
GD65	65	Groningen-Drenthe	frequency	improvement	1x/h > 2x/h	Off-peak	Weekdays	Student	Regional line	Rural
GD61b	61	Groningen-Drenthe	frequency	improvement	2x/h > 3x/h peak direction	Peak	Weekdays		Regional line	Rural
GD309a	309	Groningen-Drenthe	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays	Student	Qliner	Rural
GD300a	300	Groningen-Drenthe	frequency	improvement	2x/h > 4x/h	Full day	Saturday	Student	Qliner	Rural
WL305	305	Waterland	frequency	improvement	2x/h > 4x/h	Peak	Weekdays	Student	HOV	Randstad
WL314	314	Waterland	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays	Student	HOV	Randstad
VPR403	403	Voorne-Putten Rozenburg	frequency	improvement	2x/h > 4x/h + R-net	Full day	Saturday	Infrequent user	HOV	Randstad
VPR85	85	Voorne-Putten Rozenburg	frequency	improvement	2x/h 12m > 4x/h 8p	Full day	Weekdays	Student	City line	Randstad
VPR84	84	Voorne-Putten Rozenburg	frequency	improvement	4x/h > 6x/h	Off-peak	Weekdays	Student	City line	Randstad
GD309b	309	Groningen-Drenthe	frequency	improvement	5 à 6x/h > 8x/h (PM peak)	Peak	Weekdays	Student	Qliner	Rural

Figure 7.9: Example of usage of the CSSE 1.

However, it is likely that the user wants to further specify the search, mainly if further data is available. The user can open the user interface again and fill in further (or new) criteria. The user can find in the column 'Change' which frequency increase is relevant for each case. In this case the user can select all cases from 2x/h to 4x/h from the list, in case of a change which is not present, the user can interpolate between nearby changes. The user then enters e.g. 'Weekday' under criteria 3, 'Full day' under criteria 4. Since the main user type is not known, criteria 5 is left empty, such that no filter is applied based on main user group. The line type is entered under criteria 6, Region Randstad under criteria 7 and no further specification of concession is given. The search engine then finds 1 case (figure 7.10).

You have requested:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
			frequency	improvement		Full day	Weekdays		City line	Randstad

For you have been selected:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
VPR85	85	Voorne-Putten Rozenburg	frequency	improvement	2x/h 12m > 4x/h 8p	Full day	Weekdays	Student	City line	Randstad

Figure 7.10: Example of usage of the CSSE 2.

The possibility exists that no case is found based on the selection criteria, or that the user finds the case(s) found not suitable. In the example, this might be because the single case found is also subject to a change in bus type. The user can reopen the search engine interface and change search criteria. E.g., the user could include 'Saturday' in the type of day selection, if the user thinks that a case from a Saturday would provide helpful input. Or the user can choose to no longer filter based on the type of line. If both is done, the search engine finds an additional case (figure 7.11).

You have requested:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
		All	frequency	improvement		Full day	WE+SA		All4	Randstad

For you have been selected:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Region
VPR403	403	Voorne-Putten Rozenburg	frequency	improvement	2x/h > 4x/h + R-net	Full day	Saturday	Infrequent user	HOV	Randstad
VPR85	85	Voorne-Putten Rozenburg	frequency	improvement	2x/h 12m > 4x/h 8p	Full day	Weekdays	Student	City line	Randstad

Figure 7.11: Example of usage of the CSSE 3.

If the user has difficulty finding a case with the search engine, e.g. because there seem barely any cases comparable, the user can also find the full list in the second tab and search the list manually. The user can also use the filters manually, if wanted.

All in all, the search engine provides the resulting cases within a minute of time and the data sheets provide plenty of information; fulfilling the requirement of a flexible and fast model. The design of the data sheets is explained in the next subsection.

7.3.1. Design of the data sheets

The model leads to a selection of cases which are relevant to the user. To provide the user with sufficient and clear data of the case, a data sheet is designed for each case. On this data sheet, information of the area, the line itself, the usage and the results from the analysis are presented (figure 7.12). It is up to the user to decide if the resulting elasticities are suitable for their request, in which the data sheets helps by providing as clear and sufficient information as possible; therewith meeting the requirement of understandable and traceable outputs.

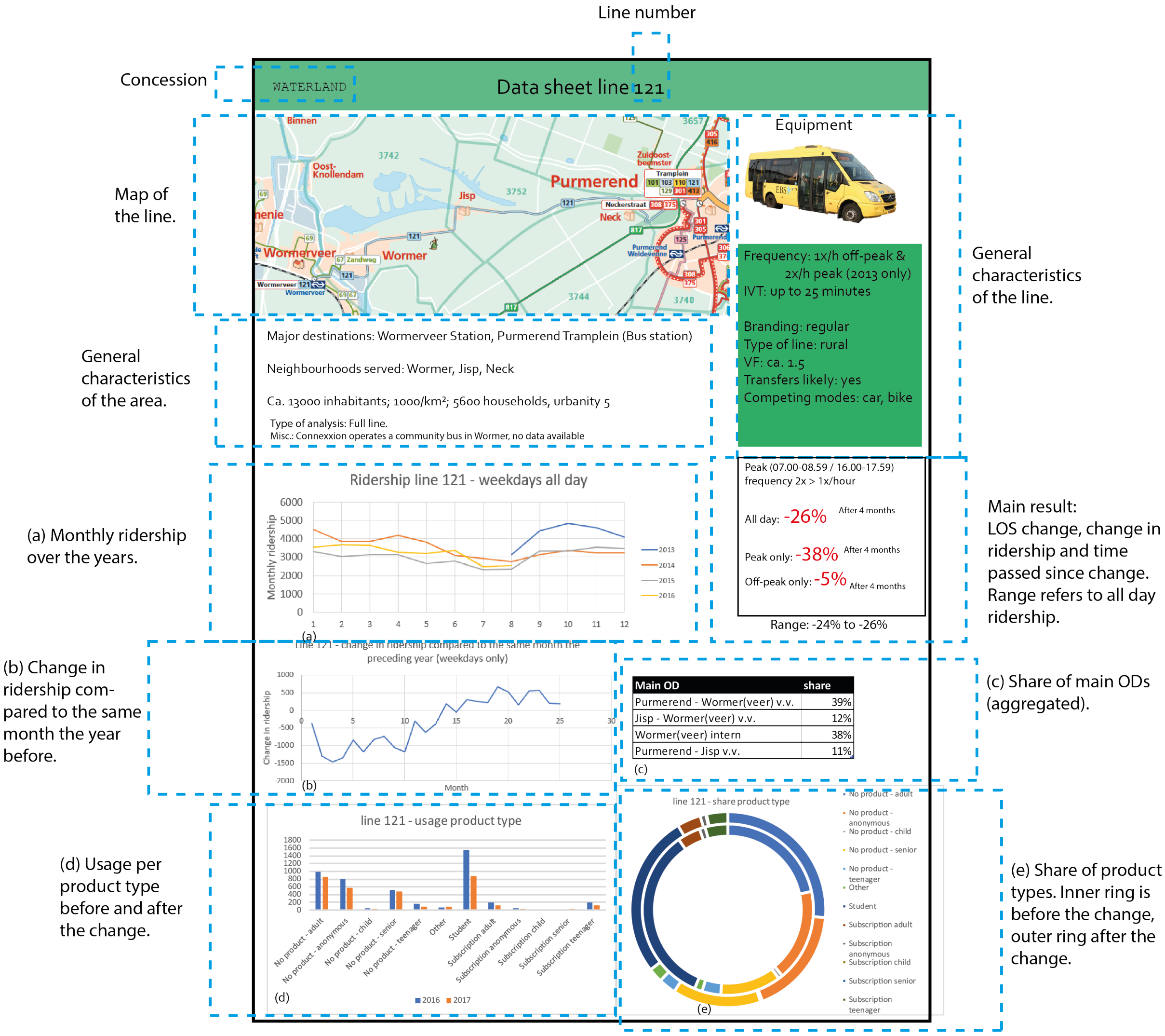


Figure 7.12: The design of the data sheets and all that that can be found. Note that in several cases, not all data is available, therefore lacking on the data sheets.

The data sheet provides the characteristics of the line, such as the concession, line number, equipment used; but also what the VF and IVT are, as well as competing modes. Furthermore the characteristics of the area are shown, such as the major destinations, number of inhabitants and possible qualitative factors which can be of influence on ridership changes. How this information is gathered and summarized, including assumptions, can be found in Appendix C, where an example (WL121) is elaborated upon. On the right hand side, the LOS change with the elasticity found are shown. This is, when relevant, split up in time periods (e.g. peak and all day) and the time passed since the change is mentioned. When possible, five graphs/tables are shown:

(a) The monthly ridership over the years.

(b) The change in ridership, compared to the same month the year before. E.g. first month shows the change in ridership of the first month after the change, compared to that same month the year before. The second month shows the change in ridership of the second month after the change, compared to that same month the year before.

(c) The share of main origin-destinations (aggregated). The line is split up in large aggregated zones and the share of trips between the zones is presented.

(d) The usage per product type, the month analyzed before the change and the same month a year later. Note that for Groningen-Drenthe, product data applies for the full line, not the (cleaned) section only.

(e) Again the product type, but now the share of each product type, instead of the absolute numbers. The inner ring is the month analyzed before the change, the outer ring the same month a year later.

The model thus provides the user with much more than only a growth factor for ridership. It provides insight in ridership changes in different time periods (full day, peak and off-peak), sensitivity of user groups and the time path along which ridership changes. It enables the user to not only predict ridership after a set amount of time, but also to predict which user groups are affected and how the ridership develops over time.

The consistency of the data analysis results entered into the model is tested in the plausibility check during the expert meeting (Expert meeting EBS, Appendix A.2). Furthermore, the development of data sheets provides the user with a standard format in which the information is provided. Therewith the requirement of consistency is met, both in the data as in the modelling concept.

7.4. Validation

For validation purposes, several steps are undertaken. The plausibility check performed during the expert meeting (Expert meeting EBS, Appendix A.2) has been performed to validate all data points/cases in the model. The concept of the model and the format of the data sheet has been introduced to the experts (and future users) and has been updated accordingly; this has for example led to the addition of a generalized OD-table. The model has been tried for use by former and current members of the tender team of EBS as a validation step to test the usability and suitability for the tender environment. Their comments and suggestions included saving the initial request made and to rearrange the order of the user manual. The model and user manual have been updated accordingly. The model is further validated with use of real-world cases. Two validation steps are taken. Firstly, the applicability of the tool during a tender is reflected upon, by applying the model to a case: a (not to be specified) recent tender.

For the tender of the concessions, a total of 54 measures required a ridership prediction. By classifying them into categories (figure 7.13), it can be determined how complete the CSSE is. The Case Study Search Engine is able to provide a prediction for the categories *Frequency*, *IVT*, *Branding/HOV implementation* and to a lesser extent *Network redesign*, for which a single case is present in the CSSE. This means that for 75% of the measures a ridership prediction can be estimated with the model. This can either be done by finding a directly comparable case (this cannot be guaranteed), or by interpolating between cases. The originally used method of estimation by EBS could provide a prediction for 67% of the measures. Additional prediction had to come from other sources/tools or could not be estimated at all.

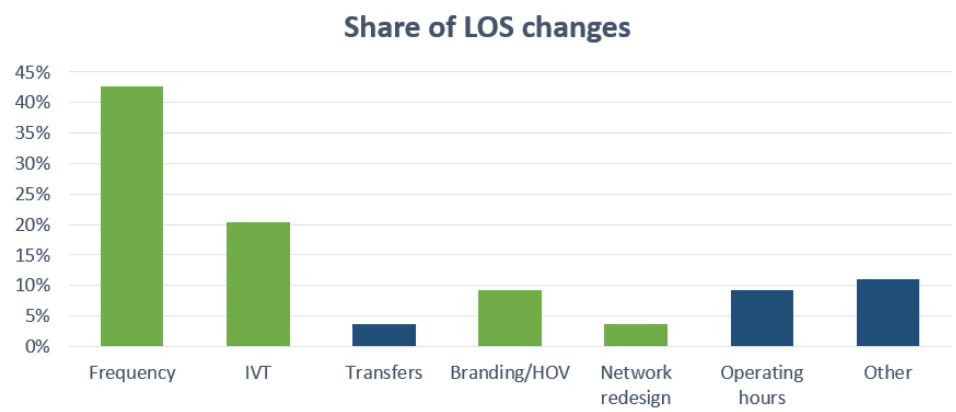


Figure 7.13: Share of categories of level-of-service changes for which a ridership prediction is required (based on a recent tender). Green indicates the CSSE can provide a prediction for the category, blue indicates it cannot.

The categories of LOS changes that cannot be estimated with the CSSE are *Transfers*, *Operating hours* and *Other*. The category *Other* includes servicing of previously not serviced destinations, scholar lines and servicing of an airport. The main limitation of this model, apart from a potential deficit in cases, lies thus in the lack of ridership prediction with added/removed transfers, when extending operating hours and *Other* LOS changes.

A second validation step is to validate the outcome of the model. This validation can only be performed with comparison to actual cases. These cases are limited, since public transport operators rarely share data and all data within EBS has been used for the input of the model. A few cases from throughout The Netherlands have been found in publications and are compared to estimation with the CSSE (table 7.1).

Table 7.1: Validation outcome model. Note that the estimations of the CSSE are subject to assumptions, since not always comparable cases are present.

LOS change	Published growth	Estimation CSSE
R-net branding Zoetermeer-Leiden	+15%[1]	+13% to +16%
Peak service Zaandam 4x/h >3x/h	-16% [2]	-19%*
Network change, skipping stops Amstelveen	+5% [3]	+12%
Train Tiel-Arnhem 1x/h >2x/h	+26%[4]	> +10%
Rosmalen 2x/h >4x/h	+39.5%[5]	+8% to +32%
Den Bosch Pettelaarpark 4x/h >2x/h	−22.1%[5]	> -11% to -38%
Den Bosch Empel IVT +6 min	+3.3%[5]	-32% to +6%*

1 Ligtermoet & Partners (2016)
2 Connexxion Zaanstreek (2016)
3 Vervoerregio Amsterdam (2018)
4 Arriva Oost Nederland (2017)
5 Arriva (2019)
*estimated with interpolation/extrapolation, subject to assumptions

The comparison shows that in most cases, growth factors are roughly comparable and in, or close to the range of estimation of the CSSE. However, it also shows that there can be large deviations, dependent on the case chosen in the CSSE. This deviation illustrates the importance of all context available on the data sheets and stresses the need for expansion of the number of cases in the model. For the published growth values in table 7.1, in some cases context factors are necessary to for interpretation of the growth factor. An example of this is the last case: Den Bosch Empel IVT +6 min. The ridership growth after increasing IVT is remarkable. The explanation can possibly be found in the new route, which now services an additional train station halfway along the route. If the users continue by train, the total travel time for the full trip might actually be decreasing instead of increasing. The CSSE on the one hand provides a case which shows that the change in destinations serviced due to the route change can lead to a-typical behavior, on the other hand it allows for inclusion of such essential information when data is added to the data base.

7.5. Model development conclusions

All requirements for the model (section All requirements set by De Keizer et al. (2009) have been met in the design of the model and data sheets. The requirements containing recent (present day) data and predicting on short-term level have been met in the selection of data, which is used as data base for the model. The requirement of reliable and accurate prediction of ridership is partly accounted for by the selection and analysis of the data which is used as data base for the model; as well as by the design of the model. However, fully meeting this last requirement is also subject to future addition of cases. The type of model that has been developed is directly inherited from the results: bundling of data would lead to inaccurate results, thus a model with a database of all case studies is developed. This database of case studies can be used for comparison. The Excel model is easy to adapt and expand (which is described in the User manual in Appendix G.2), such that it is future proof. A vision (implementation plan) on how the model should be implemented within the EBS organization is described in Appendix G.1. This implementation plan must enable that the model is not only easy to maintain and control in its current form, but that this requirement also holds when expanding the model.

The user is not presented a single elasticity value for each case. The model only presents comparable cases and the responsibility for usage of the elasticity value is for the user; not the model. The data sheets provide sufficient information for the user to make its decision. This way, a model could be developed honoring the results of the before-after study. Furthermore, it enables inclusion of context, user sensitivity and interaction between peak and off-peak ridership. This is an advantage over many other elasticity models. Despite, the model is explorative and further development in the future is advised. With the development of the CSSE, sub-research question (D) has been answered.

The validation shows that the model, if matching cases can be found, can provide an accurate ridership prediction for most of the LOS changes. The largest gaps, for which the model does not provide prediction, are extension of operating hours and the category *Other*, including new destinations, scholar lines and airport servicing. To tackle those gaps in the model, specific cases are analyzed to provide a source for ridership prediction: Chapter 8.

8
In-depth analysis of specific cases

Summary: In-depth analysis of specific cases is performed, in order to find additional insights which can help in ridership prediction, but cannot be added directly into the model. The effect of urban development on both new and existing lines is analyzed. The effect of longer operating hours is estimated with the ratio of ridership with the preceding hour. Furthermore the main users per time of day and type of day are determined. The analysis of implementation period shows that it can take up to 2 years for ridership to stabilize after a LOS change, although the main growth is already in the first year. No direct relation between usage of bus stops near schools or scholar lines and number of students can be found. An example is analyzed which shows how the usage of the bus towards the airport increases significantly after implementation of a dedicated airport liner. Lastly, it is analyzed what the effect of implementation of a new community service bus line is; i.e. who is in the bus, how does ridership develop and how is the usage on Saturdays.

8.1. Analysis of specific cases

The validation of the model (section 7.4) shows that there is a selection of LOS-changes for which the model is not able to provide a ridership prediction. However, during a tender, a substantiated predicting is necessary. This chapter presents additional data analysis for those specific cases. This includes connecting new urban development to the bus network, influence of schools and airports and the implementation period of lines. These specific cases can in the first place help with determining which factors to take into account during a tender (for example schools and airports), but it also provides key figures for e.g. ridership generation in new urban areas. The following cases are analyzed:

- New urban development; both growth in urban development near an existing line as implementation of a new line in new urban development.
- Extension of operating hours; how many travelers can be expected and who are the users?
- Implementation period; on which time scale does growth/decline occur?
- Schools; is there a relation between stops at schools and number of students and between scholar lines and number of students?
- Airports; what is the effect of implementation of a dedicated airport liner?
- Community service buses; who are the first users when a new line is introduced, what is the effect of a LOS change and is there a relation between weekday usage and Saturday usage?

New urban development

To evaluate the effect of new urban development on the ridership of the bus network, multiple cases are analyzed. In the concession Waterland one major project has been developed: Broeckgouw in Volendam; ca. 800 houses, a shopping center and a school (Personal communication T. Schilder municipality Edam-Volendam). In August 2014, the neighborhood has been included in the route of line 110 (figure 8.1). The trends in usage of the bus stops and number of households and inhabitants is plotted over time. Numerically, the slope of the trendline of inhabitants is ca. 0.69; for households ca. 0.30 and for the total usage of the two stops ca. 0.22. The usage of the two bus stops is therefore roughly in line with the growth in number of households, while the number of inhabitants grows significantly faster.

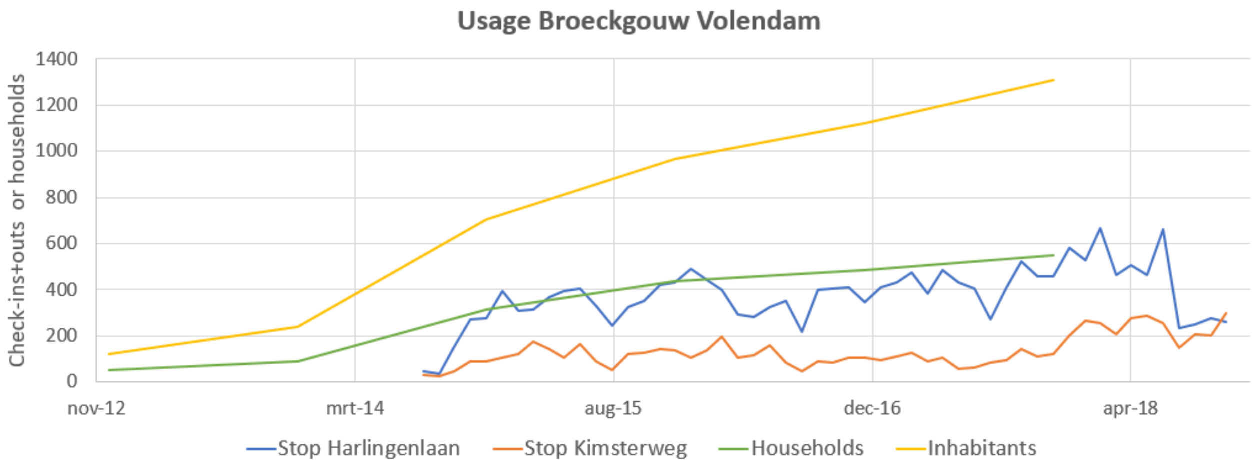


Figure 8.1: The usage of the stops Harlingenlaan and Kimsterweg (line 110) which are located in the newly developed neighborhood Broeckgouw (Volendam). Note that the growth in usage seems to be approximately in line with the growth in households.

In the first three months of operation, the usage of the bus stops is rather low: respectively 0.29, 0.24 and 0.70 monthly check-ins/outs per household. This is calculated by dividing the number of check-ins/outs at both bus stops combined by the (interpolated) number of households present in Broeckgouw in that month. After the third month of operation, on average 1.11 check-ins/outs per household are generated when usage of both bus stops is combined. Remarkably the first month of operation (0.29 check-ins/outs per household) is more popular than the second (0.24 check-ins/outs per household), even when considering the first month is a summer month (August) with generally fewer users than September. Assuming that a person starts and finishes his trips at the same stop, this means each household produces ca. 0.5 bus traveler or 1 trip per month.

Another area with new urban development is Purmerend Weidevenne. As opposed to Broeckgouw, this area has already frequent bus service, but the effect of the growing number of households and inhabitants on the usage is analyzed. Near bus stop Neckerstraat, a new residential area has been developed. Bus stop Neckerstraat is the new terminating stop of line 308 since November 2016 and in December 2016 also the terminating stop of the peak-only Bizzliner 375. Growth of the lines and urban development is shown in figure 8.2. Bus stop Melkwegbrug (Purmerend) has not been included, since this was a temporary replacement stop for the bus station (in operation in the years 2014 and 2015).

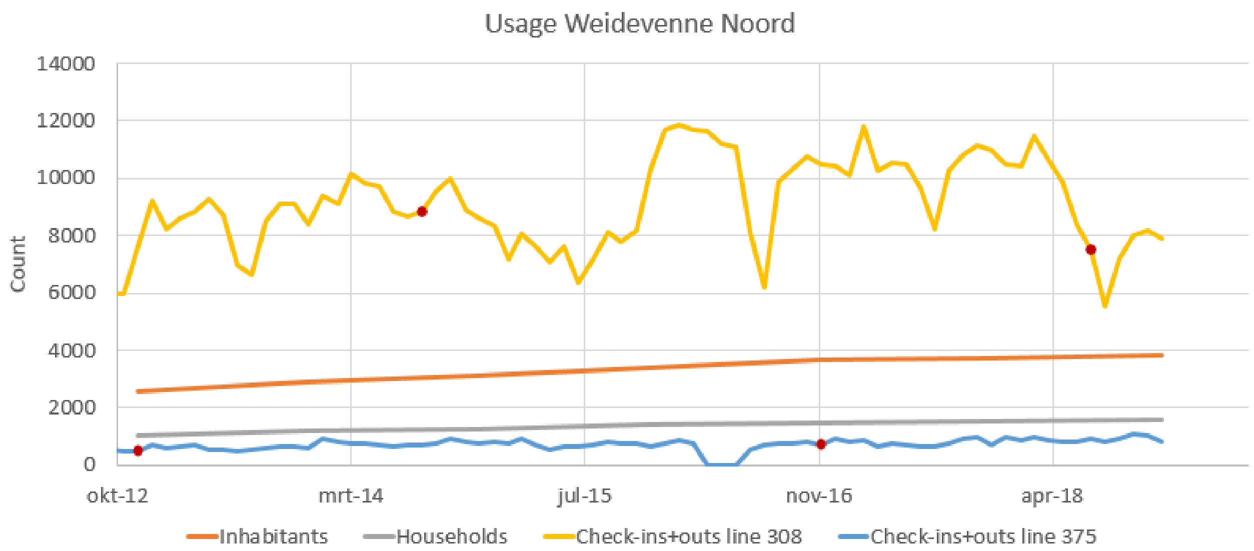


Figure 8.2: The number of check-ins and check-outs combined for the bus stops in Weidevenne Noord (Europa neighborhood) and the number of inhabitants and households. Red dots imply a level-of-service change for that specific line.

The slope of the trendline of inhabitants is ca. 0.60; for households ca. 0.24; for line 308 ca. 1.40 and for line 375 ca. 0.15. The results show that Bizzliner, which provides more specialized transport, grows much less than a HOV line such as line 308. A difference per line seems to exist. For both lines hold that the usage deviates far from both the slope of inhabitants as the slope of households. Though the large slope of line 308 seems to be caused mainly by the jump in usage in late 2015. The average number of check-ins/outs per household is ca. 6.8 for line 308 and ca. 0.5 for line 375.

A third case in Waterland is the new (industrial) business park that has been developed in Purmerend: Baanstee Noord. As of December 2017, line 110 between Purmerend and Edam has changed its route, now providing service to this business park. Stops Polderweg and Visserijweg have been added. Usage of the stops are plotted over time (figure 8.3). Visserijweg is barely used; only 3 industrial buildings are in use which are accessible within a 500m radius. Polderweg is used more often, and has more buildings within its reach (ca. 19), built mainly in 2017 and 2018 (Kadaster, 2019). Since the number of employees and month in which the companies started operation are unknown, a direct relationship cannot be identified.

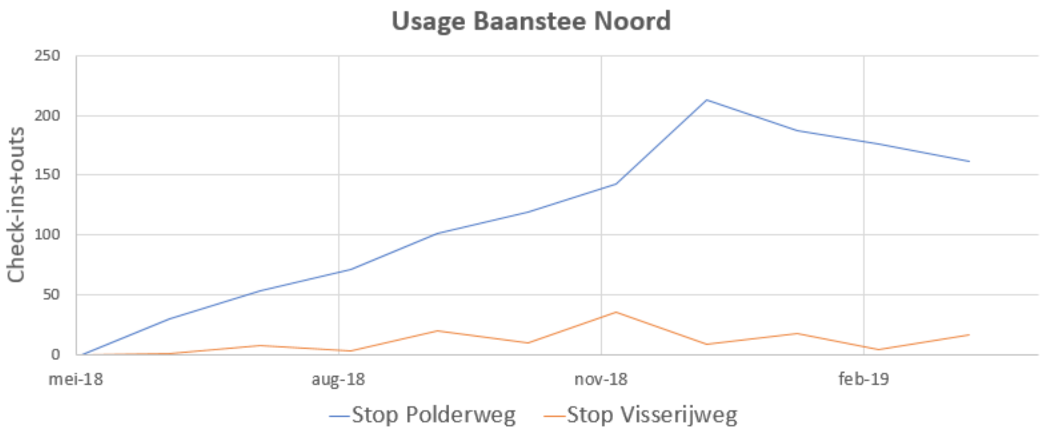


Figure 8.3: The usage of the stops Polderweg and Visserijweg (line 110) which are located in the newly developed business park Baanstee Noord (Purmerend).

The last example is the opening of P+R Meerstad and the operation of Q-link 5 to Meerstad (figure 8.4). The slope of the trendline for inhabitants is ca. 1.22; for households ca. 0.47; for the new stops in Meerstad ca. 0.13 and for P+R Meerstad ca. 11.29. Opposed to Broeckgouw, the growth of usage of the stops is far lower than the growth in households. The initial growth period of P+R Meerstad is ca. 6 to 7 months, from September 2017 to March 2018. On average 2.6 check-ins/outs per household are produced in the year 2018.

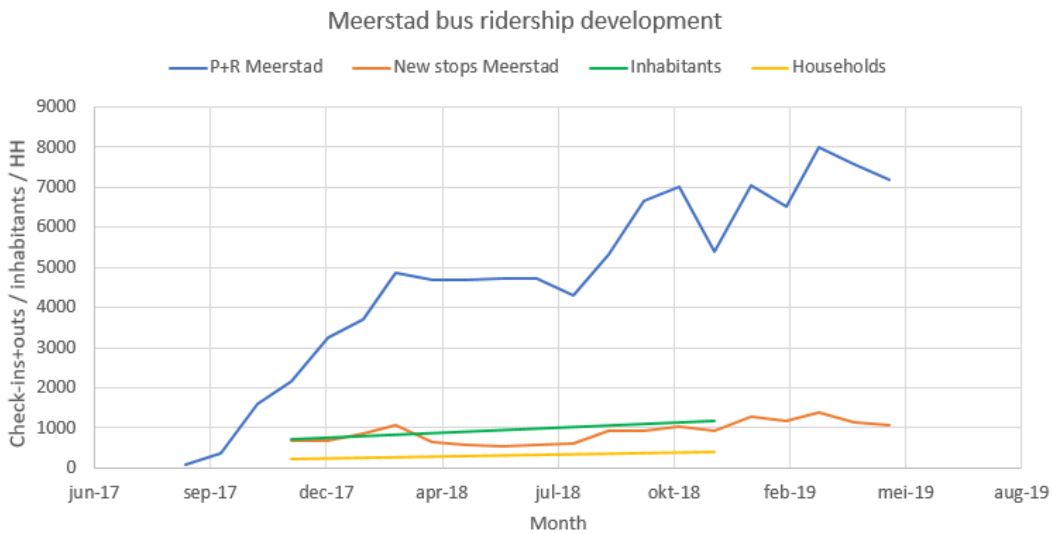


Figure 8.4: The usage of the stops in Meerstad (Groningen) and the usage of P+R Meerstad.

Interpretation
All in all, the results provide the following insights:

- There is no clear relation between number of check-ins/outs and inhabitants or households, in one case it has roughly the same slope as households, in a second the same slope as inhabitants and in a third case a very different slope to both.
- The amount of check-ins that can be expected is very dependent on the type of line and the type of neighborhood: Broeckgouw (which has a local bus service) has ca. 1 monthly check-in/out per household, while Weidevenne Noord (which has a R-net bus service) up to ca. 7 monthly check-ins/outs per household.
- When placing new stops, as in Broeckgouw, it takes ca. 4 months before usage is at a steady level in line with future growth; i.e. it takes 4 months for people to start using the bus stops in their travel routine. This is in slightly faster than the time period for usage of P+R Meerstad, with takes ca. 6 to 7 months until usage reaches its first equilibrium.
- For the business park Baanstee Noord, ca. 6 to 7 months are needed as build-up period.

Longer operating hours

The effect of longer operating hours is described by two characteristics: the characteristics of the main traveler in each hour block and the relative contribution of each hour block to the total daily ridership. This can be determined for Waterland over the years, for Voorne-Putten & Rozenburg only for 2019 and for Groningen-Drenthe no data on this level of detail is available. For VPR, lines 81 and 85 are excluded due to faulty data. The most recent available data is used: March, April, May and June 2019. The usage per product type varies over the concessions (figure 8.5, 8.6), students represent the largest share of users in VPR, while Waterland has more mixed usage. The results are split up in six sections: Night hours (00.00-04.59), wide morning peak (05.00-09.59), day (10.00-14.59), wide afternoon peak (15.00-18.59), early evening (19.00-20.59) and late evening (21.00-23.59); in accordance with industry standards.

Waterland	00.00-04.59	05.00-09.59	10.00-14.59	15.00-18.59	19.00-20.59	21.00-23.59
No product - adult	25%	21%	16%	21%	21%	22%
No product - anonymous	25%	11%	24%	18%	24%	22%
No product - child	0%	1%	1%	1%	1%	0%
No product - senior	1%	3%	10%	4%	5%	4%
No product - teenager	4%	6%	4%	3%	3%	3%
Other	0%	0%	0%	0%	0%	0%
Student	19%	18%	24%	19%	20%	22%
Subscription adult	18%	26%	10%	22%	19%	19%
Subscription anonymous	4%	5%	3%	5%	4%	4%
Subscription child	0%	0%	0%	0%	0%	0%
Subscription senior	0%	0%	1%	1%	0%	0%
Subscription teenager	3%	9%	8%	6%	3%	3%
total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Figure 8.5: Productshare per hour block Waterland. Colorscale is conditionally formatted per column. Weekdays only, for the period March-June 2019.

Voorne-Putten R.	00.00-04.59	05.00-09.59	10.00-14.59	15.00-18.59	19.00-20.59	21.00-23.59
No product - adult	16%	16%	12%	17%	16%	16%
No product - anonymous	26%	17%	20%	19%	22%	23%
No product - child	0%	1%	1%	1%	1%	0%
No product - senior	0%	3%	8%	4%	4%	2%
No product - teenager	4%	5%	6%	5%	4%	4%
Other	0%	0%	0%	0%	0%	0%
Student	44%	36%	38%	35%	37%	40%
Subscription adult	5%	12%	4%	11%	9%	7%
Subscription anonymous	2%	2%	1%	2%	2%	2%
Subscription child	0%	0%	0%	0%	0%	0%
Subscription senior	0%	1%	2%	1%	1%	1%
Subscription teenager	4%	8%	7%	6%	4%	4%
total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Figure 8.6: Productshare per hour block Voorne-Putten & Rozenburg. Colorscale is conditionally formatted per column. Line 81 and 85 are excluded. Weekdays only, for the period March-June 2019.

The product usage can also gain insight in the type of traveler during each type of day. A distinction is made between Weekday, Saturday and Sunday. Waterland and VPR (figures 8.7, 8.8) have more detailed data than Groningen-Drenthe (figure 8.9), but all show a significant difference in usage between Weekdays and Weekends. Between Saturdays and Sundays, less significant differences can be observed.

Waterland	*Weekdays*	*Saturday*	*Sundays*
No product - adult	20%	23%	21%
No product - anonymous	18%	34%	36%
No product - child	1%	2%	2%
No product - senior	5%	8%	8%
No product - teenager	4%	3%	3%
Other	0%	0%	0%
Student	20%	12%	11%
Subscription adult	20%	12%	13%
Subscription anonymous	4%	3%	3%
Subscription child	0%	0%	0%
Subscription senior	1%	1%	1%
Subscription teenager	7%	3%	3%
total	***100%***	***100%***	***100%***

Figure 8.7: Productshare per daytype Waterland

Voorne-Putten R.	*Weekdays*	*Saturday*	*Sundays*
No product - adult	15%	19%	21%
No product - anonymous	19%	31%	30%
No product - child	1%	2%	2%
No product - senior	5%	10%	8%
No product - teenager	5%	5%	6%
Other	0%	0%	0%
Student	37%	20%	20%
Subscription adult	9%	6%	5%
Subscription anonymous	2%	2%	2%
Subscription child	0%	0%	0%
Subscription senior	1%	2%	2%
Subscription teenager	7%	3%	4%
total	***100%***	***100%***	***100%***

Figure 8.8: Productshare per daytype Voorne-Putten & Rozenburg. Line 81 and 85 excluded.

Groningen-Drenthe	*Weekdays*	*Saturday*	*Sundays*
Subscription	12%	5%	5%
Student	51%	28%	33%
Smart card	33%	63%	58%
Ticket	4%	4%	4%
total	***100%***	***100%***	***100%***

Figure 8.9: Productshare per daytype Groningen-Drenthe. Only months March and April 2019 included.

Apart from determining who is using the bus services in which hours/on which days, the amount of use that can be expected is essential for ridership prediction.

Figures 8.10, 8.11 and 8.12 show the factor with which the ridership must be multiplied compared to the hour before. With this distribution, it can be estimated how many passengers can be expected when implementing longer operating hours. A distinction is made for four categories: Waterland line 110, city service Spijkenisse (line 84, 87 VPR), R-net lines in Waterland and R-net lines in VPR. For all lines holds that they do operate in the described hours.

The frequencies vary largely during the day, except for WL110, which operates 2x/h all day except late evenings. For Spijkenisse city, R-net Waterland and R-net VPR holds that the early morning frequency is 4x/h (until ca. 07.00, after which peak frequencies start), for WL110 this is 2x/h. Evening operations are as follows: WL110 1x/h after 22.00; Spijkenisse city 2x/h after 20.00; R-net Waterland 2x/h after ca. 21.00; R-net VPR 2x/h after ca. 21.00.

The four categories of lines in figures 8.10, 8.11 and 8.12 provide insight in both local as regional bus lines in both the Waterland and VPR concessions. During weekdays (Monday-Friday), the factors are rather consistent, with WL110 being the most out of line (figure 8.10). Saturdays and Sundays provide a larger spread in factors (figure 8.11, 8.12).

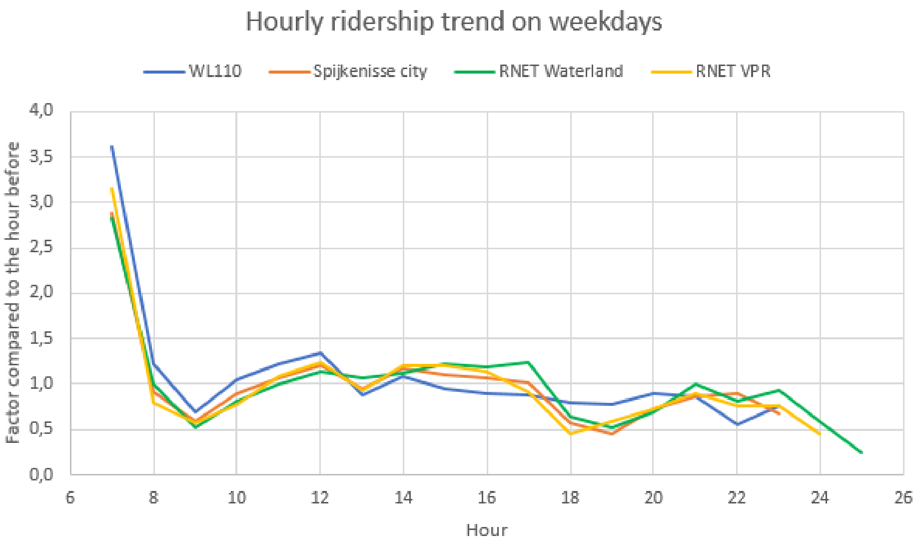


Figure 8.10: Hourly ridership trend weekdays. Note that frequencies vary per category.

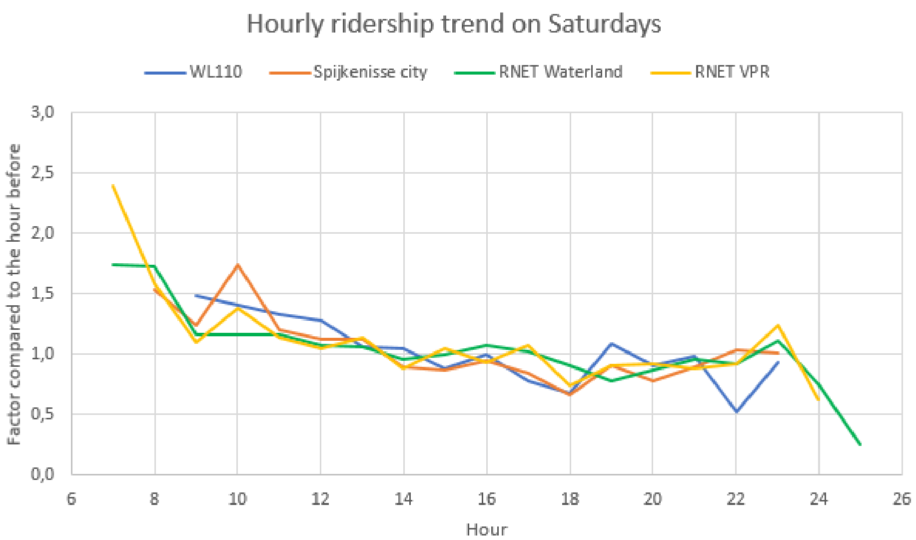


Figure 8.11: Hourly ridership trend on Saturdays

This data can be used to predict ridership when expanding the operating hours. An example: Increasing the operating hours of a city line from 20.59 to 23.59 on a weekday in a concession similar to Voorne-Putten & Rozenburg, would target mostly students and infrequent travelers (no product - adult and no product - anonymous) (figure 8.6). Judging by figure 8.10, hours 21, 22 and 23 have a ratio of respectively 0.85, 0.9 and 0.7. Assuming that ridership in the previously last hour block changes as well (since it is no longer the latest option), the ratios are linked to hour 19 and the ridership in hour 20 is recalculated by its ratio (0.75). If 1000 passengers use the bus service in hour 19 (19.00-19.59), 1000*0.75 = 750 users can be expected in hour 20; 750*0.85 = 638 in hour 21; 638*0.9 = 574 in hour 22 and 574*0.7 = 402 in hour 23. This only holds when LOS is not decreased significantly compared to the hour before.

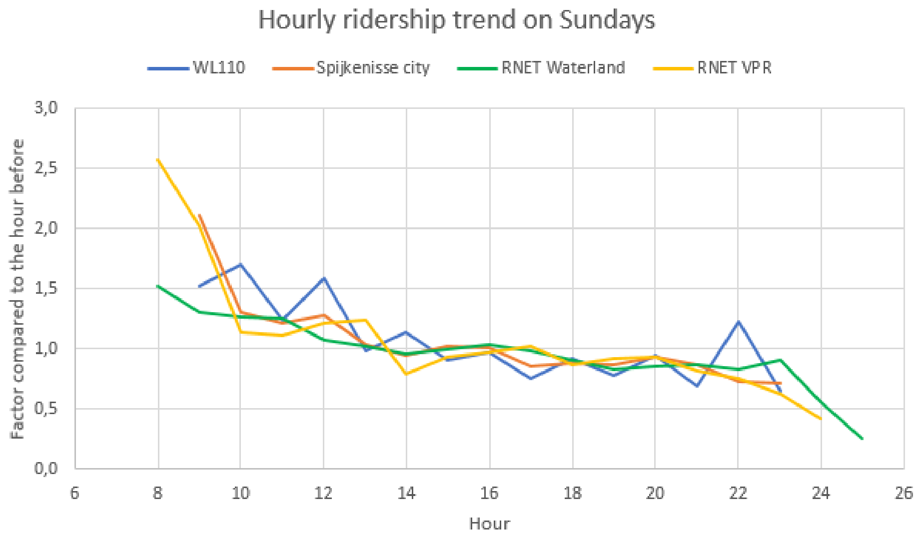


Figure 8.12: Hourly ridership trend on Sundays

Interpretation
For interpretation of the results, the same user group classification is used as before:

- Infrequent travelers (all 'No product' product types except teenagers)
- Commuters (Subscription adult)
- Scholars (No product - teenagers and Subscription teenagers)
- Students (Student product)

The night hours in Waterland are mostly used by students and infrequent travelers. In Waterland, adults are more present in the night hours, while students only take a third place. This is likely caused by Amsterdam, which is a touristic hot spot and is well known for its extensive nightlife. Waterland is therefore expected to be only representative for regions near large cities, for regional concessions VPR is likely more representative. In both concessions, the share of commuters decrease significantly during the day hours; they travel mostly in the peak hours, but also in the evening. Seniors on the other hand, prefer to travel during the day; not only in market share, but also in absolute numbers this block is the highest for seniors. In the evening, like the night, most travelers are students and infrequent travelers. In Waterland, the high amount of commuters in the evenings are remarkable compared to VPR; although this is likely to be caused by the city of Amsterdam.

The comparison between product type and type of day, infrequent travelers and seniors have a larger share in the weekends, than during the week. Also the No product - anonymous class is significantly higher in the weekends, in all regions. These are likely people with a social-recreational travel motive. Students and commuters are, as expected, lower in the weekends. Whereas the shares during the weekdays differ largely between Waterland and VPR, in the weekends the shares are very similar. Groningen-Drenthe has an even larger share of students than VPR. The high share of students might also explain the sensitivity to the free SOV for MBO students.

Shortly, the analysis of extension of operating hours provide the following insights:

- Waterland has a significantly larger share of commuters (subscription adult)(figure 8.7) than VPR (figure 8.8) and Groningen-Drenthe (figure 8.9).
- Buses in concession Groningen-Drenthe on weekdays are mostly used by students (51%).
- Judging by the product shares, in Waterland more choice travelers seem present and in Groningen-Drenthe more captives.
- There is hardly any difference in user type between Saturdays and Sundays (figures 8.7, 8.8, 8.9).
- During early night hours, infrequent travelers and students have the largest presence (over 85% in VPR and over 70% in Waterland).

- During late evening hours, again student and infrequent travelers have the largest presence and will be the most affected by the change in operating hours.

- Seniors have a larger share during off-peak hours and during the weekends. However, total passenger numbers are lower in off-peak hours and during weekends.

- Ridership trends per hour show the ratio that must be applied to the ridership of the previous hour to estimate ridership. The pattern is roughly the same for all types of lines, although in the weekends more variation is present.

Implementation period

This case study means to answer the question: How long does it take for ridership to reach a new equilibrium after the LOS changes? Two hypotheses come up with this questions. First, it being the amount of time after the change that is relevant. Expert opinion approximates two to three years, with the largest gains/losses in ridership in the first year (Expert interview F. van der Blij). Another hypothesis is that people are most likely to change their (travel) behavior when their routine changes. Routine changes can include a change in school, job, place of residence etc. While some of these can change all over the year, September is prone to be the most important one with the start of the new school/study year. Furthermore, in the summer holiday (July-August) PTO's have a summer schedule, often with lower frequencies. This means that even for people not changing jobs or residences, a change in routine. When in September the new school year starts, it is a moment where travel behavior changes are very prone to occur. Therefore, it is hypothesized that the main changes in ridership after a LOS change occur largely in/after the September month. What is seen in the results of Waterland is that the growth or decline in ridership after 15 months is often larger than after 3 months. Both growth factors have been calculated for all changes in August 2014, since the standard after a year has not been possible. This raises the question how long the growth period is. For Waterland, the following results are found (table 8.1).

Table 8.1: Ridership growth over time in Waterland. The ratio refers to the ratio of growth that has been reached in the first 3 months. I.e., the 21% growth of WL315 in the first three months is 64% of the growth it reaches after 15 months.

Case	LOS change	Day	3 months	15 months	Ratio
WL110	-3 min	Weekdays	xx	9%	unknown
WL315	peak -7 min, off-peak -3 min	Weekdays	21%	33%	0.64
WL312	-10 min	Saturdays	45%	57%	0.79
WL121	peak 2x >1x	Weekdays	-26%	-22%	1.18
WL103a	off-peak 2x >1x	Weekdays	-16%	-17%	0.94
WL314	off-peak 2x >4x	Weekdays	0%	8%	inf.
WL122	-7 min and peak 2x >1x	WE	-19%	-12%	1.58
WL312	4x fast iso 2x fast + 2x slow + peak 4x >6x	WE	0%	4%	inf.

An increase in ridership seems to grow further in the next 12 months, while a decrease in ridership seems to catch up and grow slightly in the next 12 months (though the number of data points is very limited). Since growth factors after 15 months are higher than after 3 months, this also implies that in Voorne-Putten & Rozenburg, the growth factors will further develop; since only results 3 months after the change could be calculated.

A more visual illustration is needed to obtain better understanding of the development of the growth factors over time. 4 examples are shown: WL121 (figure 8.13), WL103a (figure 8.14), WL103b (figure 8.15) and WL315 (figure 8.16).

WL121 shows the largest decrease in ridership in the first year and a recovery in the second year (figure 8.13). The decrease occurs almost immediately.

WL103a shows that the largest decrease occurs almost immediately; the ridership does not regrow after the summer trough. The year after sees a very small further decline.

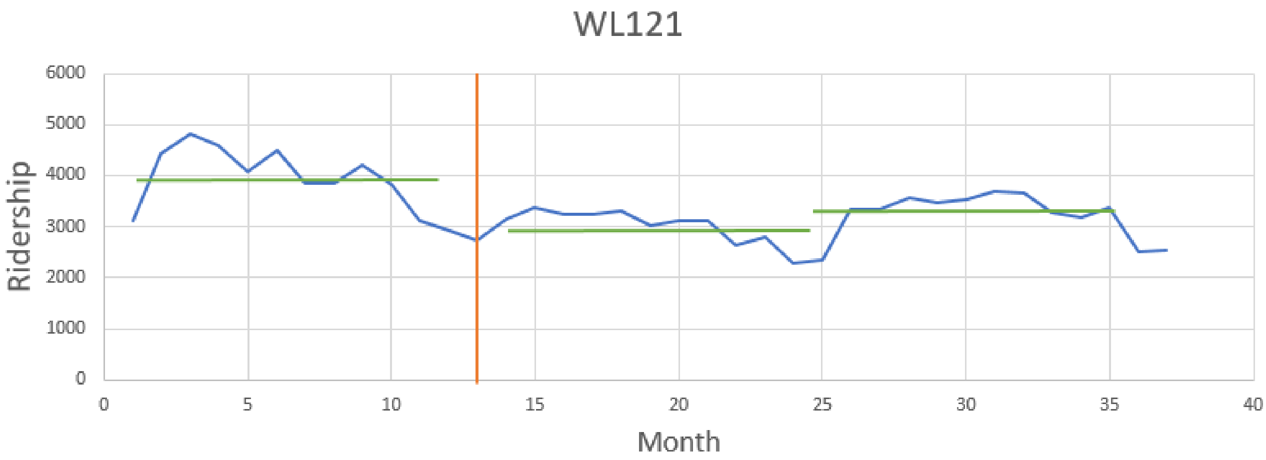


Figure 8.13: Ridership WL121 over time. The orange line marks the LOS change (peak 2x/h > 1x/h) and the green line the yearly average ridership.

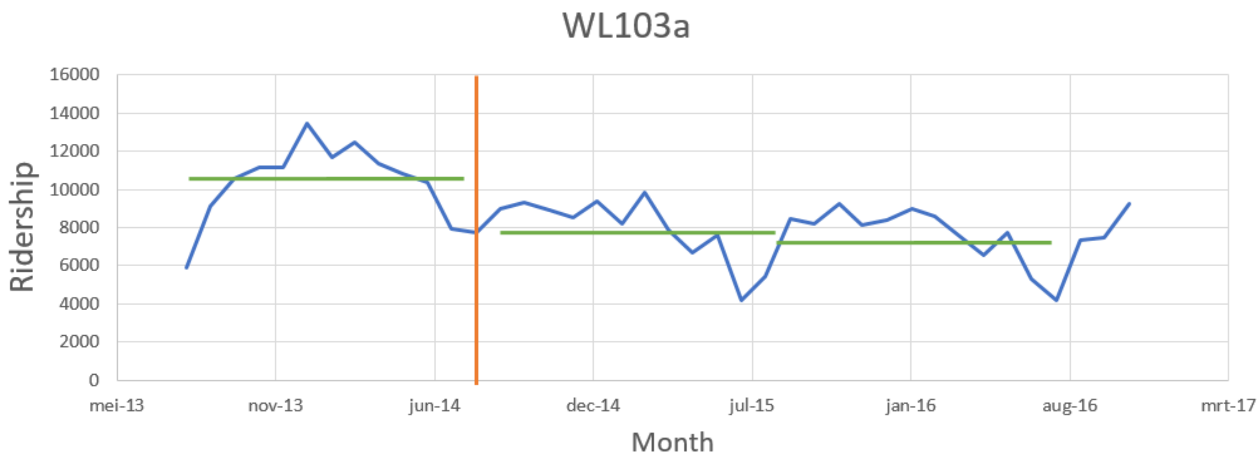


Figure 8.14: Ridership WL103a over time. The orange line marks the LOS change (off-peak 2x/h > 1x/h) and the green line the yearly average ridership.

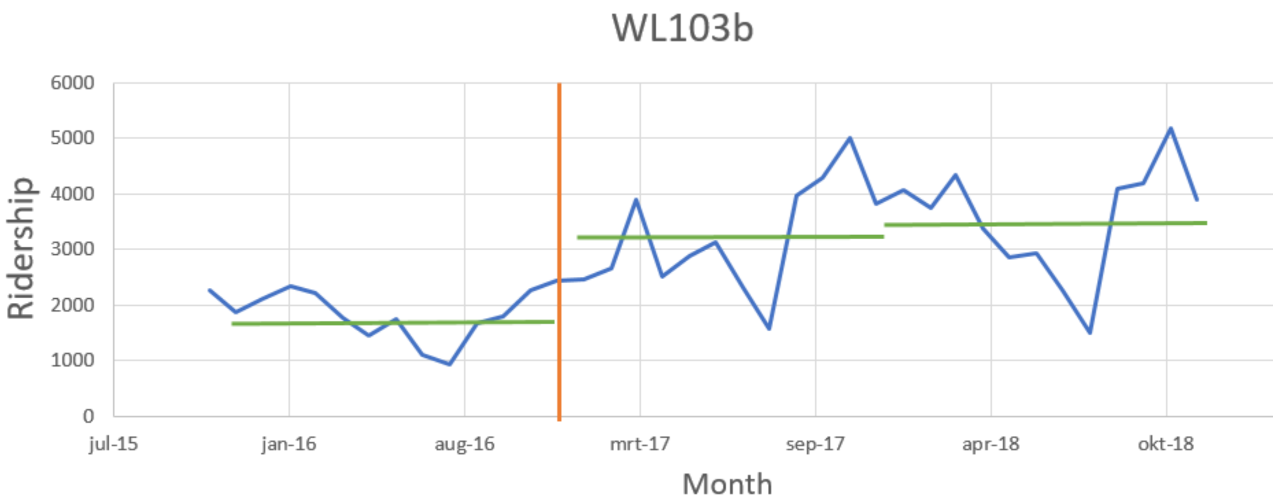


Figure 8.15: Ridership WL103b over time. The orange line marks the LOS change (IVT -10 min and price -1.50) and the green line the yearly average ridership. Note that the figures are not comparable to figure 8.14, since WL103b is based on only a section of the line.

WL103b (figure 8.15) shows that there is additional increase in the second year. However, the first November after the change, such as used in the analysis, the line is already equivalent to the November a year later.

WL315 (figure 8.16) shows again the largest increase in the first year, again a small further increase in the second year.

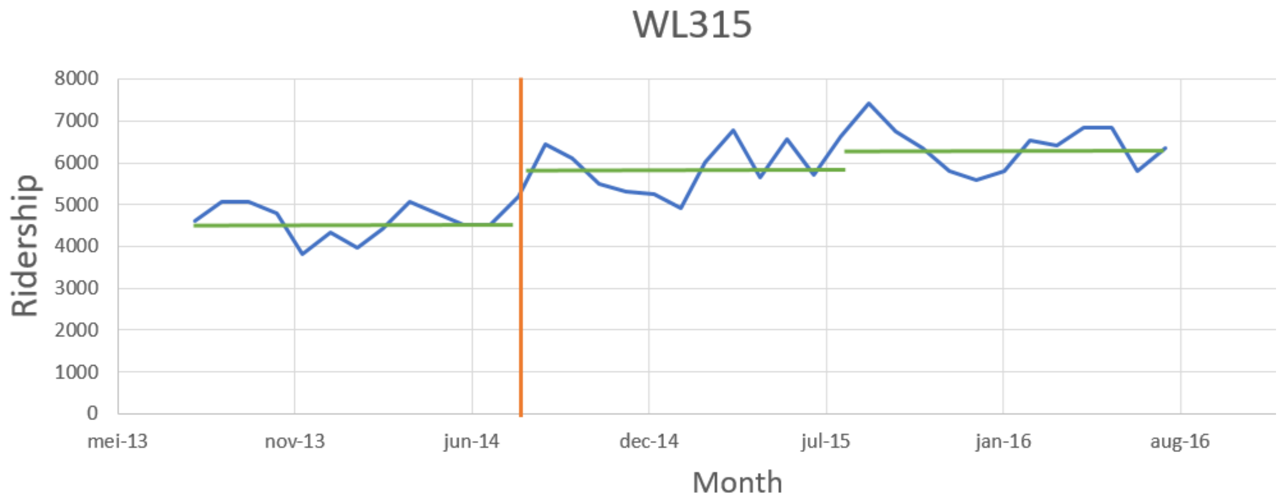


Figure 8.16: Ridership WL315 over time. The orange line marks the LOS change (IVT -7 min peak, -3 min off-peak) and the green line the yearly average ridership. Note the relative low seasonality, which is likely a consequence of tourism to Marken.

Interpretation
Table 8.1 shows that there is often a further development in ridership after 15 months, compared to 3 months after the LOS change. The ratios (the growth after 3 months / the growth after 15 months) show values above and below 1; implying that in some cases the line continuous to grow further and in some cases recovers.

The visual analysis of figures 8.13 to 8.16 shows that in the first year the most significant part of the growth has occurred and in the second year continuous moderately. For the lines with a decline in LOS (WL121 and WL103a) the decrease in ridership is sudden and almost immediate. In WL121 the line recovers slightly the year after, in WL103a the line loses slightly more users. The sudden decrease is in line with expert opinion (Expert interview F. van der Blij, Appendix A.1). On the other hand, the longer the time period of analysis, the larger the influence of non-LOS related factors, e.g. autonomous growth (or decline) and not all changes should be attributed to the LOS change. The analyses also show that the analysis only 3 months after the change might be a bit fast, (slight) additional growth can be expected. This is shown in table 8.1 and also implies that the results obtained for Voorne-Putten & Rozenburg might grow/decline more as time passes.

WL103b also shows that the large increase in ridership occurs in the first September after the change (figure 8.15), as hypothesized. WL103 is mainly used by scholars, such that the main change in behavior is indeed in September. WL315 also shows a significant increase in ridership starting each September (figure 8.16). This builds to the hypothesis of behavior change being most prominent when routine changes.

The main learnings of this analysis are:

- The largest part of the growth occurs within the first year after the change. In the second year there might be a small, further growth/decline, but it can also occur that a line recovers.
- Significant changes in ridership are seen starting each September. This might be related to most people changing their routines (and thus behavior) after the summer.

Schools
Within the concession Waterland, several high schools are located. By knowing the effect of scholars/students and schools on bus ridership, a better prediction of bus usage can be made.
First, three large schools in Waterland are evaluated. Hoorn is excluded in the analysis, due to the large amount of alternatives there are available, which are not present in the data sets. All stops near the schools are included, for all lines, based on November data. This means that the results are not limited to scholars/students only, but represent all users of those bus stops. For stop Technische School Edam, 2014 data has been removed due to erroneous data. For a 1:1 relation between students and check-ins, the line should be horizontal.

Since the ratio between check-ins and usage near the schools varies largely over the years (figure 8.17), no direct relation can be determined. If the bus stop usage would be 100% related to the number of students, only horizontal lines would be present; i.e. a constant ratio. For all three schools, the number of check-ins increases faster than the

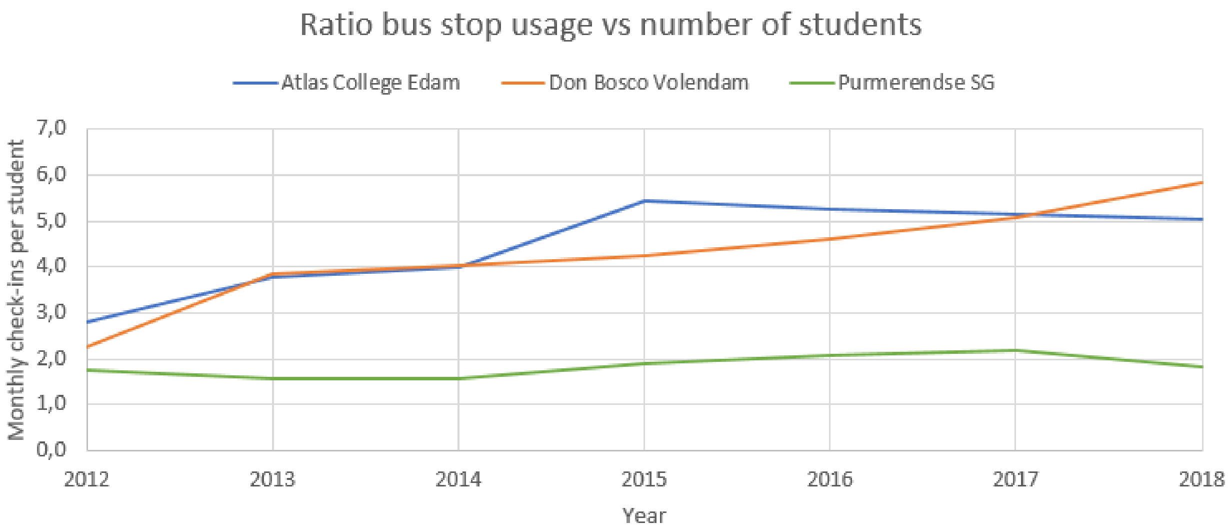


Figure 8.17: The ratio of monthly check-ins at nearby bus stops versus number of students. Based on the usage in Novembers of each year, all lines. Scholar data based on Dienst Uitvoering Onderwijs (DUO), 2019.

number of students; causing the monthly check-ins per student ratio to increase. No direct relation between number of students and bus ridership can be therefore be found. In all cases, the bus stops serve more purposes than only the schools, which might cause interference. Further insight can be gained by analysis of the dedicated school lines, of which line 614 in Waterland is the most prone example. This is a dedicated line for the schools in Hoorn. Again, large variability is shown (figure 8.18) and no direct relation between number of students and ridership is found; i.e. no constant ratio is found. Possibly scholars' mode choice are very sensitive to weather conditions, which are not accounted for.

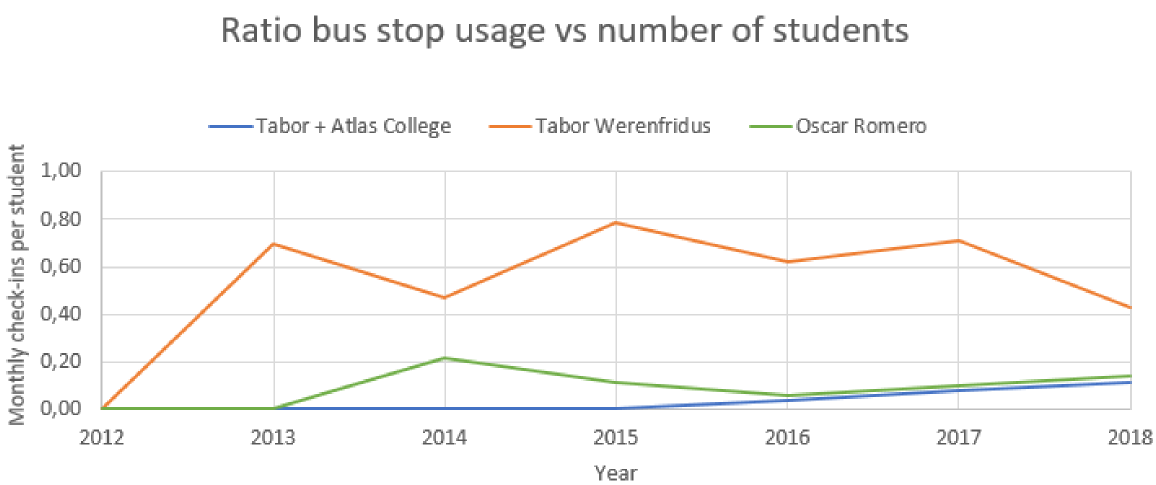


Figure 8.18: The ratio of monthly check-ins at nearby bus stops versus number of students for line 614 in Hoorn. Note that Tabor + Atlas is close to the station and accessible by numerous bus lines. Scholar data originates from Dienst Uitvoering Onderwijs (DUO) (2019).

Interpretation

The analysis per bus stop not showing any clear relations is possibly caused by the diffusion of data, since the stops can be used by anyone. Scholar lines might be very weather sensitive and other options within the PT network exist. In addition, the number of students can grow or decline, but this does not provide information about the change in amount of students outside of cycling range. The analysis only works if the same ratio of mode choices is assumed.

The main findings of this case are:

- The usage of bus stops and scholar lines cannot be directly related to number of students, at least not in a dense network as Waterland.

Airports

Within the concession Groningen-Drenthe an airport is present. The usage of the bus lines to/from the airport shows a clear relation with the passenger numbers of the airport (figure 8.19); the seasonal peaks in the airport passengers is similar to the peaks in the bus usage. OV-bureau Groningen Drenthe and Qbuzz decided to start operating a dedicated airport liner 100 to the airport in September 2016. Before the airport liner was implemented and only the city bus provided access, the bus was barely used with a ridership below 50 a month. A significant increase has been caused by implementing the dedicated airport liner (figure 8.19). The city bus line takes ca. 38 min to reach Groningen Airport Eelde; while the dedicated airport liner takes ca. 20 minutes. Usage of the city bus grew as well, since the airport liner often only provides a connection to departing flights, such that the arriving passengers have to use the city bus. It is already in the third month of operating that the usage of the airport liner is on its base level.

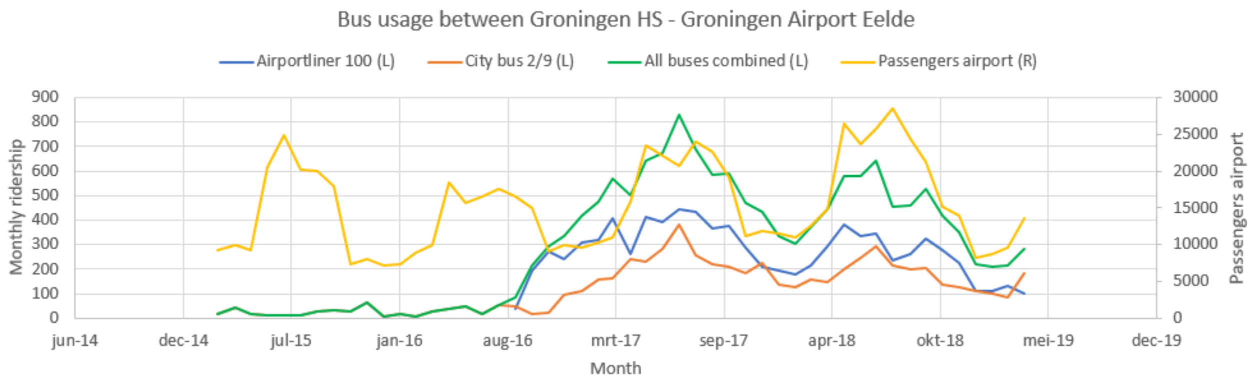


Figure 8.19: Usage of the bus lines to/from Groningen Airport Eelde. Airport passengers based on Centraal Bureau voor de Statistiek - Statline, 2019).

Interpretation

A clear increase in usage after implementation of the airport liner can be seen. Marketing might have played a role; the dedicated airport liners have a special livery and are therefore very recognizable as well. Remarkably, the second year of operation the usage of the bus to/from the airport decreases, while flight passenger numbers increase. Possibly this has to do with the type of flights that have been operated; i.e. leisure versus business and therefore a difference in mode preference. However, this has not been evaluated further.

The main findings of this case are:

- The dedicated airport liners significantly increased the number of passengers traveling by bus.
- The airport liner has a start-up phase of ca. 2 to 3 months.

New community service bus line

Within the concession Waterland, a new community service bus (buurtbus) line has been started: line 419, initially between Purmerend, Monnickendam, Uitdam and Broek in Waterland. With a very low frequency of once per 2h20m, operation started in July 2015 with an 8-person capacity minivan (figure 8.21).

Figure 8.20: Operating vehicle community service bus 419; a 8-person minivan.

This new line enables insight in which users start using the line first and how fast the line grows. Already in October 2015, the line services 86 passengers, being above the monthly average of 2016 (85), i.e. after 3 months the line is nearing its regular usage level (figure 8.21). Also noticeable is the first month of operation being more popular than the second and the third. The sharp increase in ridership from December 2016 onward (month 18 in figure 8.21) is caused by LOS changes. The route has been changed, no longer servicing Purmerend, but providing better service to Uitdam and Broek in Waterland and a frequency increase to once every 1h30m. Comparing October 2016 to October 2017, only the line section which is operated both before and after the route change, a ridership increase of 464% is revealed. If the scholars (both with and without product) are removed, there is still an increase of 179%. The initial users of the community service bus or mainly non-product users, i.e. infrequent travelers (figure 8.22).

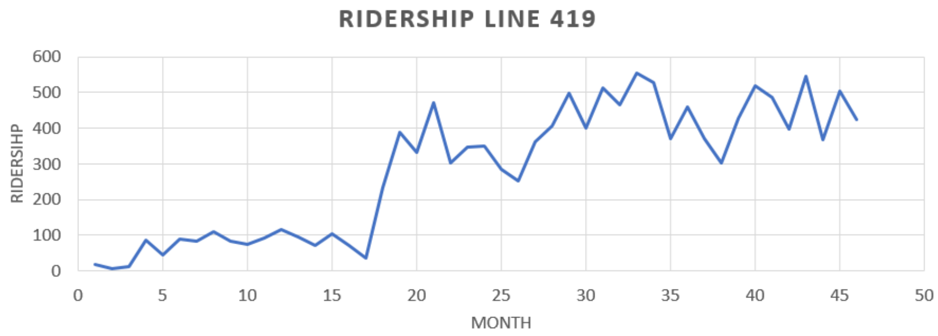


Figure 8.21: Monthly ridership line 419. Note the route and frequency changes in December 2016 cause a significant increase in ridership.

Weekdays+Saturdays	Jul 15	Aug 15	Sep 15	Oct 15	Nov 15	Dec 15	Jan 16	Feb 16	Mar 16	Apr 16	May 16	Jun 16	Jul 16	Aug 16	Sep 16	Oct 16	Noc 16	Dec 16	Jan 17	Feb 17
No product - adult	3	3	4	17	8	11	11	17	7	16	15	19	18	14	10	13	10	22	46	33
No product - anonymous	4	1	8	55	30	49	37	47	30	32	73	68	56	50	63	40	16	37	72	67
No product - child		2		2		6	2	5	11	2	2	3		4				9	11	10
No product - senior	9	5	2	11	9	21	26	23	17	17	20	35	42	39	33	16	13	32	37	39
No product - teenager			3	8	3	3	18	20	11	17	11	14	4	3	7	5	1	42	111	77
Other					1	1							1							
Student				1	4	2	3	9	5				4	5	1		1	4	18	12
Subscription adult				5	3	14	12	14	13	10	1	6		5	3	3	3	12	16	12
Subscription anonymous	4							4	3	1		3	4	1		2		10	12	7
Subscription child								2											1	1
Subscription senior	2			4	4		8	10	5	12	9	11	21	14	7	20	13	16	12	8
Subscription teenager				3		2	6	2	1		2	4			4	8	4	80	87	88
total	22	11	17	106	62	109	123	153	103	107	133	163	150	135	128	107	61	264	423	354
share of subscription:	27%	0%	0%	12%	18%	17%	24%	27%	26%	21%	9%	15%	19%	19%	12%	31%	34%	46%	35%	36%

Figure 8.22: Monthly ridership line 419 by product type. Note the route and frequency change in December 2016 causes a significant increase in ridership, largely caused by scholars.

Lastly, the ratio of usage between Saturdays and Weekdays is described, since a implementing/cancelling the community service bus on Saturdays a possible measure to be taken. The results show the Saturday usage to be 90% of an average weekday before the LOS change of line 419 and 56%. after the LOS change (table 8.2). When calculating the shares of the Saturdays, the number of weekdays and Saturdays each year is taken into account.

Table 8.2: Community service bus usage weekdays vs Saturdays. Ridership numbers represent yearly ridership in 2017.

Line	Ridership weekdays	Ridership Saturdays	Ratio Saturday
413	6463	831	64%
416	9555	831	44%
419 (before LOS change)*	1249	495	56%
419 (after LOS change)	4393	223	90%

*Since the LOS change took place in December 2016, the ridership from December 2015 to November 2016 has been used.

Interpretation

The first month being more popular than the second and the third is possibly caused by curious travelers. The LOS increase in December 2016 caused a huge increase in ridership. This is partly caused by the route change of line 103, which was used by scholars traveling between Ilpendam and Monnickendam (Personal communication transport engineer Waterland). After removing all scholars from the ridership after the change, there is still an increase of 179%; showing that indeed a large part of the growth is caused by the scholars, but there still is a significant increase in ridership due to the LOS improvements. The Saturday usage is dependent on the type of community service bus line. When it has value for scholars, students and/or commuters (like the 413, 416 and 419 after LOS change), it is around 50%. Line 419 before the LOS change had a very low frequency and inefficient routing, such that it (barely) had value for those groups. This shows, by a Saturday usage of ca. 90% compared to the weekdays. The effect implementing bus service on Saturdays is thus dependent on the characteristics of the line. This information is valuable if adding Saturday service of a community service bus is considered.

The main findings of this case are:

itemsep0emThe early users of the new community service bus line are infrequent travelers (figure 8.22). In the 4th month of operation, the line is roughly at its equilibrium (figure 8.21). I.e., after three months the main growth has occurred and the year after a small further growth can be observed. A level-of-service improvement can have a great effect on ridership; even though this is also largely caused by low passenger numbers. Major growth can occur if it has a function for frequent travelers such as scholars. Saturday usage is ca. 40%-60% of weekday usage when it has value for commuters/students/scholars (table 8.2). When it does not have value for those user groups, the relative usage is much more comparable (ca. 90%).

8.2. In-depth analysis of specific cases conclusions

For urban development, no direct relation between number of households or inhabitants and ridership can be found. The four cases presented can however help as substantiate ridership prediction. Early morning / late evening hours are mainly used by infrequent travelers and students. Hourly trends for four types of lines have been analyzed, such that the ratios can be used to predict ridership in when the operating hours are extended/shortened. Most of the ridership change after LOS changes is already in the first year, however it takes until the second year until new stability is reached. No direct relation between usage of bus stops near schools or usage of scholar lines and the number of students at schools is identified. The implementation of a dedicated airport shuttle increases bus usage to/from Groningen Airport significantly. A new community service bus line is used mainly by infrequent travelers. The Saturday usage can be predicted as ratio of the weekday usage and is dependent on the function of the line for the users.

As the validation of the CSSE in Chapter 7 has shown, the CSSE is not able to provide ridership prediction for the specific cases treated in this chapter. Whereas the CSSE can predict up to 75% of the measures as mentioned in the validation, with addition of these specific cases this now grows to >90%. With the addition of the specific cases, the flow chart of the data analysis and model development can be expanded (figure 8.23). This concludes the results of this thesis, which will be discussed in the next chapter: Discussion.

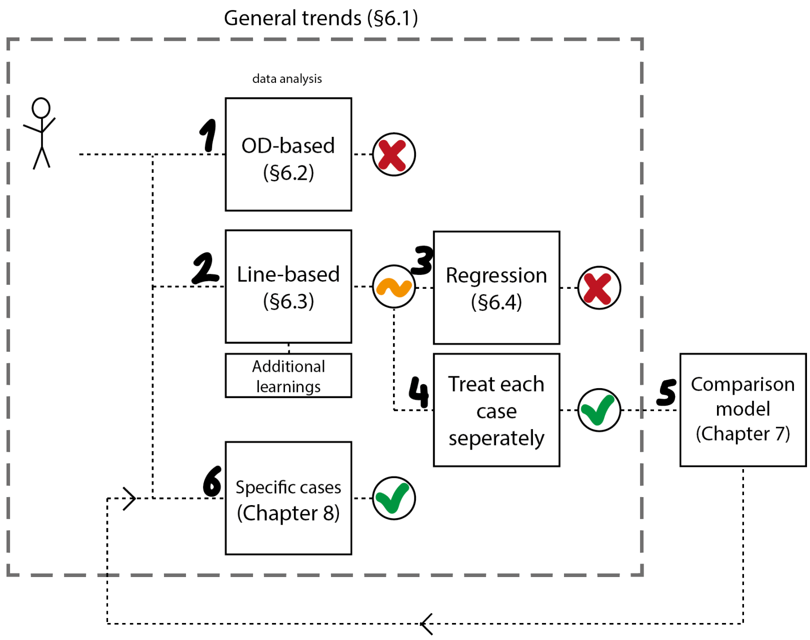


Figure 8.23: Flow chart of how the data analysis results lead to the model design and how the specific cases add to the knowledge.

9 Discussion

Summary: First the approach and reliability of the case study results are discussed. The consequences of the methodological choices are described, as well as reliability of the data. Then the results are discussed further and linked with literature (section 9.2). Sensitivity to month of analysis and autonomous changes shows that there can be a large variation in ridership changes, dependent on the month chosen. Furthermore it shows that lines without changes can have ca. |10%| ridership variation. Next the impact of the results and interpretation is described: How do the results impact the scientific understanding of the subject, how do the results impact EBS and how useful is the model to them. Whereas the first three sections all build to each other, the last two sections are more stand alone. The outlook is described (section 9.4); what do results imply and should be further researched? A reflection on this thesis and the choices made during the research is presented in section 9.5.

The discussion is structured in 5 sections (figure 9.1). To develop an understanding of the significance of the results, first the data and methodology are discussed. Then the analysis results and model, as shown in Chapter 6, 7, 8, are discussed and compared with literature. The results are put further into perspective by connecting them to related disciplines and an indication on sensitivity. Thirdly, the impact of the results and their interpretation is described. The outlook is described, in which those results that are indicative, but not conclusive are discussed. In the reflection, the choices made in the research are evaluated and discussed how the choices would be made differently with the gained knowledge.

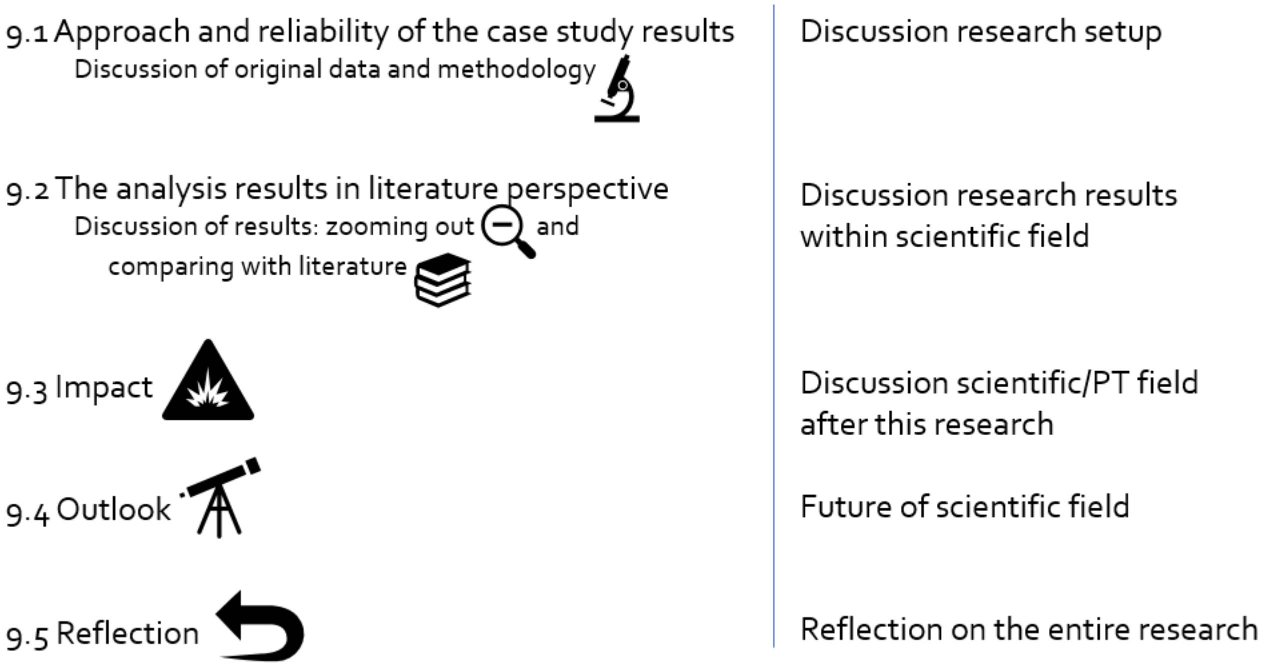


Figure 9.1: Overview of the discussion. Symbols originate from Microsoft Office.

9.1. Approach and reliability of the case study results

This section discusses the input data and consequences of the methodological choices, to gain insight in the reliability of the case study results. The input data for the analysis is based on processed smart card data, which have been further cleaned in this research. The usage of smart card based data has implications on the results. First, payment by smart card is not the only option, buying tickets at the driver is still possible. Therefore, it only captures part of the passengers (Pelletier et al., 2011). Dependent on the year and concession, ca. 85% to 97% of the passengers are registered in the smart card system (table 6.2). Despite this limitation, it offers an enormous amount of data. A lot of insights on behavior of passengers can be obtained by analyzing this data. Smart cards generate large quantities of complex data, such that cleaning the data is essential (Pelletier et al., 2011). This is partly done by the systems processing the smart card data; despite further cleaning is necessary. One of the choices made in the cleaning process is to exclude all stops which are not serviced by the line. However, in reality it can occur that a certain line continues after reaching its final destination and passengers stay put. This data is then removed (since its destination is not on the line), but in fact the passenger is using the line as intended.

It is assumed that all data extracted from the systems (Zight) is correct. This is not always the case. One example was seen near Rockanje (VPR), where bus stop Boomweg, a rural bus stop with only a few houses in its vicinity, had thousands of monthly users. After consulting the transport engineer of the concession, it is suspected and assumed that data was linked to the incorrect bus stop. Rockanje data has therefore been excluded from the analysis. Another issue is missing check-ins/outs when smart card software or hardware is not correctly working. This often means that smart card transactions are not possible, i.e. passengers are not registered and ridership appears lower than reality. When ridership or frequency is low, the effect is easily observed and can be compensated for/excluded from the analysis. However, with large frequencies and usage, data issues in a single bus are lost, masked by the large numbers. If unreliable or unrealistic data is found/suspected, it is not used in any analysis. Despite, it cannot be guaranteed that all faulty data is removed. Furthermore, frequency per line per bus stop was found to be incorrect in the data. This has manually been corrected, but limits the possibilities with the frequency analysis per OD-pair. It is recommended to EBS to improve the data storage in the systems such that it is correct and complete at all times. Furthermore, the same bus stop names should be used in all systems.

For the data analysis, two essential choices have been made: using MIPOV-format (aggregated) smart card data and using a before-after study as method. The use of MIPOV-format smart card data means loss of detail on the one hand; i.e. an individual traveler is no longer traceable and transfers cannot be seen. The data only shows part of the journey. A transfer to another bus or other mode is untraceable. Furthermore, the chain is as strong as the weakest link, so a frequency increase of a bus line is only experienced as a frequency increase by the passenger if its transfer also has the higher frequency. E.g. in case of a bus having a frequency of 4x/h, connecting to a train with a frequency of 2x/h, for the total journey only a frequency of 2x/h is provided. However, the advantage and main reason to use it, is that the data is (pre)cleaned, large amounts of quantities can be handled and data is available over a much longer range of time and for multiple concessions.

Using a before-after study as method of analysis brings a set of advantages and disadvantages to the table. A before-after study is the only objective method to measure the success of a forecast (Ortuzar and Willumsen, 2011). However, the method is blindsided, since it only describes the behavior of bus passengers and not of the users of other modes. Furthermore, it is a numbers-only analysis, in which motives for behavior change do not come to the surface. On the other hand, it is a very efficient method and is easily use-able for developing elasticities. In addition, it gives unbiased results based on recent data; which has been one of the main purposes of this thesis: no longer relying on expert opinions and (ancient, foreign) elasticities, but actually analyzing what effects of LOS changes are in the current Dutch bus networks. The methodology behind a research can be essential in interpreting the results. Some researches focus on the effect of the modal split and assume in that sense that there is only interchange of users between the modes (sometimes even only car vs public transport), while a changed LOS level or network can also lead to a decrease or increase in total trips made. This is also one of the limitations of the before-after study approach; only the total change in ridership is seen, but not whether this is caused by more/less total trips, a shift in mode choice or a shift in trip assignment (same mode, different route).

For an analysis per line, the main limitation has been the lack of data suitable for the cases. Only isolated line (-sections) are used for this; and those with changing level-of-service are scarce. Eventually data from 3 concessions has been gathered, though often limited in amount and level of detail. The methodology to extract elasticities varies, due to data limitations. This means that in some cases full lines are analyzed, sometimes only line section or clusters. Each with the goal to isolate the LOS change as much as possible. Therefore no distinction is made between the three, but one must keep in mind that the results are dependent on the (reasoned) choice made. Furthermore, comparability of the data is not 100%, since Groningen-Drenthe has no data per hour and VPR has a larger uncertainty and different time period. The usage of the three different concessions makes that it is likely that the outcomes can be generalized for all Dutch concessions of regional bus transport. City bus transport, where more interaction with trams and metros exist, is likely less comparable.

9.2. The analysis results in literature perspective

This section describes the discussion of the results and places them in perspective with relation to literature. First the data analysis results are discussed, then the developed model and finally the specific cases. A next step is to connect the results to related disciplines. A last subsection present a perspective on sensitivity by analyzing the effect of the month used for analysis and provides an overview of the range of autonomous growths that are present in Dutch bus public transportation.

The data analysis results - elasticities

An analysis of ridership per OD-pair shows a large variability. Despite the R^2 of the analyses per OD-pair are very low, it does show a trend in the hypothesized direction. A perfect fit would not be expected, since it depicts the travel behavior of persons, who not always show rational, predictable behavior. Oostra (2004) also finds a very low R^2 when fitting an elasticity model through survey data. He suggests this is caused by distortion of data by factors not included in the model. This is also a possibility for this research; i.e. there are many factors which can influence travel behavior. It is unlikely that all factors are or can be accounted for. Regarding the travel time elasticity, the question arises whether changes in travel time are significant enough to be of effect. Bakker (1979) describes examples of cases where the growth was actually in line with the growth predicted in the Effov tables; classifying the change in travel time by the terms "exceptionally spectacular decrease in travel time", thought not providing any quantities; suggesting that changes must be of sufficient quantity. The R^2 of the travel time elasticity improves when changes in travel time <3 minutes are not included, but is still insufficient. Furthermore, it can be questioned whether the case studies are representative and results can be generalized. The results per OD-pair are based on data from Waterland only. Waterland is a rather unique concession, in which the buses are able to compete with the train and car. It can be hypothesized that LOS changes do not show a clear effect on ridership, since there is not much to win by better competing against other modes. At the same time, the public transport network in The Netherlands is rather extensive, so network effects are present in all concessions. The two lines from Groningen-Drenthe analyzed per OD-pair indicated the same issues as the Waterland data. The OD-based approach is therefore likely to be unsuitable, regardless of the region.

The line-based analysis results in growth factors and elasticities. Resulting growths are not always fully in line with analyses by transport operators, since operators often analyze full lines, while this research means to isolate the LOS changes. Since only isolated sections are analyzed, one could consider this cherry picking; opposed to the OD-based analysis in which all ODs in the full concession have been included. This is possibly one of the reasons why the results are more in line with the hypothesis. The elasticities found in this thesis are compared to elasticities found in literature (see Chapter 6). However, it should be discussed why literature, expert opinions and analysis results differ. During the expert meeting, experts have been asked to predict ridership of all data points without providing them with context details. Their estimation is thus not necessarily fully compatible with the data analysis results. The difference between expert estimation and data analysis results can possibly lay in the context of the lines. The ranges of elasticities found in this research are much larger than ranges acknowledged by literature (figures 6.8, 6.12). Also the elasticities from the expert meeting have a much larger range than literature. Nevertheless, mainly for IVT elasticity the difference in range with the data analysis results is still large. Most IVT elasticities found in this thesis are significantly higher than literature. Most frequency elasticities fall within the range as estimated by experts and what is found in the literature study (Chapter 2). Regarding the latter, on the one hand this argues for the reliability of the results. At the same time, the range of frequency elasticities that this thesis shows is already the full range of what is known in literature. I.e. the variability that seems present over a whole range of researches with different approaches, cases, methodologies seems to be present here in a single research. Five reasons are hypothesized to be the cause of the mismatch of the elasticities/growth factors with literature:

1. Literature is often foreign based and might not be based on comparable cases, data and/or methodology. Time period of analysis is influencing the magnitude of the elasticity (MuConsult B.V., 2015). Elasticities in The Netherlands are expected to be higher, due to high share of bicycle as mode, which makes mode substitution easier for those dependent on public transport (Nijkamp and Pepping, 1998).
2. The mental effect of (eliminating) detours when lowering IVT can improve ridership as well (Expert interview F. van der Blij). For frequency, a similar mental effect can be reached. If the frequency is sufficiently high, one does no longer have to plan a trip and this comfort might add additional ridership.
3. Some of the elasticities in the results do have context factors which can explain part of the growth.

4. Whether the change in IVT or frequency is experienced as relevant is also dependent on car travel time and bicycle travel time and the availability to these alternatives (MuConsult B.V., 2015).
5. The definition of elasticity should be adjusted to magnitude, which it is not. E.g., IVT from 4 minutes to 2 minutes with X% more ridership has the same elasticity as an IVT from 60 to 30 minutes with the same amount of X% additional ridership. Obviously, for passengers there is a large difference between the two (Expert interview EBS). The same holds for frequency, a relative change from 1x/h to 2x/h is equal to 2x/h to 4x/h, but for example the experienced waiting time is completely different. Linear relations should likely not be expected.

Whether literature research might be comparable to this research (item 1) will be discussed further. It is acknowledged by MuConsult B.V. (2015) that there is a lack of recent, empirical studies to elasticities in The Netherlands. Almost all results are foreign (often UK based), which can deviate in magnitude from elasticities in the Dutch PT environment (De Beer, 2011). Remarkably, most prevalent (international) literature on elasticities, such as Balcombe et al. (2004) or MuConsult B.V. (2015), consists of literature studies, or even literature studies of literature studies. Details, side notes and remarks of the original study get easily lost. Evaluating all original literature is unrealistic, but to provide real insight in the elasticities from literature, it seems relevant to evaluate a selection of the actual researches on which the literature studies are based.

All IVT elasticity studies used by MuConsult B.V. (2015) are literature studies. One of those leads to Koonce et al. (2006). They apply a very simple methodology: the total change in ridership of a set of adapted lines (after 6 years) is related to the total change in vehicle hours allocated to the lines. Of the entire data set, one single value is determined, which also explains the lack of (understanding of) ranges. MuConsult B.V. (2015) refers for Dutch elasticity values mainly to De Beer et al. (2011), which is based on the author's own Bachelors thesis: De Beer (2011). He describes the methodologies on which the literature elasticities are based. For travel time elasticity, all international studies are either based on 'unknown methodology' (4x), 'meta analysis' (1x) and 'cross sectional analysis' (1x); the Dutch literature is 'model' based. For frequency elasticity, the international literature is based on 'unknown methodology', 'meta analysis' and 'time series'; the Dutch literature 'models' and 'stated preference' (surveys). One of the seemingly most relevant elasticities, referred to by both De Beer (2011) and Balcombe et al. (2004), based on a frequency increase from 4x/h to 6x/h (Catoe, 1998; though untraceable), is referred to as 'telephone interviews' and seems therefore of an incomparable methodology. Stanley (1998), referred to by both De Beer (2011) and Balcombe et al. (2004), uses an aggregated approach in which the ridership changes for a full region is determined and linked to LOS and non-LOS changes by use of expert interviews from the regions. Elasticities of two of those regions have then separately been adopted by Balcombe et al. (2004). One of those regions is Los Angeles and 21 nearby cities, which has all been translated into a single elasticity. This would be somewhat similar to translating the full concession Waterland added with the city of Amsterdam, to a single ridership growth factor. The elasticity is calculated by simple dividing the total increase in ridership over a few years time by the increase in total service hours. Other factors which could possibly explain growth are mentioned, but not compensated for in the elasticity. The level-of-detail is thus completely different and no sense of behavior and variation of behavior on individual lines is known. Furthermore, the factors which could also explain growth are completely lost in the further literature studies. Above mentioned papers and the methodology overview by De Beer (2011) shows that elasticity studies are mainly all referring to each other and ancient research; and based on a variety of methodologies with a remarkable absence of empirical studies; potentially explaining differences with findings of the empirical data analysis presented in this thesis. The lack of these empirical data analyses might be caused by the deficit of ridership data in the past; performance of empirical studies has become easier since the introduction of smart cards (Van Oort et al., 2015) and should be promoted for future research.

Results from this research also raise the question how it is possible that scientifically accepted elasticities exist, while this has shown to be difficult in this thesis. It is often acknowledged that elasticities differ depending on location, time period (long vs short-term), peak vs off-peak, etc., but rarely to the range and variation within a single research. E.g. Litman (2004) states that elasticities should be given in ranges, not in averages. However he makes the statement based on the large ranges in literature, not the large ranges within a single research. This is something that should be recognized and applied.

Already in 1998, Nijkamp and Pepping (1998) recognizes the large variability in price elasticities. Nijkamp and Pepping (1998) identifies clear differences between modelling methods, as well as country, number of competing modes and the type of data used as factors of influence on the size of the elasticity. It is likely that the same factors hold for LOS-elasticities as well. Van Wee and Banister (2016) describes the difficulty of isolating individual variables in transport engineering. This is also something stumbled upon in this thesis. It might not only be context factors, but also the choices made in the modelling method and the isolation of the variables which lead to differences in elasticities between literature.

The regression results are only indicative, but the results imply that a model can be developed if the data set would be sufficiently large. However, the question would still be what the fit of the model would be. In the line-based analysis there is less a-typical behavior compared to the OD-based analysis. A larger R^2 is therefore expected, which is also shown in the (indicative) results. Further regression results can also be used to update the developed model, since the selection parameters could be adjusted to those variables being significant in the regression analysis.

The model
The line-based analysis results have been used to develop a model suitable for operation in a tender environment. The three known models as presented in table 3.7 imply the ability of predicting the ridership after a LOS change. This research has shown that this prediction is far from straightforward. In Chapter 6, the outcomes of the line-based data analysis have been compared to the outcome of the three models, in which large deviations could be seen. That can partly be explained by the context of the results, but also the question arises how accurate and suitable those models actually are.

Conceptually, comparability with Van Goeverden and Van den Heuvel (1993) is limited, since their model is based on data from both car and public transport and refers to a modal share. This research has only observed and analyzed the behavior of bus passengers and is in that sense blindsided; behavior of the car users is unknown. Furthermore, Van Goeverden and Van den Heuvel (1993) is based on national data (instead of regional), is only based on trips >10km and the public transportation mode is a mix of BTM and train; whereas this research has no limit on the trip distance and uses only bus ridership as input data. Furthermore, Van Goeverden and Van den Heuvel (1993) only describes the growth caused by a shift in mode choice. It therefore assumes that the total demand for transport does not change, which might not be true. Therefore, the growth or decline in ridership would be even higher than the growth/decline calculated by Van Goeverden and Van den Heuvel (1993). Since Van Goeverden and Van den Heuvel (1993) uses national survey data (it is a revealed preference survey study, not an empirical study), it has an enormous data set compared to this thesis. A manual best fit has been applied to obtain model parameters.

The Effov tables are based on research from AGV (Adviesgroep voor Verkeer en Vervoer) (Bakker, 1979), however the original research and methodology has not been found. For both the Effov tables and the VF model from Van Goeverden and Van den Heuvel (1993) applies that the data on which the models were based and the models itself are over 40 years of age and are therefore possibly outdated.

Waaier van Brogt (Goudappel Coffeng, 2013) shows travel time elasticities based on several past researches. However, the elasticities are for the long-term (>2 years). Frequency elasticities are not based on research and are likely expert judgments. IVT (cross-) elasticities are presented as a single value, not as a range as suggested in this thesis. Waaier van Brogt claims that a decline in level-of-service has a larger absolute elasticity than an increase in level-of-service. This research is not able to confirm or refute that claim: The number of data points of LOS changes both to the positive and negative side (e.g. frequency 2x/h to 4x/h and 4x/h to 2x/h) is limited and the spread is large.

This research has experienced great difficulty in finding converging model parameters. How have the above described models found converging model parameters, whereas this thesis did not find these? As mentioned before, the amount of data available can be one of the causes; with more data available (which is the case in e.g. Van Goeverden and Van den Heuvel, 1993), there might be a more clear convergence. One could work with only averages or rules of thumb, such as Waaier van Brogt and the result is a data based model, but it lacks any information about the ranges and therefore accuracy.

Apart from the above described known models for bus transportation, the NS has its own model for train ridership prediction. Its model 'De Kast' uses a station based OD-matrix and determines growth/decline with elasticities (De Keizer et al., 2009). This approach is very similar to the OD-based approach in this thesis, which did not find a proper fit or elasticities. The fact that NS does find this, can imply that for train transportation the methodology does work (perhaps due to a more aggregated network and different characteristics than bus transit) or that this methodology is perhaps not empirically tested and should be up for discussion.

In-depth analysis of specific cases
A selection of in-depth analyses of specific cases is performed, with the intention to add knowledge and prediction power for those changes that could be implemented during a tender, but could not be part of the before-after study. Furthermore, the analysis of the implementation period provides feedback to the choices made in the before-after study per line and is reflected upon in section 9.5. One of the limitations of the specific cases are that often only one or a small selection of data points is available. The dedicated airport liner is based on a single case, the school analysis only on a small selection of schools and the community service bus is based on a single example. The results

are valuable and provide predictive power, but their accuracy should be seen in the context of the low number of cases. More cases should be analyzed for further conclusions. The extension of operating hours is based on a large data set, but can also be implemented in the model as developed in this thesis. A before-after study of cases with extended/shortened operating hours could be performed.

9.2.1. Connection to related disciplines

The results of the research have been discussed in perspective of literature within the discipline of transportation science. This subsection makes the step to link results of this research with other, related disciplines. Results are thus viewed with a different perspective. (Transport) psychology seems the most prevailing and relevant related discipline. Fujii and Kitamura (2003) e.g. states that a LOS change in itself does not change behavior, but only influences mode choice if the LOS change influences the psychological factors that the behavior is subject to. Murtagh et al. (2012) finds that resistance to change relates to past travel behavior, previous intentions to change as well as identity. This might also imply differences in elasticity for different users and/or regions. Fujii and Kitamura (2003) finds that drivers who are given incentives to take the bus for a limited period of time were more likely to use it afterwards; i.e. attitude towards bus became more positive and habits were changed. This implies that a LOS improvement does not have to be permanent to have effect. Assuming that mode choice is often part of a habit, it raises the question how long it takes to change habits. Transport psychologist M. Dicke (Goudappel Coffeng) claims that it takes ca. 6 months to familiarize with new behavior (OV Pro, 2019). Lally et al. (2010) finds that for regular behavior it takes between 18 and 254 days to form a habit. The time analysis period in this research of sometimes only 3 months might therefore be too small from the habitual perspective. The large ranges also implies why differences of time duration are found in the specific cases (Chapter 8).

Mode choice is seen as a reasoned decision (Bamberg et al., 2003). Bamberg et al. (2003) also comes up with an essential conclusion: Past travel choices only contribute to prediction of future travel choices if circumstances remain sufficiently stable. This thesis is subject to the fundamental assumption that past travel choices do in fact provide basis for a prediction of future travel, this is essential when using elasticities. This assumption and therefore the use of elasticities is therefore only justified with sufficiently stable circumstances. With the limited time period of the before-after study (1 year difference) this has been honored as much as possible. Still, this thesis shows that using elasticities can be difficult, due to very different boundary conditions and environment; which is in line with the findings of Bamberg et al. (2003).

From a marketing perspective, Currie and Wallis (2008) finds in literature that marketing/passenger information can lead up to a 20% increase in ridership, though often lower values are seen. Balcombe et al. (2004) describes a range of 5-15%, in which higher values are only obtained if drastic measures are taken, such as reduced bus fares and car parking fares. In this research any effect of marketing has been disregarded.

Research in the field of (transport) geography finds that neighborhood type is statistically associated with mode choice (Schwanen and Mokhtarian, 2005). This relates to the differences seen over the concessions and even within the network. Lines serving different neighborhoods show a different effect. The approach of this thesis to include the context (a.o. region and line type) into the model seems therefore justified.

9.2.2. Perspective on sensitivity

To place the results in perspective and to obtain a feeling of reliability, two questions will be elaborated upon. First, what is the consequence of using November instead of another month? I.e., would results change if another month was used. Secondly, how large is the range of variation in ridership of lines in which no changes are applied?

For the consequence of using November, no full analysis is presented, but two extreme examples are highlighted to place the results in perspective. The first example is the increase in frequency of Qliner 309 from Groningen to Assen Kloosterveen. For the analysis Novembers have been used, showing an increase of 5% in ridership after increasing the afternoon peak frequency from 5/6x/h to 8x/h. If Aprils would have been used, again 5% ridership increase is obtained. This means there is no significant difference. Also somewhat remarkable, since a few months after the increase the growth is equal to the growth almost a year after the change; while a small continued growth would have been expected.

Another extreme case is GD39/133 from Surhuisterveen to Groningen v.v., which experienced an increase of 83% based on Novembers. Would the analysis have been based on Octobers, the growth would have been 58%, while in April it would have been 111%. Monthly passenger numbers are around 5000, which is relatively low, but not so extreme that they are expected to be extremely sensitive to stochastic variation. This variation can impact the results significantly. The difference in growth factor between April and October is almost double, meaning the elasticities between April and October differ with almost a factor 2. This again emphasizes that elasticities should not be perceived as a single value, but more in the range in which they occur. Despite these two extreme cases, for most cases the difference would only be a few percent point.

For lines where no LOS changes are implemented, ridership is often not fully stable. Data from Connexxion of the concession Voorne-Putten & Rozenburg is available, giving an indication of the amount of change in ridership is shown when no LOS changes are implemented. This shows that on average the changes per line are rather small (3% in 2015 and 0% in 2016), however ranges show up to 10% growth and -8% decline (table 9.1). This already indicates that there is reasonable variability, even when nothing is changed on the supply side. And that this is not for each individual line matching with e.g. economic growth, which has been assumed when compensating for non-LOS factors. Not included in the selection are a.o. growth of the community service bus (+16% in 2016) and a scholar line (+24% in 2016). Connexxion explains these growths by introduction of the smart card in the community service bus in 2014 and the better fit of arrival/departure times with school times. This shows that even larger variability can be expected, with only minor changes which are not even classified as LOS changes by the public transport operator.

Table 9.1: Statistics of lines with no LOS changes in VPR in the years 2015 (compared to 2014) and 2016 (compared to 2015). Data is based on Connexxion (2015) and Connexxion (2016).

Unchanged lines VPR	**2015**	**2016**
number of lines	11	11
median growth	3%	1%
average growth per line	3%	0%
standard deviation growth	0.034	0.030
total growth	2%	1%
max increase	10%	4%
max decrease	-1%	-8%
min change	0%	0%

9.3. Impact of the results and interpretation

This section describes the impact of the results and interpretation of the results on the scientific understanding of bus ridership prediction and the practical applicability within EBS.

This research shows that an analysis per OD-pair does not lead to a satisfying and converging result. In itself this is an important conclusion. It indicates that further research should not focus on OD-level of aggregation, and existing models using a OD-based approach should be reviewed critically. Furthermore, it provides insights into the behavior of passengers. If their bus service is subject to changes in level-of-service, they do not necessarily do what one would expect. Network effects are essential. This is also entangled with another conclusion: there appear to be many factors relevant for the behavior of passengers. This research does not provide a full framework of all factors relevant for behavior changes, however it does indicate that level-of-service in itself is not covering the full spectrum. Therefore it is recommended to execute further research on those other incentives for changing behavior of (former/potential) bus passengers.

The analysis per OD-pair shows the effect when a large part of the network is changed (Waterland 2013-2014). This is a unique case, since most major network changes occur when a new concession starts. This often means a change of operator and therefore a lack of data from either before or after the network change. Making the data public/open source can already decrease this barrier for research and is recommended. The analysis results also show that when the network is changed, more changes occur than what is just expected on a line basis. There is a network effect, which is not sufficiently acknowledged in literature yet. Beforehand, the effect of LOS changes is often expected on the lines with a LOS improvement or deterioration, but the analysis implies that the effect can migrate further into the network. For ridership prediction, not only mode choice, but also route choice must be considered. This should be monitored such that the network can be fine tuned and optimized.

The line-based analysis shows results more in line with literature. However, it is remarkable that elasticities are generally accepted in estimating ridership changes. Many of those elasticities lack context information and/or have incomparable context characteristics; while experts emphasize the importance of context (Expert meeting EBS; MuConsult B.V., 2015). Elasticities occur in ranges much wider than acknowledged by current literature. An elasticity should no longer be seen as a single value, of which the magnitude can be dependent on e.g. country, time period and method of analysis; elasticities should be perceived as a range per definition. Elasticities from literature should not be applied blindly, without respecting the large range and importance of context. This also means that current models which make use of elasticities (e.g. multimodal 4-step models or the OV-lite model) should incorporate this wider range of elasticities, instead of using a single, average value. It can be said that there is a gap in the current models, with elasticities being too generalized and over-simplified, while the larger 4-step models require too much input. This thesis stumbles upon this gap and tries to fill it with the newly developed model. The model is explorative, but it provides a framework which can be expanded in the future. Elasticities are favorable in the sense that they always provide a solution, since they are generalized rules. At the same time, it cannot be expected of a model, nor an elasticity, to always predict ridership 100% correctly. However, the deviations and the ranges are very large and this is something that should be emphasized more when presenting elasticities in researches. Not only the final average of the average should be presented, but also include which ranges are found within a study.

The analyses have shown that there is a deviation from the known models, which has been elaborated upon in the previous section. Despite the differences of real life cases as analyzed in this thesis, this does not make all the models necessarily wrong. As Johnston (2004) recognizes, a model is only a simplification of reality. It cannot be expected of a model to always provide an accurate and precise answer. However it does prove that one should always be sceptical when using models and not blindly rely on them, once they are in use.

The framework that has been developed in this thesis can help in ridership prediction after LOS changes. It provides a model based on actual, recent cases in the Dutch context. The model contains more detail than many other models, since the interaction between hour blocks is analyzed and presented; as well as the sensitivity of user groups. However, it does not provide a set of rules which are generically applicable. There will be situations for which the model does not have a comparable case. Despite, during a tender a ridership prediction is required. Multiple options then follow. If an exact match is not available, the data in the model can provide ranges to what growth to expect. For example, a decrease in IVT of -5 minutes is not in the model, but might be estimated by the IVT elasticities of -7 and -3 minutes in comparable context, providing a likely range in which it will fall. In the same manner, it might provide an estimate of a lower or upper bound of the ridership changes to expect. Despite, there can still be cases which cannot be estimated with the model, both within the existing categories as within other variables, such as transfers. For now, another tool must be used. Comparison of the results with literature shows that dependent on the change often the Effov tables or Van Goeverden and Van den Heuvel (1993) provides the best fit. It is advised to consult figures 6.9 and 6.13 to determine the most suitable alternative model. The number of cases for which no comparison is available can be lowered in the future, if the model is expanded. EBS is advised to keep analyzing and registering the effect of ridership after LOS changes and to add those to the model. For future development, it is recommended to include transfers, though different data sources are required. The model also has advantages over others. First it is based on recent, Dutch data. It provides a lot of information about a case and of the effect, since for example the effect on user groups is shown. Besides, as opposed to other elasticity models, it enables the user to estimate the effect on other hour blocks than the change is implemented (e.g. effect on off-peak hours when peak hours LOS is changed). Lastly, the model can be expanded such that more LOS factors are included in the model. At the moment there is only IVT, frequency and 'other', but if sufficient cases are analyzed, this could be expanded to all level-of-service factors described in Chapter 2 (see figure 2.7). It becomes clear that the development of such a fully sufficing model will be a long-term investment. However, the model is easily expandable and constructed for future adaption. The framework developed in this thesis is thus a basis on which can be built further and it already provides a ridership prediction for many LOS changes. By using the CSSE, a better prediction of ridership change after LOS changes can be made. Better predictions can lead to a better distribution of resources which meet the demands of (potential) users. By investing in those places where it has most effect on ridership means that a higher quality network can be obtained with lower costs. A better prediction of the effect of LOS changes can thus lead to a better network, schedule and operation and thus to an improvement in LOS.

The specific cases provide further insight in aspects that must be substantiated during a tender. It provides knowledge on operating new neighborhoods and urban development and how this relates to growth in bus usage. Furthermore, it enables prediction when one does not improve/decreases LOS, but provides new service. E.g. the expansion of operating hours, a new community service bus line and operation of a community service bus line on Saturdays. It also provides a time scale on which growth can be expected. This provides feedback towards a before-after study and on what time scale the growth should be considered, as well that it provides EBS a time scale which they can incorporate in the business model and a time period for which they do need to analyze the performance of new/changed lines.

The use of the model is not limited to the tender context. In the daily operation of current concessions, also LOS changes are implemented (mostly) once per year. The model is just as suitable to them as for the tender department. For example, the cost effectiveness of proposed measures can be determined. Furthermore, the results include information that is useful for non-transport engineering purposes, such as marketing. The share of product types has been evaluated for the concessions, both distinguished in type of day and hour blocks. By knowing who is in the bus (and who is not) and which users are sensitive to changes, it can be better estimated where to market and who to market for.

The outcome of the research shows that context is essential. This implies that within the public transport operators, the transport engineer who is familiar with the region cannot solely be replaced by a data analyst with no knowledge about the area. The large variety in elasticities can and should lead to the discussion whether the request from PTAs to have a substantiated growth prediction is not leading to a false sense of accuracy and a more indicative, rough estimation would be more suitable.

9.4. Outlook

Some of the results do not provide information to obtain scientific results; however they do provide an outlook to what can possibly be found in further research.

First, there seems to be a strong interaction between off-peak and peak ridership, even when only one of them is subject to a LOS change. The correlation coefficient is large (>0.9). However, the magnitude of the interaction and the factors this is subject to is unknown. This is a valuable subject for further research.

Secondly, the average elasticity in Waterland are higher than in other regions. Due to the low number of data points, the average elasticity is very sensitive to possible outliers and this statement is therefore not conclusive. The potentially higher elasticities in Waterland can possibly be explained by the network effects and the proper competition with the car (and therefore also a smaller share of captives).

The network effect seems very relevant in the analysis per OD-pair, but possibly also in the line-based analysis. This is not separately quantified, but is interesting for further research. As mentioned during the expert meeting (Expert meeting EBS), many options within the PT network exist. Response to changes might therefore not necessarily be a mode shift, but can also be a route change. More research is needed to quantify this.

Research about the implementation of the free public transport usage for MBO students (SOV) is very limited. However the results from Groningen-Drenthe imply that there is a indeed a growth in ridership, which was predicted by and is acknowledged by the OV-bureau Groningen Drenthe. A further evaluation of the effect of free SOV for MBO students is interesting and should be aware of differences per region.

Since results from three concessions are present with a large variety in types of lines, no different results are expected when using a new data set. In fact, more attention should be given to expanding the data set, with data from the same and/or other concessions. This way it could be analyzed whether data starts converging, or spread becomes even larger.

9.5. Reflection

As a final step before the conclusions, a reflection on the research is presented. In a research with limited time, in the end the results and possibilities are subject and limited to the choices made in steps before. This review reflects on those choices made.

The choice has been made to use aggregated data instead of raw smart card data. This has been done such that more data was available. However, it does mean the loss of detail, since individual passengers can no longer be traced. Though it is emphasized that disaggregate data can lead to more valuable insights, in retrospect it has been the right choice to use aggregate data. Following behavior of individuals is interesting, but it is unlikely to lead to elasticities and thus less useful for the goal of this thesis: development of the model. Despite, it is recommended to explore the possibility for a research combining both disaggregate and aggregate data. This enables linkage between behavior of individuals and the aggregated data which can lead to a model.

Initially only Waterland was intended for the research, with Groningen-Drenthe as reference case to check if results could be extrapolated to other concessions. For this reason, the Waterland area has been visited on multiple occasions and municipalities have been contacted to obtain a better understanding of non-LOS related factors possibly influencing bus ridership. In the end the research shifted more towards an aggregated study over multiple concessions. Though the information obtained is still used, it might not have been used to its full ability.

In the data analysis, two approaches have been used: OD-based and line-based. An intermediate option exist: a zonal approach. By clustering stops, part of the variability shown in the OD-based analysis would likely disappear. A zonal approach has as advantage over line-based analysis that more data points would be available. This might lead to further insights. However, this remains open for further research.

In the methodology, the choice has been made to analyse the effect 1 year after the LOS change. Reasons for this choice are that the largest growth is in the first year, it limits the effect of external (non-LOS) factors and because a longer period of analysis would mean a loss of significant part of the data points. In Voorne-Putten & Rozenburg, the only option was to compare March 2016 with March 2019 (with LOS changes in December 2018), but for Groningen-Drenthe and Waterland more options exist. The in-depth analysis of implementation period shows that three months after the LOS change might be too soon to capture the full effect. For consistency reasons, the effect of LOS changes in August in Waterland has been determined by the effect 3 months later, but 15 months after seems better with regard to the implementation period. For the same reason, it is also recommended to public transport operators to analyze the effect of LOS changes for at least one to two years

Despite the potential of the CSSE, a reflection towards model type seems necessary. It is different than foreseen in the start-up phase; since no generalized model parameters could be identified. In Chapter 3 it was concluded that an elasticity model would be most suitable, on which further data analysis was based. Has the choice in Chapter 3 for an elasticity model been correct, or should a model more in line with the multimodal (4-step) models have been aimed for in the first place? The findings of this research show that it is not a single elasticity value that can be derived from a specific LOS change, but a range of elasticities with context factors playing a role where in this range the elasticity for a specific case can be found. Shortly, an elasticity on its own is too simplified and inaccurate. The main reason for unsuitability of the multimodal (4-step) models have been described as being too extensive, time consuming and a rigid separation of modes. The issue with tenders is that every single tender is in a new region, such that the network and characteristics of this region must be rebuild. Firstly, the time is not available, secondly, a lot of the input required is not or only limited available (e.g. information on other modes). It would require huge investments to develop a model for every concession. With the increasing time-span of concessions (towards 10 to 15 years) and the constant developments in merging and splitting regions, it is unlikely the model can be re-used for tender purposes. A mulitimodal 4-step model as e.g. OmniTrans costs ca. €5000 to €25000 per license for governmental use (Personal communication DAT Mobility), without considering the investment in education of personnel and time investment. Commercial prices are even higher. Though the value of tenders can be enormous, in the range of hundreds of millions (OVPro, 2018), it is questionable whether the investments for these models would be made. The solution can possibly be found in a model placed between a multimodal 4-step model and an elasticity model. The CSSE is in a sense already a model in between those two types, since it includes context factors in finding the most suitable elasticity from a range. In future research, this could be developed even more towards a multimodal 4-step model. A simplified multimodal 4-step model in which the network can be simply rebuild to match with the concession. Only the important corridors for bus transportation would be included and the size of zones adjustable to the level of detail required. Another option would be to implement the simplified multimodal 4-step model in a GIS environment. GIS data bases are available and include a.o. number of inhabitants/households per municipality/zone, the road network, important destinations, etc. The public transport network can be extracted in a GIS format from existing systems and is thus also easily available. GIS also allows for calculation of zones of influence. The full network can be quite easily developed in a GIS environment, but the translation of changes to ridership prediction is not yet possible based on the data analysis results. With more data and data analysis for the purpose of a simplified 4-step model, there might be potential for tender usage. It is recommended to further research the possible suitability and applicability of a simplified 4-step model.

10 Conclusions

10.1. Conclusions

Predicting of ridership of buses is essential for optimization of public transport systems. Understanding of behavior of (potential) users after changes in the bus public transport system is still underdeveloped. This thesis focuses on ridership predicting after level-of-service (LOS) changes. A model is requested, suitable for use during tenders. Models currently used in transport engineering are not suitable for the tendering process. Many are too extensive, the simple ones do not provide realistic results and there is a large variety in results. Furthermore, no recent Dutch elasticities are known/used. This research performs a before-after study of LOS changes. Data from concessions Waterland, Voorne-Putten & Rozenburg and Groningen-Drenthe is available.

A variety of LOS variables are found to have significant elasticities in literature. Of those, travel time, frequency and transfers are most prominent. Due to data limitations, no data analysis on transfer elasticities can be performed. Travel time, interpreted as in-vehicle time, and frequency are thus analyzed for inclusion into the model; when data allows more LOS changes are included.

Numerous non-LOS variables are also of influence on ridership, such as price, urban development, weather and economic and demographic growth. The methodology is chosen in such a way, that the influence of these non-LOS variables is diminished: isolated line (sections) are analyzed which have not (knowingly) been subject to large urban development or changes; with growth factors calculated a year later such that the influence of economic and demographic growth is limited.

An analysis per OD-pair is not suitable for finding a relation between ridership and LOS changes and therefore not suitable for answering the main research question: 'Which relations between level-of-service and ridership can be derived from Dutch bus transportation, being both recent and data based and how can they be translated into a model suitable for tendering?' The results show a large variation in behavior, including many data points contradicting the hypothesis that an increase in LOS leads to an increase in ridership. Further analyses imply that elasticity plots per OD-pair do not give a representative overview of the effect of a LOS change. Analysis per line give results which are often in line with expectation, however, the range of values is large: elasticities for IVT from -3.3 to 1.0 and elasticities for frequency from -0.04 to 0.84. Context seems to play an important role. In general, the results are as hypothesized: an increase in LOS leads to an increase in ridership. The results deviate from literature; IVT elasticity in the before-after study is larger than literature predicts, while frequency elasticity is smaller than literature predicts. No clear distinction is found for the time of day on which the LOS changes are implemented; i.e. measures applied peak only, off-peak only and full day spread throughout the ridership growth graph, whereas a more clear distinction is hypothesized. More data is needed to research whether elasticities converge or that ranges become even larger. Quantitative compensation for non-LOS changes, such as economic growth, provide a range for the growth factors. The magnitude of these ranges is vary largely between cases. However, also when taking these ranges into account, no converging relations can be identified. From the line-based analysis, it is found that students and infrequent travelers are the most sensitive user groups. Furthermore, a strong interaction (correlation coefficient > 0.9) between peak and off-peak LOS and ridership is found. A linear regression with the line-based results shows a significant, positive relation between ridership and frequency and a significant, negative relation between ridership and IVT. However, the quantification of the relation is very dependent on the design of the regression and for IVT the amount of data points is too low. Certain additional predictors can be relevant, dependent on the regression design: urbanity, main user group, type of line and price change. The regression is interpreted as indicative, but not conclusive. Therefore, the line-based results show the results most suitable for a model.

Based on the outcomes of the before-after study, which shows large variability in elasticities, a comparison model is proposed and developed: the Case Study Search Engine. This Excel based model provides the user with a (set of) comparable cases to measure the user wants to predict the effect of. For each case, a data sheet presents the characteristics of the line and the growth factor(s). The data sheets lay part of the responsibility by the user, but can lead to a substantiated prediction of ridership growth in a transparent way. The model is able to present comparable cases after selection of 8 criteria, meaning that the required input is limited and usage is suitable for the tender environment. Future expansion of the number of cases can increase the value of the model.

The in-depth study of specific cases leads to more insights in (changing) behavior during network changes. Case studies show that it takes up to 2 years after a LOS change for the ridership to reach a new equilibrium, but that this is already largely reached in the first year. Analysis for longer operating hours show that early morning / late evening hours are mainly used by students and infrequent travelers, to whom longer operating hours will have the most effect. Hourly trends in ridership show that ratios between ridership of different hours are largely comparable between line types and concessions, such that with ratios the effect of longer operating hours can be determined. Four cases of urban development have been analyzed. It shows it takes ca. 4 to 6 months time before regular use is reached. No constant relation between households and ridership is found. Also no clear relation between number of students at schools and ridership at nearby stops and/or usage of dedicated scholar lines has been found. A dedicated airport shuttle has a positive effect on public transport usage to/from Groningen Airport. Analysis of a new community service bus line shows that mainly infrequent travelers are the (early) users. Saturday usage of community service bus lines is dependent on the character of the line.

With the above described findings, the research question can be answered as follows:

> *Which relations between level-of-service and ridership can be derived from Dutch bus transportation, being both recent and data based and how can they be translated into a model suitable for tendering?*
>
> The before-after study on line basis shows that there is a large variability in ridership growth with level-of-service changes, based on 31 cases. On an aggregated scale, an increase in level-of-service leads to an increase in ridership; on an OD-based level of detail there is more variation. Elasticities have a large range; context and network effects play a vital role and influence the magnitude of the elasticity and resulting ridership growth. Graphs, tables and/or single elasticity values can be misleading, since they lack context. Integrating elasticities into a model is complex. The Case Study Search Engine, a comparison model, enables inclusion of the context and honoring of the results, while still the requirements for tender suitability are met.

The findings in this research have impact on the existing understanding of bus ridership prediction. Elasticities as found in literature cannot be blindly applied; they cannot be seen as universally applicable rules. Elasticities focus too much on a single average value and lack context. Results have shown that ranges of elasticities can be large and that such an average from literature can deviate far from reality. The results often show larger growth than predicted by experts. This might be the consequence of non-LOS related factors and context. The unsuitable results from the OD-based analysis shows that in bus transportation, behavior is far from straightforward on a disaggregate level of detail and suggest that for ridership prediction not only mode choice, but also route choice must be considered. More attention should be given to network effects, such as travelers changing their behavior within the public transport network. This can include changing departure and arrival stop, route/line taken and even direction in which is traveled.

The insights obtained and the framework developed in this thesis provide transport engineers a better prediction of what the effects of proposed LOS changes are. Empirical data analysis has been performed, providing recent, Dutch elasticity values for bus transportation, which was a lack of in literature. The large range of elasticities found in this thesis should promote critical attitude towards models using single elasticity values. The Case Study Search Engine enables a fast and easy overview of historic LOS changes and their effects. This enables a better substantiation of measures applied by the public transport operator and ridership predictions; e.g. during tenders. Therewith it fills the gap of a model suitable for tendering. Better predictions of the effect of LOS changes on ridership can improve the network, schedule and operation of the bus services for (potential) passengers. Improved predictions can thus lead to LOS better meeting the demands of the (potential) users and a more optimized network.

To finalize, a summary of the recommendations is presented.

10.2. Summary of recommendations

Within Chapter 9, several recommendations have been given. This section shows a summary for easy overview and classifies them into one of four categories: recommendations for further research, for the scientific world, for EBS and for the public transport world. The background and explanation for the recommendations have all been described in Chapter 9.

10.2.1. Recommendations for further research

- The effect of adding/removing transfers should be added to the model. Analysis of more detailed data (raw smart card data) is necessary.
- More specific cases can be evaluated and some of the current specific cases can be included in a before-after study (e.g. extension of operating hours).
- This thesis has analyzed effects on an OD-level and per line, but there is a level in between. If instead of per stop, per (isolated) cluster of stops the ridership changes are analyzed, possibly there is less variation than per OD-pair, but a much larger amount of data than per line.
- Further research on incentives for (potential) passengers for changing transport behavior is required. This would enable a better estimation of what amount of the growth observed in the data analysis results should be assigned to non-LOS changes or perhaps changes in their personal life.
- A combination of disaggregate and aggregate data and research on the same subject would be very insightful. Often a choice is made between either, but both have their limitations. With a combination of the two on the same case study, possibly far better insights and relations between the two can be obtained.
- Further research in the network effect, i.e. how ridership in the entire network responds to changes on only a single line, as well as a large redesign of the network, should be performed.
- Research the interaction between peak and off-peak ridership. This thesis shows that there is strong correlation between the two, even if a change is only implemented in one of the two.
- A modelling approach more in line with multimodal 4-step models should be evaluated.

10.2.2. Recommendations for the scientific world

- Be aware of ranges of elasticities and context.
- Make use of the emerging availability of big data to analyze elasticities on different levels of detail.

10.2.3. Recommendations for EBS

- Improve data storage in systems; i.e. frequency is not stored correctly (at least not in 2013/2014) and make sure frequency is stored for all stops instead of only a selection of stops. This enables proper and efficient data analysis.
- Make sure all bus stops have the same name in all systems (e.g. Zight, Hastus and TMWalker); this can save a lot of time in data analysis.
- Update the model with new cases.

All recommendations for the public transport world are also recommendations for EBS.

10.2.4. Recommendations for the public transport world

- Make all data publicly available.
- Do not blindly implement elasticities from models, context is essential.
- Analyze the effect of new changes implemented for at least one to two years to determine whether a change is successful.
- Do not only incorporate the effect of a single line that is changed, but know that there is more interaction with other lines in the network.

With these recommendations, this thesis is concluded.

Bibliography

[1] Amsterdam Marketing. Bezoekersprofiel 2016 Gemeente Edam-Volendam, 2016.

[2] ANWB. ANWB: 20 procent meer files op nederlandse wegen, 2018. URL `https://www.anwb.nl/verkeer/nieuws/nederland/2018/december/anwb-20-procent-meer-files-op-nederlandse-wegen`.

[3] Arana, P. , Cabezudo, S. , and Penalba, M. . Influence of weather conditions on transit ridership: A statistical study using data from smartcards. *Transportation Research Part A*, 59:1–12, 2014.

[4] Arriva. Exploitatieplan 2020 Oost-Brabant, 2019. URL `https://s-hertogenbosch.raadsinformatie.nl/document/7790372/1/118651c5-8159-41fa-a97e-734fd68d4799`.

[5] Arriva Oost Nederland. Vervoerplan 2019 Gelderland, 2017.

[6] Bakker, P. . De marktpositie van het openbaar reizigersvervoer in beweging. *Tijdschrift voor vervoerswetenschap*, 15.4:417–433, 1979.

[7] Balcombe, R. , Mackett, R. , Paulley, N. , Preston, J. , Shires, J. , Titheridge, H. , Wardman, M , and White, P. . The demand for public transport: a practical guide. Technical report, TRL limited, 2004.

[8] Bamberg, S. , Ajzen, I. , and Schmidt, P. . Choice of travel mode in the theory of planned behavior: The roles of past behavior, habit, and reasoned action. *Basic and Applied Social Psychology*, 25:175–178, 2003.

[9] Bass, P. , Donoso, P. , and Munizaga, M. . A model to assess public transport demand stability. *Transportation Research Part A*, 45:755–764, 2011.

[10] De Beer, P. , Tiemersma, D. , and Ploeg, R. Van der . Modal split onder druk? gevolgen bezuinigingen openbaar vervoer in amsterdam. In *Colloquium Vervoersplanologisch Speurwerk 2011*, 2011.

[11] De Beer, P. . Modal split onder druk? gevolgen bezuinigingen ov op modal split, 2011. Bachelor thesis Universiteit van Amsterdam.

[12] Ben-Akiva, M. , Bottom, J. , Gao, S. , Koutsopoulos, H.N. , and Wen, Y. . Towards disaggregate dynamic travel forecasting models. *Tsinghua Science and Technology*, 12:115–130, 2007.

[13] Berveling, J. , Bakker, P. , Harms, L. , and Werff, E. van der . Imago en openbaar vervoer. Technical report, Kennisinstituut voor Mobiliteitsbeleid, 2009.

[14] Borjesson, M. , Fung, C.M. , and Proost, S. . Optimal prices and frequencies for buses in Stockholm. *Economics of Transportation*, 9:20–36, 2017.

[15] Bourgeat, P. . A revealed/stated preference approach to bus service configuration. *Transportation Research Procedia*, 6:411–423, 2015.

[16] BPD. Planning nieuwbouw De Keyser, 2019. URL `https://www.nieuwbouw-middenbeemster.nl/planning#`.

[17] Brands, T. , De Romph, E. , Veitch, T. , and Cook, J. . Modelling public transport route choice, with multiple access and egress mode. *Transportation Research Procedia*, 1:12–23, 2014.

[18] Brechan, I. . Effect of price reduction and increased service frequency on public transport travel. *Journal of Public Transportation*, 20:139–156, 2017.

[19] Brielle.nu. Toerisme, 2019. URL `http://www.brielle.nu/over-brielle/toerisme/`.

[20] Bronsvoort, K.A. . Exploring alternative public transport in rural areas. Master's thesis, TU Delft, The Netherlands, 2019.

[21] Centraal Bureau voor de Statistiek - Statline. Regionale kerncijfers Nederland, 2018. URL `https://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=70072ned&D1=0-88&D2=0,4,8,20,91,312,768&D3=21-23&VW=T`.

[22] Centraal Bureau voor de Statistiek - Statline. Grootste groei toerisme in ruim tien jaar, 2018. URL https://www.cbs.nl/nl-nl/nieuws/2018/14/grootste-groei-toerisme-in-ruim-tien-jaar.

[23] Centraal Bureau voor de Statistiek - Statline. Luchtvaart; maandcijfers Nederlandse luchthavens van nationaal belang, 2019. URL https://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37478hvv&D1=11,14,17,20-25,31,35&D2=l&D3=230,234,238,243-247,274-276,278-280,282-284,286-288,291-293,295-297,299-301,303-305,308-310,312-314,316-318,320-322,325-327,329-331,333-335,337-339,342-344,l&HDR=T&STB=G2,G1&VW=T.

[24] Centraal Bureau voor de Statistiek - Statline. Motorvoertuigenpark; inwoners, type, regio, 1 januari, 2019. URL https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7374HVV/table?fromstatweb.

[25] Centraal Bureau voor de Statistiek - Statline. Jaarmutatie consumentenprijsindex; vanaf 1963, 2019. URL https://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=70936NED&D1=0&D2=623,636,649,662,675,688,701,711-727&HDR=T&STB=G1&VW=T.

[26] Centraal Bureau voor de Statistiek (CBS). Onderzoek verplaatsingen in Nederland (ovin) 2017, 2018.

[27] Centraal Bureau voor de Statistiek (CBS). CBS in uw buurt, 2019. URL http://www.cbsinuwbuurt.nl/.

[28] Cervero, R. and Guerra, E. . *Urban Densities and Transit: A Multi-dimensional Perspective*. UC Berkeley Center for Future Urban Transport, 2011.

[29] Chen, Z. . Who ride the high speed rail in the United States —the acela express case study. In *Proceedings of the 2010 Joint Rail Conference JRC2010 April 27-29, 2010, Urbana, Illinois, USA*, 2010.

[30] Connexxion. Vervoerplan voorne-putten / rozenburg 2017, 2015. URL https://mrdh.nl/system/files/projectbestanden/Vervoerplan%202017%20Connexxion.PDF.

[31] Connexxion. Vervoerplan voorne-putten / rozenburg 2018, 2016. URL https://mrdh.nl/system/files/projectbestanden/Vervoerplan%202018%20Connexxion%20Voorne%20Putten-Rozenburg.PDF.

[32] Connexxion Zaanstreek. Zaanstreek vervoerplan 2018, 2016.

[33] Creemers, L. , Wets, G. , and Cools, M. . Meteorological variation in daily travel behaviour: evidence from revealed preference data from the Netherlands. *Theoretical and Applied Climatology*, 120:183–194, 2015.

[34] CROW. *Kencijfers parkeren en verkeersgeneratie*. CROW, Ede, 2012.

[35] CROW. Staat van het regionale openbaar vervoer 2016, 2017.

[36] Currie, G. and Wallis, I. . Effective ways to grow urban bus markets – a synthesis of evidence. *Journal of Transport Geography*, 16:419–429, 2008.

[37] Curry, G. . The demand performance of bus rapid transit. *Journal of Public Transportation*, 8:41–55, 2005.

[38] dell'Ollio, L. , Ibeas, A. , and Cecin, P. . The quality of service desired by public transport users. *Transport Policy*, 18:217–227, 2011.

[39] Dienst Uitvoering Onderwijs (DUO). Open databestanden, 2019. URL https://duo.nl/open_onderwijsdata/databestanden/.

[40] EBS Public Transportation B.V. Vervoerplan Waterland 2018, 2016. URL https://www.ebs-ov.nl/fileadmin/user_upload/Overig/Formulieren/Vervoerplan_2018_20161012.pdf.

[41] EBS Public Transportation BV. Lijnennetkaart geheel waterland 2018, 2018. URL https://www.ebs-ov.nl/fileadmin/user_upload/Overig/Noord_Zuidlijn/Lijnennetkaart_Waterland_22-7-18.pdf.

[42] EBS Public Transportation B.V. Lijnennetkaart Voorne-Putten Rozenburg 2019, 2019. URL https://www.ebs-ov.nl/fileadmin/user_upload/Voorne-Putten_Rozenburg/Lijnennetkaart_EBS_VPR_2018_v8low.pdf.

[43] Ecola, L. and Wachs, M. . Exploring the relationship between travel demand and economic growth. Technical report, The RAND Corporation for Federal Highway Administration, 2012.

[44] Fehr Peers. Direct ridership forecasting: Out of the black box. Technical report, Fehr Peers, 2004.

[45] Flügel, S. , Flötteröd, G. , Kwong, C.K. , and Steinsland, C. . Evaluation of methods for calculating traffic assignment and travel times in congested urban areas with strategic transport models (tØi report 1358/2014). Technical report, Institute of Transport Economics - Norwegian Center for Transport Research, 2014.

[46] Fujii, S. and Kitamura, R. . What does a one-month free bus ticket do to habitual drivers? an experimental analysis of habit and attitude change. *Transportation*, 30:81–95, 2003.

[47] Garber, N.J. and Hoel, L.A. . *Traffic & Highway Engineering*. Cengage Learning, SI edition fifth edition, 2015.

[48] Garcia-Martinez, A. , Cascajo, R. , Jara-Diaz, S.R. , Chowdhury, S. , and Monzon, A. . Transfer penalties in multimodal public transport networks. *Transportation Research Part A*, 114:52–66, 2018.

[49] Gemeente Amsterdam: Dienst Infrastructuur Verkeer en Vervoer. Effecten bezuinigingen openbaar vervoer – verkenning naar de effecten van maatregelen. (not public). 2011.

[50] Gemeente Emmen. Achtergrond vernieuwing centrum Emmen, 2019. URL `https://gemeente.emmen.nl/vernieuwing-centrum-emmen/achtergrond`.

[51] Gemeente Landsmeer. Goed wonen in Landsmeer - woonvisie 2016-2024, 2016.

[52] Van Goeverden, C.D and Heuvel, M.G. Van den . De verplaatsingsfactor in relatie tot de vervoerwijzekeuze. Technical report, TU Delft / Projectbureau Integrale Verkeers- en Vervoersstudies, 1993.

[53] Goodwin, P.B. and Williams, H.C.W.L. . Public transport demand models and elasticity measured: An overview of recent British experience. *Transportation Research Part B*, 19B:253–259, 1985.

[54] Goudappel Coffeng. Waaier van Brogt versie 2a, 2013.

[55] Graehler, M. , Mucci, R.A. , and Erhardt, G.D. . Understanding the recent transit ridership decline in major US cities: Service cuts or emerging modes? *98th Annual Meeting of the Transportation Research Board*, 2019.

[56] Guo, Z. and Wilson, N.H.M. . Assessing the cost of transfer inconvenience in public transport systems: A case study of the london underground. *Transportation Research Part A*, 45:91–104, 2011.

[57] Haaijer, R. , Pol, M. , and Vaessens, B. . Trein in de ov keten. In *Bijdrage aan het Colloquium Vervoersplanologisch Speurwerk 2007 Antwerpen : 22 en 23 november, 2007*, 2007.

[58] Hemily, B. and King, R. . The use of small buses in transit services. *TCRP Synthesis*, 41:1–81, 2002.

[59] Holmgren, J. . Meta-analysis of public transport demand. *Transportation Research Part A*, 41:1021–1035, 2007.

[60] I&O Research. Toerisme en Recreatie Voorne-Putten 2015, 2015. URL `https://voorne-putten.incijfers.nl/`.

[61] I&O Research. Toerisme en Recreatie Voorne-Putten 2017, 2017. URL `https://voorne-putten.incijfers.nl/`.

[62] Johnston, R.A. . *The urban transportation planning process*. The Guilford Press., third edition, 2004.

[63] De Jonge, M.J.W. . Herstructurering stadsdienst Harderwijk, 2014. Universiteit Twente + Provincie Gelderland (Confidential).

[64] Kadaster. Basisadministratie adressen en gebouwen, 2019. URL `https://bagviewer.kadaster.nl/`.

[65] De Keizer, B. , Vries, B. , and De Bruyn, M. . Nieuw prognosemodel “De Kast” als beleidsinstrument. In *Colloquium Vervoersplanologisch Speurwerk 2009*, 2009.

[66] Kennisinstituut voor Mobiliteit. Values of time and reliability in passenger and freight transport in the netherlands, 2013.

[67] Kennisinstituut voor Mobiliteitsbeleid. Effecten ander ov-studentenreisproduct, 2014.

[68] Kennisinstituut voor Mobiliteitsbeleid. Mobiliteitsbeeld 2017, 2017.

[69] Kerkman, K. , Martens, K. , and Meurs, H. . Predicting travel flows with spatially explicit aggregate models on the benefits of including spatial dependence in travel demand modelling. *Transportation Research Part A*, 118: 68–88, 2018.

[70] Khattak, A.J. and De Palma, A. . The impact of adverse weather conditions on the propensity to change travel decisions: a survey of Brussels commuters. *Transportation Research Part A*, 31:181–203, 1997.

[71] Koonce, P. , Ryus, P. , Zagel, D. , Park, Y. , and Parks, J. . An evaluation of comprehensive transit improvements—trimet's streamline program. *Journal of Public Transportation - BRT Special Edition*, pages 103–115, 2006.

[72] Lally, P. , Van Jaarsveld, C.H.M. , Potts, H.W.W. , and Wardle, J. . How are habits formed: Modelling habit formation in the real world. *European Journal of Social Psychology*, 10:998–1009, 2010.

[73] Lee, A. , Van Nes, R. , and Van Oort, N. . Service reliability in a network context: impacts of synchronizing schedules in long headway services 3 services. *93rd Annual Meeting of the Transportation Research Board 2014*, pages 1–18, 2014.

[74] Lee, A. , Molin, E.J.E. , Maat, K. , and Sierzchula, W. . Electric bicycle use and mode choice in the Netherlands. *Transportation Research Record Journal of the Transportation Research Board*, 2520:1–7, 2015.

[75] Li, L. , Wang, J. , Song, Z. , Dong, Z. , and Wu, B. . Analysing the impact of weather on bus ridership using smart card data. *IET intelligent transport systems*, 9:221–229, 2014.

[76] Li, Y.T. , Schmöcker, J.D. , and Fujii, S. . Demand adaptation towards new transport modes: Case of high speed rail in Taiwan. *Transportmetrica*, 3, 2015.

[77] Ligtermoet & Partners. Reizigersgroei R-net 400 - evaluatie eindrapportage fase 1, 2016.

[78] Litman, T. . Transit price elasticities and cross - elasticities. *Journal of Public Transportation*, 7:37–58, 2004.

[79] Litman, T. . Transportation elasticities how prices and other factors affect travel behavior. Technical report, Victoria Transport Policy Institute, 2007.

[80] Litman, T. . Transit price elasticities and cross-elasticities. Technical report, Victoria Transport Policy Institute, 2019.

[81] Marketing Groningen. Toerisme & Groningen 2017 in een oogopslag factsheet, 2019. URL `https://www.marketinggroningen.nl/kerncijfers/kerncijfers-toerisme`.

[82] MBO Raad. Kaart mbo-scholen, 2019. URL `https://www.mboraad.nl/kaart-mbo-scholen`.

[83] Mishalani, R.G. , McCord, M.M. , and Wirtz, J. . Passenger wait time perceptions at bus stops: Empirical results and impact on evaluating real-time bus arrival information. *Journal of Public Transportation*, 9:89–106, 2006.

[84] Mitrani, A. , Kincaid, I. , Edwards, D. , and Hobbs, G. . London underground and bus demand analysis 1970-2000. Technical report, 2002.

[85] MuConsult B.V. Literatuurstudie tijd- en convenience gevoeligheden openbaar vervoer, 2015.

[86] Murtagh, N. , Gatersleben, B. , and Uzzel, D. . Self-identity threat and resistance to change: Evidence from regular travel behaviour. *Journal of Environmental Psychology*, 32:318–326, 2012.

[87] NBTC Holland Marketing. Onderzoek inkomend toerisme 2014, 2014.

[88] Nelson, N.M. , Foley, E. , O'Gorman, D.J. , Moyna, N.M. , and Woods, C.B. . Active commuting to school: How far is too far? *International Journal of Behavioral Nutrition and Physical Activity*, 5, 2008.

[89] Nijkamp, P. and Pepping, G. . Meta-analysis for explaining the variance in public transport demand elasticities in Europe. *Journal of Transportation and Statistics*, 1998.

[90] Noord-Hollands Dagblad. Luijendijk-zuid is de blikvanger van Landsmeer, 2018. URL `https://www.noordhollandsdagblad.nl/cnt/dmf20180924_71723211/luijendijk-zuid-is-de-blikvanger-van-landsmeer?utm_source=google&utm_medium=organic`.

[91] Van Oort, N. . *Service reliability and urban public transport design*. PhD thesis, Delft University of Technology, 2011.

[92] Van Oort, N. . Incorporating service reliability in public transport design and performance requirements: International survey results and recommendations. *Research in Transportation Economics*, 2014.

[93] Van Oort, N. . Lecture data driven predictions and service reliability - advanced transportation modelling cie5802-09 (tu delft - 06/12/2018), 2018.

[94] Van Oort, N. , Brands, T. , and De Romph, E. . Short-term prediction of ridership on public transport with smart card data. *Transportation Research Record: Journal of the Transportation Research Board*, 2535:105–111, 2015.

[95] Oostra, R. . Elasticiteitsonderzoek HTM. Master's thesis, TU Delft, The Netherlands, 2004.

[96] Ortuzar, J.D. and Willumsen, L.G. . *Modelling Transport*. John Wiley & Sons, Ltd., fourth edition, 2011.

[97] OV in Nederland. Ov-chipkaart, 2019. URL `http://wiki.ovinnederland.nl/wiki/OV-chipkaart`.

[98] OV in Nederland. Concessiekaart, 2019. URL `https://wiki.ovinnederland.nl/wiki/Concessiekaart`.

[99] OV Pro. Automobilist in ov krijgen is lastig, maar niet onmogelijk, 2019. URL `https://www.ovpro.nl/bus/2019/04/30/automobilist-in-ov-krijgen-lastig-maar-niet-onmogelijk/`.

[100] OVPro. Geen extra drukte verwacht in ov door uitbreiding studentenkaart, 2017. URL `https://www.ovpro.nl/bus/2017/01/10/geen-extra-drukte-verwacht-in-ov-door-uitbreiding-studentenkaart/?gdpr=accept`.

[101] OVPro. Ebs wint busconcessie Haaglanden Streek, 2018. URL `https://www.ovpro.nl/bus/2018/07/11/ebs-wint-busconcessie-haaglanden-streek/`.

[102] De Palma, A. and Rochat, D. . Understanding individual travel decisions: results from a commuters survey in Geneva. *Transportation*, 26:263–281, 1999.

[103] Paulley, N. , Balcombe, R. , Mackett, R. , Titheridge, H. , Preston, J. , Wardman, M. , Shires, J. , and White, P. . The demand for public transport: The effect of fares, quality of service, income and car ownership. *Transport Policy*, 13:295–306, 2006.

[104] Peek, G.J. and Van Hagen, M. . Creating synergy in and around stations: Three strategies for adding value. *Transportation Research Record: Journal of the Transportation Research Board*, 1793:1–6, 2002.

[105] Pel, A.J. . Lecture course introduction and outline - advanced transportation modelling cie5802-09 (tu delft - 12/11/2018), 2018.

[106] Pelletier, M.P. , Trepanier, M. , and Morency, C. . Smart card data use in public transit: A literature review. *Transportation Research Part C*, 19:557–568, 2011.

[107] Pelsma, G. . Invulling ov visie voor de concessie Veluwe, 2014. Arnhem: Provincie Gelderland.

[108] Pereira, F.C. , Rodrigues, F. , and Ben-Akiva, M. . Using data from the web to predict public transport arrivals under special events scenarios. *Journal of Intelligent Transportation Systems*, 19, 2013.

[109] Plazier, P. , Weitkamp, G. , and Berg, A.E. Van den . Exploring the adoption of e-bikes by different user groups. *Frontiers in Built Environment*, 4, 2018.

[110] Pratt, R. . Traveler response to transportation system changes, interim handbook. Technical report, National Academy of Science, 1999.

[111] ProRail B.V. Stationsomgeving Assen, 2019. URL `https://www.prorail.nl/projecten/stationsomgeving-assen`.

[112] Provincie Gelderland. Betere bereikbaarheidvan modaliteit naar mobiliteit-uitwerking ov-visie, fase 1 (2020)-, 2016. URL `https://gelderland.stateninformatie.nl/document/3476027/1/Notitie_Betere_Bereikbaarheid_Gelderland_-_uitwerking_OV-visie_(PS2016-374)`.

[113] Provincie Noord Brabant. Eerste resultaten hoogwaardig openbaar vervoer Noordoost-Brabant, 2009.

[114] Purmerend in cijfers. Factsheet woningen, 2019. URL `https://purmerend.incijfers.nl/jive/report/?id=fs_abf_woningen`.

[115] Qbuzz. Lijnennetkaart Groningen Drenthe 2018, 2018. URL `https://gd-prod.cdn.prismic.io/gd-prod%2F4335f74f-0ebd-4b7e-8495-3eddd356bdda_groningen-drenthe_dec+2017_def_lowres.pdf`.

[116] Quee, J. (SWECO). De Purmer - Oost, 2016.

[117] Racca, D.P. and Ratledge, E.C. . Factors that affect and/or can alter mode choice. Technical report, prepared for Delaware Transportation Institute and The State of Delaware Department of Transportation, 2004.

[118] Rijkswaterstaat. Verkeer en vervoer: Het landelijk model systeem, 2017.

[119] Van Roosmalen, J. . Short-term forecasting of ridership with trip planner usage data. Master's thesis, University of Twente, The Netherlands, 2019.

[120] Royal Netherlands Metereological Institute. Archief maand/seizoen/jaaroverzichten, 2019. URL `https://www.knmi.nl/nederland-nu/klimatologie/maand-en-seizoensoverzichten`.

[121] Schwanen, T. and Mokhtarian, P.L. . What affects commute mode choice: neighborhood physical structure or preferences toward neighborhoods? *Journal of Transport Geography*, 13:83–99, 2005.

[122] Stam, B. . Access/egress facilities at railway stations: An exploratory study on the future development of railway station areas. Master's thesis, TU Delft, The Netherlands, 2019.

[123] Stanley, R. . Continuing examination of successful transit ridership initiatives. *Transit Cooperative Research Program - Research Results Digest*, 29, 1998.

[124] Steg, L. . Can public transport compete with the private car? *IATTS Research*, 27:27–35, 2003.

[125] Sultana, Z. , Mishra, S. , Cherry, C.R. , Golias, M.M. , and Trabizizadeh Jeffers, S. . Modeling frequency of rural demand response transit trips. *Transportation Research Part A*, 118:494–505, 2018.

[126] Ton. Lecture Mode Choice - Advanced Public Transportation Operations and Modelling (TU Delft - 12/02/2019), 2019.

[127] Ton, D. , Duives, D.C. , Cats, O. , Hoogendoorn-Lanser, S. , and Hoogendoorn, S.P. . Cycling or walking? Determinants of mode choice in the Netherlands. *Transportation Research Part A*, 123:7–23, 2019.

[128] Transtec adviseurs B.V. Invloedgebied hov haltes - de invloed van de fietser onderschat, 2010.

[129] Twisk, J.W.R. . *Inleiding in de toegepaste biostatistiek*. Bohn Stafleu van Loghum, fourth edition, 2016.

[130] Uber. Waar is uber actief in Nederland, 2018. URL `https://www.uber.com/nl/blog/wat-is-uber/`.

[131] Upchurch, C. and Kuby, M. . Evaluating light rail sketch planning: actual versus predicted station boardings in Phoenix. *Transportation*, 41:173–192, 2014.

[132] VCC-Oost. Rapport openbaar vervoer regio Achterhoek basismobiliteit, 2014.

[133] Veeneman, W. . Public transport governance in the Netherlands: More recent developments. *Research in Transportation Economics*, 59:116–122, 2016.

[134] Van de Velde, D. , Eerdmans, D. , and Westerink, H. (inno-V) . Public transport tendering in the Netherlands, 2010.

[135] Vervoerregio Amsterdam. Notitie vervoerplan AML 2019: Stand van zaken per 1 juli 2018 (memo), 2018.

[136] Vigren, A. . How many want to drive the bus? analyzing the number of bids for public transport bus contracts. *Transport Policy*, 72:138–147, 2018.

[137] Van Wee, B. and Banister, D. . How to write a literature review paper? *Transport reviews*, 36:278–288, 2016.

[138] Van Westerop, S. . Vervoersvoorzienings-plan voor de Achterhoek, 2015. Hogeschool van Arnhem en Nijmegen + Rocov Gelderland.

[139] Yap, M. , Cats, O. , and Van Arem, B. . Crowding valuation in urban tram and bus transportation based on smart card data. *Transportmetrica A*, 2018.

[140] Yap, M. , Nijenstein, S. , and Van Oort, N. . Improving predictions of public transport usage during disturbances based on smart card data. *Transport Policy*, 61:84–95, 2018.

[141] Zhao, F. , Li, M.T. , Chow, L.F. , Gan, A. , and Shen, L.D. . Fsutms mode choice modeling: Factors affecting transit use and access. Technical report, prepared for National Center for Transit Research in cooperation with Florida Department of Transportation., 2002.

[142] Zhou, M , Wang, D. , Li, Q. , Yue, Y. , Tu, W. , and Cao, R. . Impacts of weather on public transport ridership: Results from mining data from different sources. *Transportation Research Part C*, 75:17–29, 2017.

A

Appendix Expert Interviews

In order to conduct this research, several expert have been consulted (nonetheless in an informal manner):

Kees van Goeverden (TU Delft) - 18 December 2018
Jorne Bonte & Rick Meinen (OV Bureau Groningen-Drenthe) - 14 January 2019 and 3 June 2019
Fred van der Blij (TransTec/Provincie Utrecht) - 16 January 2019
Menno Yap (TU Delft) - 1 February 2019
Tom Schilder (Gemeente Edam-Volendam) - 30 January 2019

Furthermore, an plausibility check/expert judgment session has been conducted within EBS.
The expert interview with Fred van der Blij has been conducted in a formal manner. An approved summary of the interview is shown below. Since the interview has been conducted in Dutch, the summary of the transcript is in Dutch as well.

A.1. Interview Fred van der Blij

Fred van der Blij
Voormalig NZH, Connexxion (managementteam)
Voormalig directeur Transtec Adviesbureau
OV-specialist Provincie Utrecht

16 januari 2019 | 15.15-16.30 | tramremise Nieuwegein

Wat is de motivatie achter netwerk- of vervoerkundige wijzigingen die vervoerders toepassen?

Je ziet daarin een verschuiving in de loop der jaren. In het verleden moesten nieuwe woonwijken vaak worden opgenomen in het lijnennet. Dat leidde tot het Hoge Hoed model, dat voornamelijk geldt voor het streekvervoer. Lijnen gingen hierbij een stukje omrijden om nieuwe woonwijken te ontsluiten. Je ziet nu eigenlijk dat het omgekeerde zich weer voordoet. Als je de lijnen strekt, dan is dat gunstiger voor de meeste doorgaande reizigers en nadelig voor de enkele instappers in de lus die eruit wordt gehaald. Vervolgens kunnen met de besparingen weer frequentieverhogingen worden gefaciliteerd, wat weer tot meer reizigers kan leiden. Dan is er nog wel altijd de discussie over ouderen in de woonwijk, voor wie het te ver lopen zou zijn. Als vervoerder wil je dan kunnen beargumenteren aan je opdrachtgever dat de voordelen ruimschoots opwegen tegen de nadelen. Daar heb je een model voor nodig, om dat te kunnen onderbouwen.

Zit achter het doorvoeren van dit soort wijzigingen, zoals het strekken van lijnen, ook echt een gefundeerde cijfermatige onderbouwing, of is het vaak meer een kwestie van gevoel en ervaring?

Er zit vaak wel een stukje cijfermatige onderbouwing in. Het rechttrekken van lijnen betekent echt een verlaging van kosten, maar ook een verminderde kans op vertraging. Er zijn ook wel onderzoeken geweest met een groot panel, waarbij is gevraagd of reizigers een grotere halte afstand over hebben voor een frequentere, snellere buslijn. Daar kwam toch wel uitgebreid uit dat als de frequentie maar hoog genoeg is, dat mensen dat er wel voor over hebben. Dat hebben wij bij Transtec ook wel gemerkt bij bijvoorbeeld de Zuidtangent. Waar bij reguliere haltes de loopafstand maximaal 500m was en niemand op de fiets kwam, bleek bij de Zuidtangent dat loopafstanden opliepen tot 800m en er een groep fietsers was die een afstand tot 2km aflegden. Je ziet bijvoorbeeld ook dat als iemand op 1km van een treinstation woont, dat deze persoon zijn OV ontsluiting als heel goed beschouwd; terwijl iemand die 500m van een bushalte woont zijn OV ontsluiting aanzienlijk minder waardeert. Dat is een kwestie van het imago van de trein, maar ook van snelheid en zekerheid. Soms speelt frequentie daar ook een rol in, maar niet altijd. Overigens wordt ook het aandeel ouderen in het OV vaak overschat. In streekvervoer is 5% tot 10% 65-plusser, in de stad misschien 15%, maximaal 20%. Een dan zit er ook nog een verschil in fitheid van deze groep. Dus soms is het meer de perceptie waar je last van hebt, dan de daadwerkelijke statistieken.

Zit er een verschil in ontwikkelingen van het busvervoer in stedelijke gebieden (bijv. de randstad) en in landelijke gebieden?
Ja, ik denk dat de randstadreiziger verwender is. Op het platteland is een frequentieverhoging vaak een relatief grote verveelvoudiging van het aantal reismogelijkheden, omdat daar de basisfrequentie vaak lager is. En dat heeft voordelen, op het moment dat je terugreist hoef je minder rekening te houden met wanneer je bus gaat. Voor andere verplaatsingen, bijvoorbeeld een trip naar de bakker, zit daar een hele andere schaal in op het platteland dan in de stad.

Zit achter de vervoerkundige wijzigingen altijd een vervoerkundige afweging, of hebben politieke belangen hier ook mee te maken?

Er zijn vaak politiek maatschappelijke beslissingen die samenhangen met de vervoerkundige wijzigingen. De gemeente heeft vaak geen directe invloed. De provincie (vervoerregio's daargelaten) brengt het bestek voor een aanbesteding op de markt. Daarin wordt de vervoerder gevraagd een lijnennet aan te bieden. In sommige gevallen ligt het lijnennet al grotendeels vast. In andere gevallen kan het zijn dat een provincie op een andere manier eisen stelt. Bijvoorbeeld de provincie Zuid-Holland, waarbij dorpen met meer dan 300 inwoners tussen 7.00 en 19.00 minimaal 1x per uur een bus bediening moesten krijgen. De vervoerder heeft hierin dus veel meer vrijheid om het netwerk te veranderen. Politieke elementen spelen altijd wel een beetje een rol in de beoordeling van het plan van de vervoerder, maar zolang het aan de eisen voldoet zullen ze het moeten accepteren. Een voorbeeld van politieke druk was te zien in Leusden. De gemeente heeft zich nooit gerealiseerd wat de gevolgen van het bestek konden zijn en waren niet tevreden met de wijzigingen in Leusden. De gemeente heeft op dat moment geen macht, maar wel politieke druk. Echter, de provincie grijpt niet zo snel in, want als ze wel de lijn laten veranderen dan opent dit de mogelijkheden tot protest en/of procedures van verliezende vervoerders. Een concessie zit niet voor 10 jaar in beton gegoten, dus de provincie kan daar nog wel een beetje in sturen. Dat hangt er ook vanaf of ze bang zijn voor procedures. Maar het voornaamste moment van sturen is tijdens de aanbesteding. Daarnaast ook bij het jaarlijks nieuwe vervoerplan. Hierin kan de provincie de vervoerder vragen om aandacht te besteden aan een bepaalde situatie. Dan kan de vervoerder wel zeggen 'we hebben het uitgerekend, dit is geen goed plan', maar dan moeten ze wel argumentatie hebben.

Op wat voor manier wordt momenteel geprobeerd te voorspellen wat het effect is van veranderingen in het busvervoer?

In projecten waar wij bij betrokken waren, soms op verzoek van de overheid en soms de vervoerder, gebruikten wij het model van Van Goeverden, 1993 (ook wel bekend als het model Van Ommeren, 1990). Dat werd als voldoende onderbouwing beschouwd. De bewijslast ligt meestal bij de vervoerder, dus het komt niet heel vaak voor dat modellen worden gebruikt om de overheden te ondersteunen. Vaak verschuilen vervoerders zich achter bedrijfsgeheimen om te voorkomen dat ze hun onderbouwing moeten prijsgeven. Een modelberekening ontbrak daarom vaak, slechts de uitkomst werd gegeven.

Kentallen, zoals de Waaier van Brogt, worden maar beperkt gebruikt. Dit is vooral omdat er niet voldoende instaat, niet zozeer vanwege mogelijke (on)betrouwbaarheid. Maar het zijn vaak hele grove modellen en factoren; het zijn vaak vuistregels. Soms weten ze het niet, dus maken ze maar een aanname of grove schatting. Daar ligt dus zeker nog een gat in de kennis, wat betreft het gedrag van de reiziger bepalen. Een ander model dat in de jaren 60 is ontwikkeld, door AFGV (wat nu Movares is), gebruikte bijvoorbeeld een zwaartekracht model waarbij inwoneraantallen zijn gebruikt bij de voorspellingen.

Is het gebruikelijk dat vervoerders na de invoering van een maatregel of een concessiewissel checken of hun voorspelling klopten?

Er wordt enkel gekeken of er financieel gezien net zoveel binnenkomt als voorspeld, want dat is nodig voor de businesscase. Maar er wordt, voor zover ik weet, niet gekeken of wel het juiste model gebruikt is voor de voorspellingen. Terwijl de data toch heel duidelijk aanwezig is. Er wordt hooguit in specifieke gevallen gekeken om beslissingen opnieuw te onderbouwen.

In mijn model ligt het voor de hand om te focussen op de harde, vervoerkundige aspecten als reistijd en frequentieverhoging. Maar er zijn ook zachtere aspecten zoals comfort en betrouwbaarheid. Wat is de interactie tussen

alle aspecten en welke zijn belangrijk om toe te voegen aan het model?

Vanuit mijn perceptie speelt comfort, mits voldaan aan een bepaald minimum, niet echt een grote rol in reizigersgroei. Hooguit op de lange afstanden en dan is het een klein aspect. Ik denk dat reistijd, frequentie en betrouwbaarheid wel een belangrijke rol spelen. Al is er nog niet heel goed bekend wat de weging van die factoren is, er schijnen toch veel verschillende resultaten uit onderzoeken te komen. Dit wordt deels ook veroorzaakt door verschillende definities. Voor de vergelijking autoreistijd versus OV-reistijd, pak je bijvoorbeeld de afstand vanaf de voordeur, of van halte tot halte; neem je parkeertijd mee etc. Vaak maak je ook gebruik van aannames, bijvoorbeeld in de voortransport en natransport tijd. Maar de aannames die je daarin doet zijn wel van invloed op je uitkomst, terwijl het model er niks over zegt. Verder lijkt betrouwbaarheid wel een lastige om op te nemen in je model, want hoe ga je dat beschrijven. Qua betrouwbaarheid is er een omslagpunt. Er kan altijd wat misgaan, maar als er te vaak iets misgaat dan gaan reizigers hun reisgedrag aanpassen. Maar dat is heel gevoelsmatig. Waar dit omslagpunt ligt, is wel de vraag. Maar de betrouwbaarheid zal vooral boven een bepaald omslagpunt moeten liggen. Stel dit kantelpunt is 90% op tijd, dan zal of het nu 93% of 95% op tijd is niet zoveel meer uitmaken. Zie het in het kader van de Maslow piramide.

Wat zijn wijzigingen waarvoor de reiziger het meest sensitief is?

Ik denk dat frequentie daarin het meest belangrijk is. Dat verkort de totale wachttijd ook het sterkst. Het grootste comfort is spoorboekloos rijden, dus dat de bus vaak genoeg gaat dat je niet meer hoeft te kijken wanneer deze gaat. Reistijdwinst in de range van 2 minuten zal, zeker met de rijtijdspreiding die je toch al hebt, maar beperkt effect hebben. Op den duur leidt dit misschien tot reizigersgroei, maar dat zal heel langzaam gaan. Maar psychologisch kan het wel een effect hebben. Een bus die merkbaar omrijdt zal tot negatieve ervaringen bij de reiziger leiden. Het elimineren van dit omrijden kan de reiziger een positievere reiservaring geven. Dus zeker in de range van 2 à 3 minuten zal het meer het psychologische effect zijn dan de feitelijke minuten.

Hoe lang duurt het voordat reizigers hun gedrag aanpassen, nadat een verandering wordt doorgevoerd?

In het geval van reizigersgroei zit grofweg 60%-70% in het eerste jaar. 25% in het tweede jaar. Na die twee jaar ben je wel een heel eind, de laatste stukjes komen dan in het derde jaar er nog bij. Echter, bij reizigersverlies na een maatregel verlies je vaak van de een op andere dag alles. Daar zit dus een hele andere termijn aan vast en daar moet je als vervoerder dus ook wel rekening mee houden bij je plannen.

Is het moment waarop zo'n wijziging wordt doorgevoerd nog relevant voor de effecten? Bijvoorbeeld dat bij een concessiewissel de maatregelen een groter/sneller effect hebben omdat mensen hun reis toch gaan heroverwegen, terwijl dat bij een kleine wijziging minder snel zou zijn?

Niet heel het netwerk wordt gelijkmatig gebruikt door iedereen. Als iets niet op een van de grote lijnen is, dan is de kans groot dat je het niet zo vaak tegenkomt en toch weer opnieuw moet uitzoeken. Dus dat speelt minder een rol dan je denkt. Het is wel zo dat nu de meeste wijzigingen bij de dienstregelingswijziging in december worden doorgevoerd. Eigenlijk zou aan het begin van de zomer beter zijn; er zijn dan minder reizigers en dat maakt het makkelijker om kinderziektes op te lossen.

Wat is de periode na zo'n wijziging waarin je nog te maken hebt met kinderziektes?

Na aanbestedingen is dit meestal 1 à 2 maanden voordat het stabiel is. In uitzonderlijke gevallen kan dit oplopen tot een jaar. In het begin moet de chauffeur vaak nog aan zijn nieuwe route wennen, waardoor deze toch minder vlot rijdt.

Wordt er door vervoerders dan ook te scherp ingeschreven op concessies?

Ja, als je het chargeert is het dat. Een tenderteam haalt alleen succes als ze een tender winnen. Achteraf zijn mensen van de productieafdeling daar soms wat minder blij mee, omdat ze iets moeten leveren wat niet zomaar kan. Maar een beetje opportunisme hoort er wel bij. Vervoerbedrijven hebben een heel laag rendement, met 2% zijn ze vaak al gelukkig. Op de omzet en een concessieduur van 10 jaar is dat heel marginaal. En soms wordt er ook scherp ingeschreven met de gedachte dat als er problemen komen, dat er dan valt te praten met de aanbestedende overheid. Er is geen overheid die zich kan veroorloven dat de vervoerder failliet gaat, dus die is nog wel eens bereid hierin mee te gaan.

Ligt daar dan ook niet een rol voor de overheden om kritischer te zijn op wat er wordt aangeboden en dat de bieding door van de vervoerders beter onderbouwd zou moeten worden?

Vaak kun je als aanbestedende overheid heel lastig concreet plannen van de vervoerder als onrealistisch bestempelen. Dan zou je een week later bij de rechter staan; en dat verlies je. Vaak durven ze het niet aan, omdat ze simpelweg te weinig argumenten hebben. Je wilt ook voorkomen als overheid dat je op de stoel van de vervoerder gaat zitten; dat was niet het idee achter de marktwerking in het OV. Maar het is wel een dilemma, ook hoe je het bestek opschrijft. Als je bijvoorbeeld een punctualiteit van 90% eist, zullen alle vervoerders dit aanbieden, terwijl dit bij weggebonden OV in de praktijk helemaal niet geleverd kan worden.

Afgezien van vervoerkundige wijzigingen, zijn er ook secundaire effecten die van invloed zijn op de reizigersgroei. Wat zijn belangrijke aspecten en wat voor rol spelen ze in de reizigersgroei?

Schaalvergroting leidt tot extra vervoersvraag. Zie bijvoorbeeld de schaalvergroting in het onderwijs: zeker op het platteland wordt de afstand tot instellingen steeds groter. Daarnaast wordt de financiële situatie steeds beter, waardoor ouders sneller hun kind met de bus i.p.v. de fiets laten gaan. Dat is van belang in het regionale OV, maar ook in de stad zie je wel schaalvergroting.

Daarnaast neemt het sociaal recreatieve reismotief af. Mensen winkelen toch vaker online. En niet in de laatste plaats, er is sprake van verspreiding. Waar vroeger alle faciliteiten in het centrum waren, zit de bioscoop tegenwoordig langs de snelweg, het stadhuis in een nieuwe wijk en dat maakt het voor OV veel lastiger. OV moet het namelijk hebben van gebundelde vervoersstromen. De spreiding zal de invloed van de schaalvergroting grotendeels tenietdoen.

De groei die nu op buslijnen te zien zijn, wordt die groei meer veroorzaakt door de vervoerkundige veranderingen of juist door secundaire effecten?

Over de verdeling daarvan is het gissen. Ook omdat in verschillende gebieden binnen Nederland de situatie verschillend is. In de randstad zijn er meer keuzereizigers. Daarnaast krijg je ook steeds meer combinatieritten, waarbij ouders bijvoorbeeld op de terugweg na hun werk nog langs de crèche moeten. In de stad lukt dat misschien nog wel, maar in ruraal gebied is dat zonder auto niet te doen. Ook de hoeveelheid ouderen die een auto en een rijbewijs hebben is de afgelopen tiental jaren sterk toegenomen. En dat zijn dingen die van invloed zijn op het OV gebruik.

Aan de andere kant kan OV gebruik ook groeien, bijvoorbeeld door parkeerproblemen in de randstad. Ook werkgevers kunnen daarin een rol spelen met hun reisvergoeding. En er is een trendverandering geweest de afgelopen generaties. Waar vroeger de opvatting was dat als je in de auto stapt je nog steeds thuis was; je hebt je radio, je kan vrij roken en je hebt pas het gevoel dat je op het werk bent als je uit je auto stapt. De nieuwe generatie heeft dat juist bij het OV, want daar kunnen ze nog gewoon appen en een filmpje kijken.

In kleine steden (tot ca. 70.000 inwoners) zie je nog een cultuurverandering. Hier wordt namelijk steeds meer gebruik gemaakt van de fiets, terwijl het stadvervoer afkalft. Dit heeft te maken met o.a. de OV fiets, de elektrische fiets en dat ouderen steeds fitter zijn. En in kleinere steden kun je vaak nog goedkoop parkeren met de auto en hem thuis voor je deur parkeren. Het stadsvervoer heeft hier dus een afzwakkende rol.

Voor het model dat in deze thesis geproduceerd zal worden, wat zijn belangrijke aspecten om mee te nemen?

Het uitgangspunt is duidelijk, het moet hanteerbaar zijn. Vergelijkbaar met het Van Ommeren (Van Goeverden and Van den Heuvel, 1993) model, dat een kwestie is van een paar waarden in een spreadsheet invullen. Zo makkelijk zou het moeten werken. Doe een aantal praktijktoetsen, op basis van historische data en zeker ook op gezond verstand. Daarmee moet je kijken of je de gebruikers voldoende gebruiksgemak geeft. Het is ook van belang dat duidelijk is hoe het model is opgebouwd, want dan kun je ook de uitkomsten beter toetsen en controleren. Grote modellen hebben wel hun waarde, maar worden niet voor niets 'mist in – mist uit' modellen genoemd. Probeer het simpel te houden.

Het aantal inputfactoren moet ook niet te groot zijn. Deels vanwege de hanteerbaarheid, maar ook hoe meer variabelen, hoe groter de kans dat gegevens onbekend zijn en er inschattingen en aannames gemaakt moeten worden.

Wat ook een relevant kengetal is, is het aantal OV gebruikers per 100 inwoners. Wel onder de aanname dat dit spiegelbaar is, dus evenveel mensen gaan heen als terug. Op 100 inwoners is 50 OV gebruikers het maximum wat in Nederland haalbaar is. In rurale gebieden zakt het gebruik naar 1 of 2 verplaatsingen per 100 inwoners. In OV chipkaartdata zou je zoiets makkelijk kunnen terugvinden en daar een patroon in kunnen zoeken. Het OV gebruik in industrie/bedrijvengebieden is vaak zeer beperkt. Dus dit kengetal op basis van inwoneraantal is goed bruikbaar. Bij 25 OV-verplaatsingen op de 100 inwoners heb je het al heel goed gedaan. Sommige wijken rond de Zuidtangent gingen naar 35, maar dat geeft toch wel de grenzen aan. In heel Nederland ligt het rond de 5. Het is een grof, maar heel bruikbaar cijfer, want het geeft een grenswaarde aan.

En qua zonering keek ik soms op wijkniveau, soms op dorpsniveau. Dit was afhankelijk van de context. De mate van potentie van een zone is gebiedsafhankelijk en kwaliteitsafhankelijk; frequentie bijvoorbeeld.

A.2. Expert meeting EBS

Present: Frans de Kok, Joost Rienderhoff, Marcel Fledderus, Robin Berghouwer
Vervoerkundigen / transport engineers within EBS (a.o. concession Waterland, concession Voorne-Putten & Rozenburg, concession Haaglanden and tender department)
EBS Public Transportation BV.

23 July 2019 | 13.00-15.00 | EBS Purmerend

A summary of the meeting is shown here.

The meeting was structured as follows:

1. Introduction and goal of the expert meeting
2. Introduction and goal of the research, incl. methodology
3. Description of the results per OD pair
4. Discussion of the results per OD pair
5. Expert judgment on elasticities (tables) and general questions
6. *Break*
7. Description of the results per line
8. Plausibility check of all entries
9. Discussion of the data sheet and proposed model

After introducing the results per OD-pair, a small discussion has taken place about whether the results are recognized by the experts and what could be the causes of the results. The main remarks are that there are many alternatives within the public transport system in Waterland (an alternative is available even without a mode shift) and the difficulty that passengers can no longer be identified after they transfer.

Before continuing with the results per line(section), some questions have been asked to gain further insight in the subject:

- *Is there an effect when changing a regular bus line to a community service bus (Buurtbus) and are there different elasticities for those buses?* The bus becoming a community service bus has on its own not an effect. However, the decreasing size of the bus probably does. This is related to accessibility and traveling in larger groups, but also about perception and social status.
- *Is there a 8-person bus vs 12m bus elasticity?* Yes, an 8-person bus is often experienced as less comfortable and pleasant compared to a 12m bus, even regardless of a lower capacity/crowding.
- *Are elasticities different in the weekends?* Yes, this is related to different user groups (and therefore region). Generally the elasticities on Saturdays are comparable to elasticities during off-peak hours.
- *Which user group is most/least sensitive to LOS changes?* This is mostly related to captives. Captives don't have other options, so they will be less sensitive: scholars, students and people without a car. Sensitivity of commuters depends on the region and its characteristics, such as alternatives and congestion. Car users are the most sensitive users, also because it is such a large group.
- *How many minutes of travel time change is necessary for a relevant effect?* On the total journey, so including access, egress, transfers etc., a travel time decrease of ca. 10 minutes is necessary to have a significant effect on ridership. But this is also dependent on the alternatives available and possible transfers. However, experience from Waterland has also shown that passengers massively chose an express service over the regular service, despite being only 3 minutes faster. However, the growth in the express service are unlikely to be all new bus passengers, rather ones switching from the slower to the faster service.
- *What is the effect of changing a peak hour LOS / off-peak hour LOS on the ridership the rest of the day?* Since the LOS during off-peak hours is often worse, it can be essential for those traveling at least one leg of their journey during off-peak hours. The chain is as strong as the weakest link. It helps when the LOS is attractive during the full day, since it also offers some freedom. A change in off-peak has effect on peak, more than a change in peak on off-peak.

- *Are differences per concession expected?* Yes, car ownership is also an important factor and this varies over the concession. Furthermore, the users are different over the regions. Elasticities are expected to be higher in Randstad-like areas.

Furthermore, the following points came up during the expert meeting:

- Arrival/departure times can be important as well, mainly for schools. Increasing frequency does not necessarily increase the number of options, when the arrival/departure time of the passenger is fixed.
- Community service bus lines are expected to be less sensitive to changes, with a very loyal customer group.
- The amount of changes in the total network might have effect. If only one small changes is implemented, less effect is expected.
- Marketing is important. When people don't know about a faster/better alternative, they tend not to use it and counter intuitive behaviour is the result.
- Busier lines are expected to have larger elasticities.

After the questions, the experts are asked to estimate the elasticities based on their experience/knowledge (before the results of the analysis are shown) (figure A.1 and figure A.2). Explicitly no context about the concessions, usage or lines is given, such that a clean result of the effect of the measure is estimated (and it is thus not an estimation of the results of each specific case analyzed in this thesis). This can be used to determine how much of the effect found in the results of this thesis are caused by external effects i.s.o. the measure itself. Though there has been given additional information, as to the total amount of IVT and the frequencies in the unmentioned hours, enabling a proper understanding of the LOS changes.
Next the plausibility check has been performed on all data entries of the analysis per line. Two entries have been classified as non-plausible, all others as plausible or possible. In some cases remarks have been added, often context related; those will be added to the data sheets in the model.

Finally the model and the data sheets have been discussed. An example of a data sheet is shown (Waterland line 121). It is suggested to add an OD-table showing the main travel relations of the line.

Frequency	Weekday	Peak	Off-peak	Saturday	Sunday
1>2x			8%		
2>1x		-14%	-9%		-23%
2>3x		5%			
2>4x	31%	18%	8%	16%	
4>2x			-8%	-21%	
4>6x			5%		
0,67>1x				19%	
5/6>8x		5%			
peak>full day	21%				

IVT	Weekday	Peak	Off-peak	Saturday
| -3 min	4%		0%	
| - 7 min	13%	12%	8%	
| - 10 min	14%			11%
| - 18 min			12%	

Other	Weekday
peak 2>1x and -7min full day	-5%
Implementation Qlink (of eq)	13%
12m iso 8-person bus	6%
8p iso 12m bus	-10%
Additional transfer	-18%
8p with add. transfer	-29%
Off-peak -3 min Peak -7 min	9%

Figure A.1: The average results of the estimations during the expert meeting

Frequency	Weekday	Peak	Off-peak	Saturday	Sunday
1>2x			3 to 20%		
2>1x		-7 to -20%	-5 to -20%		-1 to -40%
2>3x		2 to 10%			
2>4x	20 to 40%	10 to 20%	2 to 20%	5 to 30%	
4>2x			-3 to -20%	-5 to -40%	
4>6x			0 to 10%		
0,67>1x				1 to 40%	
5/6>8x		2 to 10%			
peak>full day	2 to 50%				

IVT	Weekday	Peak	Off-peak	Saturday
| -3 min	0 to 5%		0 to 1%	
| - 7 min	7 to 20%	4 to 20%	2 to 20%	
| - 10 min	6 to 20%			5 to 20%
| - 18 min			5 to 30%	

Other	Weekday
peak 2>1x and -7min full day	0 to -10%
Implementation Qlink (of eq)	5 to 20%
12m iso 8-person bus	0 to 10%
8p iso 12m bus	-5 to -20%
Additional transfer	-10 to -20%
8p with add. transfer	-20 to -40%
Off-peak -3 min Peak -7 min	6 to 10%

Figure A.2: The range of results of the estimations during the expert meeting

A.3. Workfloor experience check EBS

Present: Robin Borgmeijer (bus driver in concession Voorne-Putten & Rozenburg) and Kenneth Semeyn (team manager in concession Voorne-Putten & Rozenburg)

10 September 2019 | 09.45-11.00 | EBS Hellevoetsluis

The meeting took place in an informal setting. Firstly, the topic and goal of the research have been explained. Then, guided by some questions, a discussion was held, summarized below:

In the previous concession under Connexxion, not many LOS changes were implemented in the concession. In an already profitable concession there was not sufficient incentive to implement level-of-service changes. This resulted in roughly stable ridership, although there is always some variation within lines. Most variation originated due to road works. The first thoughts about the major change with the new concession, R-net introduction including stretching of lines with a higher frequency, was scepticism. However, that scepticism has been replaced by enthusiasm after it has been seen in practice. It seems to be working and passenger numbers seem to increase. Whereas initially people would walk 5 minutes to a nearby bus stop with low frequency and slow routing, they now cycle 5 minutes to a R-net stop and actually prefer it. However, bus stops are not adjusted to R-net quality and lack parking facilities for bikes and sufficient shelter. Most people do not seem to value R-net just by its branding, their perception is based on line number and the frequency and travel time with that line. In fact, R-net is sometimes not even recognized as a brand, but as a company name. An additional advantage of the higher frequency is that it is no longer necessary to plan a trip; with a random arrival of the passenger at a bus stop, there is always a bus arriving within a few minutes. The removal of this psychological barrier can also be advantageous. In the first months after implementation of R-net and the new network, there were many complaints. This decreased significantly after 2 to 3 months; people began to get used to the new network.

Important to consider is that Connexxion line 104 also operates between Hellevoetsluis and Spijkenisse, complementing R-net line 404. However, Connexxion line 104 has a lower tariff; with a small difference when using smart card, but with significant differences >€1 with ticket sales. In some cases, passengers rather wait for the cheaper Connexxion bus, instead of traveling with EBS. Furthermore, the timing is not always with constant headway. Though in the statistics it is often assumed that a simple ratio is sufficient to estimate the Connexxion passenger numbers, this might not be entirely true.

Voorne-Putten is an island with mostly low educated, but high income workers; often working in the port of Rotterdam. This is disadvantageous for public transport ridership, since car ownership is high. The network is mainly based on large travel flows to/from Spijkenisse Centrum, where one can transfer to the Metro to Rotterdam. A rough estimate is that 80% of the bus trips in Voorne-Putten are to/from Spijkenisse while 20% is within the island. Recently, urban development has taken place in Zuidland, Brielle and Spijkenisse. Maaswijk is a young and growing neighbourhood of Spijkenisse with rather well used bus service. De Akkers/Waterland used to be a neighbourhood with a lot of passengers and bus services, however, due to aging and the decreasing presence of children and youth, but also poor reliability of the buses, service and usage has been decreasing over the years.

The dedicated, bi-directional bus lane to/from Spijkenisse makes the bus very competitive to the car; during peak hours congestion can be a major issue on Voorne-Putten. Cycling can be an alternative, mainly during good weather conditions. What is often seen is scholars cycling in summer months and then getting a bus subscription for the winter months. In the concession, shared bikes are available, but hardly/not used, possibly because it is expensive when regularly used.

Tourism is mainly located along the beaches, with various camp sites. However, outside the summer months this is hardly relevant.

Furthermore it is suggested that students are more dynamic in their behaviour, they easily change their behaviour and/or line or time of departure; while older commuters who have been taking the same bus for years are less dynamic.

Level-of-service factors which are thought to be essential are, besides frequency and in-vehicle time, reliability, prices, operating hours and the ability to find a seat. Operating with a 8-person minivan instead of a 12m bus is expected to have a negative effect, since comfort is lower and perception towards these smaller vehicles is negative. For data analysis, both March and November are thought to be valuable months to analyze.

Lastly, some of the changes analyzed in this thesis have been discussed:

- Line 87 from peak only to full day operation: seems to have significant growth. However, it must be noted that previously people might have used stop Halfweg 2 which is/was serviced by multiple lines.
- R-net and network reform in Hellevoetsluis: after a short period of settling down, the usage seems to have grown.
- Line 84 to Maaswijk off-peak from 4x/h to 6x/h: Maaswijk is a neighbourhood with a lot of potential and buses are barely/never empty so it seems to be servicing a demand.
- Line 85 from 2x/h 12m to 4x/h minivan: Growth is expected, during peak hours the maximum number of passengers is already reached on occasion.
- Line 102 from 4x/h to 2x/h during off-peak hours: Cycling to R-net 404 is now a well used alternative. In addition the line used to be continue as line 101, however the link with line 101 is lost; i.e. the center of Hellevoetsluis can no longer be reached with line 102, a transfer is necessary. This probably causes the main loss, though the line has never been very busy.

B
Appendix OD-based analysis reflection

The question arises why the analysis per OD-pair provides a large spread of results, whereas a clear trend is hypothesized. First it is noted that a significant part of journeys made are infrequent. As indication, in Waterland about a third to a half of the trips are made with OV-chipcard without product (see also figure 8.5), implying infrequent use. This means that stochastic variation will always be present in usage of the bus. With lower usage, this stochastic variation will have a larger effect. The unexpected results might be partly subject to this stochastic variation. However, there are more factors of influence.

A GIS analysis is performed, in which the absolute change in ridership is plotted per stop (figure B.3). One of the issues is that there is a large variability in growth/decline of passengers at each stop. Usage of a certain stop can grow, while usage at the neighboring stop declines and vice versa. In general there is a decline in total passengers numbers, which can be explained by the decrease in number of timetable hours due to the network changes and is confirmed by the trend in table 6.1. The GIS analysis suggests that there is interaction between the stops and in the network, which is not captured in an OD-based analysis.

The results are further analyzed by checking the passenger behavior on individual lines. This analysis is shown for line 121, since it is an isolated line, where network effects likely play the smallest role. In August 2014, the frequency during peak hours has been decreased from 2x/h to 1x/h, which is equal to the frequency during the off-peak hours. The histogram of the ridership changes per OD-pair show that indeed most ODs lay on the negative half, but large quantities of data on the positive half (i.e. seeing an increase in ridership) (figure B.1). This shows the large variability of ridership between OD-pairs.

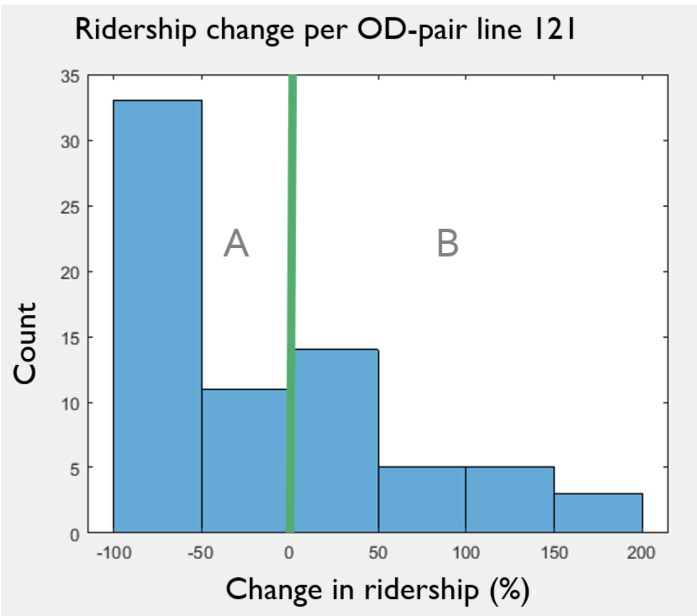


Figure B.1: Frequency elasticity histogram of the OD-pairs of a single line (121) (November 2013 vs November 2014), weekdays only. Only those ODs with monthly ridership > 3 in both years. All values > 300% have been removed.

The OD table increases insight in the passenger behavior, which shows the difference in ridership between November 2013 and November 2014 (figure B.2). This pivot table shows that the main mutations are found at stops *Wormerveer, Edisonstraat* and *Wormerveer, Station*. Those stops are both at walking distance of the station. The effect is thus largely a trade-off between two stops servicing the same destination. Most of the values are rather low, with a mutation of just a few passengers. There are also significant mutations which are opposite to hypothesized. E.g. *Wormer, Spatterstraat* to *Purmerend Tramplein* grows 61 passengers a month.

When checking the results per OD-pair, it also shows a large variability over the different hour blocks. For example, when the frequency increases in the peak hours, the hour block just after the peak can be subject to a decrease in ridership. Possibly this is caused by a change in travel behavior by passengers. If a more suitable option becomes available in the peak (due to the frequency increase), they might shift their time of departure. Another effect is seen on hour block level on e.g. line 121 between *Wormerveer, Station* and *Purmerend, Tramplein.* Both ends are transfer stations, either to the train or a large set of buses. When frequency was decreased, in some cases the usage in one direction decreased, while the other direction increased. Since most trips are likely to be part of a larger journey, possibly their trip is now faster by traveling in the opposite direction and to transfer somewhere else.

Also of influence is the following: *Wormerveer, Edisonstraat* wasn't used often in 2013, meaning it often had 0 ridership. Going up from 0, no growth percentage can be calculated; all ODs with 0 have been thrown out. If *Wormerveer, Station* sees most of its passengers go to *Edisonstraat*, but not all, it does see a large decrease in usage; but the growth in *Edisonstraat* is not shown, since it was 0 the year before.

OD table	Destination																									
Origin	Purmerend, Tr	Purm	Purm	Neck,	Jisp, Ji	Jisp, Ji	Jisp, D	Jisp, B	Jisp, D	Jisp, D	Jisp, 't	Worm	Worm	Worm	Worm	Worm	Worm	Worm	Worm	Worm	Worm	Worm	Worm	Wormer	(leeg)	Total
Purmerend, Tramplein		-1	-8	-62	3		7	12	-21	5	-12	-17	-7	-12	-8	-34	-60	17	23	-9	-40	-45	73	-126		-322
Purmerend, Sluisbrug	0		0	-7			-2	-2	-4	-1	-2	-2			-2	-1	-12	-18		-2	-5	-3	-2	-41		-106
Purmerend, Graanmaalderij															1			3			1			0		5
Neck, Neckerbrug	-52	-6			-1					-1	5					0	1	4	-1		1	-2	10	-15		-57
Jisp, Jisperdijkje Nr 3	-1								-1							-1	0					3				0
Jisp, Jisperdijkje Nr 6	0									1								1						-14		-12
Jisp, Dorpstraat Nr 137	0																	1			-1					0
Jisp, Brandweerkazerne	18	0	-1												-1		-1	3	0		-3	0	21	-13		23
Jisp, De Bonte Os	0	-1		1											1		2	2			-5	1	9	-13		-3
Jisp, De Lepelaar	-21	0		-1			-3									-1	-2	-4			0	1	40	-95		-86
Jisp, 't Weiver	-3	-3		3											-4		-1	-3	-1			-1	17	-61		-57
Wormer, Keerlus Wormer Oost	-18													-1			0						6	-9		-22
Wormer, Oosteinde	-15																	6			-2	-1	10	-37		-39
Wormer, Raadhuis	-17													-1			-1	-5					24	-35		-35
Wormer, Mariastraat	-26	-3	1	-1				1	-1	-3	-1			1				0				0	15	-39		-56
Wormer, Wezenland	-8	-1		1				-2		-2								1			2	-1	34	-26		-2
Wormer, Prins van Oranjestraat	-72	-38	2	1				3	2	-3	-2	1		-1	-1				4		1	16	172	-175		-90
Wormer, Zaandammerstraat	20	-12	1	3	-1			2	1	-6	-6		0	-2	0	1			-6		-2	-2	64	-148		-93
Wormer, Spatterstraat	61	-1		-1						6	0		1	1			-1	-1		-1	0	2	98	-141		23
Wormer, Waterzolder	-1	-1																			-1	1	50	-55		-7
Wormer, De Balk	-5	-4	2				1	-1	-2	-2	-3		2	3	1	2	1	1				-2	29	-26		-3
Wormer, Nieuweweg	-41	-8	-7			-2	-1	-1	-1	3	-3	1	2	3	-3	-2	2	0	1				4	-22		-75
Wormerveer, Edisonstraat	-65	-14	-12	-4		-3	-5	-11	-3	-48	-33	-5	-19	-42	-14	-22	-60	-47	-80	-31	-14	-2		-12		-546
Wormerveer, Station	20	-18	-7	14		-3	-1	5	0	11	-6		-4	15	-9	18	62	11	38	22	20	17	7			212
(leeg)																									0	0
Total	-226	-111	-29	-53	1	-8	-4	6	-30	-40	-63	-22	-25	-36	-39	-40	-70	-28	-22	-21	-48	-18	681	-1103	0	-1348

Figure B.2: Mutations in ridership between November 2013 and November 2014 for line 121. All stops are in order of the bus route.

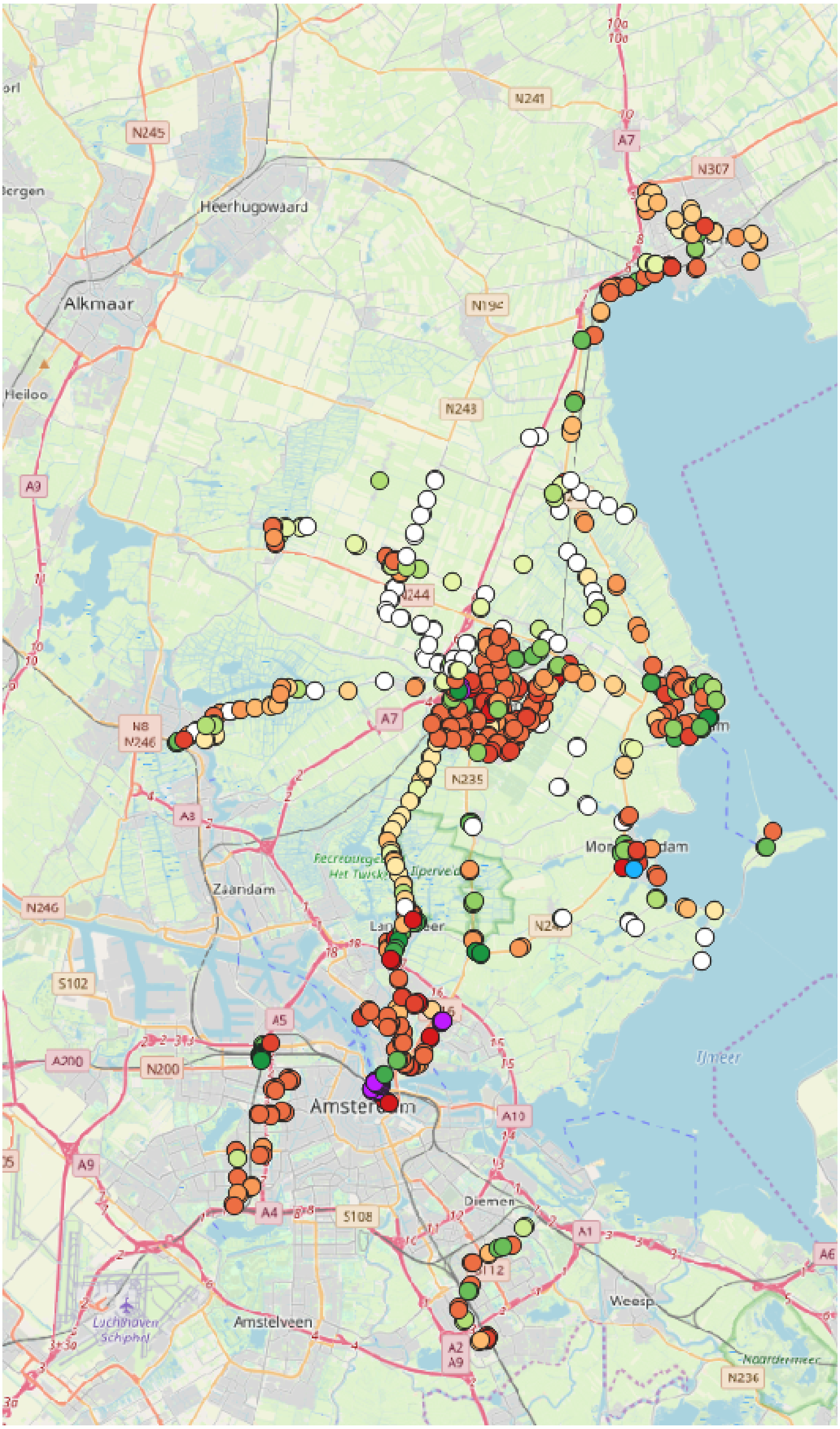
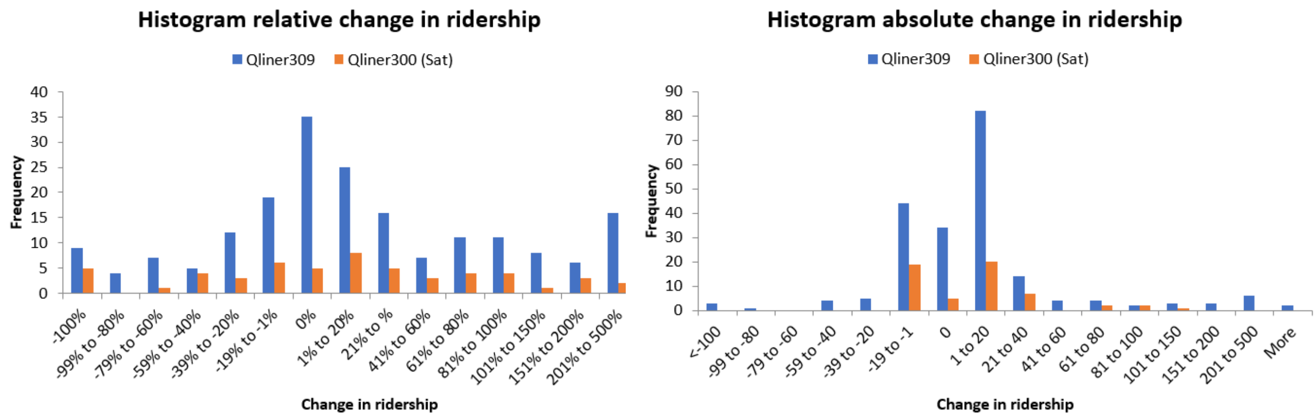


Figure B.3: Change in number of entries per stop in November 2013 versus November 2014. A gradual color scale is used, based on absolute user numbers; green implies an increase in ridership, red a decrease, blue an extremely sharp increase and purple an extremely sharp decrease.

The question also arises whether the methodology would work in another concession, e.g. Groningen-Drenthe, or that the methodology in general does not lead to suitable results. Two lines from the concession Groningen-Drenthe have been analyzed per OD-pair to answer this question. The off-peak frequency increase from 2x/h to 4x/h from Qliner309 on weekdays and the frequency increase from 2x/h to 4x/h from Qliner300 on Saturdays both show that numerous OD-pairs show a decrease in ridership whereas an increase would be expected (figure B.4). For Qliner 300, only the OD's between Groningen and Emmen station have been included. Most OD-pairs show an increase, but comparable to what has been seen in Waterland, there is a large spread over the spectrum. The effect is thus probably not limited to the concession Waterland, but can likely be generalized.



(a) Relative ridership change per OD pair.

(b) Absolute ridership change per OD pair.

Figure B.4: The change in ridership of two lines in Groningen-Drenthe. Note that both in relative as in absolute numbers, there are numerous OD-pairs with a decrease in ridership, whereas an increase was hypothesized.

Furthermore, the stops at the Qliner in Groningen-Drenthe are often further apart. E.g. on line 300, none of the stops lay in each other's zone of influence; most lay tens of kilometers apart. This contributes to the understanding that interchanging between stops is not the only issue that causes the unsatisfying fit of the results, possibly larger network effects are essential. As recognized during the expert meeting (Expert meeting EBS, Appendix A2), network effects may also play a large role in the OD-analysis of Waterland, since there are many alternatives within the public transport network.

Furthermore, non-LOS related factors could play a role. This would most likely have to do with the urban area around a certain bus stop. On the level of detail of the analysis, with this many stops, it is unrealistic to trace all the possible factors near each bus stop.

Lastly, other, not analyzed LOS related factors could play a role. As identified in Chapter 2, there are more LOS factors than only IVT and frequency. E.g. a change in reliability might not have been a consciously taken measure, but can be the consequence of the network redesign and thus of effect on passengers.

To summarize, 5 reasons are identified which can explain the difficulty in finding converging elasticities:

1. Stochastic variation, i.e. there are infrequent trips that are made in one year but not in the other, which leads to (limited) natural variation. This has a larger effect on smaller numbers, which occur when working per OD-pair.
2. Interchanging between nearby stops, i.e. one stop decreasing and the other increasing, while they are in each other's zone of influence. This is shown in the line 121 example.
3. Network effects, i.e. passengers do not only experience individual lines or OD-pairs. Mainly when they have to transfer anyway, different options can be attractive and preference can change even if only one of them is subject to a LOS change. An example is seen in line 121 (Waterland), where transfer are likely. The line connects to a railway station on one side and a bus station on the other side. When the frequency decreased, at certain stops a change in main used direction could be seen, i.e. people traveling to the train station instead of bus station, possibly because on the larger journey that option became more attractive.
4. Non-LOS related factors playing a role.
5. Other, not analyzed LOS factors playing a role.

C

Appendix Further data analysis per line - example line 121

The description of the characteristics of the line, which are presented on the data sheets, include the ones listed in table C.1.

Table C.1: Check list data sheets per line.

Check list	**Remark**
Line number	Public line number
Concession	Waterland, Groningen-Drenthe or VPR
Product branding	
Type of line	e.g. city line, regional, rural, long-distance, etc.
Type of equipment used	e.g. 12m bus, midi bus, touringcar, 8-person vehicle.
Route/line section analyzed	
Main OD's along the line	
Moment of LOS change	
Frequency old vs frequency new	
IVT	IVT is mentioned for the main/most important OD pairs
VF	average / most relevant VF factor
Transfers likely?	Classified as 'unlikely', 'possible' or 'likely'
Urban development	
Neighborhoods served	Neighborhoods incl. inhabitants, density, households, urbanity

The equipment used mainly refers to capacity and comfort level. A distinction is made between 5 types: 8-person vehicle, midi bus, 12m standard bus, high capacity bus (18m articulated or 15m regular) and touringcar (figure C.1).

The in-vehicle time refers to the most common scheduled in-vehicle time. Which modes are competing depends on the infrastructure and the distance. Bike is seen as a reasonable alternative if the distance between major destinations of the line is below 10km. For e-bikes the range is larger; this is not taken into account (also since it is was less common in the past).

Regarding the VF factor, a door-to-door factor is assumed. The car travel time is determined by using the Google Maps travel time. The bus travel time is calculated by using the scheduled in-vehicle time and adding access and

Figure C.1: Distinction between types of equipment used. Top left: 12m standard bus. Top right: high capacity (18m articulated) bus. Bottom left: 8-person vehicle/midibus (dependent on amount of seats). Bottom right: touringcar.

egress times. It is assumed that the access and egress distance is on average the maximum distance of influence of a bus stop: 450m (Transtec adviseurs B.V., 2010); i.e. on average 450m walking as access and 450m walking as egress. With an average walking speed of 5km/h, this takes ca. 11 minutes. In addition, 3 minutes of waiting time at the stop is added.

For the quantitative section, the following five graphs are produced for each line (for Waterland all graphs can be produced, for VPR and Groningen-Drenthe, not all graphs can be produced due to lack of data):

- The monthly ridership for the required type of day.
- The change in ridership compared to the same month in the preceding year; i.e. showing growth factors.
- The generalized OD-table, such that a rough indication of the usage can be seen.
- The absolute usage of each product type class on that line for the months used in the comparison.
- The share of each product type class on that line for the months used in the comparison. Together with the previous graph, this can offer insight in the type of user of the line and the type of user that is most sensitive to the change in LOS.

Finally, in the qualitative section, those effects which are thought to be of effect, but cannot quantitatively be compensated for, are mentioned. This includes urban development (though a numerical analysis is shown in section 8.1, the specific cases) and competing modes.

The application of this full analysis of a line is shown below, line 121 in Waterland is used as an example.

Waterland Line 121 | Wormerveer Station - Purmerend Tramplein

Line type: regional
Concession: Waterland
Equipment: midi bus LOS change: peak hour frequency from 2x/h to 1x/h (August 2014)
Line 121 is a rural line connecting Wormerveer Station with bus station Purmerend Tramplein, driven with midibuses (21-person Mercedes Sprinter City).

Effects to keep in mind: Purmerend Tramplein out of order in 2014, replaced by Melkwegbrug nearby. This has been accounted for in the quantitative analysis.

The full route has a length of 14.1 km, the bike would therefore be an alternative (however not a very favorable one). By car the full route takes 25 minutes, however between Wormerveer Station and Purmerend Tramplein an alternative route can be taken, in only 19 minutes. The main destinations along the route are the towns Wormer, Neck and Jisp. Wormer is also serviced by Connexxion, though the overlap is limited to the first three stops of the route of line 121. The center of Wormer can be reached within 7 minutes by car from Wormerveer Station, Jisp in 12 minutes and Neck in 20 minutes. From Purmerend Tramplein, Neck is 8 minutes by car and Jisp is 15 minutes by car. Jisp and Neck are not serviced by any other public transport services. Purmerend Tramplein to/from Wormerveer Station can also be travelled by train in combination with another train or bus, with a travel time between 43 minutes to over an hour. Bus 121 takes 28 minutes for the full route and is therefore way faster. However, due to the low frequency, taking the detour by train/bus can be faster (dependent on your time of departure).

The ridership of line 121 sees a clear decrease in usage after the frequency decrease in August 2014 (figure C.2).

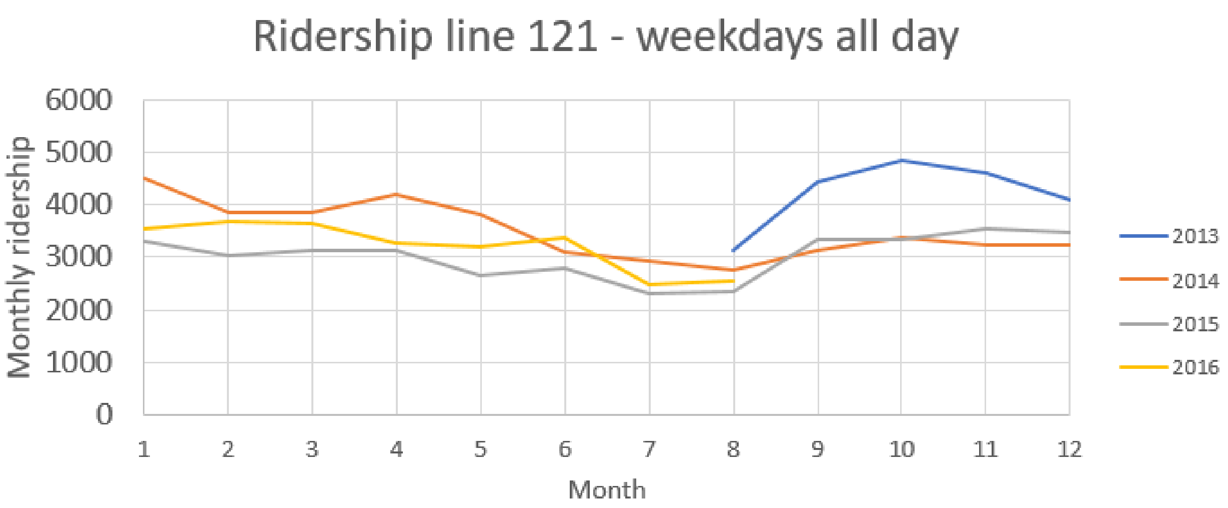


Figure C.2: The monthly ridership of line 121 for weekdays only, all operating hours.

The decrease in ridership is consistent over the days (figure C.3), i.e. all days there is a clear decrease in ridership. Figure C.3 also shows that the line is used most often on Tuesdays and Thursdays.

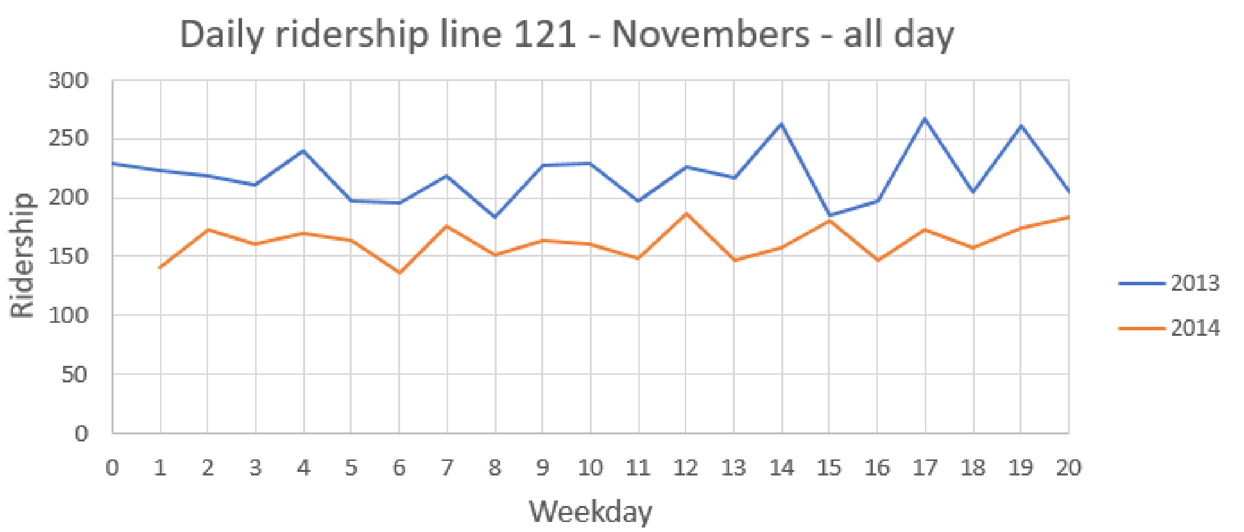


Figure C.3: The daily ridership of line 121 for weekdays only, all operating hours, Novembers only. Day 1 is a Monday, day 2 a Tuesday etc. Since November 2013 started on a Friday, this is day 0.

Most of the passengers lost were using the Student OV product, i.e. they were students (figure C.4). Figure C.5 shows that the decrease in passengers varies over the months. Although this is partly caused by the variation in number of weekdays in a month, which differs per year.

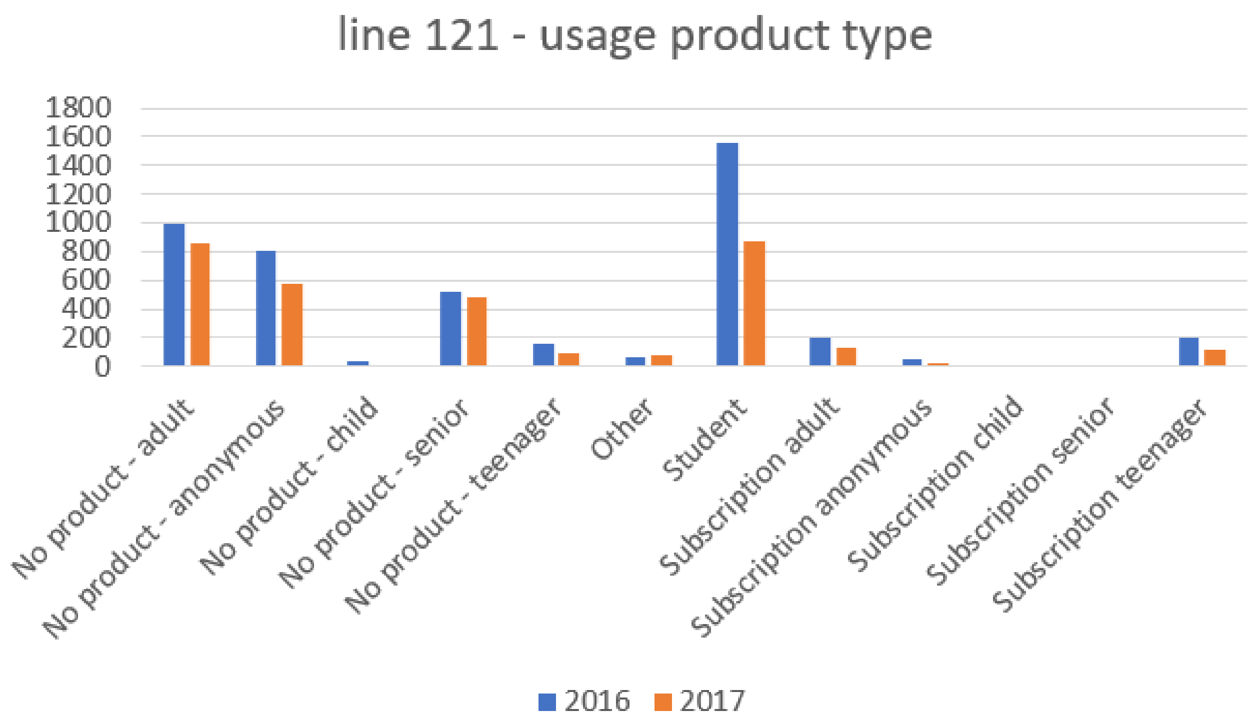


Figure C.4: Product type used in line 121 - weekdays only for November 2013 vs November 2014. Note that non-smart card sales are not included.

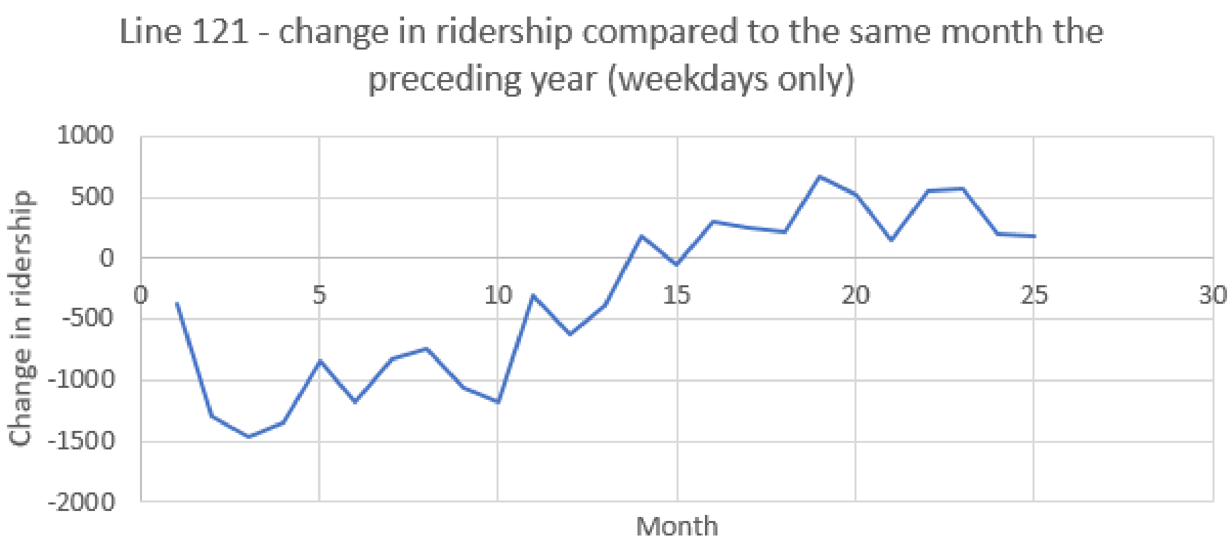


Figure C.5: Change in ridership of line 121, each month compared to the same months in the preceding year. Weekdays only. Month 0 is the month of the LOS change.

D

Appendix Full set of results line-based analysis

Category	Line	Concession	LOS change	Type of day	Growth full day	Growth peak	Growth off-peak
freq	301	WL	2x > 1x	Sunday	-9%		
freq	87	VPR	peak only to full day	Weekdays	43%		
freq	85	VPR	2x 12m > 4x 8p	Weekdays	8%		
freq	102	VPR	off-peak 4x > 2x	Weekdays	-38%	-45%	-34%
freq	84	VPR	off-peak 4x > 6x	Weekdays	-2%	-2%	7%
freq	403	VPR	2x > 4x + R-net	Saturday	32%		
freq	403	VPR	off-peak 4x > 2x + R-net	Weekdays	-11%	-12%	-13%
network	404	VPR	R-net, stretching of lines, higher freq	Weekdays		12%	14%
other	32	GD	1 additional ride (+stud OV MBO)	Weekdays	23%		
other	13	GD	off-peak with 12m i.s.o. 8p bus	Weekdays	3%		
freq	Q309	GD	off-peak 2x > 4x	Weekdays	21%		
freq	Q309	GD	afternoon peak 5/6x > 8x	Weekdays	5%		
ivt	119	GD	-3 min, improved connections	Weekdays	-6%		
freq	65	GD	off-peak 1x > 2x	Weekdays	10%		
other	Q12	GD	Qlink Emmen - Klazienaveen	Weekdays	16%		
freq	Q300	GD	2x > 4x	Saturday	20%		
ivt	39+133+139	GD	off-peak -18min	Weekdays	83%		
freq	26	GD	0,67x > 1x	Saturday	18%		
freq	61	GD	peak direction 2x > 3x	Weekdays	14%		
other	Q6	GD	Qlink6, PM peak 2 > 4x on a section	Weekdays	13%		
other	14	GD	1 additional ride (+stud OV MBO)	Weekdays	26%		
freq+ivt	122 vs 125	WL	peak 2x > 1x en -7min all day	Weekdays	-19% | -12%	-19% | -12%	-9% | 7%
ivt	311 vs 315	WL	peak -7min, off-peak -3min	Weekdays	21% | 33%	32% | 49%	7% | 11%
ivt	103	WL	IVT -10 min (-€1,50)	Weekdays	121%		
freq	103	WL	(super) off-peak 2x > 1x	Weekdays	-16% | -17%	-14% | -13%	-20% | -26%
freq	121	WL	peak 2x > 1x	Weekdays	-26% | -22%	-38%	-5%
freq	305	WL	peak 2x > 4x	Weekdays	78%	84%	66%
ivt	110	WL	IVT -3 min	Weekdays	47% | 9%		
ivt	118 vs 312	WL	IVT sometimes -10 + freq peak 4x > 6x	Weekdays	0% | 4%		
ivt	118 vs 312	WL	IVT -10min (except PM peak)	Saturday	45% | 57%		
freq	314 + 317	WL	(super) off-peak 2x > 4x	Weekdays	0% | 8%	2% | 9%	-2% | 7%

Figure D.1: Results per line - total overview (1/2).

Line	#1 product	#2 product	Most sensitive absolute	Most sensitive relative
301	No subscription adult/anon/studs	No subscription adult/anon/studs	Students	commuters
87	Subscription adult	No product - anonymous		
85	Student	No product - anonymous		
102	Student	No product - anonymous		
84	Student	No product - adult		
403	No product - anonymous	Student		
403	Student	No product - adult		
404	Student	No product - adult		
32	OV chip | Student	Student | OV chip		
13				
Q309	Student	OV chip		
Q309	Student	OV chip		
119	Student	OV chip		
65	Student	OV chip		
Q12	Students !	OV chip		
Q300	Students + OV chip	Students + OV chip		
39+133+139				
26	OV chip	Student		
61	OV chip | student	Subscription | OV Chip		
Q6	Student	OV chip		
14	Student	Subscription | OV Chip		
122 vs 125	No product - anonymous	Student | no product adult	students	students
311 vs 315	Students	Subscription teenager	infrequent users	scholars
103	Subscription teenager	Subscription adult	scholars	students
103	Subscription teenager	No product - anonymous	infrequent users	students
121	Students	No product - adult	Students	students
305	Students	No product - adult	Students	students
110	No product - anonymous	No product - adult	infrequent users	students
118 vs 312	Students	Subscription adult | no product adult	infrequent users	infrequent users
118 vs 312	No product - anonymous	No product - adult	infrequent users	infrequent users
314 + 317	Students	Subscription teenager	scholars	commuters

Figure D.2: Results per line - total overview (2/2).

E

Appendix Ranges line based analysis

E.1. Tables with ranges

Tables E.1, E.2, E.3 provide an overview of the ranges of growth factors when compensated for non-LOS changes. The third column shows which effects have been compensated for by using the following abbreviations:
EC = Economy and demography
TS = Ticket sales
UD = Urban Development
TO = Tourism
FA = Fares

Table E.1: Ranges of growth factors for IVT changes.

Case	IVT change	Compensated for	MIN growth	Original growth	MAX growth
WL110	-3 min	EC,TS,UD	3%	9%	9%
GD119	-3 min	EC,TS	-6%	-6%	-10%
WL315	peak -7 min, off-peak -3 min	EC,TS,TO	15%	21%	23%
WL103	-10 min (-€1.50)	EC,TS,FA	90%	121%	140%
WL312	-10 min	EC,TS	45%	45%	48%
GD39	-18 min (off-peak)	EC,TS	77%	83%	83%

Table E.2: Ranges of growth factors for frequency changes.

Case	Freq change	Compensated for	MIN growth	Original growth	MAX growth
GD65	off-peak 1x >2x	EC,TS	4%	10%	10%
WL103a	off-peak 2x >1x	EC,TS	-14%	-16%	-16%
WL121	peak 2x >1x	EC,TS	-24%	-26%	-26%
WL301	2x >1x	EC,TS	-7%	-9%	-9%
WL305	peak 2x >4x	EC,TS,UD	71%	78%	78%
WL314	off-peak 2x >4x	EC,TS	0%	0%	2%
GD309a	off-peak 2x >4x	EC,TS	16%	21%	21%
GD300	2x >4x	EC,TS	10%	20%	30%
VPR403a	2x >4x	EC,TS	25%	32%	32%
VPR85	2x 12m >4x 8p bus	EC,TS	3%	min 8%	8%
VPR403b	off-peak 4x >2x	EC,TS	-11%	-11%	-15%
VPR102	off-peak 4x >2x	EC,TS	-38%	-38%	-41%
GD26	0,67x >1x	EC,TS	8%	18%	27%
GD61	peak direction 2x >3x	EC,TS	2%	14%	22%
VPR84	off-peak 4x >6x	EC,TS	-2%	-2%	-6%
GD309b	afternoon peak 5/6x >8x	EC,TS	0%	5%	5%

Table E.3: Ranges of growth factors for other LOS changes.

Case	LOS change	Compensated	MIN growth	Original growth	MAX growth
WL122	-7 min and peak 2x >1x	EC,TS	-17%	-19%	-19%
WL312	more express buses	EC,TS	0%	0%	1%
GD6	Q-link, PM peak partly 2x >4x	EC,TS	3%	13%	22%
GD12	Q-link (new branding + buses)	EC,TS	10%	16%	16%
VPR404*	R-net, network change	EC,TS	-	12%	-
GD32	1 add. trip (+ stud OV MBO)	EC,TS	12%	23%	32%
GD14	1 add. trip (+ stud OV MBO)	EC,TS	15%	26%	36%
GD13	off-peak with 12m iso 8p bus	EC,TS	-6%	3%	10%
VPR87	peak only to full day	EC,TS	36%	43%	43%

*Since this is an estimation, no range can be calculated.

E.2. Example line 121

Waterland line 121 is again used as example. The line has been subject to a frequency decrease in the peak hours, from 2x/h to 1x/h, equal to the frequency in off-peak hours. This caused a decrease in ridership from 4592 users in November 2013 to 3251 users in November 2014. If November 2014 would have had the same number of weekdays as November 2013, the ridership in November 2014 would be equivalent to 3414. This is a decrease of 26% (table E.4).

Table E.4: Ridership changes line 121, for full day and for peak only and off-peak only, after the peak hour frequency reduced from 2x/h to 1x/h in August 2014. Ridership change is measured over November 2014 compared to November 2013.

Line 121	Ridership change
Full day	-26%
Peak hours only	-38%
Off-peak hours only	-5%
All hours except peak	-15%

The first effect to be compensated for, is economic and demographic growth, causing autonomous growth (or decline) of ridership, which would have occurred even if nothing changed. As described in Chapter 2, this can be compensated by referring to the total change in vehicle kilometers. Other methods include a.o. parameters such as population, employment rates, car ownership etc. and are too extensive for this research. Furthermore, it leads on a short timescale to a false sense of accuracy. Between 2013 and 2014, the BTM-vehicle kms changed by ca. 1.8% (OVIN 2017 (Centraal Bureau voor de Statistiek (CBS), 2018); see also table E.5). In some years, there is quite a deviation between the national change in BTM kms and the change in check-ins in the concession. Since a range is calculated, the maximum change of the two is applied as factor for economic & demographic (autonomous) growth. In case of both a positive and a negative growth factor, a range is applied to both the positive and the negative side. For WL121, this has the following effect:

The change is implemented in 2014, which means that a growth of -1.8% is expected compared to 2013 based on the national BTM change (table E.5). Based on the check-ins in Waterland, a growth of -1% is expected. -1.8% is the maximum value, so the new range is calculated with this value. With a -1.8% decrease accounted for, a decrease of -24% can be assigned to the LOS change. The new range is thus -24% to -26%.

Table E.5: Change in BTM kms per year, referring to the growth compared to the preceding year (based on table 2.1). For easy comparison, the change in check-ins per concession has been added to the table as well (table 6.1).

Year	Change BTM kms national	Check-ins WL	Check-ins GD	Check-ins VPR
2013	3.8%	4%	-	-
2014	-1.8%	-1%	-	-
2015	7.4%	2%	-	3%
2016	1.7%	2%	3%	1%
2017	-6.8%	4%	6%	-

A fare elasticity of -0.3 is applied, as described by Balcombe et al. (2004) (see also Chapter 2). This elasticity is applied for the yearly change in fares. If a route change leads to a significant decrease in fare (e.g. WL103b), then the same elasticity of -0.3 is applied to compensate. For WL121, +0.3% in ridership would be expected if no LOS changes had been applied, since public transport became relatively cheaper, comparing 2014 to 2013 (figure 2.6). This change is so small that it does not change the range; therefore fare elasticity is only applied when a significant, additional price change applies.

Whereas paper ticket sales nowadays often have a chip/bar code and are less used, in the years 2013-2014 the share of paper tickets must be taken into account. In 2014, the share of paper tickets is 5% of the total, against 5% in 2013 (table 6.2). This implies that the 2013 totals are 95% of total usage and 2014 totals are 95% of total usage. If this is compensated for and added to the already existing range, the LOS change caused 26% decrease. In this case this is obvious, since there is no change in share of ticket sales. The new range becomes: -24% to -26%.

Of special ODs, urban development and tourism no significant changes are known or cannot be quantified, so no compensation for these factors is applied. For urban development, the increased number of passengers would be subtracted from the new ridership. For tourism, figure 5.6 would have been used. The final range is -24% to -26%.

F
Appendix Data sheets

- Confidential -

G
Appendix Reference material CSSE

G.1. Implementation plan

In order to promote usage, adoption and implementation of the Case Study Search Engine within EBS, a short implementation plan is described.

First of all, the members of the tender team and all transport engineers must be informed about the model. This has already largely been done, since the transport engineers have been part of the expert meeting. Furthermore, the outcome of the model is presented to the tender team. As a second step, the model and this research should become available to all potential users; e.g. the tender team and transport engineers. This is best done by providing access through a shared folder or server. Just sending the files through email would be insufficient, since it gets lost easily and it is unavailable to potential new users. A notification should be send to the potential users that the model is now available at the specified location and with a short explanation of its background and purpose.

It is recommended to update the model for future use. To start with, more cases should be added. In the folder of the CSSE, templates for the data sheets are included and in the user manual (section G.2) it is described how cases can be added to the search engine. New cases originate by applying a before-after study to new level-of-service changes. The responsibility and/or coordination of addition of new cases can therefore best be put by one of the transport engineers in the tender team. This person can request the new cases at transport engineers of the regions/concessions from EBS. The best moment to do this is when finalizing the new network/timetable for every year (which is often implemented in December). The transport engineers often have to evaluate their own LOS-changes from the year before, the analyze whether changes have been successful. In this analysis, they can either fill in the data sheet themselves, or provide input for the data sheet to the responsible transport engineer of the tender team. Filling the data sheets by themselves has as advantage that a structured method of evaluation for the transport engineer is presented. An advantage of leaving the data sheet formatting to the responsible tender transport engineer, is the improved consistency. It should be stressed that the analysis on the data sheet mean to evaluate the effect of the LOS change as sufficient as possible. This is not necessarily the same as evaluating the ridership of the full line. Adding data from other sources (e.g. published data from other PTOs) is possible, but one should be cautious. As in this research, line-based data has most value when the lines are isolated (or a cluster analysis is used). Data from non-isolated lines, or lines where non-LOS factors might play a large role, can be misleading. It should be prevented that the CSSE becomes a bin in which just any number is put, since the CSSE will lose its value. Adjustment of the data base of the search engine should always be the responsibility of the tender transport engineer. Again the importance of a shared folder or server is emphasized, since this would make the updated model immediately available to everyone, instead of having to distribute it individually. The latter could also lead to confusion of multiple versions, which should be prevented.

This research also mentions that this model is possibly only a first step, which can lead to further development of a different model concept. Therefore, the cases that are added should also be added to the plots of the line-based analysis (e.g. figure 6.7, 6.11). The responsibility for this should again be put by the tender transport engineer. If sufficient data becomes available, trends might emerge or a regression analysis might lead to the development of model parameters and/or insight in essential parameters for estimation (such as type of line, region, etc.). Apart from the developed model, it is advised to also stress the scientific findings of this thesis. The outlook (section 9.4) should also be stressed, such that newly gained knowledge in the future can be added to this.

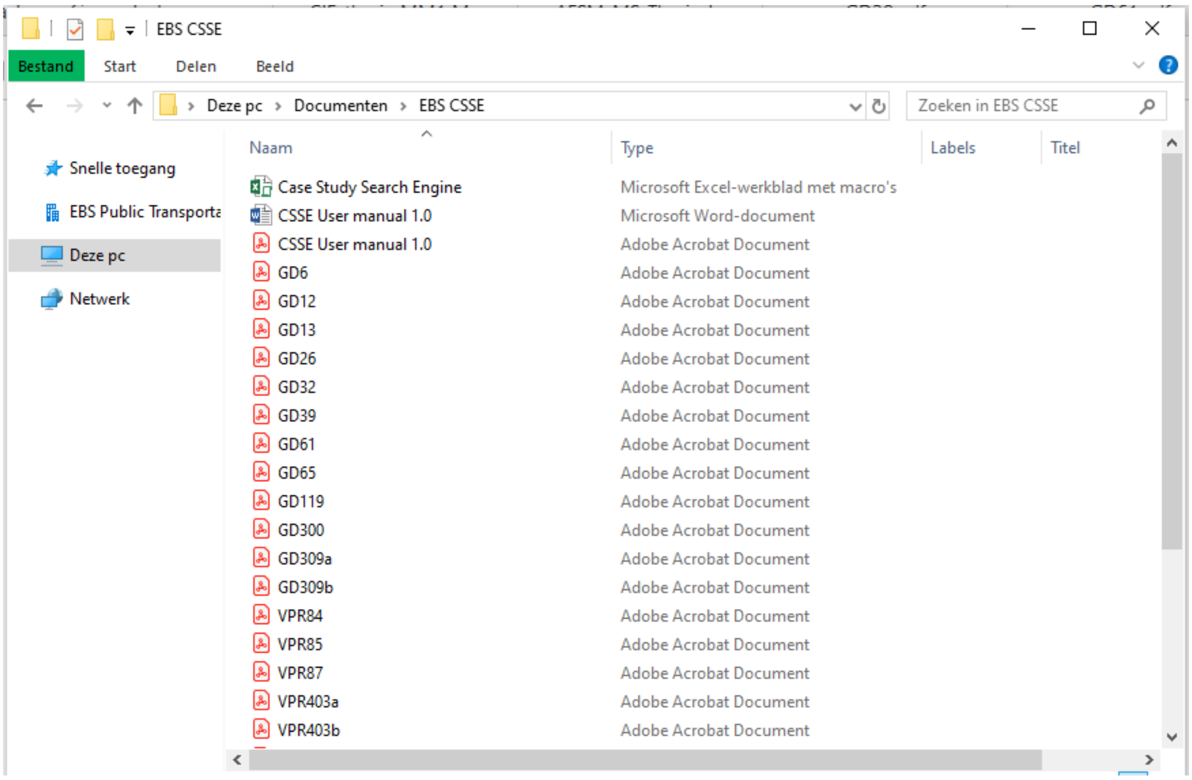
G.2. User manual CSSE

A copy of the user manual of the model is included. The user manual has been made in .docx (Microsoft Word) format. This simplifies later additions by EBS, since Word is a more generically available and mastered software than (La)TeX-like software.

Case Study Search Engine – User manual v.1.0 (October 2019)

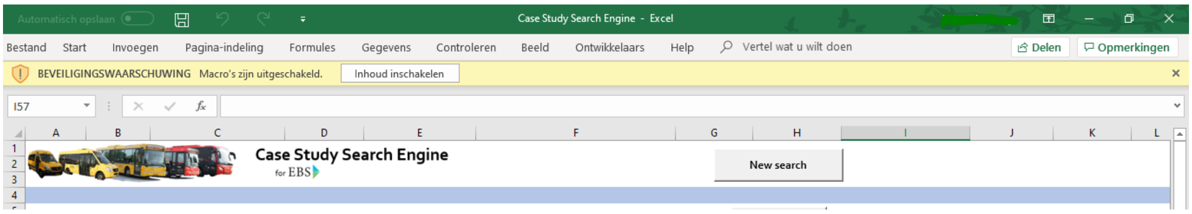
Installation

Place the EBS CSSE folder in My Documents / Documenten. The folder should contain the Case Study Search Engine (.xlsm file), the CSSE User manual (.docx file and .pdf file), the data sheets (.pdf files) and templates for the data sheets (.ai files).

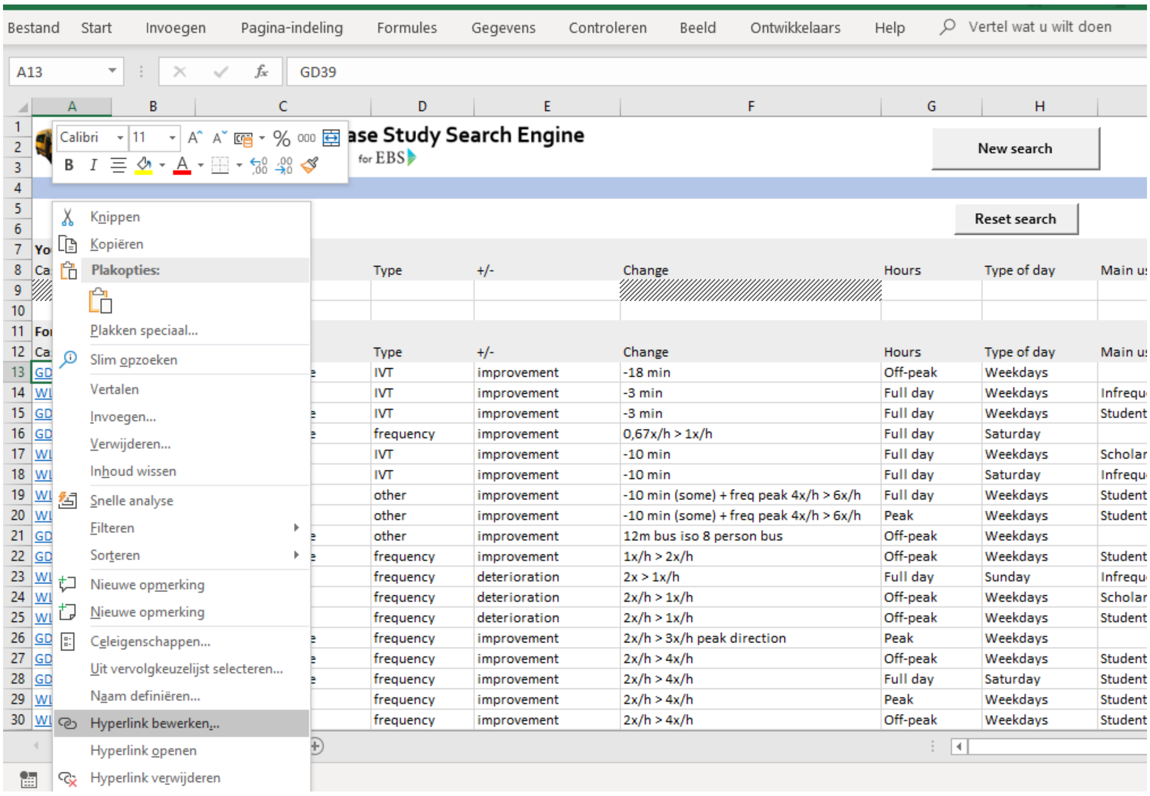


Open the Case Study Search Engine (.xlsm file).

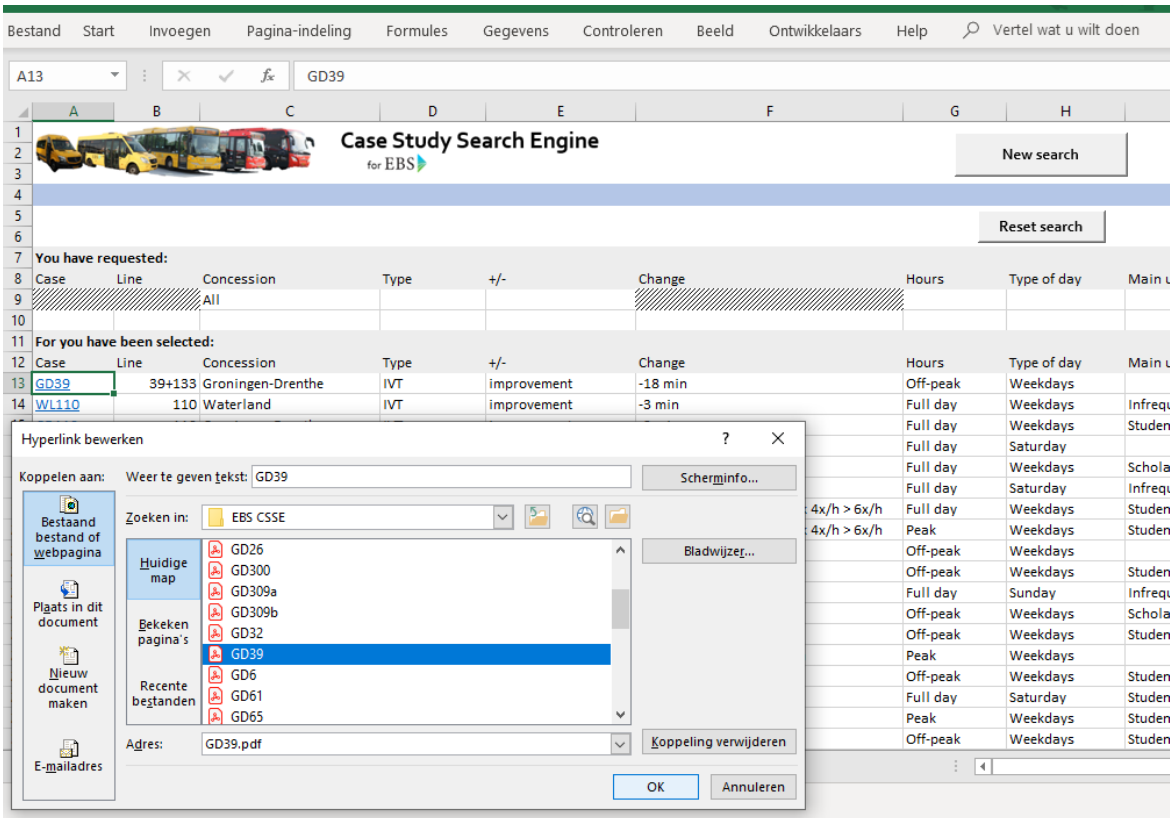
If a security warning pops-up, press ‘*Inhoud inschakelen*’ to enable the macro’s necessary for this model.



Since the model is originally designed for local use, the hyperlink of each of the cases to the data sheets must be renewed in order to work. Right click the Case and click 'Hyperlink bewerken'.



Then click the data sheet with the same name/code as the case and press OK.



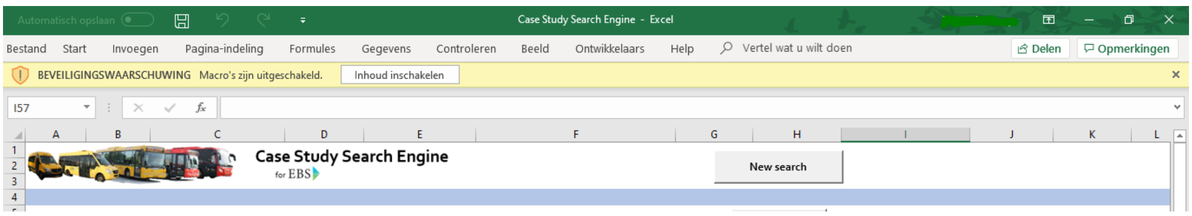
Repeat for all cases.

If the model is used infrequently, one could consider not to hyperlink all the cases and to open each of the data sheets manually.

Starting the engine

Open the Case Study Search Engine (.xlsm file).

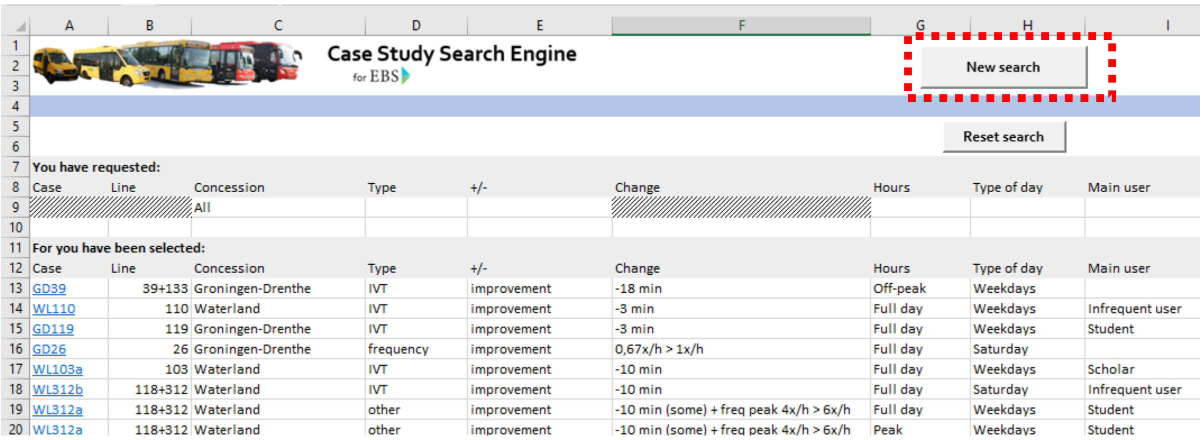
If a security warning pops-up, press '*Inhoud inschakelen*' to enable the macro's necessary for this model.



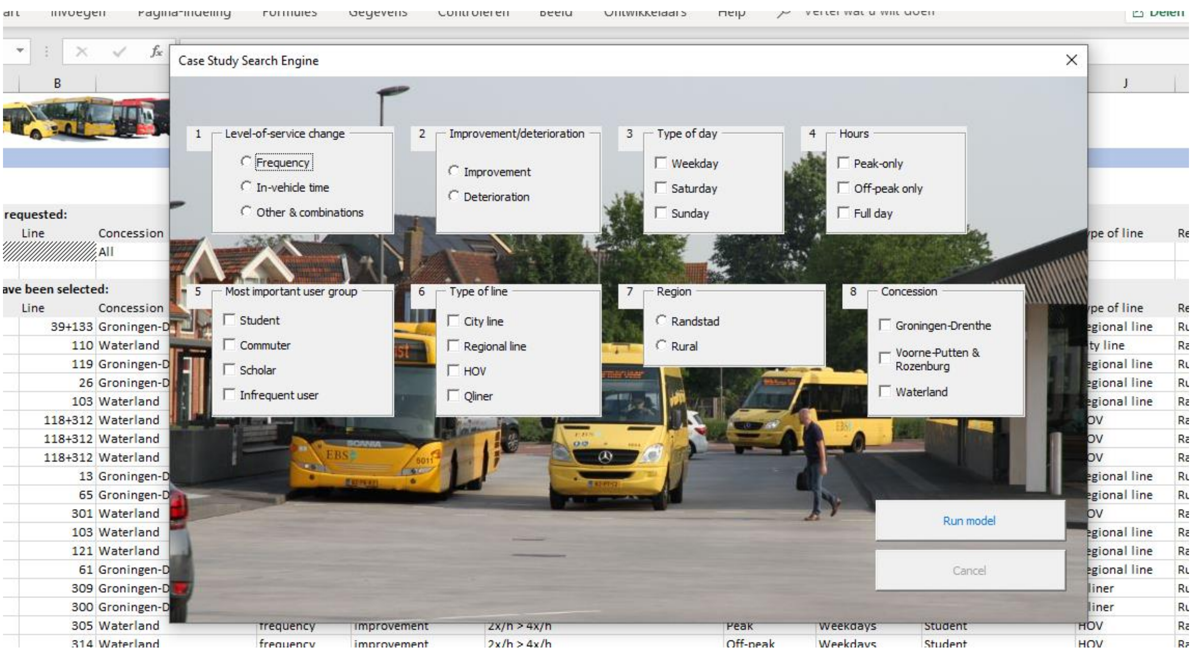
The model is now ready for use.

Operating the model

To start a new search, click the ‘New search’ button.



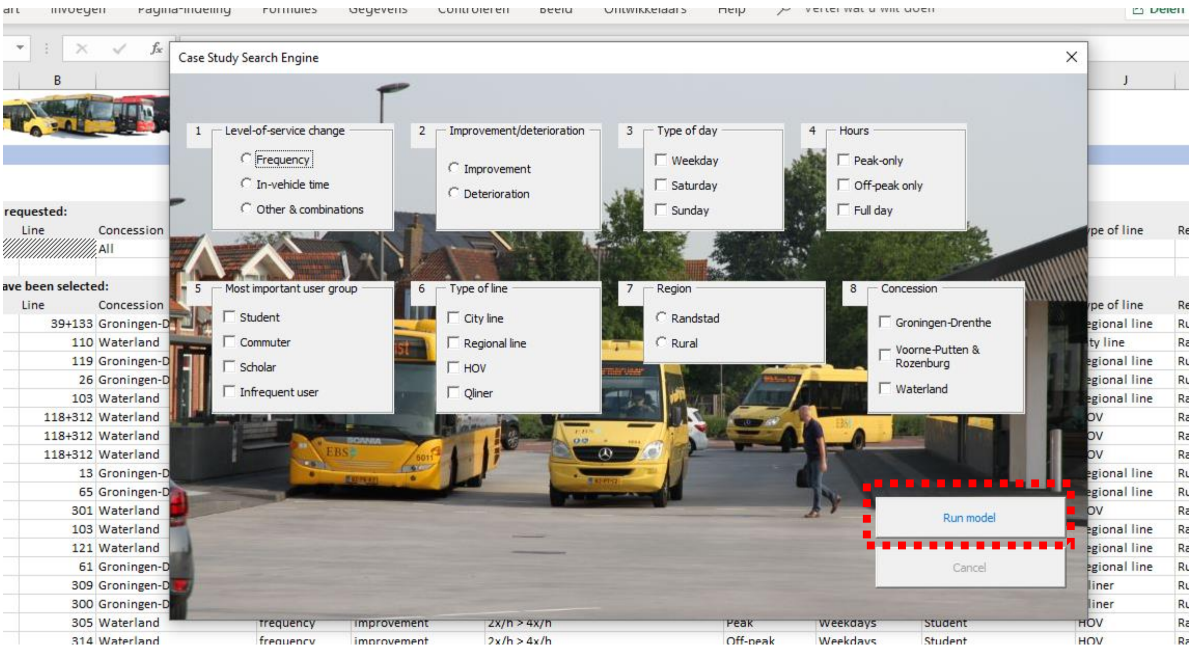
A pop-up user interface opens:



A search can be made based on 8 criteria. All criteria are voluntary, which means that if none of the options is selected under a specific criteria, the selection will not be adjusted regarding that criteria. I.e., if no option is selected, all cases under that criteria are shown.

Two types of criteria are present: Unique choices (only one can be selected) and multiple choices (multiple options can be selected). Important: Note that selecting all options is not necessarily the same as selecting no options. For criteria 5, the most important user group, selecting all four options results in cases with most important user group being one of the four options. However, there are also gaps in the data base where no user group could be assigned to the case. These cases will only show when no selecting is made based on criteria 5.

After selection of the criteria, press the 'Run model' button.



If for example frequency is selected under criteria 1, improvement under criteria 2 and Weekdays and Saturday under criteria 3, this results in the list as shown below.

Reset search

You have requested:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Regi
		All	frequency	improvement			WE+SA			

For you have been selected:

Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user	Type of line	Regi
GD26	26	Groningen-Drenthe	frequency	improvement	0,67x/h > 1x/h	Full day	Saturday		Regional line	Rura
GD65	65	Groningen-Drenthe	frequency	improvement	1x/h > 2x/h	Off-peak	Weekdays	Student	Regional line	Rura
GD61	61	Groningen-Drenthe	frequency	improvement	2x/h > 3x/h peak direction	Peak	Weekdays		Regional line	Rura
GD309a	309	Groningen-Drenthe	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays	Student	Qliner	Rura
GD300a	300	Groningen-Drenthe	frequency	improvement	2x/h > 4x/h	Full day	Saturday	Student	Qliner	Rura
WL305	305	Waterland	frequency	improvement	2x/h > 4x/h	Peak	Weekdays	Student	HOV	Ran
WL314	314	Waterland	frequency	improvement	2x/h > 4x/h	Off-peak	Weekdays	Student	HOV	Ran
VPR403	403	Voorne-Putten Rozenburg	frequency	improvement	2x/h > 4x/h + R-net	Full day	Saturday	Infrequent user	HOV	Ran
VPR85	85	Voorne-Putten Rozenburg	frequency	improvement	2x/h 12m > 4x/h 8p	Full day	Weekdays	Student	City line	Ran
VPR84	84	Voorne-Putten Rozenburg	frequency	improvement	4x/h > 6x/h	Off-peak	Weekdays	Student	City line	Ran
GD309b	309	Groningen-Drenthe	frequency	improvement	5 à 6x/h > 8x/h (PM peak)	Peak	Weekdays	Student	Qliner	Rura

All changes are ordered, such that it is easy to select a case with the appropriate change. Row 9 shows which options have been selected in the search (Concession is standard set as ‘All’, all others are empty unless the criteria has been entered).

Now three options exist:

- You have found what you need; click the case to open each of the data sheets.
- You want to further specify your search. You can use the same pop-up screen if you have left it open. If not, click the ‘New request’ button and you can continue your search.
- You want to remove a criteria you have entered in the first place. In this case, click the ‘Reset search’ button and restart your request completely.

Case Study Search Engine
for EBS

New search

Reset search

	A	B	C	D	E	F	G	H	I
7	You have requested:								
8	Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user
9			All						
10									
11	For you have been selected:								
12	Case	Line	Concession	Type	+/-	Change	Hours	Type of day	Main user
13	GD39	39+133	Groningen-Drenthe	IVT	improvement	-18 min	Off-peak	Weekdays	
14	WL110	110	Waterland	IVT	improvement	-3 min	Full day	Weekdays	Infrequent user
15	GD119	119	Groningen-Drenthe	IVT	improvement	-3 min	Full day	Weekdays	Student
16	GD26	26	Groningen-Drenthe	frequency	improvement	0,67x/h > 1x/h	Full day	Saturday	
17	WL103a	103	Waterland	IVT	improvement	-10 min	Full day	Weekdays	Scholar
18	WL312b	118+312	Waterland	IVT	improvement	-10 min	Full day	Saturday	Infrequent user
19	WL312a	118+312	Waterland	other	improvement	-10 min (some) + freq peak 4x/h > 6x/h	Full day	Weekdays	Student
20	WL312a	118+312	Waterland	other	improvement	-10 min (some) + freq peak 4x/h > 6x/h	Peak	Weekdays	Student

Repeat the process until you have found what you need. The possibility exists that no case is comparable to your request.

If, for any reason, you do not want to use the search engine, but you just want to visually inspect the data base, you can also refer to the second tab ‘Database’.

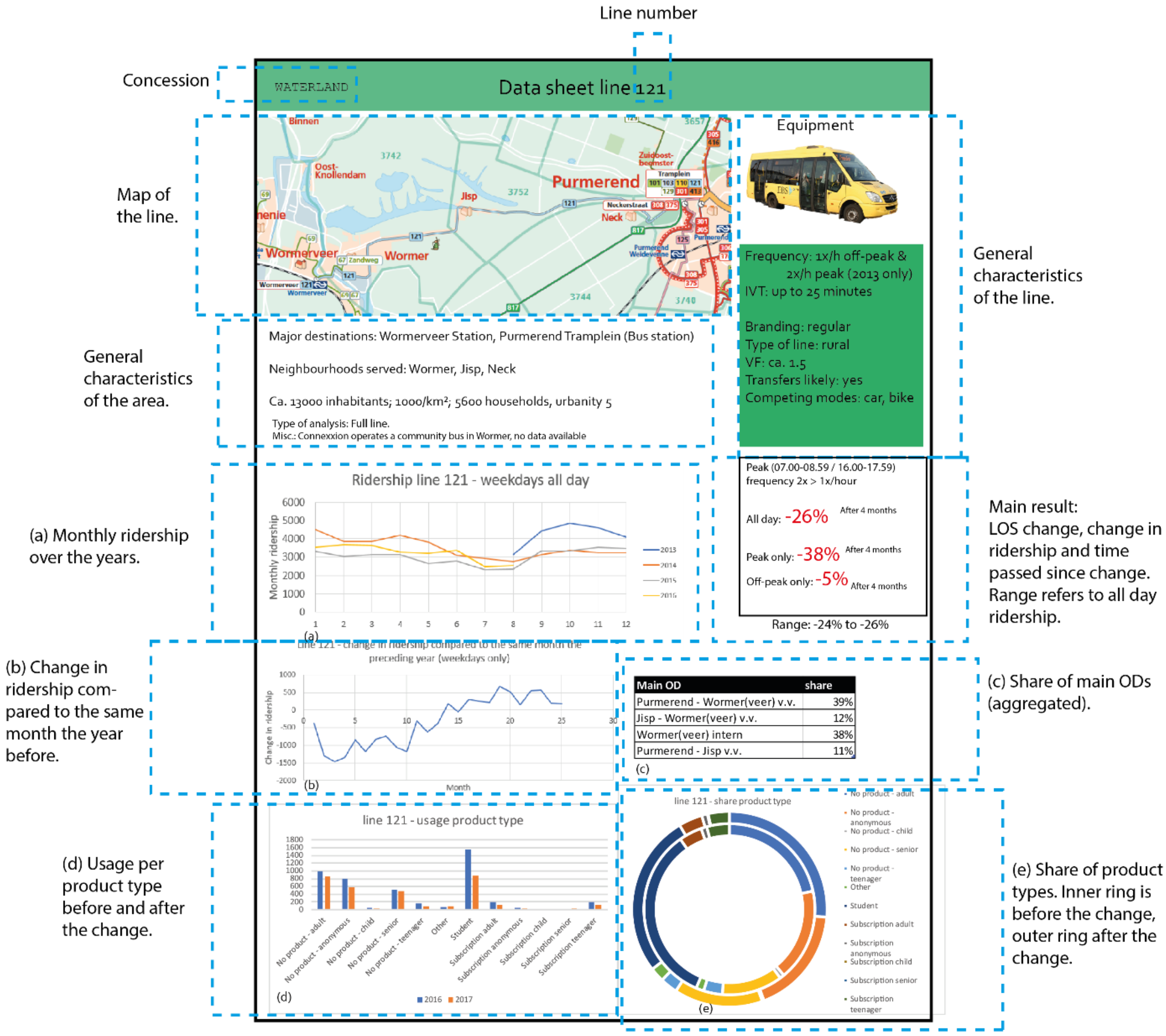
27	GD309a	309	Groningen-Drenthe
28	GD300a	300	Groningen-Drenthe
29	WL305	305	Waterland
30	WL314	314	Waterland

CSSE | Database

Note that some cases have duplicates in the data base, such that they pop-up at all necessary request. E.g., case WL122, which was subject to a frequency decrease during peak hours and an IVT decrease all day. This is thus both a frequency deterioration and a IVT improvement and is therefore twice in the list. Also note that it is a combination of the two and thus sorted under ‘other’ Clearly, both are linked to one and the same data sheet.

Interpretation of the data sheets

All information on the data sheets is explained in the figure below.



Note that not all graphs can be produced for all cases. Furthermore, for Groningen-Drenthe cases, the product usage (d) and product share (e) can only be obtained for the full line, not the specific line section or cluster.

The general characteristics of the area also states Misc. (miscellaneous), which describes which quantitative facts should be considered (e.g. the implementation of Student OV for MBO).

- The manual for usage of the model ends here -

Adjustment of the model

The model can be updated in the future. For example, additional cases can be added, but also additional criteria can be added. The two variants are discussed separately:

Adding new cases

New data sheets must be created. This is up to the user, however three templates (one for each concession at this moment) are available in the EBS CSSE folder. These templates are in Adobe Illustrator format (.ai).

The new cases should be included in the data base of the search engine. This can be done by simply entering the values/characteristics in the first empty row. However it is advised to keep the data base on alphabetic order in the column 'Change' (Column 6). Please make sure that currently no request is being handled; to be sure click the 'Reset search' button first. Note that the data base should be adjusted in both tabs (CSSE and Database). This can also be done by simple adding it in one and copying the new data base in the other. Create a hyperlink to the data sheet (as explained in the *Installation* section).

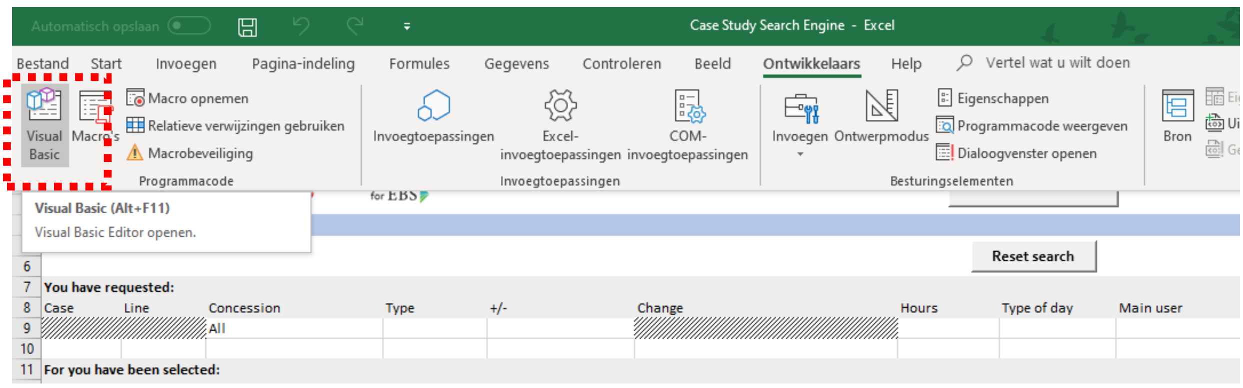
The case is now added to the data base.

Adding new criteria / changing the Excel model

For adding new search criteria and/or changing the Excel model, understanding of Visual Basic for Applications (VBA) is assumed.

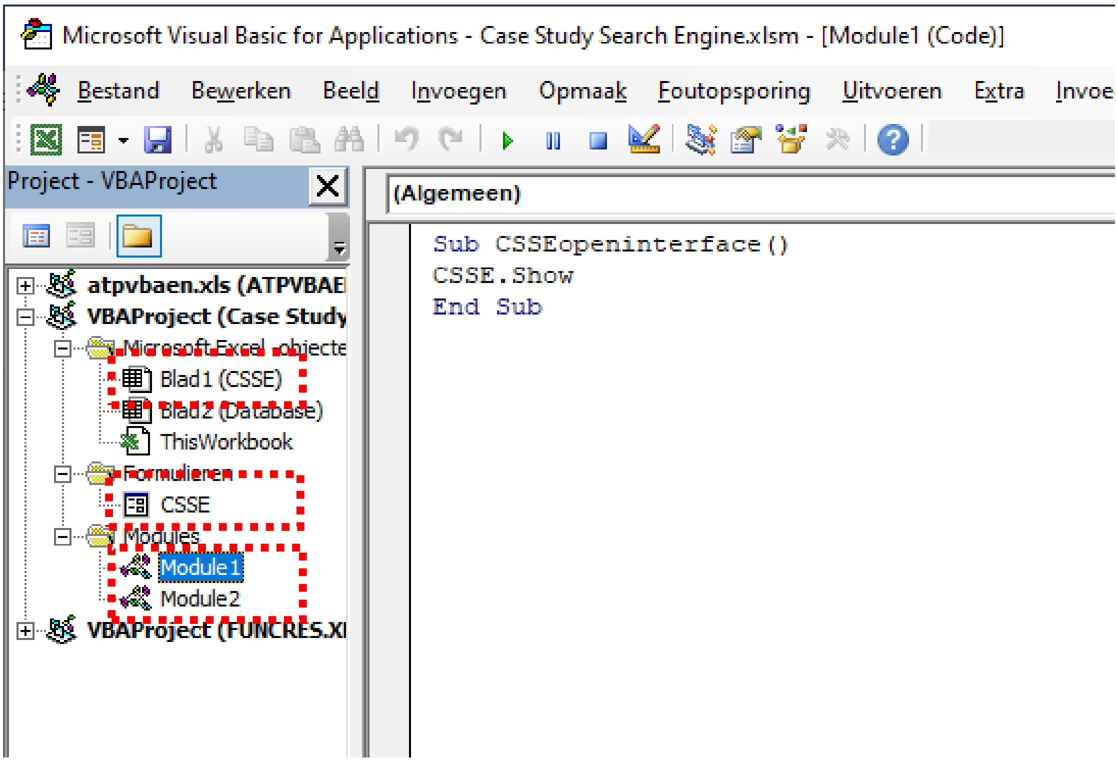
-note: please make sure the 'developer' / 'ontwikkelaar' tab is enabled (if not, open via 'Bestand'-'Opties'-'Lint aanpassen').

Open Visual Basic (or use Alt+F11):



4 tabs are relevant to the model:

- Blad1 (CSSE)
- CSSE
- Module 1
- Module 2



'Module1' operates the 'New search' button and simply opens the pop-up interface; which is the form 'CSSE'. 'Module2' operates the 'Reset search' button and simply removes all entries and re-shows the full database. 'CSSE' is the form in which the user can select the criteria. Finally, in 'Blad1 (CSSE)' is defined which filters to use for each of the selection criteria and operates on the data base by using an autofilter. After adding or changing criteria in the form 'CSSE', also 'Blad1 (CSSE)' should be adjusted, since the output of the form has changed.