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MODELLING MERGING BEHAVIOUR ON FREEWAY ON-RAMPS

Estimation of a discrete choice model to model gap choice behaviour

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Colophon

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PREFACE

This thesis marks the end of my Master Civil Engineering, track Transport & Planning, at the Delft University of Technology. This research is performed at the ITS Edulab, a collaboration between the Delft University of Technology and Rijkswaterstaat – Centre of Transport and Navigation. Due to this cooperation students can research relevant and actual topics for Rijkswaterstaat.

At the ITS Edulab a chance was given to research a topic of my interest. It offered a nice workplace and good facilities for performing the research. Therefore I would like to thank Serge Hoogendoorn and Henk Taale for providing this opportunity.

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Hans-Peter Kolen,
Delft, May 2013

SUMMARY

Microscopic traffic simulation models are a widely used tools for transport system analysis and management. These tools are used to model the complexity of the systems and to evaluate various traffic management alternatives in order to determine the optimal solution for any traffic scenario. A classical way to represent vehicle interactions at merges at the microscopic scale is to combine a gap-acceptance model with a car-following algorithm. With the gap acceptance the choice for a certain gap is modelled. Recently there are some doubts about the accuracy of the gap acceptance model for simulating a merge movement. Because of the shortcomings of gap acceptance models used in micro simulation tools, recently a new concept framework for modelling merging behaviour was proposed. This concept is based on gap selection. It means that every driver is able to find a suitable gap out of a set of offered gaps without being overtaken by drivers on the shoulder lane and without coming to a standstill at the end of the acceleration lane. The choice decision of a gap out of a set of offered gaps is the main focus for this research. It provides a model for the choice decision of a merging car what can be implemented in a merging model and a simulation tool. The focus of this research is on modelling merging behaviour with such a gap choice model.

The main research question of this thesis is:
How can merging behaviour on a freeway on-ramp be modelled so that it corresponds to actual observed merging behaviour?

With the literature review the state-of-the-art about merging behaviour is studied. The actual merging behaviour is researched with simulator studies and empirical data analyses. For modelling merging behaviour, theoretical frameworks and micro simulation tools are studied. From the studies about actual merging behaviour it is clear that drivers make a choice between gaps that are offered to them and this choice depends on several factors, e.g. vehicle type of putative follower and putative leader, gap size, traffic conditions and geometric design. With these factors, the drivers will choose a gap out of a set of offered gaps at the moment they enter the acceleration lane. Most of the existing theoretical models are based on the principles that there is no decision of which gap is most preferred out of a set of offered gaps. All studied microscopic simulation tools use a gap acceptance model to simulate merging behaviour.

With an empirical data analysis at a freeway on-ramp the merging behaviour and gap choice behaviour is analysed. The first factor analysed with the empirical dataset is the average speed per lane. There is not much difference between the average speed of the acceleration lane and the shoulder lane. This can be caused by cooperativeness between the lanes, but also because of the high flow. The second factor is the speed during the merge on the shoulder lane. It is founded that the merging speed of HGV's and passenger cars are the same. The next factor analysed is the driving behaviour on the acceleration lane. Most drivers have a relative constant speed. This means that the speed of entering the acceleration lane is almost the same along the acceleration lane. Only HGV's are accelerating in the first 25 meters of the acceleration lane. The last factor analysed for merging behaviour are the gaps. From this analysis it is clear that there is a relation between the merging location of a passenger car and the presence of an HGV on the shoulder lane. Besides the merging behaviour, also an empirical analysis of the gap choice behaviour is performed. From this analysis it is clear that different gap choice behaviour occurs in different traffic states and different vehicle types. Therefore different choice models are estimated.

The findings of the state-of-the-art and empirical data analysis about merging behaviour are compared with the results of the simulation tool FOSIM. In FOSIM vehicles are merging much earlier. The number of lane changes in the simulation results is comparable with the empirical dataset. The average speed per lane, is comparable during free flow. During congestion the average speed per lane differs a lot between FOSIM and the empirical data. There seems to be no interaction between the lanes in the simulation results of FOSIM. So the gap acceptance model of FOSIM is not simulating accurately. Especially the merge location has a large difference with an empirical dataset. Therefore the focus is put on estimating a model on the gap choice behaviour. This choice will influence the location for merging.

From the gap choice behaviour it is clear that different behaviour occurs between traffic states and vehicle types. Therefore three choice models are estimated, namely a choice model for HGV's, passenger cars in free flow and passenger cars in congestion. Two parameters are present in all three final discrete choice models, namely 'gap size' in seconds and 'distance towards a gap'. For the HGV model these are the only two parameters. The model for passenger cars during congestion has three parameter. This model also includes the parameter 'vehicle type of the putative leader'. The last model, passenger car in free flow consist of four parameters. Besides the parameters 'gap size' and 'distance towards a gap', this model also includes the parameters 'vehicle type of the putative follower' and 'vehicle type of the putative leader'. With these three models a face validation is performed.

The face validation of the three discrete choice models is performed on two aspects, namely an aggregate validity test and validity test per individual. The aggregate face validity of the three choice models is good. Only for the model of passenger cars during congestion there are some small differences in comparison with the empirical dataset. The validity test per individual was not as good as the aggregate validity. For all three discrete choice models there are large differences compared with the empirical dataset. This means the discrete choice models in general models the right gap choice distribution, but per driver, the predicted gap and the actually observed gap are not the same.

From the research done in this master thesis it is concluded that gap acceptance models do not simulate the merging behaviour accurately. In these kinds of models only one gap at the time and only the gap size is evaluated, i.e. if this gap is large enough, the merge movement is simulated. But most of the time a driver is not merging into his nearest gap. From the research it can be concluded that some drivers are choosing a gap further ahead and sometimes even two gaps further ahead. This is mostly the case during congestion, but it also occurs during free flow. The three discrete choice models are evaluating several gaps at once and take more characteristics into account for choosing a gap. Therefore it can be concluded that the three discrete choice models presented in this master thesis research are accurate models to model actual observed merging behaviour on a freeway on-ramp.

SAMENVATTING

Microscopische verkeerssimulatie modellen zijn een veel gebruikt hulpmiddel voor de analyse van verkeerssystemen en -management. Deze modellen worden gebruikt om complexe verkeerssystemen, verkeersmanagement en wegontwerpen te evalueren voor een optimale oplossing. Voor het simuleren van verkeersinteractie op microscopische schaal ter hoogte van een invoegstrook wordt een gap-acceptance model gecombineerd met een car-following algoritme. Met het gap acceptance model wordt de verplichte strookwisseling gesimuleerd. Recent onderzoek betwist de nauwkeurigheid van zo'n model voor het simuleren van invoeggedrag. Door de tekortkomingen van een gap-acceptance model is er onlangs een nieuw raamwerk voor een invoegmodel voorgesteld. Dit concept is gebaseerd op gap-selection. Dit betekent dat elke bestuurder een hiaat kiest uit een groep aangeboden hiaten. De keuze van een hiaat uit een groep aangeboden hiaten staat centraal in dit onderzoek. Dit onderzoek biedt een model voor het modelleren van de hiaatkeuze wat toegepast kan worden in een invoegmodel. De focus van dit onderzoek ligt op het modelleren van invoeggedrag met zo'n dergelijke hiaatkeuze.

De hoofdvraag van dit onderzoek is:
Hoe kan invoeggedrag op een oprit van een snelweg gemodelleerd worden, zodat deze overeenkomt met werkelijk waargenomen invoeggedrag?

Met een literatuurstudie is de huidige kennis over invoeggedrag bestudeerd. Deze studie is uitgevoerd op werkelijk invoeggedrag en invoegmodellen. Het werkelijke invoeggedrag op een oprit is onderzocht met behulp van rijsimulatorstudies en studies met empirische data-analyses. Voor de studie over invoegmodellen zijn theoretische modellen en software voor het uitvoeren van simulaties bestudeerd. Uit de literatuurstudie naar werkelijk invoeggedrag komt naar voren dat bestuurders een hiaat kiezen uit een aangeboden set hiaten. Deze keuze is afhankelijk van verscheidende factoren, bijvoorbeeld het type voertuig van de volger en leider van een hiaat, grootte van een hiaat, verkeersomstandigheden, geometrisch ontwerp, enz. Aan de hand van deze factoren maakt een bestuurder een keuze uit een set hiaten aan het begin van de invoegstrook. De meeste theoretische modellen zijn gebaseerd op een model waar geen onderscheid wordt gemaakt over welk hiaat de voorkeur heeft uit een set van hiaten. De simulatie software tools maken gebruik van een gap-acceptance model.

Met een empirische dataset is het invoeggedrag en de hiaatkeuze geanalyseerd. Het eerste element dat geanalyseerd is, is de gemiddelde snelheid per rijstrook. Hieruit komt naar voren dat het verschil tussen de gemiddelde snelheid van de invoegstrook en de rechterrijstrook niet groot is. Dit kan veroorzaakt worden door de samenwerking van invoegende bestuurders en bestuurders op de hoofdrijbaan, maar ook door de relatief hoge intensiteit.
Het tweede element, invoegsnelheid, toont aan dat de invoegsnelheid tussen vrachtwagens en personenvoertuigen niet significant verschillend is.
Het derde geanalyseerde element is het rijgedrag op de invoegstrook. Voor personenvoertuigen is de snelheid vrijwel constant op de invoegstrook. Vrachtwagens gebruiken echter de eerste 25 meter van de invoegstrook om te accelereren.
Het laatste geanalyseerde element in relatie tot invoeggedrag zijn de hiaten. Uit deze analyse komt naar voren dat de invoeglocatie gerelateerd is aan de aanwezigheid van een vrachtwagen.
Uit de empirische data-analyse van de hiaatkeuze blijkt dat verschillend gedrag optreed tijdens verschillende verkeerscondities en -voertuigtypes. Daarom zullen verschillende keuze modellen geschat worden.

De bevindingen van de literatuurstudie en de empirische data-analyse over invoeggedrag zijn vergeleken met resultaten van de simulatie software FOSIM. In FOSIM blijken de voertuigen veel eerder in te voegen dan in werkelijkheid. Het aantal rijstrookwisselingen van de simulatie resultaten komen wel overeen met de empirische dataset. De gemiddelde snelheid per rijstrook is vergelijkbaar tijdens een vrije doorstroming, maar wijkt veel af tijdens filevorming. Hierdoor ontbreekt de interactie tussen de rijstroken in de simulatieresultaten van FOSIM. Dus het gap-acceptance model van FOSIM blijkt niet accuraat te modelleren. Vooral de invoeglocatie wijkt veel af in het model ten opzichte van de empirische dataset. Om dit probleem op te lossen is een discreet keuze model bepaald gebaseerd op de uitgevoerde analyse naar empirische hiaatkeuze. Deze keuze voor een hiaat beïnvloed namelijk de invoeglocatie.

Uit de analyse over de hiaatkeuze komt naar voren dat verschillend gedrag optreedt onder verschillende verkeerscondities en -voertuigtypes. Daarom zijn drie discrete keuze modellen geschat, namelijk een model voor vrachtwagens, personenvoertuigen tijdens vrije doorstroming en personenvoertuigen tijdens filevorming. Twee parameters zijn aanwezig in alle drie de keuzemodellen, namelijk ‘hiaatgrootte’ in seconden en ‘afstand tot een hiaat’. Voor het keuzemodel van vrachtwagens zijn dit de enige twee parameters. Het keuzemodel voor personenvoertuigen tijdens filevorming bestaat uit drie parameters. Dit model bevat ook de parameter ‘type voertuig van de leider’. Het laatste model, personenvoertuigen tijdens vrije doorstroming, bestaat uit vier parameters. Naast de hiaatgrootte en hiaatafstand bevat dit model ook de parameters ‘type voertuig van de volger’ en ‘type voertuig van de leider’. Met deze drie discrete keuzemodellen is een indruk validiteitstest uitgevoerd.

De indruk-validatie van de drie discrete keuze modellen is uitgevoerd op twee aspecten, namelijk een validiteitstest op het model in het algemeen en een validiteitstest per individuele bestuurder. Uit de eerste validiteitstest komt naar voren dat de modellen in het algemeen goed presteren. Enkel het model van personenvoertuigen tijden filevorming toonde kleine afwijkingen in vergelijking met de empirische dataset. De validiteit per individuele bestuurder presteert niet zo goed als de algemene validiteit. De drie keuzemodellen tonen allen grote verschillen in vergelijking met de empirische dataset. Dit betekent dat de discrete keuzemodellen algemeen gezien de juiste hiaatkeuze verdeling modelleren, maar per bestuurder is het voorspelde hiaat niet dezelfde als de werkelijk waargenomen hiaat.

Uit het uitgevoerde onderzoek in deze Master-thesis kan geconcludeerd worden dat gap-acceptance modellen niet accuraat zijn voor het simuleren van invoeggedrag. Dit soort modellen evalueren slechts één hiaat per keer en alleen de hiaatgrootte wordt beoordeeld, dat wil zeggen, als een hiaat groter is dan het kritische hiaat wordt een invoegbeweging gesimuleerd. Een bestuurder voegt echter vaak niet in het dichtstbijzijnde hiaat. Uit het onderzoek is de conclusie getrokken dat sommige bestuurders een hiaat verder naar voren kiezen. Dit gedrag komt het vaakst voor tijdens filevorming, maar ook tijdens vrij doorstroming. De drie hier onderzochte keuzemodellen evalueren wel meerdere hiaten en beoordelen meer invoegkarakteristieken voor de invoegkeuze. Daarom hebben de drie discrete keuze modellen, zoals gepresenteerd in dit onderzoek, een hogere accuratie bij het simuleren van werkelijk waargenomen invoeggedrag op een snelwegoprit.

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1 Introduction

Microscopic traffic simulation models are widely used tools for transport system analysis and management. These tools are used to model the complexity of the systems, assess new designs or redesigns of a road section, to evaluate traffic management alternatives, etc., in order to determine the optimum solution for a traffic scenario (Hidas, 2005b). Within these models lane-changing behaviour is an important component, because lane changes are related to the traffic instabilities (Laval et al., 2008). Two types of lane changes can be distinguished, namely mandatory and discretionary lane changes. A mandatory lane change needs to be performed to keep the route, e.g. merging at a freeway on-ramp. Discretionary lane changes are performed to improve driving conditions, e.g. to overtake a slower driving vehicle to increase speed. This study is about mandatory lane changes, in particular, on merging behaviour on a freeway on-ramp.

A classical way to represent vehicle interactions at merging sections at the microscopic scale is to combine a gap acceptance model with a car-following algorithm. With the gap acceptance the mandatory lane change is modelled. A gap acceptance model determines if a driver accepts a gap or not. A driver wanting to merge must evaluate the available space. If the gap is large enough, i.e. larger than a threshold value, the so-called critical gap, the driver decides to merge, otherwise he will wait for a next gap that is sufficiently large (Hwang et al., 2005). The critical gap is an important factor in such a model. The critical gap is the minimum gap required to make a safe merge manoeuvre.

Recently, there have been some doubts about the accuracy of gap acceptance models for simulating a merge movement (Chevallier et al., 2009, Daamen et al., 2010). During congestion in particular, other merging behaviour is observed. The situation at an on-ramp appears to be more complicated than a simple gap acceptance model. A driver who wants to merge is not only looking for a gap, but there is also interaction with the main road. This interaction influences the behaviour of the drivers on the main road and the acceleration lane (Wang, 2005). With the use of a gap acceptance model the capacity and the average speed of an acceleration lane was researched and the results were lower than the observed values on a freeway merge section (Hidas, 2002). It has been determined that these shortcomings of a gap acceptance model are caused by the following factors:

- Only the gap alongside the merging vehicle is checked for the feasibility of a lane change.
- Decision depends on a gap acceptance criterion based on the desired spacing of the car following model. Empirical analysis shows that many merges occur at much shorter gaps.
- If a vehicle cannot change lane right away, it tends to slow down and even stop. Field observations show that drivers are accelerating to the average speed of the carriage way and only slow down and stop very rarely as a last resort.

Because of these shortcomings of a gap acceptance model used in micro simulation tools, a new conceptual framework for modelling merging behaviour has been recently proposed (Loot, 2009). This concept is based on gap selection. It means that every driver is able to find a suitable gap out of a set of offered gaps without being overtaken by drivers on the adjacent lane and without coming to a standstill at the end of the acceleration lane. The choice decision of a gap out of a set of offered gaps is the main focus for this research. It provides a discrete choice model for the choice decision of a merging car for a future merging model.

1.1 RESEARCH OBJECTIVE

In this section the research objective of this master thesis research is described. The problem definition, also briefly explained in the introduction, is described. Based on the problem definition a main research question is stated. To answer this main research question a set of sub research questions is compiled.

1.1.1 PROBLEM DEFINITION

The main problem is that microscopic traffic simulation models simulate merging behaviour using gap acceptance theories. These models do not seem to be able to simulate merging behaviour accurately, since there is different behaviour observed in empirical analysis, like smaller gap sizes during a merge movement, cooperation on the acceleration lane and multiple gaps are evaluated for a merge decision. That means that question marks can be raised on the results of the simulation tools. In a study by Loot (2009) a new framework for modelling merging behaviour is postulated. This framework is based on gap choice between an offered set of gaps instead of evaluating one gap at the time. The main goal of this research is to analyse merging behaviour, in particular gap choice behaviour, and to establish a discrete choice model for gap choice behaviour.

1.1.2 MAIN RESEARCH QUESTION

Based on the problem definition a research question is compiled. To find an answer on this main research question a set of subquestions is stated. The answers to these subquestions will cover the answer of the main research question. The main research question of this master thesis is as follows:

How can merging behaviour on a freeway on-ramp be modelled so that it corresponds to actual observed merging behaviour?

1.1.3 SUB RESEARCH QUESTIONS

To answer the main research question, a set of sub research questions is postulated. These subquestions are defined within the boundary of this research and will provide a foundation for answering the main research question. The sub research questions are as follows:

1. *What kind of conceptual and mathematical models are available in literature to predict merging behaviour on a freeway on-ramp?*
2. *What kind of models are used in simulation software to describe merging behaviour?*
3. *What are the characteristic influencing the merging behaviour on a freeway on-ramp according to empirical data?*
4. *How does a microscopic traffic simulation tool perform in comparison with empirical data?*
5. *What is the gap choice behaviour according to empirical data?*
6. *What is a significant discrete choice model to model the gap choice behaviour?*
7. *What is the face validity of the discrete choice model?*

The main research goal of this thesis is reached when the main research question is answered with the use of the sub research questions. In the next section the methods used to answer these questions are described.

1.2 Research approach

In this section the research approach is discussed. This consists of the research methods used in this thesis for answering the sub research questions mentioned in the previous section. The used methods are:

A. Literature study
B. Empirical data analysis
C. Case study with a microscopic traffic simulation tool
D. Estimation of a discrete choice model
E. Face validation of a discrete choice model

For every method a detailed description is given. This consists of the corresponding sub research questions of the method, the application of the method, and the goals that would be achieved with the method.

A. Literature study

The literature study gives an answer to the following sub research questions:

1. *What kind of conceptual and mathematical models are available to predict merging behaviour on a freeway on-ramp?*
2. *What kind of models are used in simulation software for merging behaviour?*
3. *What is the merging behaviour on a freeway on-ramp according empirical data?*

With the literature study the state-of-art about several topics will be researched: merging behaviour, merging models, and micro simulation tools. The first topic, merging behaviour, will offer insight into observed merging behaviour. Influences on merging behaviour will also be examined. This will be done using the differences in merging behaviour for traffic states, geometric design, vehicle types on the adjacent lane and weather. The second topic, merging models, will focus on the principle of lane change models. The development of merging models over years and different frameworks will also be examined. The last topic will focus on the state-of-art of microscopic traffic simulation tools. From the most widely used models in Europe, a model from the United States, and a model from the Netherlands the lane change component is examined. Approaches for modelling merging behaviour will be also studied.

The goals for the literature study are:

- *To gain insight into the state-of-the-art about merging behaviour*
- *To gain insight into the state-of-the-art about theoretical merging models*
- *To gain insight into the methods used for modelling merging behaviour in micro simulation* tools

B. Empirical data analysis

The empirical data analysis gives an answer to the following sub research questions:

3. *What is the merging behaviour on a freeway on-ramp according empirical data?*
5. *What is the gap choice behaviour according empirical data?*

The empirical data analysis is performed on two topics, merging behaviour and gap choice behaviour. The empirical data analysis will be performed with a trajectory dataset collected by Loot (2009) at the freeway A12 from Gouda to Utrecht near Bodegraven, from 35.6 km to 36.0 km . The analysis will be performed on the interaction between lanes of the carriage way, the speed of a driver during a merge manoeuvre, acceleration/deceleration on the acceleration lane, gap analysis in relation with the location of merge manoeuvre, and the behaviour of the gap choice out of a set of gaps. The interaction between lanes will be analysed with the average speed as function of time. The interaction will give insight into the cooperativeness between drivers on the main road and the acceleration lane. The merging speed, acceleration/deceleration on the acceleration lane, and gap analysis in relation with the location of merge manoeuvre offers insight into merging behaviour. The last analysis on the gap choice behaviour gives information for estimating a model of the gap choice of a driver who wants to merge. The gap choice analysis will be performed as function of the location on the acceleration lane, as function of time driving on the acceleration lane, and as function of time before the merge manoeuvre takes place.

The goals for the empirical data analysis about merging behaviour are:

- *To gain information about merging behaviour*
- *To gain information about the interaction with drivers on the main road*
- *To analyse the choice behaviour of a merging vehicle*
- *To gain information about the choice set of alternative gaps*

C. Case study with a microscopic traffic simulation tool

The case study with a microscopic traffic simulation tool gives an answer to the following sub research question:

4. *How does a microscopic traffic simulation tool perform in comparison with empirical data?*

To answer the subquestion about the performance of a micro simulation tool, a case study will be performed with FOSIM. This offers insight into the performance of a gap acceptance model used in a micro simulation tool. The road section where the empirical dataset is collected will be simulated in the program. Using the same traffic conditions, a significant amount of simulation runs will be performed. The results will be compared with the trajectory dataset used in the empirical data analysis. The comparison will be made on the location of merging, average speed per lane, number of lane changes performed on the carriage way, and the average total travel times. This offers insight into the performance of the micro simulation tool FOSIM.

The goals for the case study about micro simulation tools are:

- *To compare the results of a simulation tool with an empirical dataset*
- *To gain information at the performance of a simulation tool*
- *To gain information of the performance of a gap acceptance model*

D. Estimation of a discrete choice model

The estimation of a discrete choice model gives an answer to the following sub research question:

6. *What is a significant discrete choice model to model the gap choice behaviour?*

To model the gap choice behaviour of a driver wanting to merge, a discrete choice model will be estimated. The results of the empirical data analysis of gap choice behaviour will be used as basis for the model. The empirical analysis will give the framework and information about the location or time a choice decision is made, about the size of the choice set and how many choice decision are made.

The goal for the estimation of a discrete choice model is:

- *To estimate a significant discrete choice model with parameters corresponding observed merging behaviour from empirical analysis.*

E. Face validation of a discrete choice model

The face validation of a discrete choice model gives an answer to the following sub research question:

7. *What is the face validity of the discrete choice model?*

After estimating the discrete choice model, a validation is performed. The validation will be split in two face validity checks, namely an aggregate validity check and an individual validity check. The aggregate validity check offers insight into the prediction accuracy of the discrete choice model in total. This will be performed using the differences between gap choice distribution of the choice model over all drivers and the empirical dataset. The individual validity check will give insight into the performance of the choice model per driver. This will be performed using an analysis of the gap choice distribution modelled with the choice model per actual chosen gap of the empirical dataset e.g. an analysis of the modelled gap choice distribution of drivers who selected gap 2 in the trajectory dataset.

The goals for the validation of a discrete choice model are:

- *To gain insight in the face validation of the choice model in general*
- *To gain insight in the face validation of the choice model per individual*

1.3 Relevance of the research

This research contributes to both scientific and practice. Therefore a distinction is made between these two perspectives. First, the relevance on scientific viewpoint is mentioned and second, the practical relevance is given.

1.3.1 Scientific relevance

From scientific perspective this research mainly contributes to theoretical modelling of merging behaviour. This research introduces a discrete choice modelling for gap choice behaviour of a driver who needs to merge on the adjacent lane. This model evaluates more gaps at once instead of one gap at a time. Besides the gap size, the discrete choice model also takes other characteristics that influence merging behaviour into account.

These characteristics are analysed with an empirical data analysis using a trajectory dataset captured at a freeway on-ramp. This analysis enhances the understanding of merging behaviour.

Lastly this research provides insight into the shortcomings of gap acceptance models. With a case study about a simulation tool that uses a gap acceptance model, a comparison will be made with empirical data.

1.3.2 Practical relevance

From a practical perspective this research mainly contributes, with indirect effects, to microscopic traffic simulation tools. In the case study on the micro simulation tool FOSIM, the shortcomings and implications of FOSIM and a gap acceptance model are researched. These shortcomings and implications can lead to poor assessments of a design e.g. a design where a longer acceleration lane than necessary is present. This does not only contribute to FOSIM, but also to other microscopic traffic simulation tools that use a gap acceptance model for simulating merging behaviour. Five well-known models will be studied in the literature research. This will make it clear what kind of models are used to simulate merging behaviour.

This thesis introduces a discrete choice model for modelling gap choice behaviour that could be implemented in a microscopic traffic simulation tool. This model evaluates more gaps at once and takes other characteristics that influence merging behaviour into account. It can therefore provide a more accurate simulation of the actual merging behaviour at a freeway on-ramp in comparison with a gap acceptance model. This can give results more closely corresponding to field observations than the traditional gap acceptance theories, which can lead to other results when a design is assessed, e.g. a shorter length of the acceleration lane.

1.4 Thesis outline

This section describes the report outline. A schematic overview of this master thesis and the relation between the chapters is shown in Figure 1.1.

Chapter 2 discusses the state-of-art about merging behaviour. This consists of observed merging behaviour at a freeway on-ramp, theoretical models of merging behaviour, and micro simulation tools used for simulating traffic.

Chapter 3 consists of an empirical data analysis about merging behaviour. This is performed using a trajectory dataset collected by Loot (2009). The analysis concentrates on the cooperativeness between lanes and the merging behaviour. The cooperativeness is analysed with the average speed in function of time per lane. For the merging behaviour the speed during a merge movement, the speed development on the acceleration lane and a gap analysis is performed. This chapter will give insight into the characteristics influencing the merging behaviour.

In chapter 4 a comparison is made of the empirical dataset used in chapter 3 and simulation results of the microscopic traffic simulation tool FOSIM. This is a common used micro traffic simulation tool on the TU Delft and Rijkswaterstaat. The comparison will give insight into the performance of a gap acceptance model.

Chapter 5 is an empirical data analysis about the gap choice behaviour out of an offered set of gaps. This analysis offers insight in the gap choice behaviour and about the choice set of alternative gaps.

In chapter 6 three discrete choice models are estimated, because different behaviour occurred between vehicle types and traffic states. The estimated models are a discrete choice model for trucks, a discrete choice model for passenger cars in free flow traffic state, and a discrete choice model for passenger cars in congestion. For trucks there is no distinction in traffic state, because there are not enough observations in the dataset to make a significant model.

After the estimation of the discrete choice model, a face validation of these models is performed. The results of the validation are discussed in chapter 7. The validation is performed on two levels, namely an aggregate face validity and an individual face validity.

The report ends with the conclusions and recommendations described in chapter 8. In this chapter the main findings, conclusions, recommendations, and suggestions for future research are given.

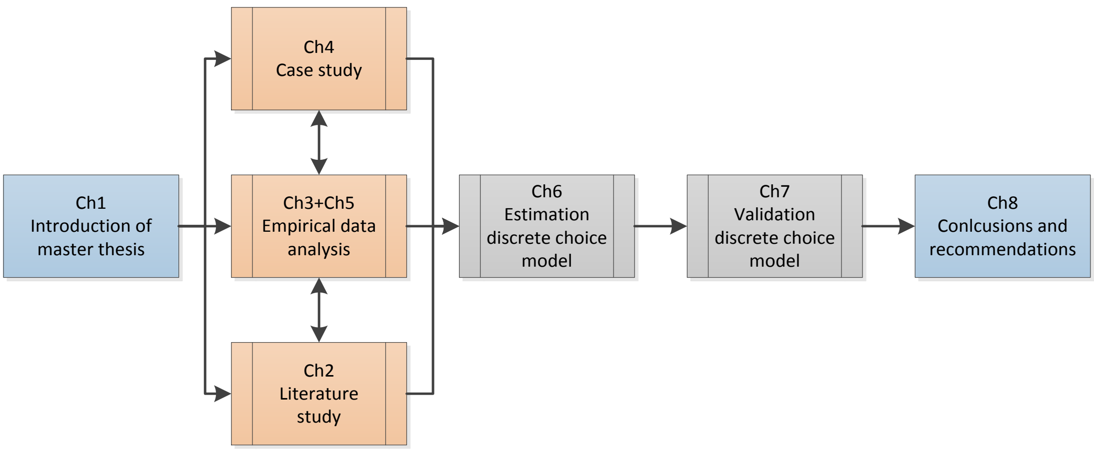


Figure 1.1 - Schematic overview of the thesis.

2 LITERATURE REVIEW

To gain more insight in actual merging behaviour and modelling merging behaviour, a literature study is carried out. It will give the state of the art about merging at freeway on-ramps. This study mainly focusses on actual merging behaviour and prediction of merging behaviour at a freeway on-ramp. A schematic overview of the literature study is given in Figure 2.1.

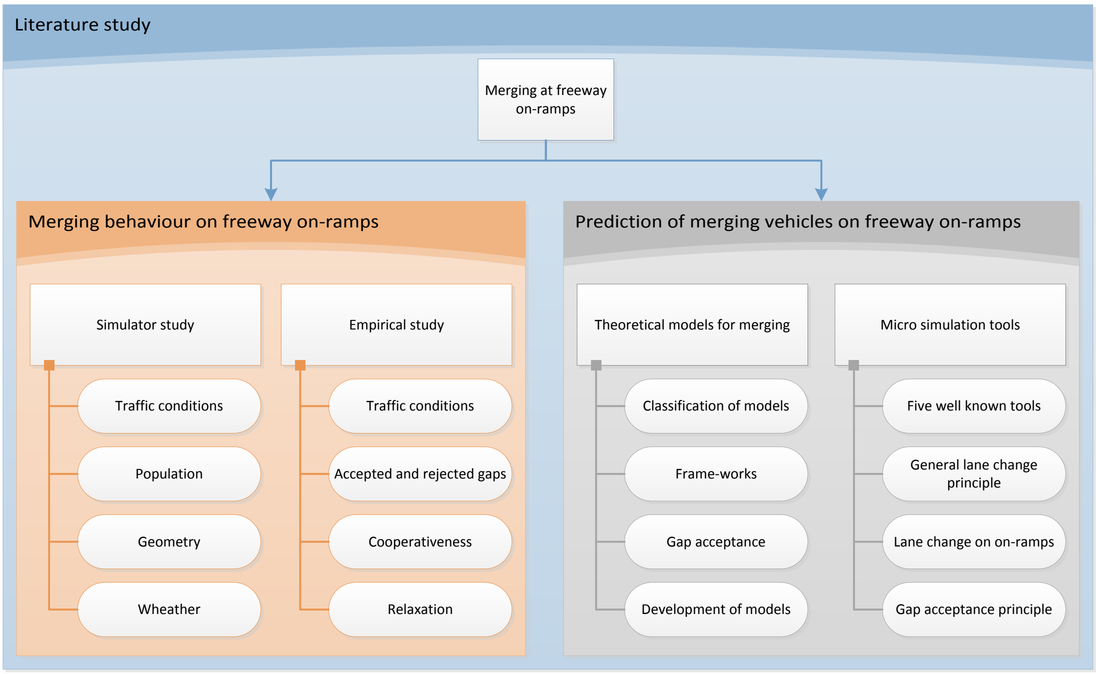


Figure 2.1 - Schematic overview of the literature study

In the schematic overview, Figure 2.1, it is clear that the literature study is divided into two main components, those being actual merging behaviour and prediction of merging behaviour. The first part offers insight into the merging behaviour at a freeway on-ramp. This is done using literature about driving simulator studies and empirical data analyses. In the literature, factors related to merging behaviour are studied. This shows which factors have an influence on merging behaviour. The resulting merge movement is studied as well. This will give insight into the gap acceptance along the acceleration lane.
The second part, prediction of merging behaviour, gives the state-of-the-art about the prediction of merging behaviour at a freeway on-ramp. This is split up in theoretical models and in microscopic traffic simulation tools. For the theoretical models, the classification of lane changes, different frameworks for modelling merging behaviour and gap acceptance are studied. Microscopic traffic simulation tools are studied with five well-known simulation tools. For every tool, the lane changing model in general, the lane changing on freeway on-ramps and the approach of the gap acceptance model is studied. A comparison on the approach for merging behaviour of the five microscopic simulation tools is given as well.

Section 2.1 focuses on literature about merging behaviour. Section 2.2 supplies an overview of existing models used to simulate a merge movement. Section 2.3 describes literature about micro simulation tools. This chapters ends with a conclusion.

2.1 MERGING BEHAVIOUR

The literature study starts with merging behaviour. It focuses on factors influencing merging behaviour (driver population, traffic conditions, geometric design and weather conditions) and on the resulting merging behaviour (gap acceptance). First the research on the factors are mentioned and secondly the resulting gap acceptance.

2.1.1 POPULATION

The research about merging behaviour on driver population is performed assuming a standard geometric design of an acceleration lane of 300 meters. The first part discusses the differences in merging behaviour between experienced and inexperienced drivers. The second part discusses the differences in merging behaviour between elderly and young drivers, who are both experienced.

In a simulator study on the effects of an increase in heavy goods vehicles, different conditions during a merge movement are tested (de Waard et al., 2007) as well as the difference between experienced and inexperienced drivers. An experienced driver is defined as someone who has held his license for at least 5 years and drives more than 5,000 km a year. An inexperienced driver is defined as having held his license for about 2 years. The effects of driving experience on merging behaviour are limited despite the group of experienced drivers displaying more speed variation in the acceleration lane. The minimum time headway after merging into the traffic was also smaller. From this, we can conclude that inexperienced drivers maintain a safer margin during merging.

In another simulator study the differences between elderly and young drivers are studied (de Waard et al., 2009). All drivers were experienced drivers. The group of elderly are 65 years or older. The young drivers are between the age of 25 and 40. In my opinion, A forty-year old driver is not a young driver. It’s better to categorize young drivers as being between 22 and 30 years old (SWOV, 2012). In the simulator study, the group of elderly people averages 70.3 years of age. The young group averages 29.5 years of age. The study shows that the group of elderly drove more slowly on the acceleration lane than the young group. On average the speed of elderly is 16 km/h lower than the speed of the younger drivers and this effect remained after merging on the main road. No difference is found in the location of lane change between the groups and there was no clear difference in the time headway after merging.

2.1.2 TRAFFIC CONDITIONS

A literature study on traffic conditions is performed on a standard acceleration lane of 300 meters. The traffic conditions in terms of traffic composition used in the simulator study are:

- only passenger cars on the main road,
- a mix of passenger cars and heavy goods vehicles,
- a situation with a convoy of heavy goods vehicles on the main road,
- a situation with a slower driving car in front of a driver on the acceleration lane.

Other than a study of traffic conditions in terms of the composition of traffic, a study is also made about the merging behaviour during free-flow traffic state as well as during congestion.

Under conditions with only passenger cars on the main road, and a relatively high intensity of 1,800 vehicles per hour per lane, most of the participants of the simulator study changed lane in the middle of the merging lane, see Table 2.1 (de Waard et al., 2007).

During mixed conditions, with 15% HGV’s and an intensity of 1,800 vehicles per hour per lane, the majority changed lane at the end of the acceleration lane (about 56%). In these conditions only 7% merged at the beginning of the acceleration lane and 37% merged in the middle. 72% of all participants

merged in front of a heavy vehicle. In an empirical study, this distribution with mixed condition of 10% HGV's is different (Loot, 2009). In these conditions, most of the merges occur in the beginning of the acceleration lane. About half of the drivers merge before 90 meters. At the end of the acceleration lane the percentages of merging vehicles has a small peak.

The differences between the empirical study and the simulator study can be explained by the fact that in the simulator study only passenger cars merge on the main road during free flow, while in the empirical study there is a mixture of vehicles who are merging on the main road. The traffic conditions also changed from free flow to congestion in the empirical study.

The last situation is a convoy of HGV's. The location of merging did not significantly differ when compared to the situation with mixed conditions. Although, during the condition with a convoy only 50% of the participants merged in front of a HGV.

In another simulator study the merging behaviour of a car driving slowly in front of the driver was studied (de Waard et al., 2009). In this case the participants changed lane much earlier in comparison with normal circumstances.

In an empirical study on merging behaviour the difference between free flow traffic state and during congestion is analysed (Daamen et al., 2010). The results show the location of merging is different between free flow traffic state and during congestion. During free flow conditions the location of merging has a lognormal distribution, while in congested conditions the merge locations are more uniformly distributed.

Table 2.1 - Percentages of vehicles merging at begin, middle of end of acceleration lane (Sim: Simulator study, Emp: Empirical data analyses study, FF: Free flow condition, Con: Congested condition).

	Merge location		
Conditions	**Begin**	**Middle**	**End**
Passengers cars (Sim) (FF)	13%	51%	36%
Mixed conditions (Sim) (FF)	7%	37%	56%
Mixed conditions (Emp) (FF & CON)	51%	23%	26%
Mixed conditions (Emp) (FF)	53%	33%	15%
Mixed conditions (Emp) (CON)	38%	32%	30%
Convoy of HGV's (Sim) (FF)	7%	37%	56%

2.1.3 GEOMETRIC DESIGN

For the literature study on geometric design, a comparison is made with a shorter and a longer acceleration lane. The standard size of an acceleration lane is 300 meters. The study on the shortened acceleration lane assumes a lane length of 150 meters and the extended version has a length of 450 meters.

In a study about merging behaviour with a simulator, the differences of a different length of the acceleration lane is studied (de Waard et al., 2009). An extension of 150 meters results in the participant changing lanes with a higher speed (about 12 km/h higher). The participants also merged later. The merging location on an acceleration lane of 450 meters was about 43 meters further than on a standard acceleration lane.

In case of a shorter acceleration lane of 150 meters the participants changed lane, on average, 50 meters earlier compared with a standard acceleration lane. None of the drivers continued on the emergency lane. Every participant found a gap to merge into the main road. This is also seen in an empirical study (Daamen et al., 2010). All of the observed merging vehicles merged into the main road before the ending of the acceleration lane.

2.1.4 WEATHER CONDITIONS

In a research with a simulator the behaviour during fog is analysed (de Waard et al., 2007). The visibility in the fog was 150 meters. The results are compared in case of bright weather. It was clear that the average speed on the acceleration lane was lower in case of fog. The average speed on the main road after merging was also lower. Accordingly, drivers do adapt their behaviour and increase time margins.

2.1.5 COOPERATIVENESS

A phenomena that can appear at small gaps is relaxation. Smaller headways are accepted during and just after the merge movement. After the merge, both drivers relax the gap from their new leaders, until their headways corresponds to gap sizes that are usually observed during normal driving conditions. In the empirical data study of Loot (Loot, 2009) was too little data available to see complete relaxation. The period of relaxation is around 20 to 30 seconds. This was too far downstream the merging section to capture. However, there are 190 unique observations in the data with at least one resulting headway (putative follower – merger or merger – putative leader) shorter than one second. In 42% of the cases the headway between merger – putative leader increase over time and 50% of the cases the headway between putative follower – merger increased over time.

Cooperativeness can also influence the decision to accept a gap. The cooperativeness studied consists of courtesy yielding and cooperative lane changing. In case of courtesy yielding, a driver on the main road decelerates to offer a gap to a driver on the acceleration lane. With cooperative lane changing a vehicle on the main road will change lane to the left to create a gap for a driver on the acceleration lane. Both of these phenomena are observed in the empirical data study of Loot (2009). It is difficult to analyse if and how many vehicles are courtesy yielding, courtesy yielding is performed very subtle. A cooperative lane change is easier to observe. In the empirical data 7% of the vehicles perform a cooperative lane change.

2.1.6 GAP ACCEPTANCE

The factors mentioned in the sections above results in a gap acceptance and the merge movement to the shoulder lane. In a recent empirical study the headways during a merge are analysed alongside the acceleration lane (Loot, 2009). It appears that smaller gaps are accepted at the end of the acceleration lane, but the difference is not big when compared to the accepted gaps at the beginning of the acceleration lane. The mean accepted gap at the beginning is 3.5 seconds and 2.8 seconds at the end of the acceleration lane. Drivers merging at the end of the acceleration lane reject gaps that are most likely larger than their critical gap. The smallest accepted gap observed is between 0.5 and 1.0 second, for free flow traffic and as well as during congestion.

2.2 Existing models for merging behaviour

This part of the literature study is about existing models for lane changing. The first part discusses different approaches of classification of lane changing. The second part offers different frame-works of lane change models, while the third part is about gap acceptance of drivers. The last part is about a game theory for merging.

2.2.1 Classification of lane changing

Models for lane changing can be divided by classifications for lane changes. Most models use the distinction between mandatory and discretionary lane changes e.g. (Gipps, 1986, Kesting et al., 2007, Laval et al., 2006). Mandatory lane changes are necessarily performed to keep the route, like merging at a freeway on-ramp. Discretionary lane changes are performed to improve driving conditions, to overtake a slower driving vehicle to increase speed, for example.

At times developments of this classification or other types of classification are used. for example free, forced and cooperative lane changes (Hidas, 2002, 2005b). Or a classification by the way the lane changes are prepared and performed (Schakel et al., 2012). This is defined as a lane change process and different processes are performed for different levels of desire.

2.2.2 Framework for lane change models

The first framework developed for lane changing is still used nowadays. It is Gipps' model (Gipps, 1986). He poses three questions for a driver's decision to change lanes, namely:

- Is it possible to change lanes?
- Is it necessary to change lanes?
- Is it desirable to change lanes?

Posing these questions, the following factors and their effects were considered to be most important for a general model:

- Whether it is physically possible and safe to change lanes: A driver will not change lanes if there is an unacceptable risk of a collision;
- The location of permanent obstructions: Drivers familiar with a road try to avoid being trapped behind known obstructions by selecting lanes that will give them free passage;
- The presence of transit lanes: Vehicles entitled to use a transit lane move into other lanes only when necessary to pass obstructions or slow vehicles;
- The driver's intended turning movement: The readiness of a driver to change lanes is affected by the distance from his intended turn and the direction of that turn.
- The presence of heavy vehicles: Drivers to avoid being trapped behind heavier vehicles because of their lower accelerations;
- Speed: Speed affects a driver's decision to change lanes is whether the traffic in the present lane or the target lane is more likely to limit his speed in the short term;

The model also considers the urgency of the lane changing manoeuvre in terms of the distance to the intended turn of the driver. The urgency of the manoeuvre is modelled through the drivers gap acceptance and deceleration. The model assumes that a lane change only takes place when a gap of sufficient size is available in the target lane. This framework is intended to cover lane change decisions in urban driving situations. It is not directly applicable to lane changing on a freeway. However, the framework is applied in several models throughout the years for lane changing on freeways e.g. (Hidas, 2002).

Hidas (2005b) developed a merging model including cooperative and forced merge movement components. However, the cooperative lane change only consists of the decision of the lag driver and not the decision of the merging driver. Therefore a unified decision framework for drivers with latent plans is introduced by Choudhury (2007), see Figure 2.2.

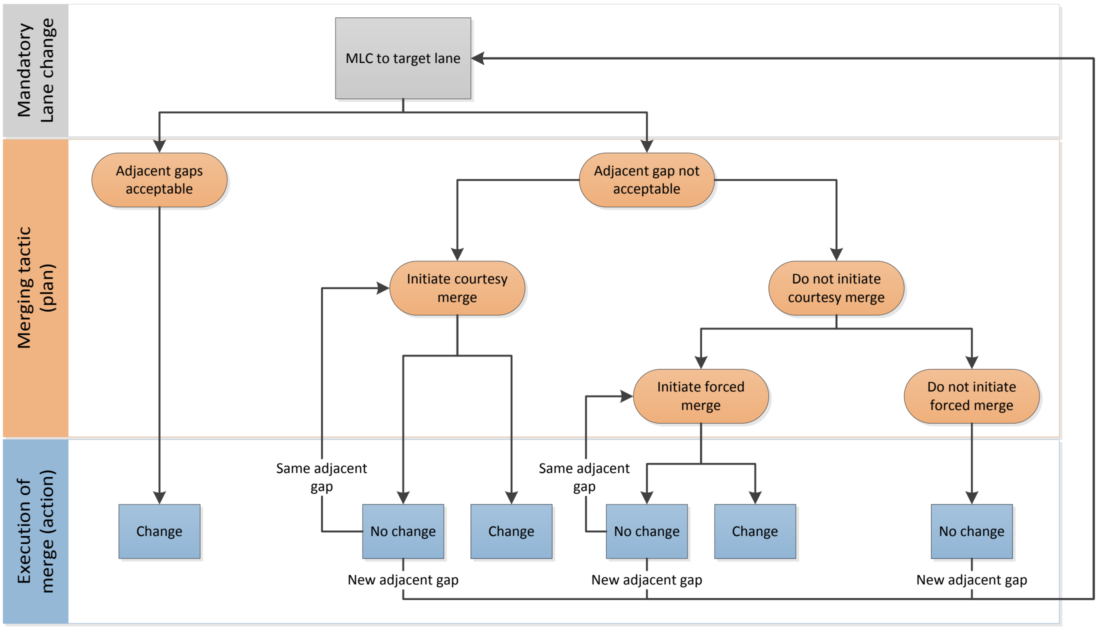


Figure 2.2 Structure of the merging model of Choudhury(2007).

The plan and decision process are latent and only the end action of the driver is observed. The latent plan for a merging vehicle consists of three opportunities, namely merge normally, merge with courtesy or a forced merge. Every vehicle starts in normal state at the top of the decision tree. If the driver is in normal state, the full decision tree is in effect. The process starts at the top and normal, courtesy and forced merging plans are sequentially evaluated. In case of a 'no change' the driver stays in the same state (courtesy or forced state) if the same adjacent gap is evaluated. If a new adjacent gap is evaluated, the driver is back in normal state and the evaluation start from the top of the decision tree. For every state different characteristics are used for the gap acceptance.

A different framework for lane changing has been proposed recently by Kesting et al (Kesting et al., 2007). The basic gist of the model, called MOBIL, is to measure both the attractiveness of a given lane and the risk associated with lane changes in terms of acceleration. Instead of a flow-chart with a certain predefined questions to determine a drivers willingness to change, like the Gipps model, MOBIL uses a generic approach using utility function for different lanes using acceleration possibilities. The model also factors in politeness. The purpose of this parameter is to vary the motivation for lane changing from purely egoistic to more cooperative driving behaviour.

Another recent framework is the LMRS model (Schakel et al., 2012). This model is built around a lane change desire that follows from a combination of the route, speed and keep-right incentives. Instead of classifying lane changes by the reason for which they are performed (mandatory or discretionary) the model classifies lane changes by the way in which they are prepared and performed. It is a lane change process and different processes are used for different levels of desire. The modelling of congestion, relaxation and synchronization is included in the model.

2.2.3 GAP ACCEPTANCE MODEL

Most of the lane change frameworks are using gap acceptance for modelling the merging behaviour (Hwang et al., 2005). Gap acceptance is the minimum gap required to make a lane change. Therefore, a gap acceptance model can help describe how a driver judges to accept a gap or not. In the model, the critical gap is an important parameter. The theory states that every driver has a certain critical gap. If an offered gap is larger than the critical gap, the driver can make a lane change. whether the driver makes the actual lane change depends on the model used. Some models only use gap acceptance, while other models have more preconditions for lane changing.

Gap acceptance models can be divided in deterministic and stochastic gap acceptance (Hwang et al., 2005). With deterministic gap acceptance, the value of the critical gap is an unique value. For estimating the critical gap, there are three representative methods, those being:

1. Determine the critical gap through the median or mean observed from accepted gaps.
2. Determine the intersection of the accumulated curve of accepted gaps and the accumulated curve of rejected gaps.
3. Determine the critical gap using the regression method of Drew which uses merge angle and acceleration lane length.

The deterministic gap acceptance has some limitations. Because the critical gap is a unique value, it has some limitations in reflecting the behaviour of a driver. The critical gap differs between drives. To avoid these limitations, we can use stochastic gap acceptance. Stochastic gap acceptance derives the critical gap using gap distributions. This can be done with logit and probit probability models. This has the advantage of having a detailed level of critical gap estimation. The downside is the many variables and parameters needed for to derive the critical gap. The stochastic methods are very time consuming.

2.2.4 GAME THEORY

In a study on merging give-way interaction, a game theory is developed (Kita, 1999). It describes the traffic behaviour of a merging car and the cars on the adjacent lane, while considering the interaction between these cars. This behaviour is modelled as a two-person non-zero-sum non-cooperative game[1]. The study is only concerned with give-way behaviour that happens when traffic conflict with a merging car. With the specification of type of game, number of players, numbers of games repeated, and whether the game is with or without cooperation, the situation can be described as a game. The merging vehicle must select one of two strategies, merge or stay in acceleration lane. The through car selects one of two strategies, give-way and not give-way at the vehicle who wants to merge. The model is based on an assumption that the driver will select the action with the lower level of risk, defined as the time to collision.

The model itself is rather simple. The payoffs for either the merging or through car in the game are assumed to be based only on its position and speed relative to the cars on the adjacent lane. There is a downside to the model. A driver of a merging car does not only check the car in the adjacent lane, he also checks the traffic conditions in a wider area up the main road. This means the model is not completely realistic

[1] Non zero sum: A gain by one driver does not necessarily correspond with a loss by another.
Non cooperative: The drivers have no way to exchange their decisions about executing the merging and giveway.

2.3 Micro simulation software

In this part of the literature study several widely used micro simulation software will be discussed. The focus will be on which lane changing models are used and specifically what approach is used for modelling merging behaviour. This literature study is done on five simulation tools, namely Aimsun, Vissim, CORSIM, Q-Paramics and FOSIM. The first four models are mostly used in comparison studies of micro simulation software (Bloomberg et al., 2000, Fang, 2003, Hidas, 2005a). Aimsun is a model developed in Spain. Besides micro simulation, it also models on a hybrid and mesoscopic level. Vissim is developed in Germany. It is a simulation program for multi-modal traffic and it simulates urban and freeway traffic. Q-Paramics is a model developed in the United Kingdom. Corsim is developed in the USA and it has the specifications of the freeways in the USA. FOSIM is a model that is specifically developed to study traffic on Dutch freeways and has been chosen because of this. The model is mainly aimed at corridors, but to a certain extent it can also deal with route choice situations if you specify the split fractions in the input.

2.3.1 Aimsun

In the model, the behaviour of every single vehicle is continuously modelled throughout the simulation period, according to several driver behaviour models such as car following, lane changing and gap-acceptance models (Xiao et al., 2005). Due to its detailed vehicle modelling, AIMSUN can replicate any kind of traffic detector, collecting basic measurements like vehicle counts, occupancy, presence, speed and density at any aggregation level defined by users.

Lane changing

The lane change model in AIMSUN can be seen as a further evolution of the Gipps lane change model (Barceló et al., 2005). A lane change is modelled as a decision process analysing the necessity of the lane change, the desirability of the lane change and the feasibility conditions for the lane change. The lane changing model in AIMSUN is a decision model that approximates the driver’s behaviour as follows:

Each time a vehicle has to be updated the model sets up the question:

Is it necessary to change lanes?

If this question is answered with YES two new questions are asked

a) Is it desirable to change lanes? This requires checking if there will be any improvement in the traffic conditions for the driver as a result of the lane change.

b) Is it possible to change lane? This requires verifying if there is a sufficient gap to make the lane change.

In order to achieve a more accurate representation of the driver’s behaviour in the lane changing decision process, three different zones of a road section are considered, each one corresponding to a different lane changing motivation. The distance up to the end of the road section characterizes these motivations. Figure 2.3 depicts the structure of these zones.

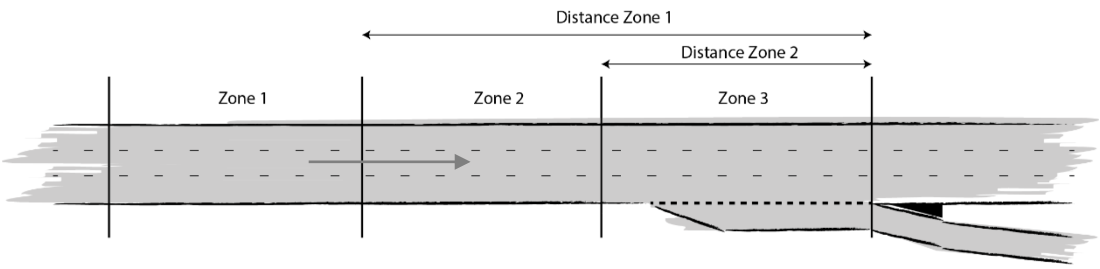


Figure 2.3 - Lane changing zones of Aimsun (Barceló et al., 2005).

Lane changing at On-Ramps

During lane changing at an on-ramp an additional zone parameter is defined (Barceló et al., 2005). This is the Time Distance On-ramp parameter. Vehicles further away than the Time Distance On-ramp till the end of the acceleration lane behave as if they are in zone 1. If they are closer than the Time Distance On-ramp until the end of the acceleration lane, they behave as if they have to merge from an on-ramp. The on-ramp model takes into account whether a vehicle is stopped or not. The Maximum Waiting Time determines how long a driver is willing to wait before getting impatient.

Gap acceptance

For the gap acceptance, Aimsun defines the reaction time as a global parameter (Hidas, 2005a). A maximum give-way time parameter is used as well. This parameter is defined as a distribution for each vehicle type. It is used to represent the growing impatience of a driver at a give-way situation. In case a vehicle has been waiting for the maximum give-way time, it will reduce its safety margins and accept shorter gaps. However, the user cannot alter the values set of these gaps in the model and the manual does not specify how short these gaps are.

2.3.2 CORSIM

CORSIM is a microscopic simulation model for signal systems, freeway or combined signal and freeway systems. It consists of an integrated set of two simulation models, namely FRESIM and NETSIM (Bloomberg et al., 2000). NETSIM represents traffic on urban streets and FRESIM represents traffic on freeways.

FRESIM lane changing

In FRESIM's model there are three types of lane changes, those being mandatory, discretionary and random lane changes (Middleton et al., 1999). During every time step, each vehicle is scanned if it has the desire to change lane. In case a lane change is performed, the vehicle is considered to remain in the target lane for three second. During this period random and discretionary lane changes will not be performed. However, mandatory lane changes may be performed in any time step in response to geometry.

An acceptable gap must be available for a vehicle that wants to change lane. Acceptance of the gap is modelled on the basis of the deceleration that is required by the lane changer to avoid a collision with the putative leader in the target lane.

FRESIM Lane changing at on-ramps

On an acceleration lane the vehicles are given a desired free-flow speed (Middleton et al., 1999). When the vehicle enters the acceleration lane they are assigned a new desired free-flow speed to facilitate the merge. This will be achieved by first scanning the speed of the vehicles in the target lane. These speeds are averaged and will be assigned to the merging vehicle as its desired speed. This improves the possibility for a smooth merge to the target lane.

FRESIM gap acceptance

In the model we can define ten different drivers types, with variable gap acceptance values (Bloomberg et al., 2000). Each gap acceptance decision is independent considering the current available gap and the personal gap acceptance value

In the model there are no major adjustments for vehicles to find a better gap (Holm et al., 2007). The modelled vehicles will only make adjustments to find a better gap based on the vehicle directly next to the merging vehicle.

2.3.3 FOSIM

FOSIM is a microscopic simulation model developed in the Netherlands especially for studies on Dutch motorways. The main aim is to study corridors with this model. The drivers behaviour in FOSIM is as follows (Dijker et al., 2006):

- The driver has a desired speed;
- If the desired speed is not achievable, the driver will try to change lane;
- If lane changing is not possible, the driver will adjust speed and follows the car in front with a desirable time headway;
- Drivers will change lane if it is necessary to keep on route, e.g. in case of a weaving section.

Lane Changing

If a driver is driving faster than his putative leader, the model checks if the driver is willing to change lane. There are two reasons to qualify the driver for a lane change, the acceleration of the leader (if it is accelerating too much, overtaking takes too much time, so the driver is not willing to make a lane change) and the amount of braking of the putative follower in the adjacent lane (if the putative follower in the adjacent lane has to brake a lot, the driver is not willing to make a lane change). If both reasons are satisfied the driver is qualified as a vehicle willing to make a lane change. This lane change will then take place if the acceleration of the lane changing vehicle and the deceleration of the putative follower on the adjacent lane is not too high. If the deceleration is too high the lane change will not be performed. This method – qualifying a vehicle as willing to make a lane change and then look at the acceptable deceleration to make the lane change – is the main principle for lane changing in FOSIM. With this principle both mandatory and discretionary lane changes are modelled. The difference is the conditions used for qualifying the driver as willing to make change and to make the actual lane change

Lane changing at on-ramps

At on-ramps the lane changes are qualified as a mandatory lane change. The acceptable deceleration develops in the acceleration lane. At the beginning the value is zero and at the end of the acceleration lane the value is the maximum deceleration for lane changing. This value depends on the type of vehicle. There are five types of vehicles in FOSIM, three passenger cars and two HGV's. Between the beginning and end of the acceleration lane the value increases linearly. This means that at the start of the acceleration lane the main principle for lane changing is used. At the end of the acceleration lane the maximum deceleration is accepted for the merging vehicle and his putative follower on the adjacent lane. With this deceleration a gap should occur.

2.3.4 Quadstone Paramics

The lane changing model in PARAMICS is loosely based on a number of other models (Duncan, 1997). It uses two devices, a gap acceptance policy, and a historical record of suitable gap availability. The gap acceptance policy is linked with a car-following model. The accepted gap is based on the target headway.

Lane changing

The lane changing model in Paramics is dependent on a couple of parameters, the signposting parameter, signrange parameter, awareness parameter, aggressiveness parameter and the wrong lane diversion time. The signposting and signrange parameters define the maximum and minimum distance at which drivers become aware of the need to change lane (Hidas, 2005a). The actual distance used by each driver vehicle unit (DVU) depends on the awareness parameter. This factor is assigned to the DVU from a distribution. The aggressiveness parameter affects the gap acceptance behaviour during lane changing. The wrong lane diversion time, a fixed parameter, is used to reroute a vehicle if it was unable to change lane.

If traffic in both the current lane and the target lane for a lane changing vehicle is moving at a constant speed, a gap must be available to merge (Duncan, 1997). If there is a speed difference between the two lanes, this expression is extended to take into account the time it would take for the lane changing vehicle to adapt the speed of the cars in the target lane.

So, if DVU0 is the DVU who wants the change lane, and DVU1 and DVU2 are the vehicles in the target lane in front and behind of the position of DVU0, then both of the following must be true to let the lane change take place:

$$g_1 > d_{\Delta V_1} + hv_1 \qquad\qquad g_2 > d_{\Delta V_2} + hv_2$$

Where:

$$d_{\Delta V_1} = t_{r0} + \frac{\Delta V_1}{D_0}$$
$$d_{\Delta V_2} = t_{r0} + \frac{\Delta V_2}{D_2}$$
$$\Delta V_1 = v_1 - v_0$$
$$\Delta V_2 = v_0 - v_2$$

v_N is the current speed of DVU_N
D_N is the maximum deceleration (braking rate) of DVU_N
g1 is the gap between the back of DVU_1 and the front of DVU_0
g2 is the gap between the back of DVU_0 and the front of DVU_2

If both these conditions are true continuously for a period of TLC seconds then the lane changing manoeuvre will take place. The value of TLC varies depending upon behaviour and location parameters and is in the range of 3 to 6 seconds.

Gap acceptance

In Paramics the critical gap for gap acceptance is dependent on the aggressiveness factor (Hidas, 2005a). More aggressive driver will accept shorter gaps. Another behavioural parameter is used; patience. This parameter simulates the patience of drivers waiting for a gap at a give-way points. If a vehicle exceeded its patience, it will push its way out into the flow of traffic.

2.3.5 VISSIM

VISSIM is a stochastic microscopic simulation model developed by PTV. It is a time-step and behaviour-based simulation model (Xiao et al., 2005). The model consists internally of two components that communicate through an interface. The first one is the traffic simulator and the second component is a signal state generator.

Lane changing

In VISSIM there are two types of lane changes, mandatory lane changes (defined in VISSIM as a necessary lane change) and discretionary lane changes (defined in VISSIM as free lane changes) (Vision, 2009). When a driver intends to make a lane change, the first step is to find a suitable gap in the target lane. For a mandatory lane change the gap depends on the acceptable maximum deceleration for the lane changing driver and his putative follower. In case of a discretionary lane change the gap depends on the desired safety distance between the merging vehicle and his putative follower. The gaps can be changed in the model with input factors for different vehicle types. For mandatory lane changes, this factor is a driver's aggressiveness. This factor does not influence the critical gap for discretionary lane changes. For this type of lane change, the desired safety distance can be adopted with different vehicle types. To complete the lane change, not only the aggressiveness and safety distance are important, but other factors as well. These are (taken from the VISSIM Manual):

Waiting time before diffusion: Defines the maximum time a vehicle can wait at the emergency stop position before it's removed from the simulation.

Min headway (front/rear): Defines the minimum distance to PL/PF that must be available for a lane change in standstill condition.

To slower lane if collision time: In case of keep right traffic rules, it describes the minimum time headway towards the next vehicle on the slow lane so that a vehicle on the fast lane changes to the slower lane.

Safety distance reduction factor: During lane changes the reduction factor is considered, which takes effect for, the safety distance of the PF, the own safety distance during a lane change, and the distance to the PL. After the lane change, the original safety distance is considered again.

Maximum deceleration for cooperative braking: Defines the maximum deceleration the vehicle would use in case of cooperative braking thus allowing a lane change into its own lane.

Gap acceptance

The gap acceptance in VISSIM is user-definable and location specific (Bloomberg et al., 2000). Therefore, gap acceptance can vary from one point to another within a particular network based on the type of operations being simulated. Gap acceptance can also be varied by vehicle type. VISSIM provides an unlimited number of user-definable vehicle types.

2.3.6 Comparison of simulation tools

In Table 2.2 a comparison is presented of the approach of simulation merging behaviour. It is clear that all the microscopic traffic stimulation tools reviewed in the previous sections are using a gap acceptance model to simulate merging behaviour. Only the approach for the determination of critical gap differs between the models.

Table 2.2 - Comparison of the microscopic traffic simulation tools.

	Gap acceptance	Critical gap based on deceleration	Critical gap based on patience	Critical gap based on aggressiveness
Aimsun	✓		✓	
Corsim	✓	✓		
Fosim	✓	✓		
Paramics	✓		✓	✓
VISSIM	✓			✓

2.4 CONCLUSION OF LITERATURE REVIEW

This chapter gives an overview on the state of the art of merging behaviour. This consists of actual merging behaviour on freeway on-ramps and about models for simulating merging behaviour. The actual merging behaviour is researched with simulator studies and empirical data analyses studies. For the models some theoretical frameworks and micro simulation tools are studied.

From the studies about actual merging behaviour it is clear drivers make a choice between gaps that are offered to them. The decision for choosing a gap is dependent on several factors, e.g. vehicle type of putative follower and putative leader, gap size, traffic conditions, geometric design. When the traffic composition changes to more HGV's on the shoulder lane, even more drivers use at least the half of the length of the lane. Some drivers even use the total length of the lane. If the acceleration lane is extended, the drivers stay on the acceleration lane for a longer time. During congestion the choice of a gap changes compared to free flow. The drivers are willing to overtake several cars and reject suitable gaps. It is clear that merging behaviour is dependent on the traffic conditions, the vehicle types and the geometric design. With these factors, the drivers will choose a gap out of a set of gaps offered at the moment they enter the acceleration lane.

The theoretical models are developed well throughout the years, but most of them are still based on the principles of Gipps's model (Gipps, 1986). The downside of these models is that they are using gap acceptance to model the merging behaviour. This means if an offered gap on the shoulder lane is bigger than the critical gap of a vehicle the gap will be accepted and the driver will merge. In the game theory model this is not the case and an offered gap bigger than the critical gap can be rejected because staying on the acceleration lane is more preferable. However, this model only takes one gap in account to reject or accept. So in the theoretical models there is no decision of which gap is most preferred by a driver out of a set of offered gaps. For micro simulation tools the same problem occurs, they all uses a gap acceptance model to simulate merging behaviour. Thus if an offered gap is bigger than the critical gap, the simulation tool simulates a merge movement from the acceleration lane to the shoulder lane. The only difference between the micro simulation tools is the approach for determining the critical gap. None of the models researched is modelling a merging movement with a choice between a set of gaps offered to a merging vehicle.

So there's a difference between the actual merging behaviour on freeway on-ramps and the approach for modelling this merging behaviour. In particular, the choice between gaps is missing in the models. This could affect the use of the acceleration lane (analysed in Chapter 4). Therefore a discrete choice model for modelling the gap choice is estimated in this thesis. This is done with the use of one dataset at a specific on-ramp (see Chapter 6). Some factors influencing merging behaviour are fixed in this dataset, e.g. the geometric design. Therefore attention must be given at the fact that the discrete choice model can differ for other locations. In the next chapter an empirical data analysis is performed to get more insight in merging behaviour and in the factors that influence the choice of a gap.

3 Empirical data analysis

Besides the factors analysed in the literature study as discussed in chapter 2, there are other factors influencing the merging behaviour. Because the main goal of the research is to create a new merging model, other factors will be analysed to get more insight into merging behaviour. This will be done using an empirical data analysis with a trajectory dataset. This is the same dataset as used in the master thesis of Loot (2009). In this case, the data analysis distinguishes between traffic state. Free flow means an average speed of 70 km/h or higher on the main road. During congestion the average speed is 50 km/h or lower on the main road.

The merging process is described in the first section of this chapter. The merging process is split up between three parts of the carriage way, namely the main road, the acceleration lane, and the gaps. The setup of the empirical dataset is described in section 3.2. In section 3.3 the location of the dataset is described. The geometric design of the junction is also mentioned. In the third section the dataset is described. Section 3.5 analyses the average speed per lane of the carriage way and in section 3.6 the merging speed is analysed. Section 3.7 studies the acceleration and deceleration in the acceleration lane. The last analysis, about offered, rejected and accepted gaps, is described in section 3.8.

3.1 Merging process

Freeway merging consists of mandatory lane changes. This means that a driver has to change from the acceleration lane to the shoulder lane of the main road, before the end of the acceleration lane. When a driver can see the traffic on the main road, he is able to identify the traffic conditions. From this point onwards the driver can start looking for a gap to merge and adjust his speed to reach a certain gap. If the driver is next to the gap and drives with a similar speed as the putative follower, he can make the merge movement and merge into the shoulder lane. This merging process depends on a couple of characteristics and phenomena that influence the merging behaviour, e.g. merging location, see Figure 3.1. The factors that influence merging behaviour can be divided into three categories, the traffic conditions on the main road, the traffic conditions on the acceleration lane and the gaps. These three categories have their own characteristics and phenomena that can be important for the merging behaviour. This is shown in Figure 3.2.

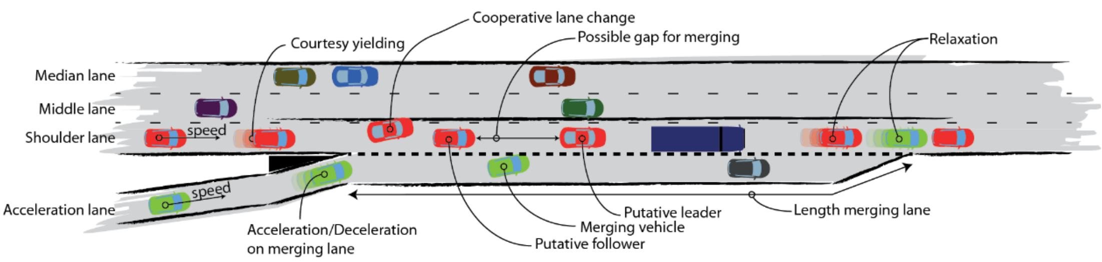


Figure 3.1 - Merging process; factors that have an influence on merging behaviour.

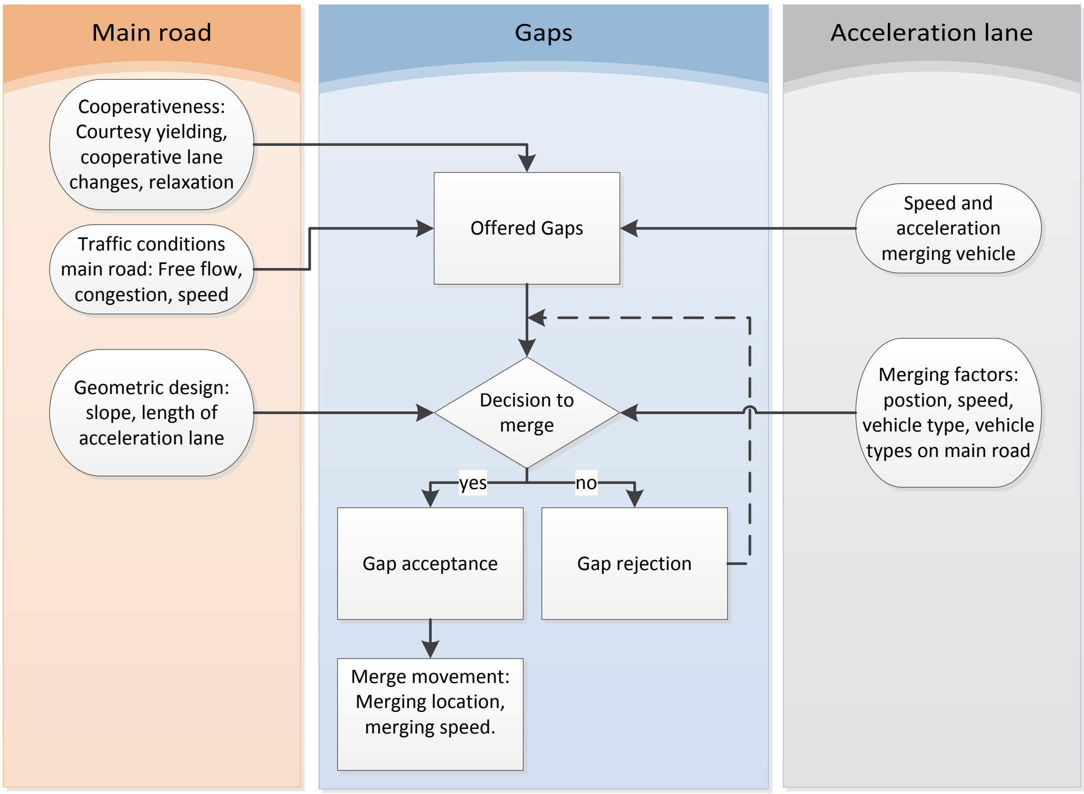


Figure 3.2 – Conceptual framework: relation of factor that influences the merging behaviour (Based on (Marczak et al., 2013)).

Merging factors influencing merging behaviour, categorized by factors of the main road, acceleration lane and gaps:

1. The characteristics for the traffic conditions on the main road are average speed, the traffic state, and cooperativeness of vehicles. This cooperativeness consists of courtesy yielding, cooperative lane changing and pre-allocation. To get insight into these factors and their influences on the merging behaviour an empirical data analysis is made on the average speed over time per lane. The other factors are studied in the literature study, section 2.1. In the master thesis of Loot (2009) the impact on merging behaviour of different traffic states and the cooperativeness of vehicles are already analysed.
2. On the acceleration lane the influencing factors on merging behaviour are speed development, merging speed, length of the acceleration lane and the location of merging. For these factors an empirical data analysis is made to get insight into their influences on merging behaviour. This analysis is performed on the acceleration and deceleration on the acceleration lane and the speed at the moment of a merge movement. The influences of the length of an acceleration lane and the merge location have already been discussed in chapter 2.
3. For the gaps the influencing characteristics are the headway between merging vehicle – putative leader, the headway between putative follower – merging vehicle, accepted gaps, and offered gaps. These factors have already been discussed in the literature study in chapter 2. To get more insight on why drivers reject gaps, a study on offered, rejected and accepted gaps is performed. First an analysis on sight of the late merging vehicles is made with pictures of these vehicles. After this, the influences of HGV's (heavy goods vehicle) on the adjacent lane is analysed with the empirical dataset

3.2 SETUP FOR EMPIRICAL DATA ANALYSIS

To gain more insight into the factors influencing merging behaviour, an empirical analysis is performed. This analysis is performed on the factors mentioned in section 3.1. Some of these factors have already been mentioned in the literature research, e.g. courtesy yielding. The remaining factors will be analysed with the use of an empirical data analysis. For this analysis, four questions are established to provide more insight in merging behaviour. The empirical data analysis will provide answers on the following questions:

1. Are drivers adapting their speeds in relation with the speed on their adjacent lanes?
2. What is the distribution of the speed during a merge movement?
3. What is the speed development on the acceleration lane?
4. What is the reason of a late merge movement?

For answering the first question the average speed per lane over time will be analysed. The average speed is plotted over time with a time period of 60 seconds. The graph provides the interaction between the lanes. The similarity of the pattern of the graph gives insight into the interaction. If the pattern is similar the drivers adapt their speed.

The second question will be answered using the distribution of merging speeds. For every merging car the speed during a merge manoeuvre is determined and the results are plotted in a bar graph. This analysis is first performed with all observations. After that, a distinction is made between traffic state and vehicle types. This will show if there is different behaviour between traffic states and vehicle types.

In order to answer the third question, the speed in relation with the location of every driver on the acceleration lane is determined. The results are plotted in a graph. The shape of the graphs will give insight in the acceleration and deceleration of the drivers. Again, in this case a distinction is made between traffic states and vehicle types.

The last question is analysed using a gap analysis. First, a manual gap analysis will be performed. In it, the accepted gap, rejected gap, traffic state and vehicle types on the adjacent lane will be analysed for late merge movements. Second, an analysis is made of the influence of vehicle types of the putative leader for merging. For every merging passenger car the vehicle types of the leader and follower is determined after a merge. The results are normalized and plotted in a bar graph in relation with the merge location. The distribution will give insight into the relation of HGV's on the shoulder lane and the merge location of a driver.

In this case, the data analysis distinguishes between traffic state. Free flow means an average speed of 70 km/h or higher on the main road. During congestion the average speed is 50 km/h or lower on the main road. The vehicle type is categorised into two groups, namely passenger cars and HGV's. If a vehicle is shorter than ten meters it is categorised as a passenger car, if it is ten meters or longer it is categorized as an HGV.

3.3 LOCATION OF MERGING SECTION

The empirical dataset used to analyse the characteristics and phenomena of merging is collected at the highway A12 from Gouda to Utrecht near Bodegraven by Loot (2009), see Figure 3.3. The acceleration lane starts at 35.6 km and ends at 36.0 km. The speed limit on the main road is 120 km/h. The road leading to the acceleration lane, the N11, has a speed limit of 100 km/h. The total length of the acceleration lane is 300 meters. This lane starts to narrow after 220 meters, see Figure 3.4 for a schematic overview. This is not the same as a standardized acceleration lane in the Netherlands (Rijkswaterstaat, 2006). On the main road the line markings indicates, by an solid line left of the lane marking between the middle lane and shoulder lane, that a lane change from the middle lane to the shoulder lane is not allowed. It is allowed to change lane from the shoulder lane to the middle lane.

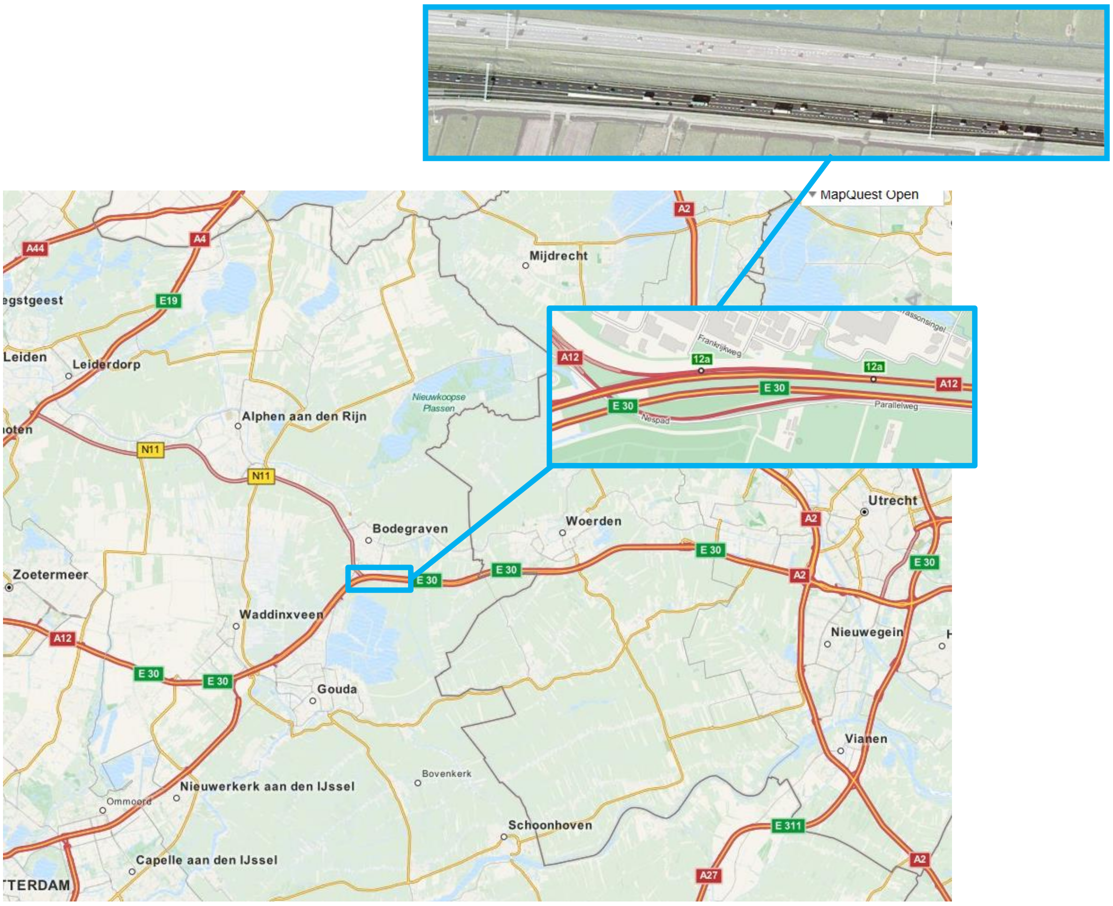


Figure 3.3 - Location of the merging section (source: www.openstreetmap.org, maps.google.com).

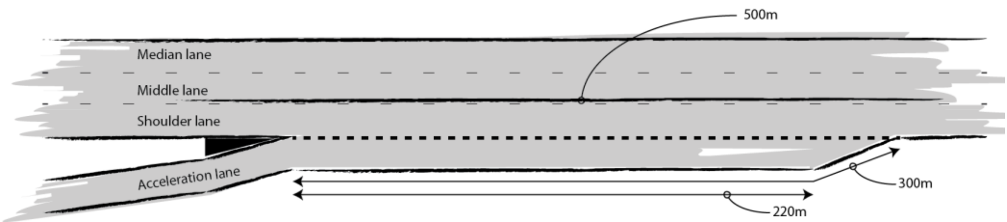


Figure 3.4 - Schematic overview of the merging section.

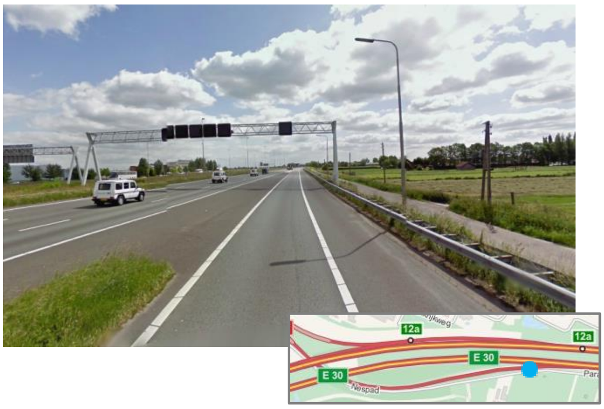
The geometric design of the on-ramp and the road leading to the on-ramp can have an influence on the merging behaviour. For example, the slope of entering the acceleration lane can influence the acceleration time and the view on the main road can influence the time to analyse the gaps. Not every junction has the same geometric design. For this reason the geometric design of road leading to the acceleration lane of the junction of the A12 and the N11 near Bodegraven will be described (Figure 3.5).

a: Picture reflecting geometric design of the N11 before the underpass with the A12.

The road section leading to the acceleration lane is coming from the N11 and passes underneath the A12. This means the road has a positive slope leading to the acceleration lane. This has a negative effect on the speed of the vehicles, because the acceleration will take more time. This is especially the case for HGV’s, because they are heavier and therefore a longer acceleration time is needed. The curvature looks normal. A passenger car can drive through with only a little amount of deceleration, but an HGV should probably decelerate to drive safely through the curvature.

b: Picture reflecting geometric design of the N11 just after the curvature leading to the A12.

Just after the curvature and before the beginning of the acceleration lane, there are a couple of trees between this road section and the main road, which are blocking the view. There is no opportunity to analyse the traffic conditions, e.g. traffic state, speeds, available gaps, on the main road at this point. It is not possible for the driver to adapt his behaviour to the conditions on the main road.



c: Picture reflecting geometric design just before the beginning of the merging section.

At the beginning of the acceleration lane, just before the merging section, there is time to analyse the main road. This gives the opportunity to analyse the traffic state, speed on the main road, presence of HGV’s and the offered gaps already. From this point onwards the merging vehicles can adapt their speed to find a suitable gap for merging onto the main road.

Figure 3.5 - Geometric design of connection section between N11 with the A12 near Bodegraven. The blue dot represents the location of the street view picture (source: maps.google.com).

3.4 EMPIRICAL DATASET

In the master thesis of Loot (2009), the data was collected using a high resolution digital camera mounted underneath a helicopter. At the A12 near Bodegraven images were taken of the merging section from 15:01 till 15:35. During the imaging, the weather was clouded but dry and the viewing distance was normal. The raw data is processed into 3,450 trajectories, which includes 700 vehicles who merge onto the main road. A trajectory describes the position of a vehicle at every time step. In this case a time step corresponds to 0.067 seconds. Using the elaborate dataset by Loot, the factors mentioned in section 3.1 are analysed.

For every trajectory the length of the vehicle is determined from images. With this information the distinction between vehicle types is made. The vehicles are categorised into two groups, namely passenger cars and HGV's. If a vehicle is shorter than ten meters it is categorised as a passenger car, if it is ten meters or longer it is categorized as an HGV. With this categorisation there are 3,181 trajectories of a passenger car and 277 trajectories of an HGV.

In the first half of the dataset, traffic is in free flow traffic state and during the second half of the dataset congestion occur. The congestion is from a stop and go wave that developed about 2 kilometres downstream the on-ramp and reaches the end of the acceleration lane halfway the data collection, see Figure 3.6. During the congestion, the traffic does not come to a complete standstill. To make a distinction in the analysis, the traffic states are defined. In case of free flow, the average speed on the main road must be 70km/h or higher. In case of congestion, the average speed must be 50km/h or lower. This means there is one period of free flow in the first half of the dataset and three periods of congestion in the second half of the dataset.

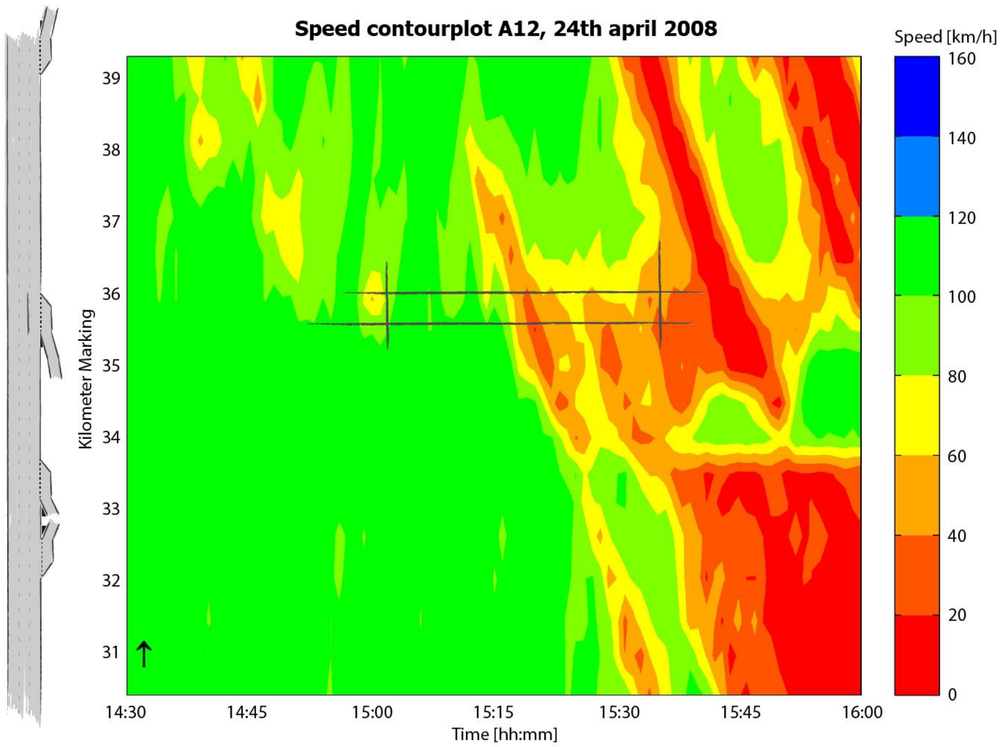


Figure 3.6 - Contourplot of the speed on the 24th of April 2008 (source: Monica). Rectangle is the location and time period of the empirical dataset.

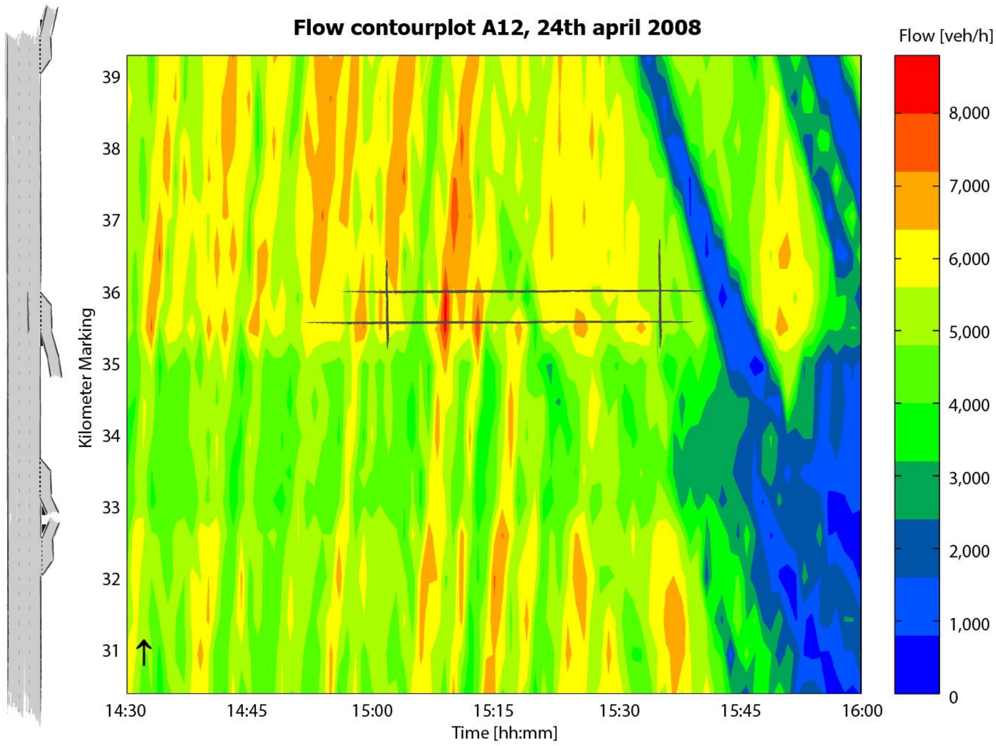


Figure 3.7 - Contourplot of flow on the 24th of April 2008 (source: Monica). Rectangle is the location and time period of the empirical dataset.

The data starts with a high flow on the main road, see Figure 3.7, while the traffic is still in free flow. Over time the traffic flow on the main road stays constant. With 700 vehicles using the acceleration lane in a time period of 35 minutes the flow on the acceleration lane is relatively high. This means relatively small gaps occur on the shoulder lane, because of the high amount of vehicles on the lane. This gives a good basis for a gap analysis on merging behaviour.

There are a few errors present in the empirical dataset. These are caused by a wrong detection of a vehicle. For example, there are some lane changes in the dataset present, where there was no lane change performed at the actual moment. These are only a few lane changes, so the influence is negligible. Another error is that at times, a pixel is wrongly detected and the actual location differs by a few meters. With a time step of 0.067, this can show up as a high change of speed. To prevent this, the speed is measured over a few time steps and averaged.

3.5 AVERAGE SPEED PER LANE

The first analysis is the average speed over time. For every lane the average speed is determined. An analysis is made on the relation between the average speed on the different lanes. This gives us insight into how traffic on the main road reacts to the merging vehicles. The relation of the shoulder lane with the acceleration lane is particularly interesting, because of the interaction of the merging vehicles with the vehicles on the adjacent lane. This works on both sides. The drivers on the acceleration lane will adapt their speed, so they can merge easily onto the main road. But also the drivers on the shoulder lane will adjust their speed to help the drivers on the acceleration lane merge more easily. So the expectation is that the speed on the median lane and the middle lane is the highest, and the speed on the shoulder lane and acceleration lane is the lowest.

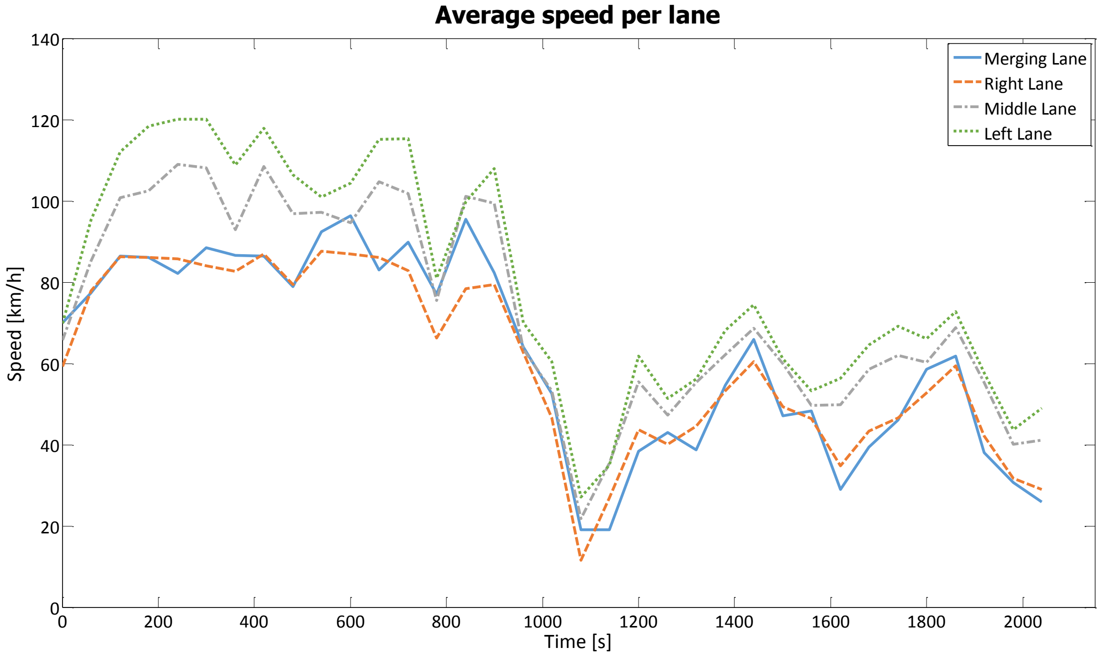


Figure 3.8 - Speed on the main road per lane and the acceleration lane over time.

In Figure 3.8 the average speed is shown on the main road and the acceleration lane in function of time. It is clear that the median lane has the highest speed. The middle lane has the second highest speed. There is not much difference between the speed of the shoulder lane and the acceleration lane. This is as expected, drivers on the acceleration lane must adapt their speed to the speed on the shoulder lane to make an easy and safe merge. The drivers in the shoulder lane adapt their speed to the drivers on the acceleration lane.

Further, only drivers on the median lane are driving around 120 km/h. This is caused by the fact of the high flow, see Figure 3.7. The other lanes probably slow down to make space for the merging vehicles. It is also possible there are cooperative lane changes from the middle to the median lane. This affects the speed on the median lane. The drop in speed around 1,000 seconds is caused by congestion appearing because of a stop and go wave downstream the main road.

3.6 MERGING SPEED

The next part is the analysis of factors on the acceleration lane. In this section the merging speed is analysed. This will give insight with which speed drivers merge on the main road. A merging speed close to the maximum speed would be expected, because in a simulator study there was an average merging speed of 110 km/h for passenger cars, with a relative high flow of 3,600 veh/h on a two lanes freeway (de Waard et al., 2009, de Waard et al., 2007).

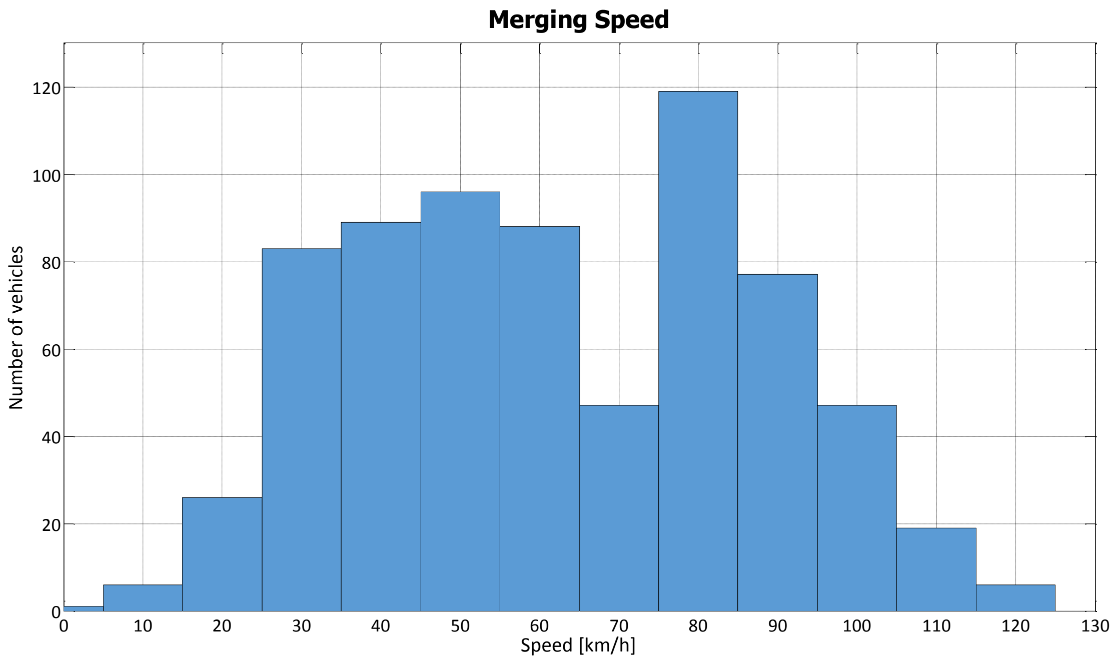


Figure 3.9 - Speed during the merge movement of all vehicles.

Figure 3.9 shows a histogram of the merging speed of vehicles. There is no distinction between traffic states or vehicles types. The figure shows two peaks, one at a merging speed of 50km/h and one at 80 km/h. Despite of a maximum speed of 120 km/h, there are only a few vehicles who merge with this speed. This is not comparable with the simulator study mentioned in the literature survey in chapter 2 (de Waard et al., 2009, de Waard et al., 2007).

To get more detailed information about the merging speed, the analysis is split up in traffic state (free flow and congestion) and in vehicle type (passenger car and HGV), see Figure 3.10. This distinction is made, because from the literature study performed in Chapter2 it became clear that different behaviour occur in different traffic conditions. It is clear from the histograms that there is a difference between the speed of merging during free flow and congestion. This is expected, the speed on the main road is much lower during congestion.

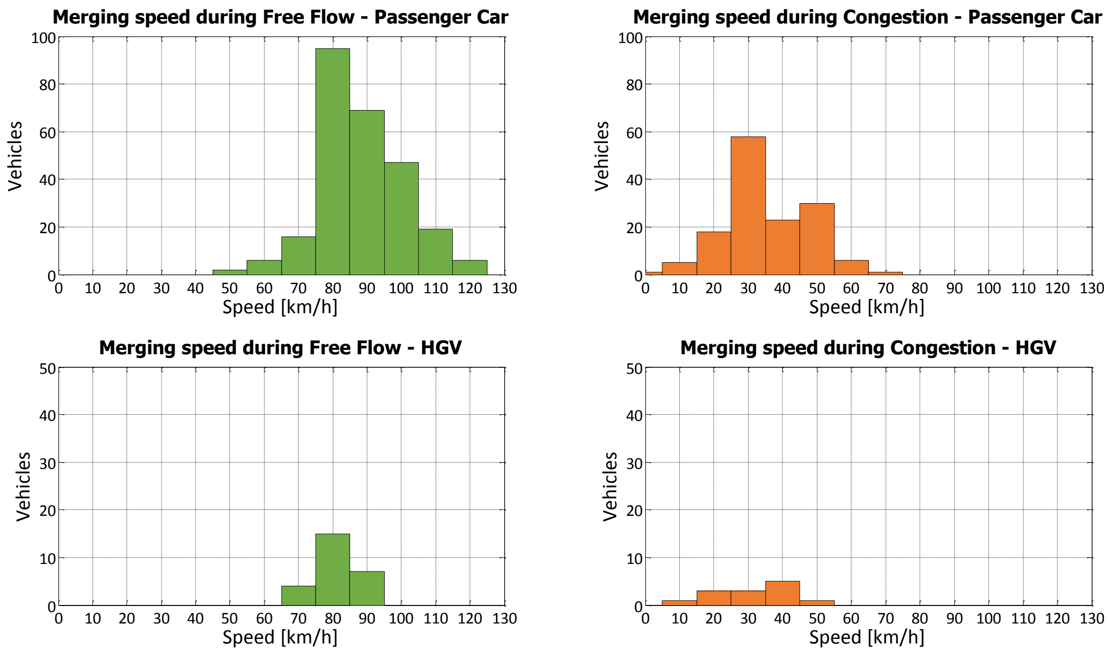


Figure 3.10 - Speed during merge movement with distinction between traffic states and vehicle types.

First the merging speed of passenger cars in free flow state is analysed. The peak is around 80 km/h, while the maximum speed on the freeway is 120 km/h. The average merging speed of passenger cars in free flow state is 88 km/h. The expectation is that the merging speed would be higher. On the shoulder lane 23% of the vehicles is an heavy goods vehicle (HGV), so perhaps this is caused by the high amount of HGV on the shoulder lane, which reduce the average speed as they have a speed limit of 80 km/h.

The merging speed of HGV in free flow state does confirm to the expectations. The peak is around 80 km/h and the average is 81 km/h. So the HGV merge into the shoulder lane with the maximum speed. It is also expected that passenger cars have an higher speed during merging than HGV. But after performing an statistical test, it is for 95% certain that the speed during merging is the same.

During congestion the merging speed is much lower. In this case the speed during merging between passenger cars and HGV also seems to be equal. After performing a statistical test, it is for 85% certain the merging speeds are equal. This is as expected, because the limit for congestion is 50 km/h, so both passenger car and HGV drive with the same speed and therefore merge with the same speed.

3.7 ACCELERATION AND DECELERATION ON ACCELERATION LANE

Besides the merging speed, the speed development in relation with the location on the acceleration lane is also studied. Every merging vehicle has its speed development on the acceleration lane plotted in order to analyse this. The first analysis is done on all vehicles. After that the data are split up in vehicle type (passenger car and HGV) and traffic state (free flow and congestion).

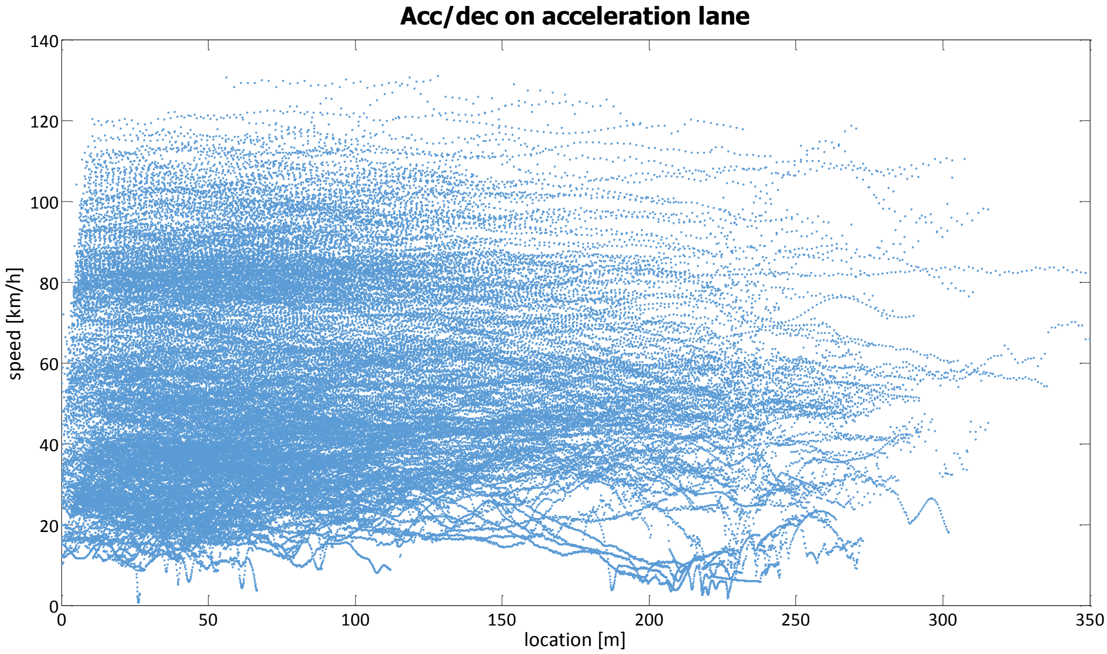


Figure 3.11 - Speed development on the acceleration lane.

Figure 3.11 shows the speed development of all vehicles on the acceleration lane. It is clear that there is a lot of variety in how long a vehicle stays on the acceleration lane. From the graph it seems that vehicles drive with a constant speed on the acceleration lane. For a clearer picture the vehicles are plotted separately to look at the speed development. From this it is clear that most of the vehicles have a constant speed on the acceleration lane. In appendix A graphs with only 25 vehicles per picture are shown.

To get a more detailed view about the speed development, also an analysis is performed on different traffic states (free flow vs. congestion) and distinction between vehicle types (passenger car vs. HGV).

Figure 3.12 shows the difference between traffic states and vehicle types of the speed development on the acceleration lane. On the left side, in green, the data is showed in free flow traffic state. On the right side, in red, the data during congestion are showed. The upper graphs represents the passenger cars and the bottom graphs of the figure represent the HGV's.

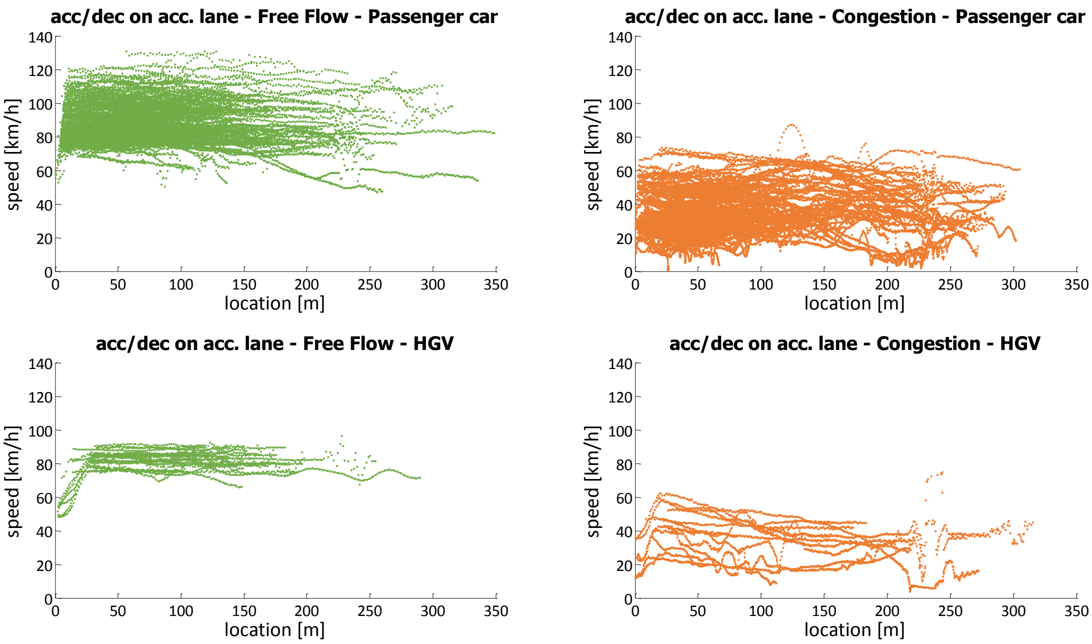


Figure 3.12 - Speed development on the acceleration lane with distinction between free flow vs. free flow and passenger car vs. HGV.

From the graphs it is clear that passenger have a constant speed on the acceleration lane and they are already at the desired speed when entering the acceleration lane. This is not the case for HGV's. They still have to accelerate to attain the desired speed for merging. If they already have the desired speed, their speed is constant till the moment of merging. In case of congestion the speed is also constant.

Conclusion: *Most vehicles on the acceleration lane have a constant speed. This means they are not frequently accelerating of decelerating in order to find a suitable gap. Only the HGV's use the first part of the acceleration lane to accelerate to a desired speed for merging. So the cars are already anticipating on the conditions of the main road before they enter the acceleration lane.*

3.8 Gap analysis

The last part of the data analysis is a gap analysis. The goal is to find out if there is a reason why merging vehicles decline an offered gap and decide to stay longer on the merging lane to merge into another gap. An offered gap is defined as a possible time period between two cars on the shoulder lane to perform a merge (see section 2.1.6).

The first step is a manual gap analysis. With a tool by Loot (2009), several hundred merging vehicles are plotted with the vehicles on the adjacent lane, see Figure 3.13. Of every merging vehicle, the offered gaps, rejected gaps and presence of an HGV are analysed. The analysis starts with merging vehicles after 300 meters (four vehicles). Only one vehicle merges during congestion. This is also the only one who rejected multiple gaps. Of the other three vehicles, only two offered gaps were rejected, by different vehicles. The vehicle who did not reject a gap is an HGV who is using the acceleration lane for acceleration. Remarkable is the presence of an HGV on the shoulder lane. In all three cases in free flow traffic state, the vehicles overtakes an HGV to merge in front of it instead of merging behind the HGV.

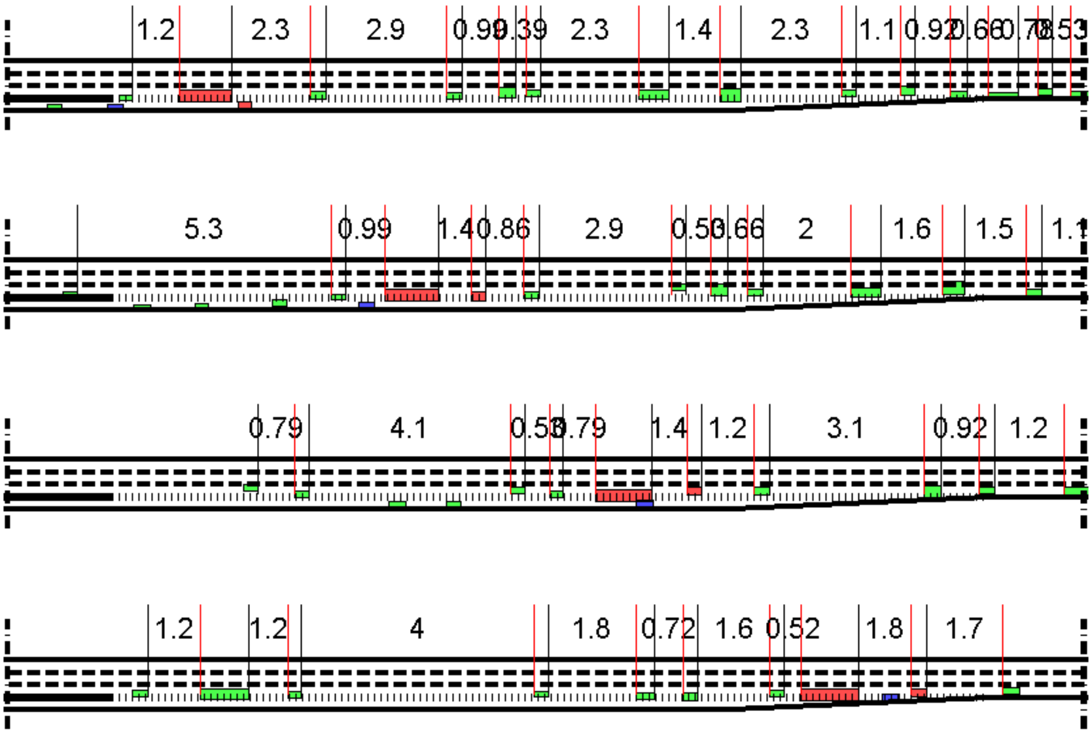


Figure 3.13 - Merging vehicle who uses the entire length of the acceleration lane to overtake an HGV, visualized in four plots. ID of merging vehicle = 40,574, entry time = 1836.33s, merging time = 1850.53s.

The next step is an analysis of merging vehicles between 275 meters and 300 meters (13 vehicles). Of these vehicles four are merging in free flow and nine of them are merging during congestion. Only during congestion a lot of gaps are rejected whilst during free flow only one gap is rejected. In case of the late merging during free flow, at all four of the merging movements an HGV is present on the adjacent lane and the vehicles merge in front of this HGV.

Lastly the merging vehicles after 250 meters are analysed (19 vehicles). Five of the vehicles are merging during congestion and fourteen vehicles during free flow. In these nineteen cases, an HGV on the adjacent lane is involved eleven times. Nine times this happen during free flow. In two cases an HGV is involved during congestion.

So it seems that the presence of an HGV on the adjacent lane is an important factor of merging behaviour. To get more insight in the relation of merge location and the presence of an HGV, a more detailed analysis on the empirical dataset is made. In this analysis all merging passenger cars are put in a bar graph in relation with the merging location. The merging passenger cars behind an HGV in relation to the merge location are also plotted in this diagram. Lastly, the merging passenger cars who merge before or in between an HGV in relation to the merge location are plotted in the same graph, see Figure 3.14. Because it seems to be, at first glance., that the relation of late merging and the presence of an HGV in the adjacent lane is more common during fee flow, a distinction is also made between traffic states, see Figure 3.15 and Figure 3.16.

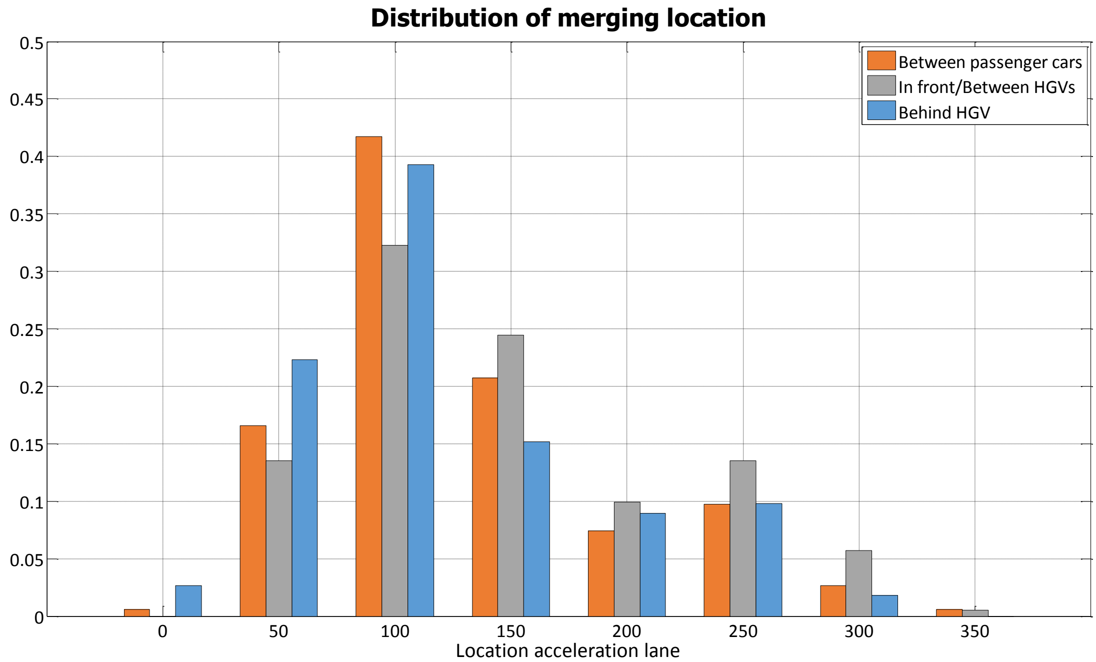


Figure 3.14 - Relation of the location of merge and the presence of an HGV.

In Figure 3.14 the merge locations of passenger cars are plotted in a bar diagram. In each section of 50 meters the merge movement of passenger cars between passenger cars (left bars), the merge movement of passengers car in front of an HGV or in between HGV's (middle bars), and the merge movement of passenger cars behind an HGV (right bars) are plotted.

From the graph it is clear that when there is no HGV present in the adjacent lane (left bars) the distribution of merge location and number of vehicles merging between two cars has a decreasing tail. In the case there is an HGV present in the adjacent lane, the distribution of merge location have a different shape (middle bars and right bars). The shape is more uniform to the end of the merging lane.

Because there seems to be a difference between the behaviour in free flow and during congestion at first glance, the data is plotted in two different plots. In Figure 3.15 the relation of merge location and presence of HGV in free flow is shown. And Figure 3.16 shows the relation during congestion.

Figure 3.15 shows that during free flow the distribution of merging between cars has a decreasing right tail. The bars with the presence of an HGV in the adjacent lane is more uniform at the right tail. So overtaking an HGV is a stimulus to make a late merge. Overtaking a passenger car is not a stimulant during free flow traffic state.

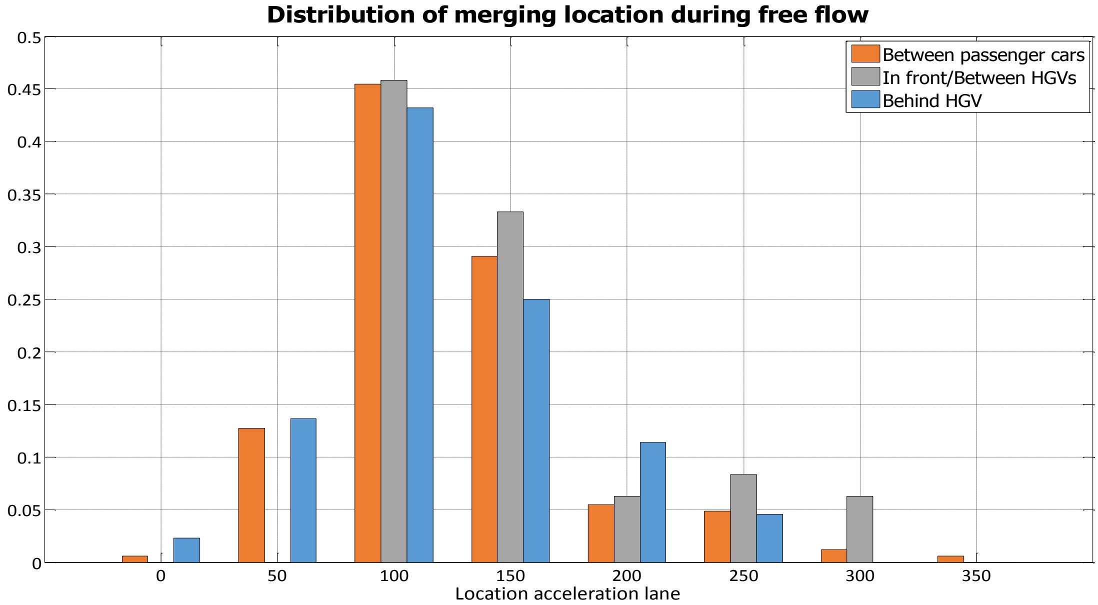


Figure 3.15 - Relation of the location of merge and the presence of an HGV in free flow.

Figure 3.16 shows that during congestion the pattern is a little different. Instead of a decreasing distribution for merging between cars, it seems that during congestion the distribution is more uniform. This is also mentioned in the master thesis of Loot (Loot, 2009). It is also clear that overtaking an HGV is a stimulus to make a late merge during congestion. So during congestion both overtaking a passenger car and an HGV are stimulus to make a late merge.

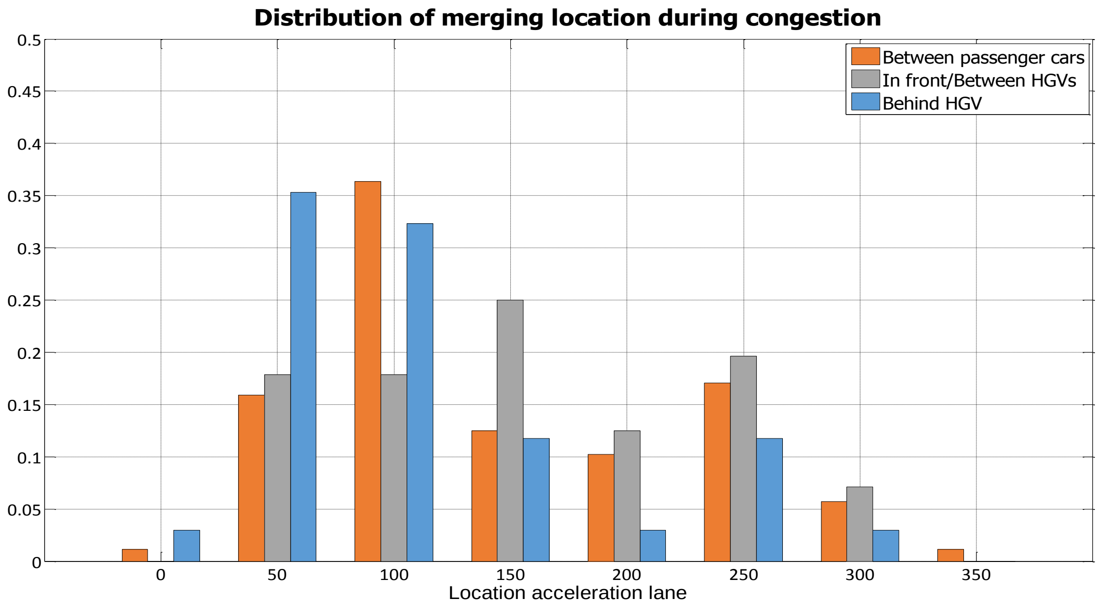


Figure 3.16 - Relation of the location of merge and the presence of an HGV during congestion.

Conclusion: *From an analysis of the relation of a passenger car's merging location and the presence of an HGV on the shoulder lane, it is clear that the presence of HGV's on the shoulder lane has a large influence. It appears to be a stimulus to overtake before merging. That means that drivers will make a later merge in comparison with no HGV on the shoulder lane. This occurs especially during free flow traffic conditions. During congestion not only the HGV's are a stimulus to overtake, but also passenger cars. During congestion the amount of vehicles overtaking an HGV with as result a late merge is very high. So the presence of an HGV on the shoulder lane is an important factor in the merging behaviour.*

3.9 CONCLUSION OF EMPIRICAL DATA ANALYSIS

In this chapter the factors influencing merging behaviour are analysed. Some factors have already been mentioned in the literature study. The remaining factors are analysed using an empirical data study. According to the acceleration lane, only analyses are performed in relation with the adjacent lane. It is assumed that merging behaviour is related with factors according to the shoulder lane and not with the factors according to the middle and median lane. The used dataset is from a previous master thesis and has been collected at the A12 near Bodegraven. The dataset consist of free flow and congested traffic state. There is a high flow on both main road and acceleration lane.

The first factor analysed with the empirical dataset is the average speed per lane. There is not much difference between the average speed of the acceleration lane and the middle lane. This is as expected, because drivers on the shoulder and acceleration lane react to each other and will adapt their speed to make a safe merge or to allow another driver to make a safe merge. It is remarkable that only the median lane is driving around the maximum speed of 120 km/h. This can be caused by cooperativeness between the lanes, but also because of the high flow. The second factor is the speed during the merge on the shoulder lane. The average merging speed of passenger cars during free flow is 88 km/h. For HGV's this is 81 km/h. After performing a statistical test it is clear that the average speeds of passenger cars and HGV's is the same. This is interesting, because it is expected that passenger cars will have a higher merging speed. That this is not the case could be caused by the high amount of HGV's on the shoulder lane and the high flow. Also during congestion the average speed of merging of passenger cars and HGV's is the same. This is as expected because during congestion there is no large speed differences between passenger cars and HGV's. The next factor is the driving behaviour on the acceleration lane. Most of the vehicles have a constant speed. This means that the speed of entering the acceleration lane is the same as the merging speed. Only HGV's are accelerating in the first meters of the acceleration lane. The last factor analysed is the gaps. From this analysis it is clear there is a relation of a passenger cars merging location and the presence of an HGV on the shoulder lane. The presence of an HGV is a stimulant to choose a gap in front of it, making a late merge on the acceleration lane. This is especially the case during free flow. During congestion it is not only HGV's but also other passenger cars that are a stimulus to overtake and therefore make a late merge.

From this chapter it is clear that there is a relation between the average speed per lane on the main road. Whether this is also the case in simulation tools will be researched in the next chapter. The relatively high flow also has an influence on the merging speed. With a high flow the average merging speed is the same for passenger cars and HGV's. For developing the model it is clear that only HGV's will accelerate in the first meters of the acceleration lane. Most of the passenger cars have the same merging speed as the speed detected at the entering of the acceleration lane. For the choice between gaps it is clear that the presence of HGV's is an important factor to reject if it is a putative leader of a gap.

4 SIMULATION TOOL STUDY – FOSIM

To gain insight into the performance of merging behaviour in micro simulation software, a simulation tool and an empirical dataset are compared. This is done using the empirical dataset used in chapter 3 and the micro simulation tool FOSIM. This is a simulation tool that is widely used on the TU Delft and Rijkswaterstaat. FOSIM is specifically developed to study traffic operations on Dutch motorways. It is therefore a representative tool to compare the dataset with the simulation results. In FOSIM the situation at the A12 freeway near Bodegraven is replicated and a realistic flow of the freeway section is implemented. Next, a significant number of simulations is performed. The results of the simulation are compared with the results of the empirical data analysis. This analysis offer insight into the performance of FOSIM on merging behaviour in comparison with the real situation at the A12 near Bodegraven. The expectation is that this simulation tool does not perform well when compared to the merging behaviour in reality. This will be analysed using the location of merging, number of lane changes, average speed and travel times.

Because not all these factors are already analysed in the data analyses of the previous chapter, an analysis is first done with the empirical dataset. This way, a comparison can be made. First the flow for setup of FOSIM is analysed, second the number of lane changes of the empirical dataset, and lastly the travel times are determined. After the empirical analysis the design of the road section is described. In section 1.2.2 the number of runs needed to get significant result is determined. The last sections of this chapter are the comparisons of the FOSIM results and the empirical data. First a comparison is made of the merge location, then a comparison of number of lane changes, and finally a comparison of speed and travel times.

4.1 DATA ANALYSIS FOR COMPARISON WITH FOSIM

Before a comparison can be made, the empirical dataset is analysed on characteristics needed to perform the comparison between the dataset and FOSIM. One of these factors is the flow. The flow is needed as input to setup the model. The factors used for the performance comparison are the location of merging, number of lane changes, average speed per lane and the travel times. With these factors it is possible to analyse whether or not the driving behaviour simulated in the simulation tool is comparable with the empirical dataset. Using the merge location the use of the acceleration lane can be compared. The number of lane changes offers insight into the weaving behaviour of drivers at the acceleration lane. Using the average speed the interaction between lanes can be analysed. When comparing the average speed of the lanes with each other, it is possible to get insight if for example the drivers on the shoulder lane adapt their speed with the drivers on the acceleration lane.

4.1.1 INPUT FACTOR FOR THE MODEL – FLOW

The first analysis concerns the flow. The flow is needed to setup the road section design in FOSIM. The flow of the dataset is analysed at the beginning of the acceleration lane (X=0m), half way the acceleration lane (X=110m), at the start of the narrowing of the acceleration lane (X=220m), and at the end of the acceleration lane (X=300m), see Figure 4.1. The time interval taken for determining the flow is 60 seconds. This analysis shows how the flow developed on the carriage way.

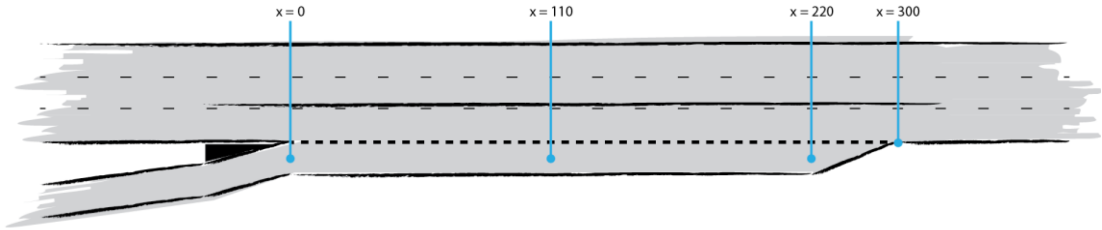


Figure 4.1 - Location of flow analyses along the acceleration lane.

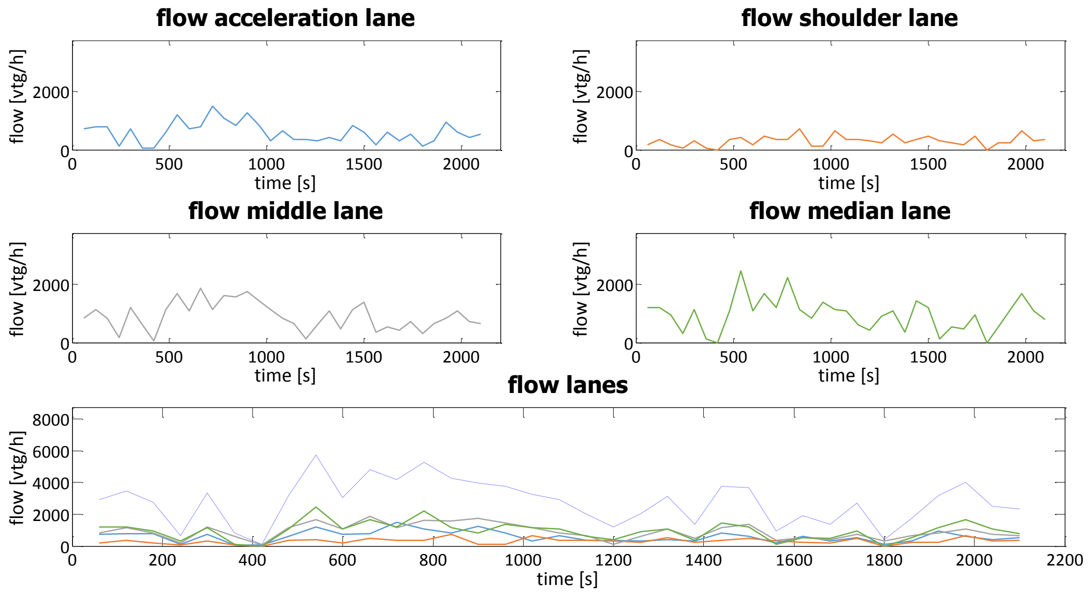


Figure 4.2 - Flow on the different lanes and the total flow at the beginning of the acceleration lane.

In Figure 4.2 the flow per lane is displayed at the beginning of the acceleration lane, X=0m. The graph at the bottom shows the flow on the lanes in one graph where the dashed line represents the total flow of the lanes. It is clear the flow on the shoulder lane is lower than the flow on the middle lane and median lane. This is common, because the flow on the main road is near capacity. In this case more drivers will choose the middle and median lane (Knoop et al., 2010). Most drivers of a passenger car want to avoid the shoulder lane, because of the slow driving HGV's on this lane. Therefore the flow on the middle and median will be higher than the shoulder lane. This effect is even stronger near on-ramps, because drivers make space for the merging vehicles (courtesy yielding). The flow on the acceleration lane is relatively high. Especially in comparison with the shoulder lane, where the flow is even lower than on the acceleration lane.

In comparison with the flows determined at the other locations along the acceleration lane (x=110, x=220, and x=300), the total amount of flow of the four lanes is lower at the location at x=0. This should not occur, because this means there are more cars on the road at the other locations, while there is no possibility to enter the road section. This means that not all vehicles are detected at the beginning of the acceleration lane. For this reason, the flow analyses halfway the acceleration lane is described.

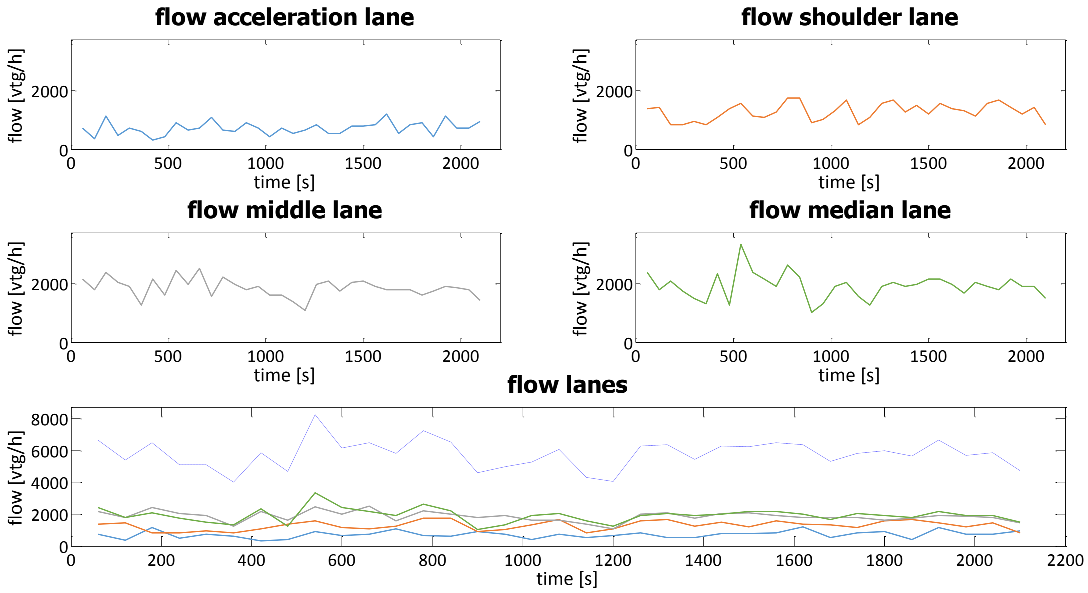


Figure 4.3 - Flow on the different lanes and the total flow halfway of the acceleration lane.

Figure 4.3 shows the flows halfway the acceleration lane, x=110m. It is clear the flow on the shoulder lane is still the lowest on the main road. Compared to the flows determined on the other locations (x=0, x=220, and x=300), the flow on the middle lane and median lane are not significantly different.

Despite of the fact not all vehicles are detected at location 0m, it is clear the flow at the shoulder lane has grown and the flow on the acceleration lane is decreased at location x=110. This means part of the vehicles have already merged before this location. Therefore it is not realistic to use the flow at location x=110 as input. But also the flow at the location of 0m is not representative, because the total flow is lower in comparison with the flow at the other location along the acceleration lane. The actual flow used as input to setup the model is the flow at the location of 25 meters. At this location most of the vehicles are detected and the flow on the acceleration lane is still representative.

4.1.2 Lane changes for a comparison with FOSIM

Lane changes can make traffic unstable. It is therefore an important characteristic in this analysis. In FOSIM it is possible to get the number of lane changes of individual vehicles. To analyse if FOSIM simulates like reality, the number of lane changes is analysed from the empirical dataset.

Table 4.1 - Number of lane changes of empirical dataset.

	Acc. lane	Shoulder lane	Middle lane	Median lane
Lane change to the left	711	349	247	0
Lane change to the right	0	1	0	63

In Table 4.1 the number of lane changes of the empirical dataset is shown. A vehicle is sometimes not detected well. A lane change is detected, while in reality the vehicle has not performed a lane change. So the numbers can deviate a little from the actual performed lane changes. From an analysis of the detected lane changes and the actual lane changes it is clear that the relative error is 0.03. Because the relative error is not high, the detected lane changes of the empirical dataset are used to make a comparison.

The first row contains the number of lane changes from the current lane to the left. This means there are approximately 349 vehicles which changed from the shoulder lane to the middle lane. In the second row, the number of lane changes to the right is mentioned. So there are approximately 63 vehicles which changed from the median lane to the middle lane.

The cooperative lane change phenomenon is clear from the numbers in Table 4.1. There are namely a lot of lane changes to the left in contrast to the lane changes to the right. A part of this is also caused by the road design. There is a solid line between the shoulder lane and the middle lane, vehicles are not allowed to make a lane change to the shoulder lane if they are in the middle lane.

The lane change from the shoulder lane to the acceleration lane is a vehicle that is overtaking vehicles on the emergency lane, see Figure 4.4.

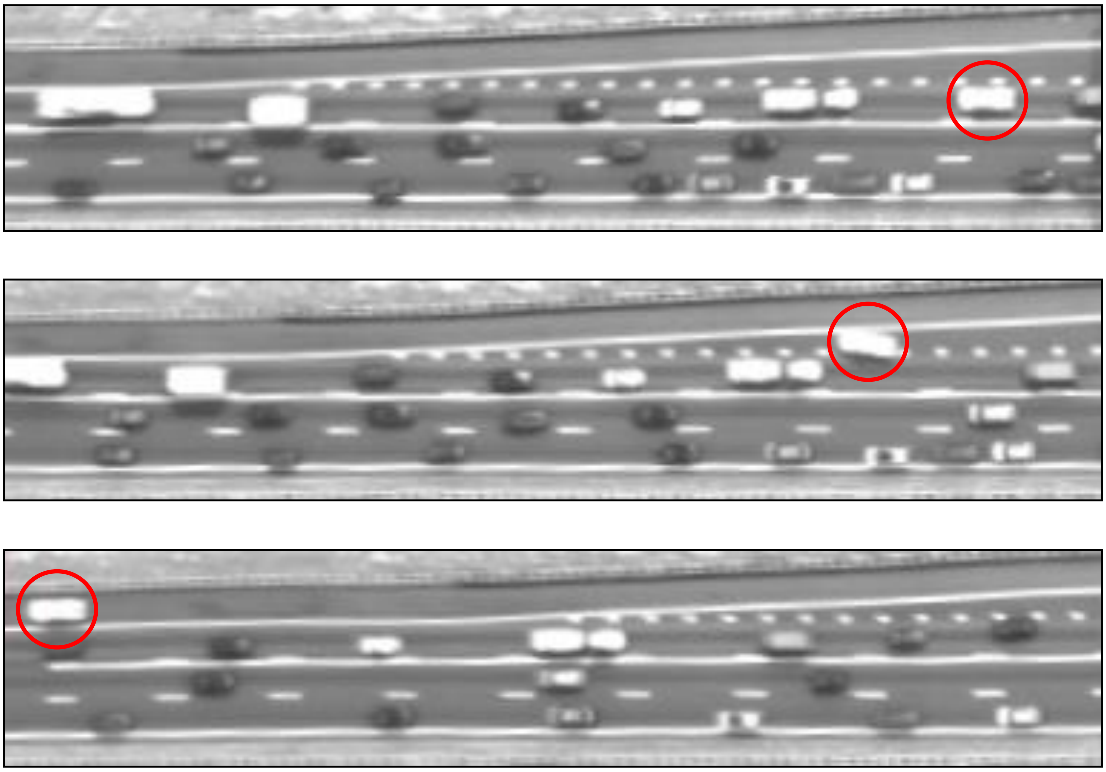


Figure 4.4 - Vehicle which is driving on the shoulder lane and changes to the emergency lane to overtake.

4.1.3 Travel Times for comparison with FOSIM

The last factor to make a comparison between the empirical dataset and FOSIM is the travel time. The travel time is determined between the start and the end of the acceleration lane. All the lanes are included in this analyses. The vehicles not detected at the beginning of the acceleration lane are not taken into account in this analysis.

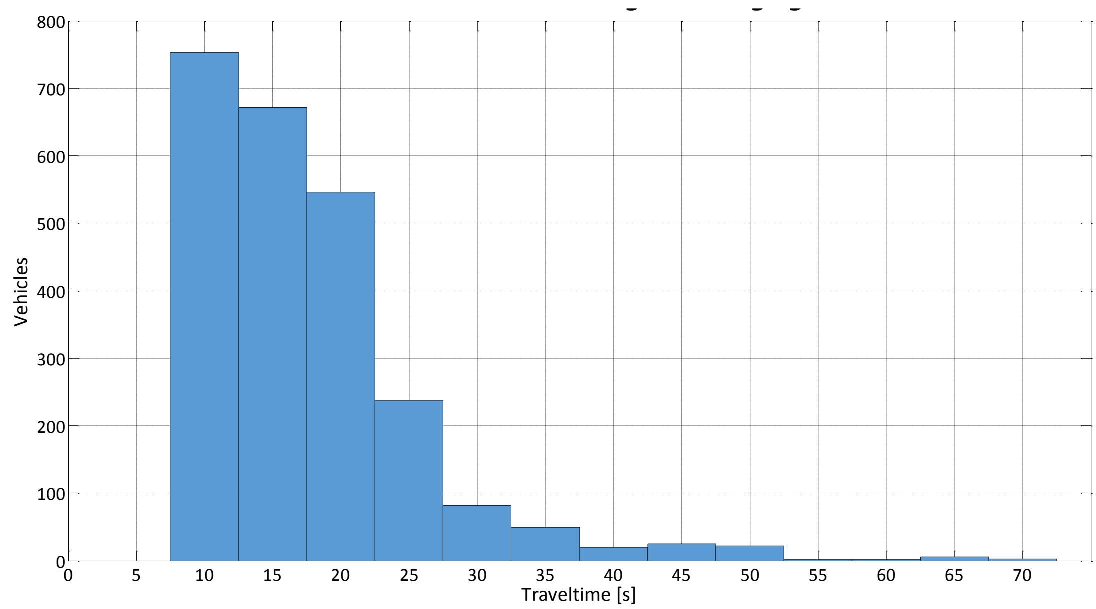


Figure 4.5 - Travel times of the vehicles from start till the end of the acceleration lane.

In Figure 4.5 the travel times are plotted in a histogram of all vehicles that travel from the beginning till the end of the acceleration lane. This road section has a length of 300 meters. The peak of the distribution is at a travel time of 10 seconds. This means the vehicles have an average speed of 108 km/h. The average travel time over all vehicles is 16.3 seconds. This means the vehicles have an average speed of 63 km/h.

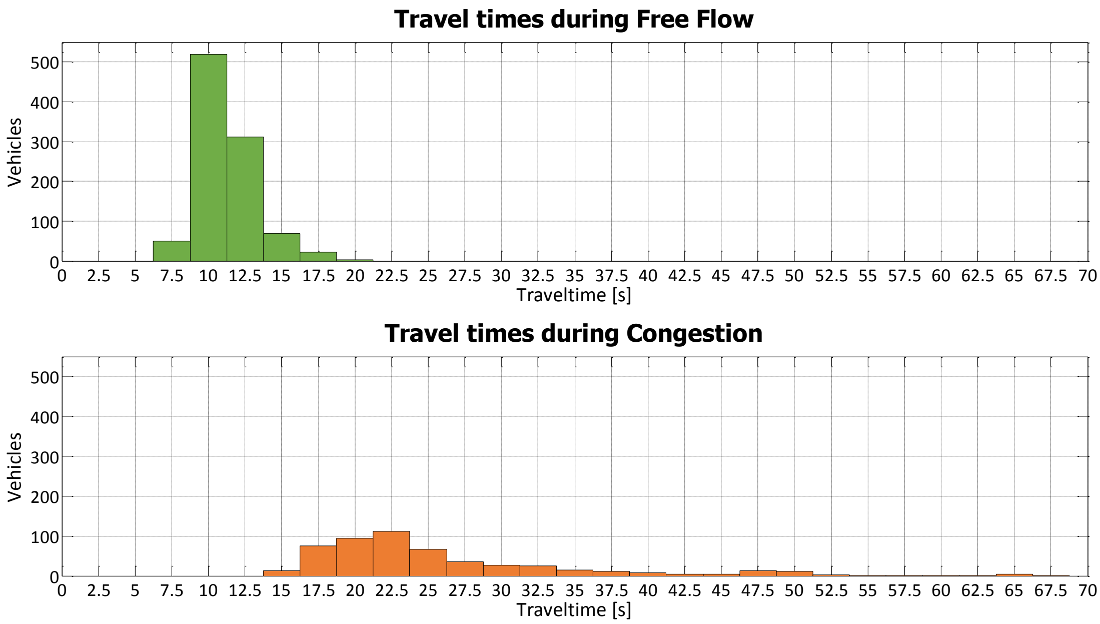


Figure 4.6 - Travel time from beginning till end of merging lane during free flow (above) and during congestion (below).

In Figure 4.6 a distinction is made between free flow traffic state and during congestion. The peak during free flow is 10 seconds, what means the vehicles have an average speed of 108 km/h. The mean travel time during free flow is 11.1 seconds. That means an average speed of 97 km/h during free flow.

The peak during congestion is 22.5 seconds. This means the vehicles have an average speed of 48 km/h. This makes sense, because the limit where we speak of congestion is 50 km/h. The mean travel time during congestion is 25.9 seconds. This gives an average speed of 41.7 km/h.

4.2 Comparison with output data of FOSIM

The second step for a comparison is to get results of the simulation tool. First, a design of the merging section of the A12 near Bodegraven is made. Second, the number of runs needed to get significant result is determined. Third, the FOSIM results are compared with the results of the empirical data analyses.

4.2.1 Design merging section A12 near Bodegraven in FOSIM

The first part to make a comparison is to design the road section in FOSIM. First the carriage way is designed, with 4 origins (1:median lane, 2:middle lane, 3:shoulder lane and 4: accelerations lane) and 1 destination. The length of the road upstream the merging section is 2 km. This is done to setup the flow, so with 120 km/h and a length of 2 km the time needed for vehicles to arrive at the beginning of the acceleration lane is 60 seconds. After the merging section the road have a length of 1 km. At the location of the merging sections an extended line is applied to prevent lane changes from the middle lane to the shoulder lane, see Figure 4.7.

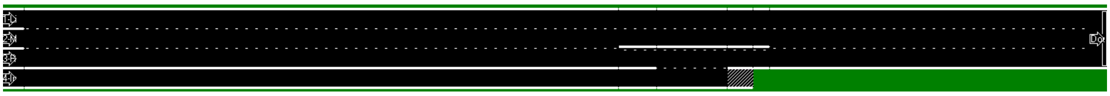


Figure 4.7 - First design of merging section of the A12 near Bodegraven.

The next step is the set-up the distribution of passenger cars and HGV. This distribution is determined using the empirical dataset.

- The median lane has 100% of passenger cars,
- The middle lane 80% passenger cars and 20% HGV's,
- The shoulder lane 62% passenger cars and 38% HGV's
- The acceleration lane91% passenger cars and 9% HGV's.

The last part is set-up the flow. Because the vehicles need 60 seconds to arrive at the beginning of the acceleration lane, the determined flow of the dataset is entered 60 seconds earlier.

After the designing the carriage way a few test runs are performed. With the output of this runs a comparison with the actual flow is made. The first problem with the simulation tool emerged here. After entering the flow of each lane separately, FOSIM redistributed the flow on the main road after generating the vehicles. Therefore the flow on the shoulder lane turned to be the highest and on the median lane the lowest. This does not correspond with reality, because normally the flow on the middle and median lane are the highest if the flow is near capacity. Higher flow on the shoulder lane leads to smaller gaps. This can be a trigger for congestion on the main stream (Knoop et al., 2010).

Figure 4.8 - Adjusted FOSIM design to avoid the problem with the flow distribution.

To avoid this problem the design of the carriage way is adjusted. To provide a realistic flow, the lanes upstream the merging section are designed in such a way it is not possible to change lane (see Figure 4.8). To avoid the problem that traffic is now going to redistribute at the merging section, the vehicle types on the lanes is modified. In FOSIM there are 5 vehicles types:

- 1: fast passenger car, desired driving speed of 125 km/h,
- 2: medium passenger car, desired driving speed of 115 km/h,
- 3: slow passenger car, desired driving speed of 100 km/h,
- 4: fast truck, desired driving speed of 95 km/h,
- 5: slow truck, desired driving speed of 85 km/h.

The vehicle types on the lanes are modified as follows:

- Median lane: 100% fast passenger cars
- Middle lane: 80% medium passenger cars, 10% slow trucks, and 10% fast trucks
- Shoulder lane: 62% slow passenger cars, 19% slow trucks, and 19% fast trucks
- Acceleration lane: 30.3% slow passenger cars, 30.3% medium passenger cars, 30.3% fast passenger cars, 4.5% slow trucks, and 4.5% fast trucks.

After a few test runs the distribution of the flow was set-up well to perform simulation runs. In order to analyse the results, detectors are placed at specific points on the road section. For analysing the usage of the acceleration lane with the flow development on this lane, separate runs are performed with detectors at every five meters at the merging section, see Figure 4.9.

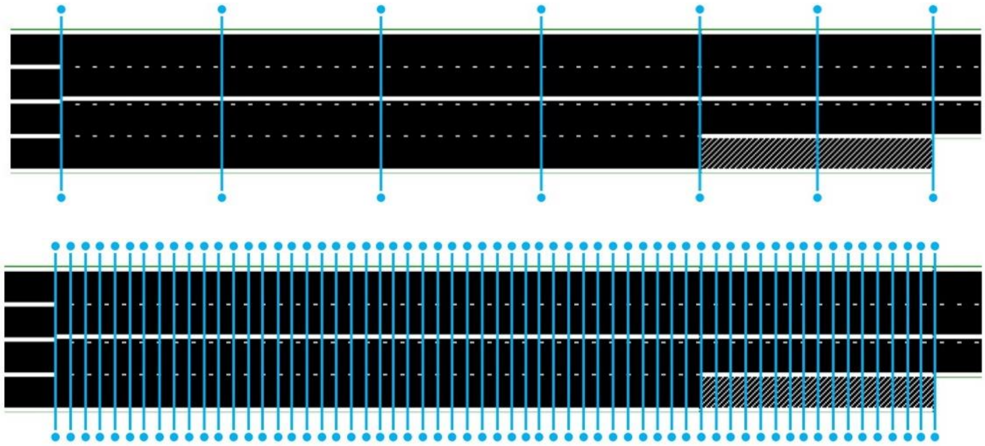


Figure 4.9 - Location of the detectors for getting results of simulations, top figure detectors for getting data about travel times and speeds. Bottom figure detectors for determine the merge location with the flows.

To make a comparison of the empirical dataset with FOSIM during congestion, the shoulder lane is closed in FOSIM, see Figure 4.10. This is done using a roadblock downstream of the merging section with a 500 seconds time period. This is not according reality. A better way to simulate congestion would be a time period with a capacity drop downstream the merging section. However, this is not possible in FOSIM and therefore a roadblock is used. The roadblock will cause a complete standstill congestion, while in the empirical dataset a slow moving traffic jam occurs. So it not possible to compare the absolute values of the simulation results with the empirical dataset.

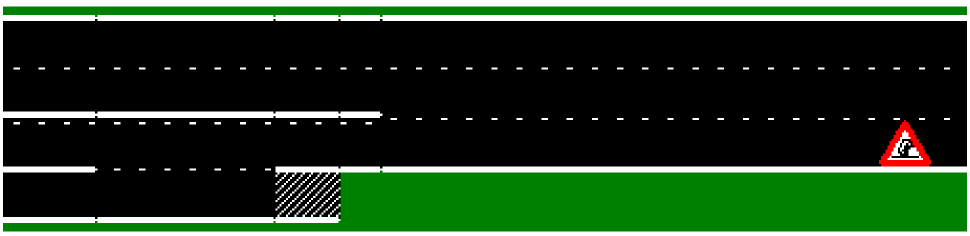


Figure 4.10 - Roadblock on the shoulder lane to create congestion in FOSIM.

4.2.2 Number of runs needed

After finalizing the design of the road section in FOSIM, the number of runs needed to make a significantly comparison between the simulation results and the empirical dataset is determined. The size of the sample is dependent of the standard deviation of a variable. To estimate the sample size a statistic formula is used *(4.1).*

$$n > \frac{Z^2}{d^2} \cdot \sigma^2 \qquad (4.1)$$

Where

- n: size of the sample size
- Z: value dependable on the desired reliability
- d: the desired accuracy
- σ: standard deviation of the variable

To determine the total number of runs, the statistic formula is applied on several variables, those being flow, speed, density, lane changes and travel time. The value of Z, with a reliability of 95%, is 1.96 and the value of accuracy is 2.5% of the mean of the variable.

Table 4.2 - Determination of the sample size of different variables.

Variable	Mean	Standard deviation	Accuracy	Sample size
Flow [veh/h]	2,625	4.3	65.6	1
Speed [km/h]	97	0.5	2.4	1
Density [veh/km]	27.0	0.1	0.7	1
Lane change to left	275	17.5	6.9	25
Lane change to right	493	30	12.3	23
Total travel time [s]	3,394	29.0	84.9	1

Table 4.2 shows the calculation of the sample size of the variables. Some of the variables have a really low standard deviation, so the needed sample size becomes really small. The needed sample size depends on the variable with the highest value, in this case the number of lane changes to the left. Using this variable, 25 runs are needed to make a significant comparison between the output of FOSIM and the empirical dataset. So for both free flow and congestion 25 simulation runs are performed to get significant results for the performance comparison of FOSIM with the empirical dataset.

The simulation runs for analysing the usage of the acceleration lanes are only dependable on the variable flow. Therefore less runs are needed according to Table 4.2. Because 1 run is not realistic, a higher accuracy is used. With a higher accuracy 5 runs are needed to perform the comparison of the usage of the acceleration between the empirical dataset en the simulation results.

4.2.3 COMPARISON – LOCATION OF MERGING

The factor used in order to make a comparison between empirical data and FOSIM of this section is the merge location. The merging location of drivers is one of the problems if a gap acceptance model is used for simulation (Loot, 2009). This comparison offers insight in the difference between FOSIM and the empirical dataset used for the data analysis. The expectation is that there will be a big difference. FOSIM uses a gap acceptance model for merging. Therefore, vehicles will merge if the offered gap is large enough, when in fact a driver will choose a gap out a set of offered gaps. So the expectation is that vehicles in a FOSIM simulation will merge earlier in comparison with the empirical data.

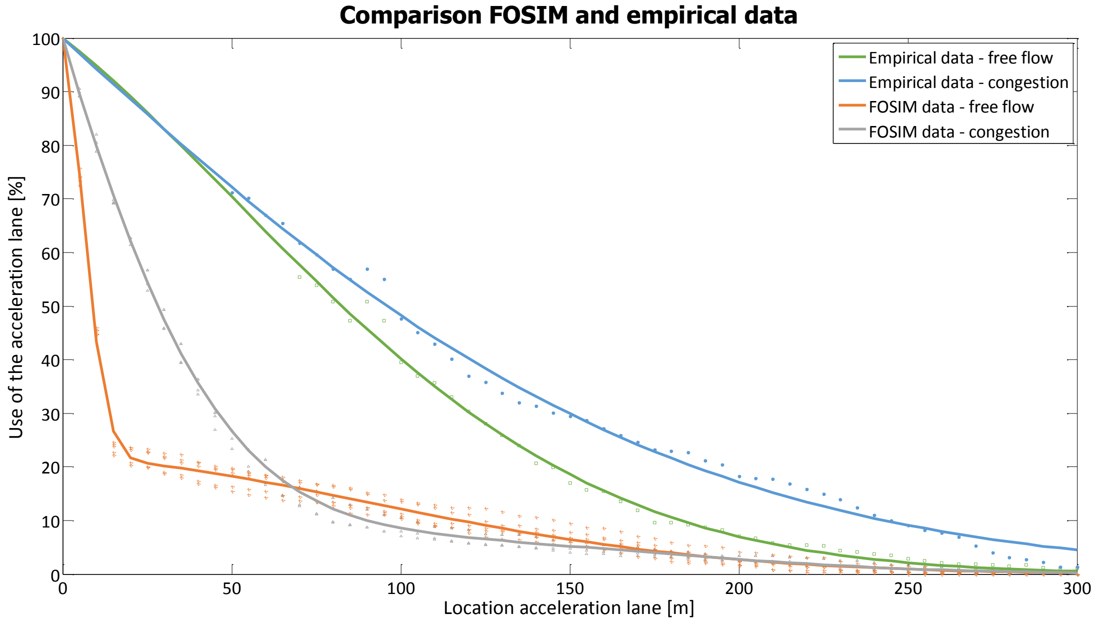


Figure 4.11 - Empirical data and FOSIM results of the use of the acceleration lane.

For the empirical dataset the decrease of the flow on the acceleration lane is analysed showing the usage of this lane. At the beginning of the acceleration lane the data is not complete, because a car is not always detected at the beginning of the merging lane. Around 70 meters, the data of the empirical dataset becomes reliable. To make a comparison, an extrapolation is made with the usable data points. The FOSIM results are derived from five simulation runs. With these results an interpolation is made. These results are showed in Figure 4.11.

In this figure, the use of the merging lane is shown based on the flow. On the x-axis the length of the acceleration lane is displayed. The origin is the beginning of the merging lane and 300 meters is the end of the merging lane. On the y-axis the percentage of the flow is displayed. Every 5 meters the flow of the simulation results and of the dataset is determined. This flow is put into a ratio. This way, the decrease of vehicles is visible over the length of the merging lane. The usage of the acceleration lane is clear, e.g. at 100 meters 85% of the vehicles has already merged on the main road according to the FOSIM results during free flow traffic state. Figure 4.11 already shows that there is a big difference between the FOSIM results and the empirical data. Despite FOSIM simulating a later merging behaviour during congestion, there is a big difference between the FOSIM results and empirical data.

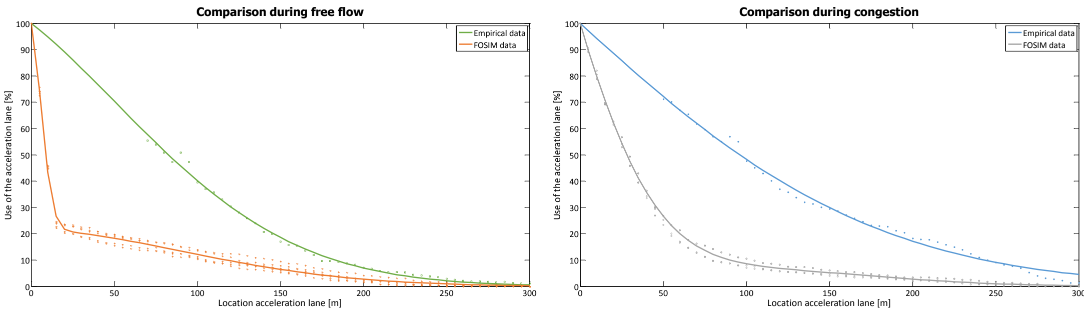


Figure 4.12 - Comparison of FOSIM results and empirical data in free flow traffic state (left) and during congestion (right).

In Figure 4.12 the results in free flow traffic state and during congestion are displayed separately. The black data points and black line are the FOSIM results and the green data points and green line is the empirical data. The FOSIM results show that a lot of cars merge within 25 meter (80%), while in the empirical dataset only 15% have merged at 25 meter. Also, in case of congestion there is a big difference between the empirical data and the FOSIM results. During congestion, the vehicles stay longer on the merging lane in the FOSIM runs, but this is still not as much as in the empirical data.

Conclusion: *Comparing the use of the acceleration lane between FOSIM results and empirical data, it is clear that there is a big difference. In the empirical data, vehicles make much more use of the acceleration lane to make a lane change to the adjacent lane. In congestion vehicles use the acceleration lane even more than during free flow traffic state. In the FOSIM results this is not the case. Vehicles merge a lot earlier and do not make much use of the merging lane. During congestion the use of the merging lane grows a little bit, but this is still not as much as in the empirical data.*

4.2.4 Comparison – number of lane changes

To make an analysis about the driving behaviour on the carriage way, a comparison is made of the number of lane changes. In Table 4.3 - Table 4.6 the number of lane changes are mentioned. In each table the absolute number of lane changes and the percentage of the total lane changes are shown. The percentage is calculated by the ratio of the total number of lane changes, e.g. in the FOSIM results during free flow 309 vehicles make a lane change from the shoulder lane to the middle lane and this is 22% of the total of 1,429 lane changes performed on the carriageway.

Table 4.3 - FOSIM data during free flow traffic state.

FOSIM data during free flow				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
To the left	597 [39%]	331 [22%]	507 [33%]	0
To the right	0	0	0	90 [6%]

Table 4.4 - FOSIM data during congestion.

FOSIM data during congestion				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
To the left	523 [51%]	258 [25%]	194 [19%]	0
To the right	0	0	0	46 [4%]

Table 4.5 - Empirical data during free flow traffic state.

Empirical data during free flow				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
To the left	287 [51%]	113 [20%]	123 [22%]	0
To the right	0	0	0	36 [6%]

Table 4.6 - Empirical data during congestion.

Empirical data during congestion				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
To the left	136 [57%]	69 [29%]	26 [11%]	0
To the right	0	1 [0%]	0	5 [2%]

The first comparison of the data is during free flow traffic state, see Table 4.3 and Table 4.5. In FOSIM there are more lane changes from the middle lane to the median lane and less lane changes from the acceleration lane to the shoulder lane. The lane changes from the shoulder lane to the middle lane and from the median lane to the middle lane are similar.

The second comparison is during congestion, see Table 4.4 and Table 4.6. In this case as well, there are more lane changes from the middle lane to the median lane in FOSIM. Furthermore, there are a few more lane changers from the shoulder lane to the middle lane and less lane changes from acceleration lane to shoulder lane.

Table 4.7 - Differences between congestion and free flow of FOSIM results.

Differences FOSIM				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
To the left	12%	3%	-14%	0
To the right	0	0	0	-2%

Table 4.8 - Differences between congestion and free flow of empirical data.

Differences empirical data				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
To the left	6%	9%	-11%	0
To the right	0	0	0	-4%

The last comparison is the differences between free flow and congestion of the empirical dataset and the FOSIM results. These differences of the lanes are mentioned in Table 4.7 (FOSIM results) and Table 4.8 (empirical data). In this case as well, there are some differences between the FOSIM results and the empirical data. In FOSIM the biggest positive difference are the lane changes from the acceleration lane to the shoulder lane, while in the empirical dataset the lane changes from the shoulder lane to the left lane has the biggest positive difference. Other than this fact the results are comparable. The lane changes of the acceleration lane and shoulder lane grow in case congestion occurs while the lane changes of middle and median lane drops in case congestion occur.

Conclusion: *From the comparison it is clear that the FOSIM results and empirical data are comparable at some points. During congestion the FOSIM results and the empirical dataset have similar ratios of lane changing vehicles. The increases and decreases of lane changes between free flow and congestion are also similar. But there are some small differences between FOSIM and the empirical dataset. In FOSIM the difference of lane changes between free flow and congestion is the highest for the acceleration lane, but in the empirical dataset it is the shoulder lane. This could be cause of more cooperativeness in the empirical set in comparison with FOSIM. Another difference between FOSIM and the empirical dataset is the lane changes during free flow. In FOSIM more lane changes take place from the middle lane to the median lane, while in the empirical dataset more lane changes from the acceleration lane to the shoulder lane occur.*

4.2.5 Comparison – travel times and average speed

The last comparison is made on the factors travel time and speed. For the average travel time a distinction is made between free flow and congestion. However, in the empirical dataset there is no complete standstill during congestion, when there is one in the simulation runs. It is therefore not significant to compare the total travel time values of the empirical dataset and the FOSIM results. The comparison of the speed is made using the average speed per lane in free flow traffic state and during congestion. To compare the average speed, the values are converted to percentages, see Table 4.9 and Table 4.10. The median lane is set on 100% and the other lanes are calculated as a ratio of the median lane e.g. the shoulder lane of the FOSIM results in free flow is 95/104*100 = 91%.

Table 4.9 - Average speed of the lanes from FOSIM results.

Average speed FOSIM [km/h]				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
Free flow	92 [81%]	88 [78%]	91 [81%]	113 [100%]
Congestion	35 [35%]	43 [42%]	46 [45%]	102 [100%]

Table 4.10 - Average speed of the lanes from empirical data.

Average speed Empirical data [km/h]				
	Acc. lane	Shoulder Lane	Middle Lane	Median Lane
Free flow	86 [89%]	85 [88%]	95 [98%]	97 [100%]
Congestion	34 [71%]	35 [73%]	44 [92%]	48 [100%]

During free flow the speed of the acceleration lane and the shoulder lane are almost the same in the empirical data. This also applies to the speed of the middle and median lane. However, this is not the case with the FOSIM results. In the FOSIM results the difference between the acceleration lane and shoulder lane is bigger. Also the speeds on the shoulder lane and middle lane are the same, while in the empirical dataset the differences of these lanes are 10%.

If congestion occurs the speed between acceleration lane and the shoulder lane of the empirical dataset still do not differ much. Also, the ratio between the middle lane and median lane is almost the same. So the relation between the average speed of the lanes are the same for free flow traffic state and during congestion. This is not the case in the FOSIM results. The differences between the acceleration lane and the shoulder lane are much bigger. The speed differences between the middle lane and median lane is different during congestion. So while in the empirical dataset there is interaction between the acceleration lane and shoulder lane, there is no interaction in the FOSIM results. The high speed on the median lane is also odd. On this lane still an average speed of 102 km/h is measured. This is caused by the fact this lane is not congested during the simulation. It indicates there is no interaction of speeds between the lanes. The smallest speed differences is 35% and the biggest 65%, while in the empirical dataset the smallest speed difference is 8% and the biggest is 29%. So it is clear that the speeds are much closer to each other in the empirical dataset, this is not the case in the FOSIM results.

Table 4.11 - Travel times of the FOSIM results and of the empirical data.

Travel times		
	FOSIM results	Empirical data
Free flow	10.99s	11.14s
Congestion	34.73s	42.25s

In Table 4.11 the average travel time is shown. This is the travel time from the beginning of the acceleration lane till the end of the acceleration lane. In free flow traffic state the travel time does not differ much between the empirical data and the FOSIM results. During congestion the average travel times differ much more. This is because during the FOSIM simulation traffic is coming to a standstill and in the empirical data this is not the case. Therefore it is not possible to make significant comparison between these two values.

Conclusion: *The average speed in free flow traffic state of the FOSIM results is comparable with the empirical dataset. However, during congestion this is not the case. The average speed per lane between FOSIM results and empirical data differs a lot. Even when the ratio of the average speeds per lane are compared. This means there is probably no interaction between the lanes in the FOSIM simulation.*
The travel times cannot be compared easily. The congestion is not the same, although during free flow the travel time does not differ much.

4.3 Conclusion of simulation tool study

In this chapter a simulation tool, FOSIM, is evaluated on merging behaviour. The results of 25 runs in free flow and 25 runs in congestion are compared with the empirical dataset used in chapter 3. Merge location, lane changes, speed and travel time are compared.

The first factor, location of merging, differs a lot between the FOSIM results and the empirical dataset. In FOSIM vehicles are merging much earlier. During congestion the vehicles uses the acceleration lane a bit more, but it is still not comparable with the merge location of the empirical dataset during congestion. The second factor, the number of lane changes, performs better in the simulation tool. During congestion the ratios of lane changes are comparable, but in free flow traffic state they differ a bit. Also the differences between free flow and congestion are compared. In this case the results are the same. The ratio of the acceleration and shoulder lane increases and the ratio of the middle and median lane decreases. Only the amount of increase of the acceleration and shoulder lane differs a bit. In the FOSIM results the acceleration lane increases the most, while in the empirical dataset the shoulder lane increases the most. This could be caused by the fact there is more cooperativeness in the empirical dataset. The next factor, average speed, is comparable during free flow, but during congestion it is not. During congestion the average speed differs a lot. There seems to be no interaction of speed between the lanes in the FOSIM simulation. The last factor, travel time, is almost the same in free flow. During congestion the results differs from each other, but because the congestion is not totally the same (there is no total stand still in the dataset, while it does appear in FOSIM) the results cannot be compared.

The shortcomings found in the comparison of the simulation results and the empirical dataset are causing implications, those being:

- *Underestimating the length of the acceleration lane*: Most of the drivers are merging at the beginning of the acceleration lane. This can be a trigger for congestion, while it could take longer for congestion to occur when more length of an acceleration lane is used.
- *Underestimating capacity of the carriage way*: The distribution of the flow is not according to reality. In FOSIM the flow on the shoulder lane is higher than in reality. Therefore congestion starts earlier, because less gaps will occur for merging vehicles. This fact has an influence on the estimation of the capacity of the carriage way.
- *Incorrect simulating congestion*: Due to the high difference between the average speed on the middle and median lane, an incorrect congestion is simulated. There is also no possibility for drivers on the middle lane to change lane to the median lane. Therefore it could be that the congestion lasts longer than it would be in reality.
- *Less cooperativeness during congestion*: During congestion large differences occur between the average speed on the median lane and middle lane. Because of this it is not possible for vehicles on the middle lane to make a lane change to the median lane. So there is no possibility to model a cooperative lane change from the middle lane to the median lane.

To conclude, FOSIM does not simulate well on some points. In particular, the merge location differs a lot compared to empirical data. This could be caused by the fact FOSIM uses a gap acceptance model for merge behaviour and therefore the first suitable gap will be chosen. From the data analyses in chapter 3 it is clear that this is not reflecting actual merging behaviour. It seems to be that driver's choice a gap of a set of gaps and this is not always the first suitable gap that occurs on the adjacent lane. Therefore, the focus for the design of model for merging behaviour will be on the choice of a gap out of a set of gaps. This choice will influence the location for merging.

5 Gap choice analysis

From the previous chapters, (literature review, empirical data analysis and FOSIM study), it is clear that gap acceptance models do not simulate merging behaviour accurately. From empirical analysis it is clear that drivers are making a choice between a set of offered gaps, while gap acceptance models only consider one offered gap. If this offered gap is larger than the critical gap, the driver will accept it and merge, according to gap acceptance theory. The comparison of a micro simulation tool with empirical data shows that gap acceptance results in a different usage of the acceleration lane. Using a gap acceptance model, less of the length of the acceleration lane will be used in comparison with the empirical data. Therefore, a different approach to model merging behaviour is needed, where a driver chooses a gap out of a set of gaps. The set of gaps is finite and the choice alternatives are discrete, so a discrete choice model will be used. These kinds of models are powerful and have played an important role in transportation modelling for the last 40 years (Bierlaire, 1998). Before the estimation of the discrete choice model, some additional empirical analyses are performed on the gap choice behaviour. These analyses are discussed in this chapter.

The first section of this chapter is about the setup for the empirical analysis. The second section is about the analysis of the gap choice along the location of the acceleration lane. The third section is about the analysis of gap choice in relation to the time period before a driver merges into the adjacent lane. The last section gives the conclusion of this chapter and the conditions and assumptions for estimating a discrete choice model in the next chapter.

5.1 Setup for gap choice analysis

Developing a discrete choice model starts with understanding the choice situation. Therefore, the choice behaviour of a driver is analysed along the acceleration lane. Using the process of merging, see chapter 3 Figure 3.1, some questions are asked about the gap choice behaviour of a merging vehicle to determine a discrete choice model. This choice analysis answers these questions:

- What is the distribution of gap choice along the acceleration lane?
- What is the choice set of alternative gaps for estimating a discrete choice model?

To answer these questions several datasets need to be derived from the empirical dataset used in previous chapters, those being: datasets at certain locations along the acceleration lane, datasets at time periods from the first detection on the acceleration lane and datasets at time periods before the merge manoeuvre happens. For every merging vehicle the gap choice between an offered set of gaps is determined. The choice datasets also include the vehicle type of the merging vehicle and the traffic state of the carriage way. The choice datasets are determined every 25 meters of the acceleration lane and every second a driver is driving on the acceleration lane.

For every choice dataset a set with a fixed number of gaps is given per vehicle. This set consists of six gaps, with two gaps behind the merging vehicle (gap0 and gap1), one gap alongside the merging vehicle (gap2) and 3 gaps in front of the merging vehicle (gap3, gap4 and gap5), see Figure 5.1. This set depends on the merging car. The gaps behind the merging vehicle are not visible on the moment the merging car is detected when entering the acceleration lane. Therefore, the position of the cars are checked every second the merging car is on the acceleration lane until the putative follower of gap0 is detected. The position of the putative leader of gap2, at the moment the putative follower of gap0 is detected, is then extracted together with the position of the putative leader of gap2 when merging car is entering the acceleration lane. This value is extracted from the positions of putative

follower of gap0, gap1 and gap2 when the follower of gap0 is detected, to determine the position of the vehicles when the merging vehicle enters the acceleration lane. Not every merging vehicle has a set of 6 gaps. To get more observations, vehicles with less than 6 gaps are also included in the choice datasets.

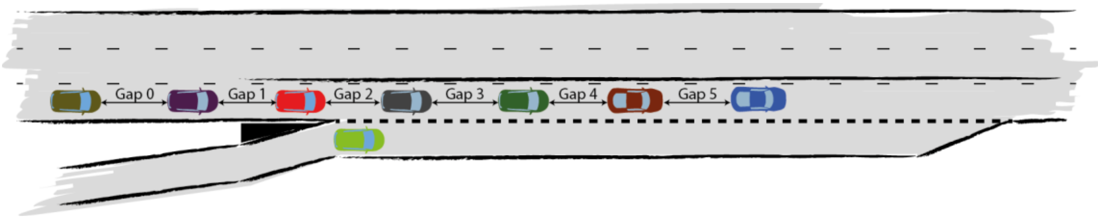


Figure 5.1 - Fixed set of gaps for the merging vehicle.

The analysis is performed with the gap choice behaviour in relation with the location on the acceleration lane, gap choice behaviour in relation with the time period driving on the acceleration lane and with the gap choice behaviour in relation with the time before the merge movement takes place. The analysis of choice behaviour in relation with the location is performed from the start till the end of the acceleration lane. For the analysis in relation with the time before the merge take place an interval is determined. The interval is dependent of the mean and standard deviation of the time period a driver is driving on the acceleration lane, see Table 5.1. In this case, 84% of the observations are taken into account. The interval differs for vehicle types and traffic states. E.g. for all observations the analysis is made from 1 second till 9.7 + 6.1 = 16 seconds before the merge movement. Some datasets do not contain enough observations to make a good analysis. Therefore, datasets with 30 or less observations are not implemented in the analysis (central limit theorem (Dekking et al., 2007)).

Table 5.1 - Mean and standard deviation of the time on acceleration lane (all veh.: all vehicles, PC: passenger car, HGV: heavy goods vehicle, Between states: between the traffic states free flow and congestion).

	All observations	Free flow	Between states	Congestion
Mean (All veh.)	9.7s	6.1s	11.5s	12.3s
St.Dev (All veh.)	6.1s	2.3s	6.3s	7.5s
Mean (PC)	9.5s	6.0s	11.2s	11.9s
St.Dev (PC)	5.9s	2.4s	6.2s	6.9s
Mean (HGV)	11.7s	6.9s	13.6s	15.8s
St.Dev (HGV)	7.0s	1.8s	6.3s	10.9s

For all three cases (location, time period driving on acceleration lane and time period before merging), the distribution of gap choice is made for several conditions:

- All observations
- Free flow observations
- In between states observations
- Congested observations
- Passenger car observations (all, free flow, inbetween states and congested observations)
- HGV observations (all, free flow, inbetween states and congested observations)

The datasets of gap choice in relation to the time spent driving on the acceleration lane is comparable with the gap choice in relation with the location. Therefore only the analysis of gap choice in relation with the location and the gap choice in relation with the time period for merging are mentioned in this chapter. In case of the conditions only the graphs for all observations, free flow observations, congested observations, passenger car observations and HGV observations are shown in this chapter. In these conditions the largest differences occurs. The other graphs can be found in Appendix C.

For every dataset the distribution of gap choices is determined. These are processed in a table which contains absolute numbers and a ratio according to the total number of observations, Table 5.2. To visualize the development of the gap choice, a graph is made using the ratio according to the total amount of observations, see Figure 5.2. e.g. at the position of 50m on the acceleration lane 0% choses gap0, 13% choses gap1, 73% choses gap2, 12% choses gap3, 2% choses gap4 and 0% choses gap5.

Table 5.2 - Numbers of gap choice of time period driving on the acceleration lane of all observations.

	Gap0		Gap1		Gap2		Gap3		Gap4		Gap5		Total	
0m	1	0%	69	15%	279	61%	83	18%	23	5%	6	1%	461	100%
25m	2	0%	71	15%	326	68%	61	13%	15	3%	3	1%	478	100%
50m	2	0%	62	13%	351	73%	56	12%	11	2%	2	0%	484	100%
75m	3	1%	31	7%	344	79%	50	11%	6	1%	3	1%	437	100%

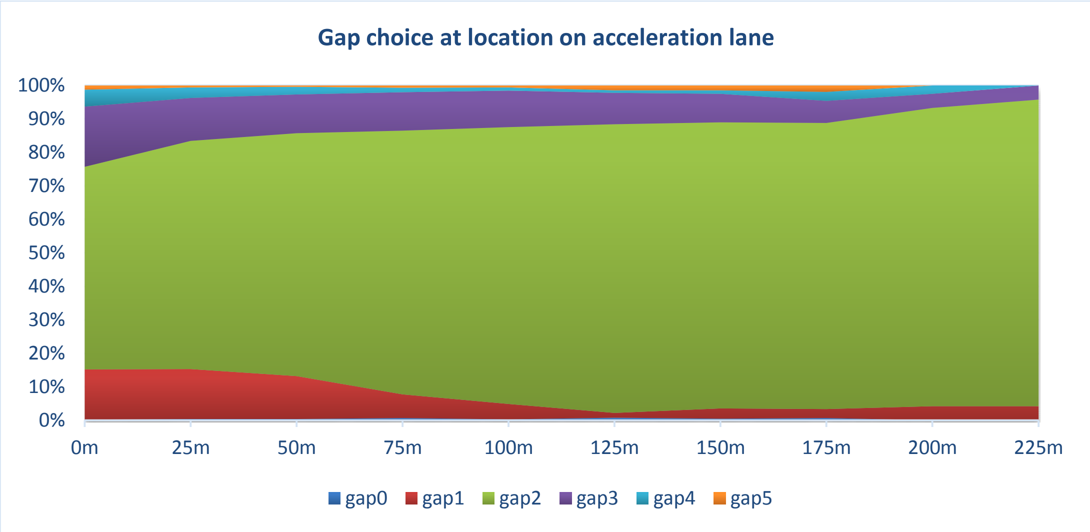


Figure 5.2 - Gap choice development in function of time driving on acceleration lane of all observations.

To answer the question the distribution of the gap choice is analysed. This will give insight in the gap choice behaviour along the acceleration lane and a time period before merging. Different vehicle types and traffic conditions are also analysed. This will show the differences of gap choice behaviour for different vehicle types and traffic states. With this information it will be clear if a choice model could be estimated for all observations at once or if a distinction in vehicle types and traffic states is needed. The analysis gives also insight into the choice set for alternatives needed for estimating a discrete choice model.

5.2 Analysis of gap choice in relation with the location on the acceleration lane

In this analysis the gap choice in relation to the merging position on the acceleration lane is analysed. With this analysis it will be clear which gaps are chosen and how these choices are distributed in relation with the location on the acceleration lane. It will also be clear if there are differences in gap choice behaviour between the different conditions.

All observations: In case of all observations all six gaps are chosen, see Figure 5.3. The gaps gap0 and gap5 are rarely chosen. Therefore these gaps are negligible for the estimation of a discrete choice model. When vehicles enter the acceleration lane gap2 is most often chosen. This gap increases along the acceleration lane, because drivers are driving to their desired gap and make a merge. The choice for gap3, gap4 and gap5 decreases along the acceleration lane, because the accessibility to reach these gaps before the end of the acceleration lane decreases.

Free flow observations: During free flow gap1, gap2 and gap3 are chosen most often. The other gaps, gap0, gap4 and gap5 are negligible in this traffic state for a discrete choice model. So during free flow the choice set of alternatives is smaller. Also the distribution is different in comparison with all observations. Gap1 is more often chosen at the first part of the acceleration lane and gap3 is less often chosen along the acceleration lane. So during free flow, more drivers choose gap1 and gap2 at the beginning of the acceleration lane.

Congested observations: If the traffic state on the main road is congested all gaps are chosen except gap0. This is caused by the fact that drivers want to overtake vehicles on the shoulder lane during congestion. Also during congestion a different distribution occur in comparison with all observations. In the first part of the acceleration lane the gaps gap3, gap4 and gap5 are chosen more often. The choice for gap2 is less in comparison with all observations. Also the decrease of the choice for the gaps in front of the merging driver is less. This corresponds with the fact drivers are willing to overtake several cars on the shoulder lane if congestion occurs, also seen in chapter 2 and in chapter 3. At the end of the acceleration lane the choice for gap1 grows a bit. This is probably due to a driver who is not able to reach a certain gap and chooses to decelerate to merge in the gap behind him.

Passenger car observations: In case a merging vehicle is a passenger car, all gaps are chosen, only gap0 is not often chosen and therefore negligible for estimation of a discrete choice model. In case of passenger cars the development of the gap choice distribution along the acceleration lane is comparable.

HGV observations: In case of HGV'S gap1, gap2 and gap3 are most often chosen. At the beginning of the acceleration lane also gap4 is selected. The pattern of gap choice of HGV's is not comparable with the pattern of all observations. The choice distribution is different in the beginning of the acceleration lane and the choices for a gap in front of a HGV is decreasing a lot faster. Also the increase of the choice of gap1 halfway the acceleration lane is larger.

Conclusion: *From the analysis of the gap choice behaviour in relation with the merge location it is clear that different behaviour occur in different conditions. Also the size of choice set of alternatives differs. Therefore it can be concluded that different choice models are needed for the modelling of gap choice behaviour.*

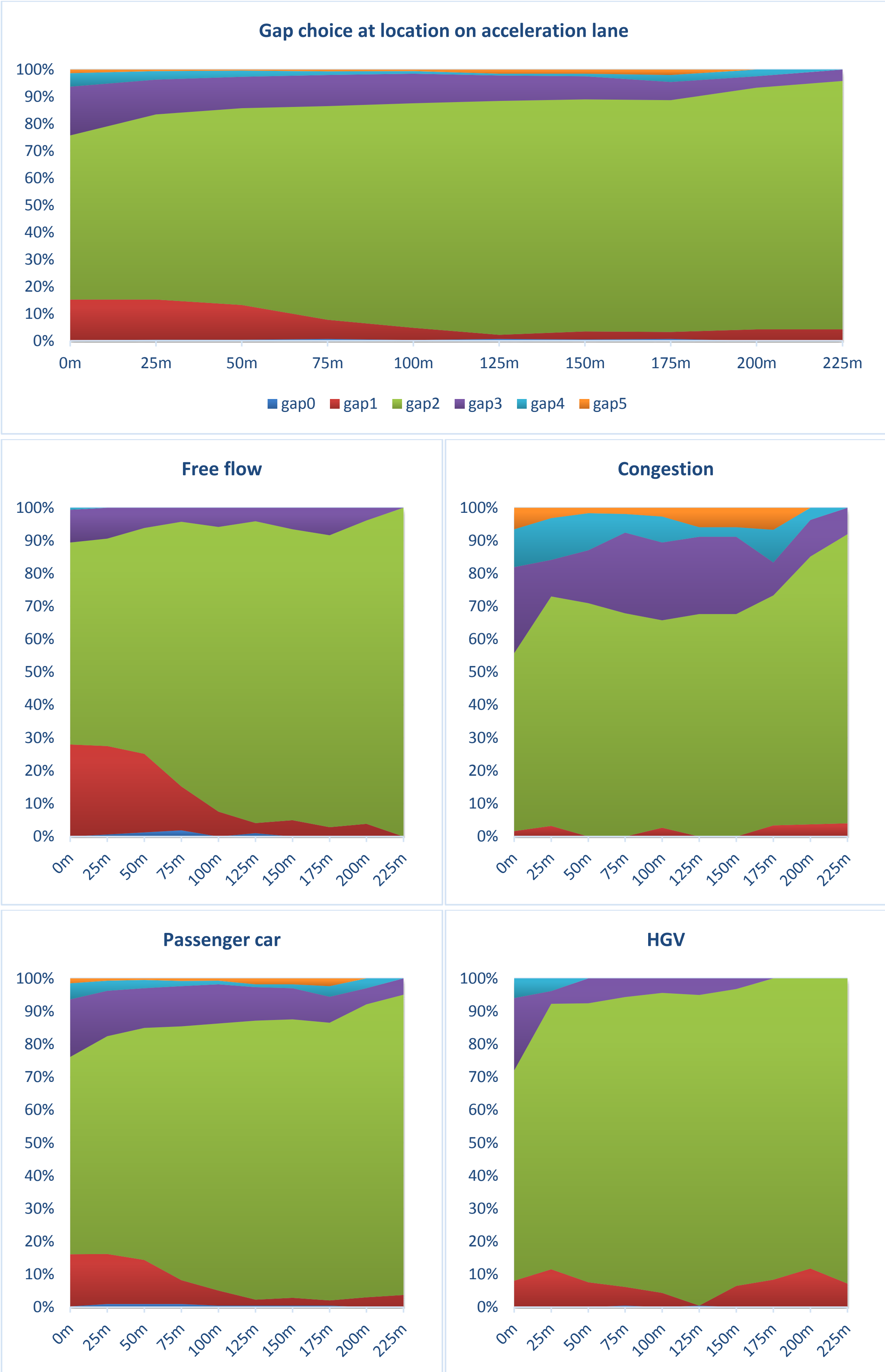


Figure 5.3 - Development of gap choices in relation with the location on the acceleration lane.

5.3 ANALYSIS OF GAP CHOICE IN RELATION WITH THE TIME PERIOD BEFORE MERGING

This analysis is about the choice behaviour of drivers in function of the time period before the merge manoeuvre take place. This will offer insight in the distribution of the gap choice and in the differences in gap choice behaviour between several conditions.

All observations: All drivers choose gap1 or gap2 just before they merge into the adjacent lane, see Figure 5.4. Gap0 and gap5 are not selected often and are therefore negligible for the discrete choice model. At 5s or longer before the merge movement takes place other gaps than gap1 and gap2 are chosen. These choices almost linearly increases with the time period before merging. The small increase of gap1 just before the merge, also seen in the previous analysis, suggest that when a driver is not capable to reach the gap he decelerates to merge into the gap behind him

Free flow observations: During free flow the distribution of the gaps is different in comparison with all observations. The choice for gap1 and gap2 is larger and the choice for gap3 is smaller. Gap3 almost linearly increases with an increasing time period before merging. In comparison with all observations the choice set for alternatives is smaller.

Congested observations: For congested observations, gap1, gap2, gap3, gap4 and gap5 are selected. The distribution is a few seconds before the merge take place different in comparison with all observations. More drivers are choosing gap2. The development of the gap choice distribution with an increasing time period for the merge movement is a bit different. During congestion the choice for gap3, gap4 and gap5 increases faster. This increase is still almost linear. The choice for gap1 is almost uniform in relation with the time period before the merge movement.

Passenger car observations: For passenger cars the gap choice behaviour is comparable with the gap choice behaviour of all observations. The distribution of the gap choices is almost the same and gap3, gap4 and gap5 are almost linearly increasing when the time before the merge increases.

HGV observations: For HGV a different pattern occurs in comparison with all observations. Gap2 is mostly chosen and the choice for gap3 start at 8s before the merge movement. The development of the choice for gap1 is comparable with all observations. The choice set for alternatives for HGV is smaller in comparison with all observations.

Conclusion: *Also from the analysis of choice behaviour in relation with the time period before merging different choice behaviour occur in difference conditions. This means different choice models for traffic states and vehicle types need to be estimated. The choice for a gap is linearly increasing when the time before merging increases. Therefore it can be assumed that the utility functions for the alternatives can be expressed linearly.*

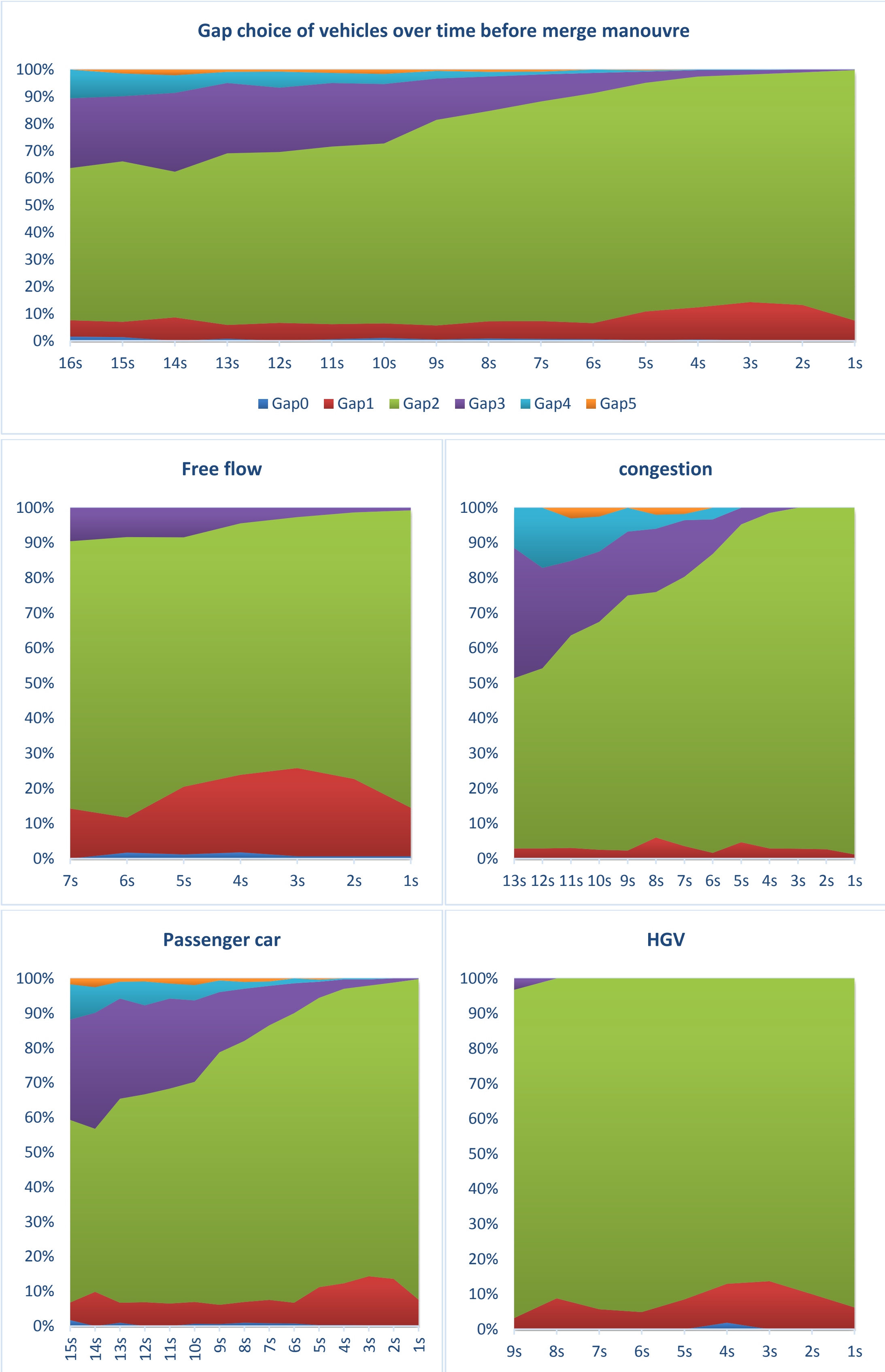


Figure 5.4 - Development of gap choice in relation with time period before the driver is merging on the adjacent lane.

5.4 CONCLUSION OF GAP CHOICE ANALYSIS

In this chapter the gap choice behaviour of drivers is analysed. This analysis is performed to answer two questions that are fundamental for determining a discrete choice model for merging behaviour. These questions are:

- What is the distribution of gap choice along the acceleration lane?
- What is the choice set of alternative gaps for estimating a discrete choice model?

For two cases an analysis is made, those being the relation of gap choice to the merge location on the acceleration lane and gap choice in function with the time period before a driver is merging into the adjacent lane. For these two cases five situations are analysed; for all observations, free flow observations, congested observations, passenger car observations and HGV observations.

From the analysis it is clear that different distribution of gap choices occur in different conditions. Also the choice set for alternative gaps is different. Because there are different patterns of merging behaviour, different discrete choice models will be predicted, see Figure 5.5. The models will be separated into vehicle type and if possible into traffic state. In case of HGV's there are too few observations to split up the traffic state (after split up the dataset contains less than 30 observations, central limit theorem (Dekking et al., 2007)). The models also have different choice sets. Passenger cars during free flow and HGV's have a choice set of gap1, gap2, and gap3. Passenger cars during congestion have a choice set of gap1, gap2, gap3, and gap4. There are too few observations where gap0 and gap5 are chosen. Therefore these gaps will not be included in the choice model. From the gap choice analysis in relation with the time period before merging it is clear that the choice for a gap is linearly decreasing when the time before merging is decreasing. Therefore it is assumed that the utility function of the discrete choice model can be expressed linearly.

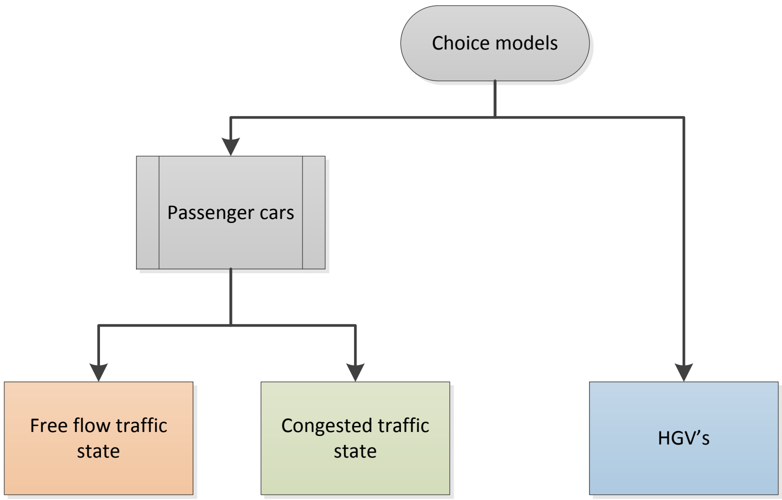


Figure 5.5 - Scheme of discrete choice models that will be estimated in the next chapter.

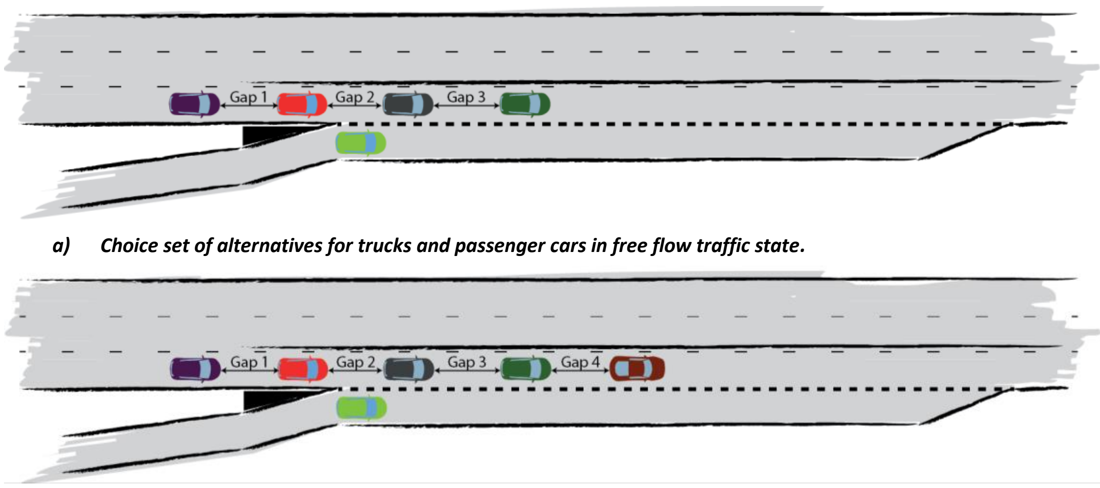
6 Estimating discrete choice model

Using the information found in the preceding chapters, a discrete choice model is estimated. In these chapters it became clear a driver makes a gap choice out of a set of offered gaps. Moreover, the choice behaviour differs between vehicle types and between traffic states. This differs from behaviour in a gap acceptance model, where only one gap at the time is evaluated. Instead of only the gap alongside the driver, a driver can choose a gap behind or in front of him. This choice will be modelled with a discrete choice model. Every merging vehicle has an offered set of gaps. The choice behaviour differs for different kinds of traffic states and vehicles types. Therefore, three discrete choice models are estimated, a choice model for passenger cars during free flow, passenger cars during congestion and HGV's with no distinction of traffic state.

The first section concerns the choice dataset. After that the choice for a multinomial logit model is underpinned. Third, the setup for estimating a discrete choice model is described. This includes which computer program is used to estimate the model, how the results of a model are interpreted, which parameters are estimated and the expected sign (positive or negative) of the parameter, and the methodology to estimate a discrete choice model. Fourth, the discrete choice models with the characteristics of the model are given. Finally, a conclusion of this chapter is given.

6.1 Choice set

From the empirical dataset used for data analysis, a choice set is derived at the beginning of the acceleration lane. Because not all vehicles are detected properly in the first part of the acceleration lane, the merging vehicles detected until 25 meter are taken into account. The gaps are determined at the moment the merging vehicle is detected in the dataset. For trucks and passenger cars in free flow the choice set consists of gap1, gap2, and gap3, Figure 6.1a. The choice set for passenger cars during congestion consists of gap1, gap2, gap3, and gap4, see Figure 6.1b.



a) Choice set of alternatives for trucks and passenger cars in free flow traffic state.

b) Choice set of alternatives for passenger cars during congestion.

Figure 6.1 - Choice set for the estimation of the discrete choice models.

For every merging vehicle the following variables, resulting from the merging process of chapter 3.1, per gap are determined:

- Gap size in distance
- Gap size in time
- Vehicle type of the putative follower
- Vehicle type of the putative leader
- Speed of the PF and its speed difference with the merging vehicle
- Speed of the PL and its speed difference with the merging vehicle
- X-position of PF
- X-position of PL
- Distance between start acceleration lane and centre of gap
- Time period between start acceleration lane and centre of gap
- Distance between centre of gap and the end of the acceleration lane

These variables are determined at the moment the merging vehicles is detected at the beginning of the acceleration lane.

After determining the dataset, it is split up in 3 smaller datasets, those being HGV's only, only passenger cars in free flow and only passenger cars in congestion. To use the whole dataset, the data of passenger cars in-between traffic states is split up. When the average speed on the main road is 60km/h or higher the observations are added to the choice dataset of passenger cars in free flow. The other observations of passenger cars in-between traffic states is added to the choice dataset of passenger cars during congestion. The dataset of HGV's is not split up in traffic states, because the datasets will be too small for estimating a discrete choice model. After splitting up the choice dataset, the number of observations are as follows:

- HGV's: 47 vehicles
- Passenger cars during free flow: 173 vehicles
- Passenger cars during congestion: 209 vehicles

With these datasets the three discrete choice models are estimated.

6.2 Type of discrete choice model

Before the estimation of a choice model, the type of a choice model is determined. First, four types of models are described and the choice for the model used to estimate the gap choice behaviour is underpinned. Second, a mathematical approach of the chosen type of choice model is described.

6.2.1 Discrete choice models

Multinomial logit: One of the most widely used discrete choice models . Can be used assuming that the random terms of each utility function. Its main advantage is the ease with which the logit formula is used. Downside of the model is that it cannot handle if there is correlation between the alternatives (Sheffi, 1985).

Nested logit: The nested logit model applies to situations where some alternatives share a common unobserved characteristic. The set of alternatives is therefore divided into exclusive groups, i.e. nests, where some aspects only pertains to members of that particular group (Sørensen, 2003).

C-logit: This model accounts for correlation between alternatives. The overlap is termed the Commonality Factor (CF). This factor is subtracted from the traditional utility function used in the MNL (Sørensen, 2003).

Probit: The models mentioned above make use of a Gumbel distributed residual terms. The probit model has normal distributed residual terms. Therefore it is possible to model with correlation between any pair of residual terms. Downside of the probit model is the calculation. It is more difficult to model a probit model (Sørensen, 2003).

With the assumption that the parameters used for estimating the discrete choice models are independent, and therefore no correlation between alternatives will occur, the most common and elementary model is chosen; the multinomial logit (MNL).

6.2.2 Mathematical approach of MNL

Utility function of discrete choice model.

$$U_k = ASC_k + \beta_1 \cdot X_k + \beta_2 \cdot Y_k + \cdots + \beta_n \cdot Z_k + \varepsilon_k$$

With:
U = utility
ASC = Alternative Specific Constant, reflecting the specific preference for an alternative, regardless of the scores on the attributes
k = Alternative
β = Parameter to be estimated
ε = Random variable with mean 0

The first part of the utility specification is the systematic component V. The last part is the random component ε. This leads to the following formula:

$$U_k = V_k + \varepsilon_k$$

Generalizing the MNL model to N alternatives:

$$P(i \mid (C_k)) = \frac{e^{\mu V_i}}{\sum_{j \epsilon C_k} e^{\mu V_j}}$$

With:
C_k = Choice set containing k alternatives
μ usually set to 1.

6.3 ESTIMATING OF A DISCRETE CHOICE MODEL

The discrete choice models are estimated with the computer program BIOGEME (Bierlaire, 2003, 2008). This is an open source software package for estimating utility models by maximum likelihood. It can be used to estimate a multinomial logit model and is easy to use. Using Matlab, BIOGEME is executed with the corresponding model file (see Appendix D) and corresponding dataset. After an amount of iterations BIOGEME gives the results of the estimated discrete choice model. With this results the performance of the utility functions can be assessed.

6.3.1 INTERPRET THE RESULTS

The results of BIOGEME are checked at the following aspects (Verhaeghe, 2007):

Model performance: The performance of the estimated choice model is assessed using the rho-square and the adjusted rho-square. The rho-square offers information about how well the model fits the dataset. If the number of parameters increases, the rho-square also increases. To avoid the problem that the number of parameters influences the rho-square, the adjusted rho-squared is used. The value of (adjusted) rho-squared is between 0 and 1. The closer to 1, the better the model performs.

Model significance: After the performance of the model is checked, the parameters themselves will be assessed. This is done with using the significance of the parameters. The significance indicates if a parameters is significant different from zero. The confidence level is set at 95%, e.g. if the t-test results have a value of 1.96 or higher, the parameter is significantly not zero with a confidence of 95%.

Model correctness: The last check of the results concerns the correctness of the parameters. The correctness is checked with the signs of the parameter value. A positive sign has a positive effect on the utility function. A higher value means higher utility. If a parameter has a negative sign, it has a negative effect on the utility function. A lower negative value means lower utility.

6.3.2 PARAMETERS

The parameters used for estimation of the choice models with BIOGEME are determined from the merging process discussed in Figure 3.1. From this merging process the following parameters are used for estimating a discrete choice model, see Table 6.1 and Figure 6.2. In Table 6.1 the expected sign of the parameters is given. The first column contains the parameters, the seconds column gives the expected sign of the discrete choice models, and the last column consists of a description why the sign of the parameter is expected positive or negative. In Figure 6.2 a schematic overview of the parameters is shown. Not all combinations of parameters will be estimated. Some parameters have the same merge characteristics but are only derived with another method, e.g. distance towards gap and distance towards end of acceleration lane, or have another unit, e.g. gap size in distance and gap size in time.

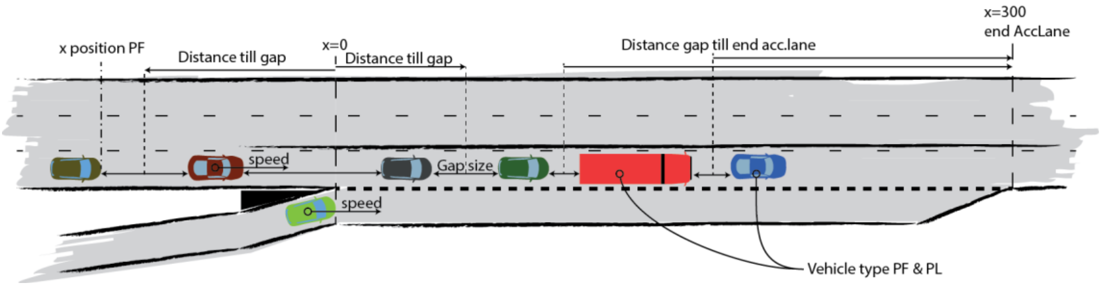


Figure 6.2 - Merging parameters for estimating discrete choice models.

Table 6.1 - Parameters with the expected sign and a description why the sign is expected positive or negative.

Parameter	Sign	Description	Name in model
Gapsize distance	+	A larger gap, in meters, is more attractive compared with a smaller gap.	$\beta_{gapsize\ dist}$
Gapsize time	+	A larger gap, in time, is more attractive in comparison with a smaller gap.	$\beta_{gapsize\ time}$
Vehicle Type PF	+	It is preferable to overtake a truck and merge in front of it. It will become the PF, therefore the sign will be positive.	$\beta_{VehTyp\ Foll}$
Vehicle Type PL	-	Merging behind a truck is less attractive then merging behind a passenger car.	$\beta_{VehTYp\ Lead}$
Distance from beginning acceleration lane towards the gap	-	A long distance towards a gap will be less attractive then a short distance to a gap.	$\beta_{Dist\ to\ gap}$
Distance from gap towards the end of the acceleration lane	+	A long distance away from the end of the acceleration lane will be more attractive than a short distance away from the end of the acceleration lane.	$\beta_{Dist\ gap\ end}$
Position of PF	-/+	Problem, because the position of the PF can be negative. So if the sign is negative a car with a long distance behind the merging car will be more attractive in relation with a car just behind the merging car. This is the exact opposite when the sign is positive.	*Not estimated*
Time till gap	-	More time needed to reach a gap will be less attractive in comparison with a short time needed to reach a gap.	$\beta_{Time\ to\ gap}$
Speed difference merging vehicle and PF	+	When the speed difference is positive, the speed of the merging vehicle is higher than the speed of the putative follower. A positive speed difference is expected to be preferable, because the follower is not closing the gap between the follower and merging vehicle.	$\beta_{V\ Diff\ Foll}$
Speed difference merging vehicle and PL	-	When the speed difference is positive, the speed of the merging car is higher than the speed of the putative follower. When this happens, the merging car is closing the gap to the putative leader. It is expected that this is not preferable, and therefore the sign is negative.	$\beta_{V\ Diff\ Lead}$

6.3.3 Methodology for estimating the utility function of a discrete choice model

The methodology for estimating a discrete choice model is shown in Figure 6.3. The methodology describes the steps needed to be taken for estimating the utility function for a discrete choice model.

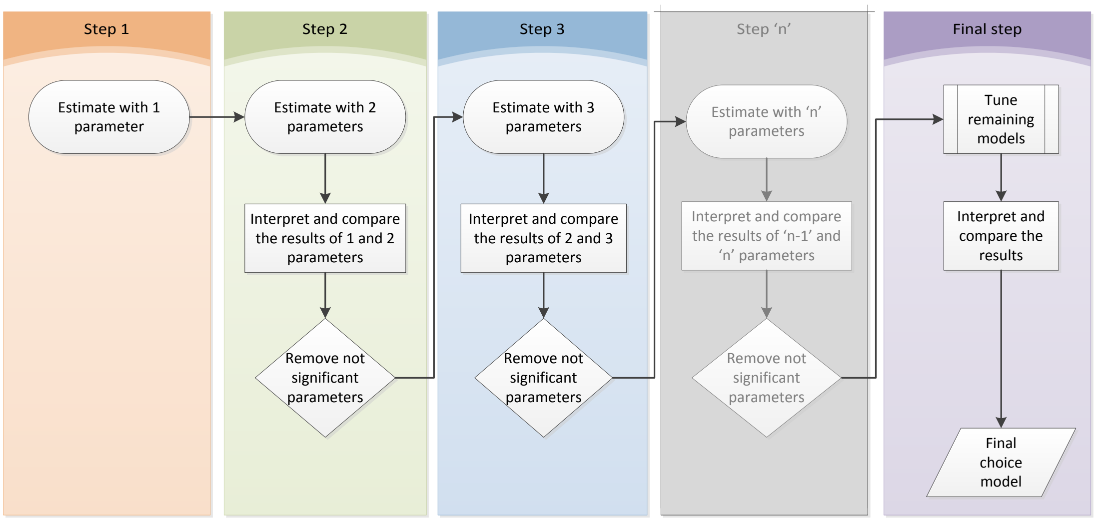


Figure 6.3 - Methodology for estimating the utility functions of a discrete choice model.

Step 1: The first step is to estimate choice models with only one parameter. Each utility function consists of an Alternative Specific Constant (ASC) and a parameter mentioned in the previous section.

Step 2: The second step is to estimate choice models with a combination of two parameters. Not all combinations will be estimated. Some parameters represent the same characteristic of a gap, but with another unit or with another computation. After estimating the models, the results of the models with 1 and 2 parameters are interpreted. It sometimes happens that a parameter is not significant in a model with one parameter but it is significant when it is used together with another parameter. The parameters that are not significant in all models are omitted. The remaining parameters are used in the next step.

Step 3: During step 3 first models with three parameters are estimated. The significant models with two parameters from step 2 are now expanded with a new parameter. Not all combinations will be estimated, because some parameters represent the same characteristic of a gap, but with another unit or with another computation. Secondly, the results of the models with 2 and 3 parameters are interpreted. If a parameter is not significant in both situation the parameter is omitted and will not be used in further steps. The significant parameters are used in the following step.

Step 'n': Repeat steps till only significant parameters with a logical sign are left. These parameters result in the remaining models for the final step.

Final step: Tune remaining models with the significant parameters, remove ASC's, fix other ASC's, check model with a smaller choice set, i.e. less gaps to choose. This can lead to a better performance of the model. After tuning the remaining choice model, the results are interpreted. Lastly the final discrete choice model is chosen.

6.4 Discrete choice model for HGV's

A total of 18 models are estimated and interpreted for trucks, see Table 6.3. From the interpretation of these models it is clear that only the parameters of gap size in time and the distance towards a gap are significant. This is model 12c in Table 6.3. This means that the gap choice behaviour of a driver of a HGV depends on the gap size and the distance towards a gap, see formula 6.1. The gap size has a positive sign like expected and therefore a gap with a larger gap size is more preferable. The distance towards a gap is negative, like expected. This means that a gap closer to the position of the merging vehicle is more preferable to a gap further away. The ratio between the gap size and the distance is 20 to 1. This means a driver of a HGV prefers a larger gap in time over the distance towards a gap in meters.

$$V_{gap1} = 1.94 + 1.05 \cdot Gapsize_{gap1} - 0.0486 \cdot Distance\ to\ gap_{gap1} \qquad (6.1)$$

$$V_{gap2} = 1.85 + 1.05 \cdot Gapsize_{gap2} - 0.0486 \cdot Distance\ to\ gap_{gap2}$$

$$V_{gap3} = \qquad 1.05 \cdot Gapsize_{gap3} - 0.0486 \cdot Distance\ to\ gap_{gap3}$$

$$\rho^2 = 0.492,\ adjusted\ \rho^2 = 0.414$$

All parameters are not zero with a confidence of 95%, except the ASC of gap 1, see Table 6.2. This value is not zero with a confidence of 90%. Because the dataset does not have many observations, a confidence of 90% is acceptable and is therefore used in the model.

Table 6.2 - Parameters of the discrete choice model for HGV's.

Name	Value	Std err	t-test	p-value
ASC_G1	1.94	1.15	1.69	0.09
ASC_G2	1.85	0.606	3.06	0.00
ASC_G3	0.00	fixed		
β Gapsize	1.05	0.317	3.32	0.00
β Distance to gap	-0.0486	0.0167	-2.92	0.00

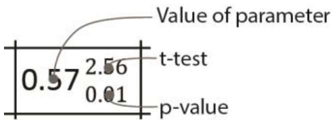


Table 6.3 - Parameters of estimated discrete choice models for HGV's. Values in red are not significant. Orange values are significant with a certainty between 90% and 95%. Green row is the chosen discrete choice model for modelling gap choice behaviour for HGV's.

Model	ρ^2	$\bar{\rho}^2$	ASC_G1	ASC_G2	ASC_G3	$\beta_{gapsize\ dist}$	$\beta_{gapsize\ time}$	$\beta_{VehTyp\ Foll}$	$\beta_{VehTyp\ Lead}$	$\beta_{V\ Diff\ Foll}$	$\beta_{V\ Diff\ Lead}$	$\beta_{Dist\ to\ gap}$	$\beta_{Time\ to\ gap}$	$\beta_{Dist\ gap\ end}$
1	0.336	0.278	Fixed	$1.78^{3.28}_{0.00}$	$0.60^{0.63}_{0.96}$	$0.02^{2.45}_{0.01}$								
2	0.369	0.310	Fixed	$1.73^{3.16}_{0.00}$	$0.58^{0.93}_{0.35}$		$0.45^{2.89}_{0.00}$							
3	0.286	0.228	Fixed	$2.28^{4.00}_{0.00}$	$1.08^{1.81}_{0.07}$			$7.62^{1.54}_{0.12}$						
4	0.263	0.205	Fixed	$2.06^{3.88}_{0.00}$	$1.00^{1.71}_{0.09}$				$1.85^{0.41}_{0.68}$					
5	0.274	0.216	Fixed	$2.16^{3.99}_{0.00}$	$1.11^{1.87}_{0.06}$					$0.03^{1.11}_{0.27}$				
6	0.273	0.215	Fixed	$2.09^{3.88}_{0.00}$	$1.05^{1.77}_{0.08}$						$-0.04^{-1.09}_{0.28}$			
7	0.274	0.216	Fixed	$1.83^{3.20}_{0.00}$	$0.71^{1.10}_{0.27}$							$-0.01^{-1.12}_{0.26}$		
8	0.265	0.206	Fixed	$1.95^{3.41}_{0.00}$	$0.86^{1.34}_{0.18}$								$-0.06^{-0.56}_{0.57}$	
9	0.342	0.283	Fixed	$3.06^{4.15}_{0.00}$	$3.16^{2.99}_{0.00}$									$0.02^{2.54}_{0.01}$
10	0.353	0.276	Fixed	$2.56^{3.04}_{0.00}$	$2.18^{1.60}_{0.11}$	$0.01^{1.09}_{0.27}$								$0.02^{1.35}_{0.18}$
11	0.376	0.299	Fixed	$2.24^{2.71}_{0.01}$	$1.64^{1.21}_{0.23}$		$0.34^{1.72}_{0.09}$							$0.01^{0.89}_{0.37}$
12a	0.492	0.414	Fixed	$-0.08^{-0.11}_{0.91}$	$-1.94^{-1.69}_{0.09}$		$1.05^{3.32}_{0.00}$					$-0.05^{-2.92}_{0.00}$		
12b	0.492	0.414	$0.08^{0.11}_{0.91}$	Fixed	$-1.85^{-3.06}_{0.00}$		$1.05^{3.32}_{0.00}$					$-0.05^{-2.92}_{0.00}$		
12c	0.492	0.414	$1.94^{1.69}_{0.09}$	$1.85^{3.06}_{0.00}$	Fixed		$1.05^{3.32}_{0.00}$					$-0.05^{-2.92}_{0.00}$		
13	0.433	0.356	Fixed	$0.52^{0.70}_{0.48}$	$-1.03^{-1.02}_{0.31}$		$0.80^{3.08}_{0.00}$						$-0.43^{-2.28}_{0.02}$	
14	0.373	0.295	Fixed	$1.85^{3.13}_{0.00}$	$0.64^{1.00}_{0.32}$		$0.43^{2.66}_{0.01}$	$3.54^{0.64}_{0.52}$						
15	0.388	0.311	Fixed	$1.63^{2.95}_{0.00}$	$0.51^{0.81}_{0.42}$		$0.53^{2.99}_{0.00}$		$7.26^{1.41}_{0.16}$					
16	0.302	0.224	Fixed	$2.36^{3.93}_{0.00}$	$1.12^{1.83}_{0.07}$			$11.2^{1.89}_{0.06}$	$6.81^{1.27}_{0.20}$					
17	0.376	0.298	Fixed	$1.83^{3.21}_{0.00}$	$0.68^{1.06}_{0.29}$		$0.46^{2.86}_{0.00}$			$0.03^{0.86}_{0.39}$				
18	0.369	0.291	Fixed	$1.73^{3.15}_{0.00}$	$0.59^{0.94}_{0.35}$		$0.45^{2.83}_{0.00}$				$-0.11^{-0.11}_{0.91}$			

6.5 Discrete choice model for passenger cars in free flow

For passenger cars during free flow traffic state, a total of 23 models are estimated, see Table 6.5. After interpreting the models it became clear that the parameters gap size in time, the distance towards a gap, vehicle type of the PF, and the vehicle type of PL are significant parameters. After fine tuning the remaining choice models with these parameters, the model using all four parameters and a fixed ASC of gap 2 performed best, see formula 6.2, model 23b in Table 6.5. This means that the choice behaviour of a passenger car in free flow depends on the gap size, distance towards the gap and the presence of a HGV – both before and behind the chosen gap – on the adjacent lane. All signs of the parameters are as expected. This is the same behaviour that is observed in the empirical data analysis of chapter 3. The ratio between the parameters is 20/1/30/20 (gapsize/distance/VT follower/VT leader). This means that the parameter of the vehicle type of the putative follower has the most influence on the choice behaviour. After this the parameters gap size and the vehicle type of the putative leader has the most influence. The parameter of the distance towards a gap has the least influence on the gap choice behaviour.

$$V_{\text{gap1}} = 0.828 + 0.636 \cdot Gsize_{gap1} - 0.031 \cdot Distance\ to\ gap_{gap1} + 0.981 \cdot VehicleType\ PF_{gap1} - 0.630 \cdot VehicleTtype\ PL_{gap1} \quad (6.2)$$

$$V_{\text{gap2}} = \quad 0.636 \cdot Gsize_{gap2} - 0.031 \cdot Distance\ to\ gap_{gap2} + 0.981 \cdot VehicleType\ PF_{gap2} - 0.630 \cdot VehicleTtype\ PL_{gap2}$$

$$V_{\text{gap3}} = -1.81 + 0.636 \cdot Gsize_{gap3} - 0.031 \cdot Distance\ to\ gap_{gap3} + 0.981 \cdot VehicleType\ PF_{gap3} - 0.630 \cdot VehicleType\ PL_{gap3}$$

$$\rho^2 = 0.299,\ adjusted\ \rho^2 = 0.268$$

All parameters are not zero with a confidence of 95%, except the parameter of vehicle type of the putative leader, see Table 6.4. This value is not zero with a confidence of 94%. Because this is still a good confidence level and the parameter is significant with a confidence of 95% in the other estimated models, the parameter is used in this discrete choice model.

Table 6.4 - Parameters of the discrete choice model for passenger cars during free flow.

Name	Value	Std err	t-test	p-value
ASC_G1	0.828	0.333	2.49	0.01
ASC_G2	0.00	fixed		
ASC_G3	-1.81	0.287	-6.29	0.00
β Gapsize	0.636	0.141	4.52	0.00
β Distance to gap	-0.0309	0.00561	-5.52	0.00
β VehicleTYpe PF	0.981	3.34	2.94	0.00
β VehicleTYpe PL	-0.630	3.35	-1.88	0.06

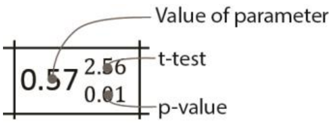


Table 6.5 - Parameters of estimated discrete choice models for passenger cars in free flow. Values in red are not significant with a certainty of 90%. Orange values are significant with a certainty between 90% and 95%. The green row is the chosen discrete choice model for modelling the gap choice behaviour of passenger cars in free flow traffic state.

Model	ρ^2	$\bar{\rho}^2$	ASC_G1	ASC_G2	ASC_G3	$\beta_{gapsize\ dist}$	$\beta_{gapsize\ time}$	$\beta_{VehTyp\ Foll}$	$\beta_{VehTyp\ Lead}$	$\beta_{V\ Diff\ Foll}$	$\beta_{V\ Diff\ Lead}$	$\beta_{Dist\ to\ gap}$	$\beta_{Time\ to\ gap}$	$\beta_{Dist\ gap\ end}$
1	0.147	0.131	Fixed	$0.78^{4.41}_{0.00}$	$-0.67^{-2.66}_{0.01}$	$0.01^{0.85}_{0.40}$								
2	0.150	0.134	Fixed	$0.78^{4.38}_{0.00}$	$-0.67^{-2.66}_{0.01}$		$0.09^{1.36}_{0.17}$							
3	0.172	0.157	Fixed	$0.84^{4.59}_{0.00}$	$-0.64^{-2.52}_{0.01}$			$0.86^{3.20}_{0.00}$						
4	0.175	0.159	Fixed	$0.79^{4.36}_{0.00}$	$-0.64^{-2.50}_{0.01}$				$-0.94^{-2.32}_{0.00}$					
5	0.147	0.131	Fixed	$0.76^{4.28}_{0.00}$	$-0.67^{-2.68}_{0.01}$					$0.01^{0.96}_{0.34}$				
6	0.149	0.134	Fixed	$0.75^{4.23}_{0.00}$	$-0.67^{-2.67}_{0.01}$						$-0.01^{-1.30}_{0.19}$			
7	0.171	0.155	Fixed	$0.33^{1.49}_{0.14}$	$-1.14^{-3.81}_{0.00}$							$-0.01^{-3.02}_{0.00}$		
8	0.161	0.145	Fixed	$0.42^{1.87}_{0.06}$	$-1.04^{-3.50}_{0.00}$								$-0.14^{-2.37}_{0.02}$	
9	0.150	0.135	Fixed	$0.57^{2.56}_{0.01}$	$-1.10^{-2.82}_{0.00}$									$-0.01^{-1.44}_{0.15}$
10	0.190	0.169	Fixed	$-0.25^{-0.81}_{0.42}$	$-2.93^{-4.49}_{0.00}$	$0.02^{3.73}_{0.00}$								$-0.01^{-3.86}_{0.00}$
11	0.208	0.187	Fixed	$-0.44^{-1.42}_{0.16}$	$-3.27^{-4.99}_{0.00}$		$0.59^{4.38}_{0.00}$							$-0.02^{-4.40}_{0.00}$
12	0.256	0.235	Fixed	$-0.84^{-2.58}_{0.01}$	$-2.65^{-5.56}_{0.00}$		$0.68^{4.98}_{0.00}$					$-0.03^{-5.45}_{0.00}$		
13	0.220	0.199	Fixed	$-0.51^{-1.60}_{0.11}$	$-2.16^{-4.91}_{0.00}$		$0.53^{4.27}_{0.00}$						$-0.49^{-4.55}_{0.00}$	
14	0.173	0.152	Fixed	$0.83^{4.57}_{0.00}$	$-0.64^{-2.52}_{0.01}$		$0.03^{0.40}_{0.69}$	$0.82^{2.94}_{0.00}$						
15	0.178	0.157	Fixed	$0.79^{4.34}_{0.00}$	$-0.64^{-2.50}_{0.01}$		$0.08^{1.13}_{0.26}$		$-0.92^{-3.16}_{0.00}$					
16	0.152	0.131	Fixed	$0.76^{4.26}_{0.00}$	$-0.67^{-2.67}_{0.01}$		$0.09^{1.32}_{0.19}$			$0.01^{0.91}_{0.36}$				
17	0.153	0.132	Fixed	$0.75^{4.22}_{0.00}$	$-0.67^{-2.67}_{0.01}$		$0.08^{1.22}_{0.22}$				$-0.02^{-1.16}_{0.25}$			
18	0.244	0.223	Fixed	$-0.78^{-2.39}_{0.02}$	$-2.60^{-5.40}_{0.00}$			$0.03^{4.75}_{0.00}$	$-0.03^{-5.26}_{0.00}$					
19	0.290	0.263	Fixed	$-0.87^{-2.63}_{0.01}$	$-2.74^{0.00}_{0.00}$		$0.65^{4.60}_{0.00}$	$1.12^{3.47}_{0.00}$				$-0.03^{-5.65}_{0.00}$		
20	0.276	0.249	Fixed	$-0.76^{-2.33}_{0.02}$	$-2.51^{-5.28}_{0.00}$		$0.64^{4.96}_{0.00}$		$-0.84^{-2.65}_{0.01}$			$-0.03^{-5.26}_{0.00}$		
21	0.190	0.164	Fixed	$0.83^{4.48}_{0.00}$	$-0.61^{-2.39}_{0.02}$		$0.03^{0.48}_{0.63}$	$0.62^{2.09}_{0.04}$	$-0.75^{-2.48}_{0.01}$					
22	0.232	0.206	Fixed	$0.23^{0.97}_{0.33}$	$-1.25^{-4.00}_{0.00}$			$0.10^{3.31}_{0.00}$	$-0.73^{-2.31}_{0.02}$			$-0.20^{-3.03}_{0.00}$		
23a	0.299	0.268	Fixed	$-0.83^{-2.49}_{0.01}$	$-2.63^{-5.42}_{0.00}$		$0.64^{4.52}_{0.00}$	$0.98^{2.94}_{0.00}$	$-0.63^{-1.88}_{0.06}$			$-0.03^{-5.52}_{0.00}$		
23b	0.299	0.268	$0.82^{2.49}_{0.01}$	Fixed	$-1.81^{-6.29}_{0.00}$		$0.64^{4.52}_{0.00}$	$0.98^{2.94}_{0.00}$	$-0.63^{-1.88}_{0.06}$			$-0.03^{-5.52}_{0.00}$		
23c	0.299	0.268	$2.63^{5.42}_{0.00}$	$1.81^{6.29}_{0.00}$	Fixed		$0.64^{4.52}_{0.00}$	$0.98^{2.94}_{0.00}$	$-0.63^{-1.88}_{0.06}$			$-0.03^{-5.52}_{0.00}$		

6.6 Discrete choice model for passenger cars in congestion

For passenger cars during congestion, a total of 24 models are estimated, see Table 6.7. Out of the interpretation of the models it was clear the parameters gap size in time, the distance till a gap, and the vehicle type of PL are significant. After fine tuning choice models with these parameters the model with all three parameters, a fixed ASC of gap 2, but only a choice set between gap2, gap3, and gap4 performed best, see formula 6.3. This is model 21b in Table 6.7. Gap 1 is excluded because this gap has only a few observations and it is clear from the gap choice analysis in the preceding chapter this gap is not often chosen during congestion. The vehicle type of the putative follower is not present. During congestion a passenger car is willing to overtake both passenger cars and HGV's as observed in the gap analysis of chapter 3. Therefore, the gap choice is not influenced by the vehicle type of the putative follower. The ratio between the parameters is 13/1/25 (gap size/distance/VT leader) and the signs of the parameters are as expected. This means the gap choice of a driver of a passenger car during congestion is influenced the most by the vehicle type of the putative leader. A passenger car is more preferable than a HGV. After that the parameter of the gap size has most influence on the gap choice. The distance towards the gap has the least influence.

$$V_{gap2} = 0.647 \cdot Gsize_{gap2} - 0.051 \cdot Distance\ to\ gap_{gap2} - 1.27 \cdot VehicleType\ PL_{gap2} \quad (6.3)$$

$$V_{gap3} = -1.46 + 0.647 \cdot Gsize_{gap3} - 0.051 \cdot Distance\ to\ gap_{gap3} - 1.27 \cdot VehicleType\ PL_{gap3}$$

$$V_{gap4} = -1.15 + 0.647 \cdot Gsize_{gap4} - 0.051 \cdot Distance\ to\ gap_{gap4} - 1.27 \cdot VehicleType\ PL_{gap4}$$

$$\rho^2 = 0.466, \qquad adjusted\ \rho^2 = 0.442$$

All parameters are not zero with a confidence of 95%, see Table 6.6.

Table 6.6 - Parameters of the discrete choice model of passenger cars during congestion.

Name	Value	Std err	t-test	p-value
ASC_G2	0.00	fixed		
ASC_G3	-1.46	0.234	-6.25	0.00
ASC_G4	-1.15	0.319	-3.60	0.00
β Gapsize	0.647	0.103	6.27	0.00
β Distance to gap	-0.0512	0.00862	-5.94	0.00
β VehicleType PL	-1.27	3.07	-4.13	0.00

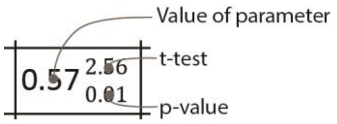


Table 6.7 - Parameters of estimated discrete choice models for passenger cars during congestion. Values in red are not significant with a certainty of 90%. Orange values are significant with a certainty between 90% and 95%. The green row is the chosen discrete choice model for modelling the gap choice behaviour of passenger cars during congestion.

Model	ρ^2	$\bar{\rho}^2$	ASC_G1	ASC_G2	ASC_G3	ASC_G4	$\beta_{gapsize\ dist}$	$\beta_{gapsize\ time}$	$\beta_{VehTyp\ Foll}$	$\beta_{VehTyp\ Lead}$	$\beta_{V\ Diff\ Foll}$	$\beta_{V\ Diff\ Lead}$	$\beta_{Dist\ to\ gap}$	$\beta_{Time\ to\ gap}$	$\beta_{Dist\ gap\ end}$
1	0.287	0.273	Fixed	$2.00^{7.77}_{0.00}$	$0.99^{3.45}_{0.00}$	$-0.10^{-0.28}_{0.78}$	$0.02^{4.34}_{0.00}$								
2	0.305	0.291	Fixed	$2.01^{7.75}_{0.00}$	$0.95^{3.33}_{0.00}$	$-0.14^{-0.40}_{0.69}$		$0.31^{5.28}_{0.00}$							
3	0.288	0.274	Fixed	$2.08^{8.02}_{0.00}$	$0.97^{3.41}_{0.00}$	$-0.08^{-0.24}_{0.81}$			$0.88^{4.34}_{0.00}$						
4	0.283	0.269	Fixed	$2.04^{7.94}_{0.00}$	$0.91^{3.25}_{0.00}$	$-0.15^{-0.42}_{0.67}$				$-0.87^{-3.93}_{0.00}$					
5	0.258	0.244	Fixed	$2.03^{7.94}_{0.00}$	$0.96^{3.41}_{0.00}$	$-0.09^{-0.26}_{0.80}$					$0.02^{1.51}_{0.13}$				
6	0.264	0.250	Fixed	$2.01^{7.92}_{0.00}$	$0.95^{3.39}_{0.00}$	$-0.10^{-0.28}_{0.78}$						$-0.04^{-2.39}_{0.02}$			
7	0.267	0.253	Fixed	$1.65^{5.97}_{0.00}$	$0.56^{1.81}_{0.07}$	$-0.11^{-0.30}_{0.76}$							$-0.01^{-2.62}_{0.01}$		
8	0.261	0.247	Fixed	$1.73^{6.20}_{0.00}$	$0.65^{2.11}_{0.03}$	$-0.10^{-0.30}_{0.77}$								$-0.09^{-1.90}_{0.06}$	
9	0.271	0.257	Fixed	$2.47^{7.91}_{0.00}$	$1.93^{4.35}_{0.00}$	$1.29^{2.26}_{0.02}$									$-0.01^{3.06}_{0.00}$
10	0.287	0.270	Fixed	$1.85^{5.13}_{0.00}$	$0.68^{1.16}_{0.24}$	$-0.54^{-0.65}_{0.52}$	$0.03^{3.09}_{0.00}$								$-0.01^{-0.59}_{0.56}$
11	0.308	0.291	Fixed	$1.68^{4.86}_{0.00}$	$0.29^{0.51}_{0.61}$	$-1.10^{-1.40}_{0.16}$		$0.40^{4.51}_{0.00}$							$-0.01^{-1.37}_{0.17}$
12	0.394	0.377	Fixed	$0.38^{1.12}_{0.26}$	$-0.88^{-2.12}_{0.03}$	$-0.91^{-2.27}_{0.02}$		$0.71^{7.18}_{0.00}$					$-0.05^{-6.14}_{0.00}$		
13	0.361	0.344	Fixed	$0.81^{2.47}_{0.01}$	$-0.37^{-0.96}_{0.34}$	$-0.57^{-1.51}_{0.13}$		$0.56^{6.73}_{0.00}$						$-0.38^{-5.14}_{0.00}$	
14	0.318	0.300	Fixed	$2.07^{7.86}_{0.00}$	$0.98^{3.41}_{0.00}$	$-0.12^{-0.33}_{0.74}$		$0.25^{4.09}_{0.00}$	$0.59^{2.72}_{0.01}$						
15	0.334	0.317	Fixed	$2.05^{7.79}_{0.00}$	$0.93^{3.22}_{0.00}$	$-0.16^{-0.46}_{0.64}$		$0.32^{5.29}_{0.00}$		$-0.92^{-3.95}_{0.00}$					
16	0.307	0.290	Fixed	$2.05^{7.79}_{0.00}$	$0.98^{3.39}_{0.00}$	$-0.11^{-0.31}_{0.76}$		$0.31^{5.20}_{0.00}$			$0.02^{1.16}_{0.25}$				
17	0.312	0.295	Fixed	$2.02^{7.76}_{0.00}$	$0.97^{3.38}_{0.00}$	$-0.15^{-0.42}_{0.67}$		$0.30^{5.15}_{0.00}$				$-0.04^{-2.03}_{0.04}$			
18	0.300	0.282	Fixed	$2.08^{8.01}_{0.00}$	$0.93^{3.28}_{0.00}$	$-0.09^{-0.27}_{0.79}$			$0.67^{3.06}_{0.00}$	$-0.60^{-2.54}_{0.01}$					
19	0.266	0.248	Fixed	$2.04^{7.94}_{0.00}$	$0.97^{3.45}_{0.00}$	$-0.07^{-0.20}_{0.84}$					$0.02^{0.92}_{0.36}$	$-2.07^{-2.07}_{0.04}$			
20	0.414	0.393	Fixed	$0.46^{1.34}_{0.18}$	$-0.87^{-2.11}_{0.03}$	$-0.84^{-2.09}_{0.04}$		$0.65^{6.54}_{0.00}$	$0.80^{3.33}_{0.00}$				$-0.05^{-6.34}_{0.00}$		
21a	0.433	0.412	Fixed	$0.43^{1.23}_{0.22}$	$-0.96^{-2.30}_{0.02}$	$-0.80^{-1.99}_{0.05}$		$0.74^{7.25}_{0.00}$		$-1.18^{-4.43}_{0.00}$			$-0.05^{-6.37}_{0.00}$		
21b	0.466	0.442		Fixed	$-1.46^{-6.25}_{0.00}$	$-1.15^{-3.60}_{0.00}$		$0.65^{6.27}_{0.00}$		$-1.27^{-4.13}_{0.00}$			$-0.05^{-5.94}_{0.00}$		
22	0.336	0.316	Fixed	$2.07^{7.82}_{0.00}$	$0.93^{3.24}_{0.00}$	$-0.14^{4.53}_{0.00}$		$0.29^{4.53}_{0.00}$	$0.27^{1.11}_{0.27}$	$-0.80^{-3.19}_{0.00}$					
23	0.327	0.306	Fixed	$1.60^{5.67}_{0.00}$	$0.38^{1.22}_{0.22}$	$-0.04^{-0.12}_{0.09}$			$0.90^{3.85}_{0.00}$	$-0.63^{-2.54}_{0.01}$			$-0.02^{-3.75}_{0.00}$		
24a	0.438	0.413	Fixed	$0.45^{1.30}_{0.19}$	$-0.96^{-2.32}_{0.02}$	$-0.76^{-1.89}_{0.06}$		$0.70^{6.83}_{0.00}$	$0.42^{1.61}_{0.11}$	$-1.01^{-3.56}_{0.00}$			$-0.05^{-6.46}_{0.00}$		
24b	0.466	0.437		Fixed	$-1.46^{-6.25}_{0.00}$	$-1.15^{-3.58}_{0.00}$		$0.64^{6.05}_{0.00}$	$0.03^{0.11}_{0.92}$	$-1.25^{-3.66}_{0.00}$			$-0.05^{-5.95}_{0.00}$		

6.7 Comparison between the discrete choice models

In order to get more insight into the estimated discrete choice models, a comparison is made between the three models. In this comparison the values of the parameters are compared and the corresponding driver behaviour is analysed, see Table 6.8.

Table 6.8 - Values of the parameters of the discrete choice models (HGV: Heavy Goods Vehicle, PC: Passenger car).

	Gap size	Distance towards gap	Vehicle type of putative follower	Vehicle type of putative leader	ρ^2	$\bar{\rho}^2$
HGV's	1.05	-0.05			0.492	0.414
PC in free flow	0.64	-0.03	0.98	-0.63	0.299	0.268
PC in congestion	0.65	-0.05		-1.27	0.466	0.442

From the values it is clear that the gap size has a larger influence on the gap choice of HGV's than on the gap choice of passenger cars. This value is almost twice as large for HGV's as for passenger cars. This is caused by the fact that a HGV is larger than a passenger car and therefore needs a larger gap. In all models the value of the gap size parameter has a representative influence. For HGV's, it is even the value with the largest influence. For passenger cars during free flow the influence is the same as for the parameter of vehicle type of the putative leader. Only the parameter of vehicle type of putative follower is a bit larger. During congestion, the parameter of gap size is the second largest. In this case the parameter of vehicle type of putative leader is almost twice as large. So the gap choice depends more on the vehicle type of the putative leader.

The distance towards a gap is the same for all vehicle types. For all three models, this parameter has the least influence. This corresponds with the literature study about merging behaviour. A driver who wants to merge always finds a gap, does not decelerate a lot, and does not come to a standstill at the end of the acceleration lane. So a driver is not concerned with driving for a relatively long time on the acceleration lane. Therefore, the value of distance towards the gap only has a small influence.

The vehicle type of the vehicles on the adjacent lane only has an influence on passenger cars. In both models the parameter of vehicle type of the putative leader is present. For both models, a gap is less preferable if the putative leader of the gap is a HGV. During congestion the influence is even bigger. The parameter of vehicle type of the putative follower of a gap is only present in the discrete choice model for passenger cars in free flow. In this model it is more preferable to merge in front of a HGV. This is the same behaviour that occurred in the gap analysis in chapter 3. From this analysis it was clear that passenger cars in free flow make a later merge movement because they want to overtake a HGV. During congestion a driver also wants to overtake vehicles on the adjacent lane, but there is no distinction in the vehicle type of the vehicles who are overtaken. So for the discrete choice models for passenger cars, the vehicle type of the vehicles on the adjacent lane has an even larger influence on the gap choice behaviour than the gap size.

The rho square of HGV's and passenger cars in congestion is comparable. But the rho square of passenger car in free flow is lower. This is probably caused by the fact there is more deviation in the parameter values in the choice dataset of passenger cars in free flow. For example, the parameter of distance towards a gap has a mean deviation of 30.3 meters for HGV's and 24.6 meters for passenger cars in congestion, while the mean deviation for passenger cars in free flow is 41.9 meters.

6.8 CONCLUSION OF ESTIMATING DISCRETE CHOICE MODEL

In this chapter the estimation of the three discrete choice models is discussed. The dataset is derived from the empirical dataset used for the data analysis in chapter 3. Some factors influencing merging behaviour are fixed in the dataset, e.g. the geometric design. Therefore attention must be given at the fact that the discrete choice model can differ for other locations. With this dataset three choice models are estimated; for HGV's, passenger cars in free flow, and passenger car during congestion.

Two parameters are present in all three final discrete choice models, namely gap size in seconds and the distance towards a gap in meters. These are the only two parameters for the HGV model. The model for passenger cars during congestion has three parameters. This model adds the parameter vehicle type of the putative leader. The last model, passenger car in free flow consist of four parameters, besides the parameters gap size and distance till gap, this model also includes the vehicle type of the putative follower and the vehicle type of the putative leader. So the parameter of vehicle type of putative leader is present in both models for passenger cars and has a negative sign. This means a gap with a HGV as putative leader is less preferable than a gap with a passenger car as putative leader. This behaviour is also observed in the data analysis in chapter 3.

From the comparison of the models it is clear that the parameter of gap size has more influence in the model for HGV's than for passenger cars. In the choice model for HGV the parameter gap size even has the largest influence. This is caused by the fact a HGV is larger than a passenger car and therefore needs a bigger gap. In case of passenger cars in free flow the parameter of vehicle type of the putative follower has the largest influence. The influence of vehicle type of putative leader is comparable with the influence of the gap size in this model. This means a driver is willing to overtake a HGV and merge in front of it. During congestion the vehicle type of the putative leader has the largest influence. This value is even bigger than in the choice model of passenger cars in free flow. So during congestion a driver is motivated even more not to merge behind a HGV. For all models the parameter of distance towards a gap has the least influence. This means drivers are not concerned to drive a relatively long time on the acceleration lane before they make a merge manoeuvre.

The face validity of the three choice models is tested in the next chapter. In that chapter, the aggregate validity of the models and the individual validity of the models is tested. The performance of the model is compared with the distribution of gap choices in the empirical dataset. With the gap specific validity check, the results of the discrete choice model per actual chosen gap of the empirical dataset are analysed.

7 FACE VALIDATION OF DISCRETE CHOICE MODELS

In this chapter the face validity of the three discrete choice models, estimated in the previous chapter, is assessed. The face validity test consists of an aggregate face validity check and an individual face validity check. The aggregate check compares the gap choice distribution of the empirical dataset to the discrete choice model. The individual face validity check compares the choice distribution per individual.

In the first section the face validation setup is explained. The next section discusses the face validity test of the discrete choice model of HGV's. The third section gives the face validation of the choice model of passenger cars during free flow, and the fourth section is about the face validity of the discrete choice model of passenger cars during congestion. The chapter concludes with the face validation results of the discrete choice models.

7.1 FACE VALIDATION SETUP

A simulation is performed using Matlab on the estimated choice models discussed in the preceding chapter. This is done using the same dataset used for the estimation of the discrete choice models. Normally, a validation is performed using an independent dataset, but in this case no other dataset was available. For every merging vehicle, the utility functions of the offered gaps are computed. With a multinomial logit, see *(7.1)*, the distribution of the gap choice of a merging vehicle is calculated.

$$P(gap1|\{gap1, gap2, gap\}) = \frac{e^{V_{gap1}}}{e^{V_{gap1}} + e^{V_{gap2}} + e^{V_{gap3}}} \tag{7.1}$$

For example

Driver ID: 1914

V_1 = -0.2420, V_2 = -0.5922, V_3 = -0.4959

P(gap1|(gap1,gap2,gap3)) = 0.4032
P(gap2|(gap1,gap2,gap3)) = 0.2841
P(gap3|(gap1,gap2,gap3)) = 0.3127

There is a 40% chance the driver chooses gap1, 28% chance of choosing gap2, and 31% chance of choosing gap3.

For the aggregate face validity check, the gap choice distribution is compared with the empirical dataset. For the individual face validity check, the gap choice distribution per chosen gap of the empirical dataset is analysed. The face validity is stated as good if the model has a maximum difference of 5%. A difference of 10% is specified as acceptable. If the difference is 11% of higher, the face validity is defined as not good.

7.2 FACE VALIDATION - MODEL FOR HGV'S

First, the aggregate face validity of the discrete choice model for HGV's is checked. This face validity check compares the distribution of gap choice of the empirical dataset and the modelled gap choice distribution of the discrete choice model. The model is executed and the mean of the gap distributions of the merging vehicles is determined, see Table 7.1 and Figure 7.1. It is clear there are no differences between the empirical dataset and the modelled gap choice distribution. So the discrete choice model's aggregate face validity is good.

Table 7.1 - Aggregate face validity test of discrete choice model for HGV's.

	Empirical dataset	Choice Model	Difference
Gap1	0.09	0.09	0
Gap2	0.68	0.68	0
Gap3	0.23	0.23	0

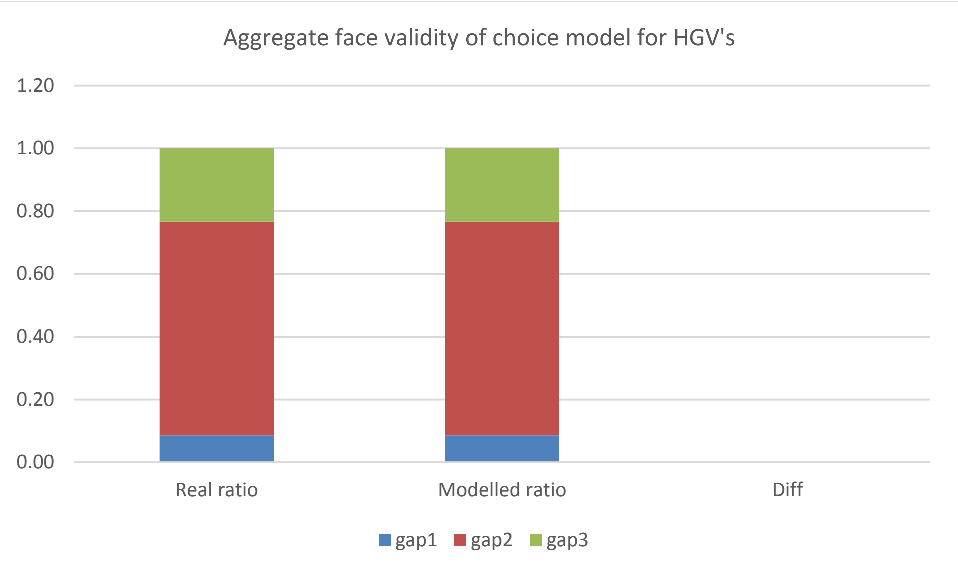


Figure 7.1 - Aggregate face validity test of discrete choice model for HGV's.

The second test is a face validity check per individual, see Table 7.2, and Figure 7.2. In Table 7.2 the choice distribution of the discrete choice model are shown. From these results it is clear that the discrete choice model does not perform well on an individual level. For example, when in the empirical dataset gap3 is chosen, the choice model simulates only 56% of these drivers to choose gap3. Gap 2 performs the best with a difference of 21%, after that comes gap 3 with a difference of 44% and gap 1 performs the least, with a difference of 84%.

Table 7.2 - Ratio of results of the face validity test of the discrete choice model of HGV's per gap.

		Empirical Dataset	Discrete choice model Gap1	Gap2	Gap3	Difference Gap1	Gap2	Gap3
Emp. Data	Gap1	1.00	0.16	0.75	0.09	-0.84	+0.75	+0.09
	Gap2	1.00	0.07	0.79	0.14	+0.07	-0.21	+0.14
	Gap3	1.00	0.11	0.22	0.56	+0.11	+0.33	-0.44

In Figure 7.2, the results of the face validity test per individual is showed in a graph. The three bars on the left are the distribution of gap choice of the empirical dataset, 100% for all gaps. The middle three bars show the gap distribution per chosen gap in the empirical dataset. The last three bars offers the differences between the gap choice distributions of the empirical dataset en the discrete choice model. The graph clearly shows that the face validity of gap 1 is the worst and gap 2 is the best. Remarkably, the gap1 has the least observations and gap2 has the most observations. This could be an influence on the face validity. This means that if there are more observations the discrete choice model will perform better.

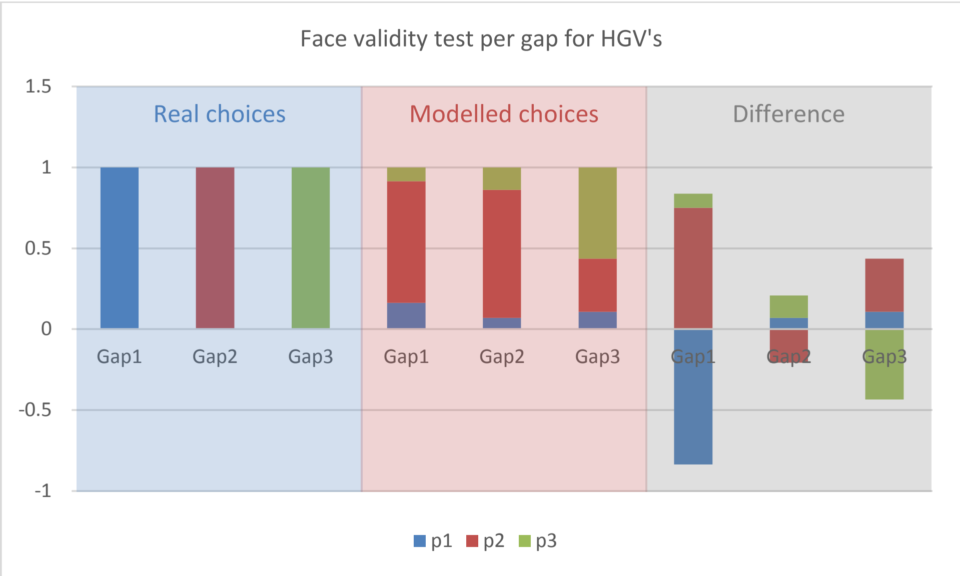


Figure 7.2 - Ratio face validity test of the HGV's choice model per gap, first the real data, second the modelled results of the choice model, and third the differences.

7.3 FACE VALIDATION - MODEL FOR PASSENGER CARS IN FREE FLOW

For the choice model for passenger cars during free flow an aggregate face validity check is performed. Only a small difference appears in comparison with the empirical dataset, see Table 7.3 and Figure 7.3. In the results of the discrete choice model gap1 has 1% fewer choice made and gap3 1% more choice made in comparison with the empirical dataset. Therefore, the discrete choice model's face validity is good.

Table 7.3 - Aggregate face validity test of discrete choice model for passenger cars in free flow.

	Empirical Dataset	Choice Model	Difference
Gap1	0.27	0.26	0.01
Gap2	0.59	0.59	0
Gap3	0.14	0.15	0.01

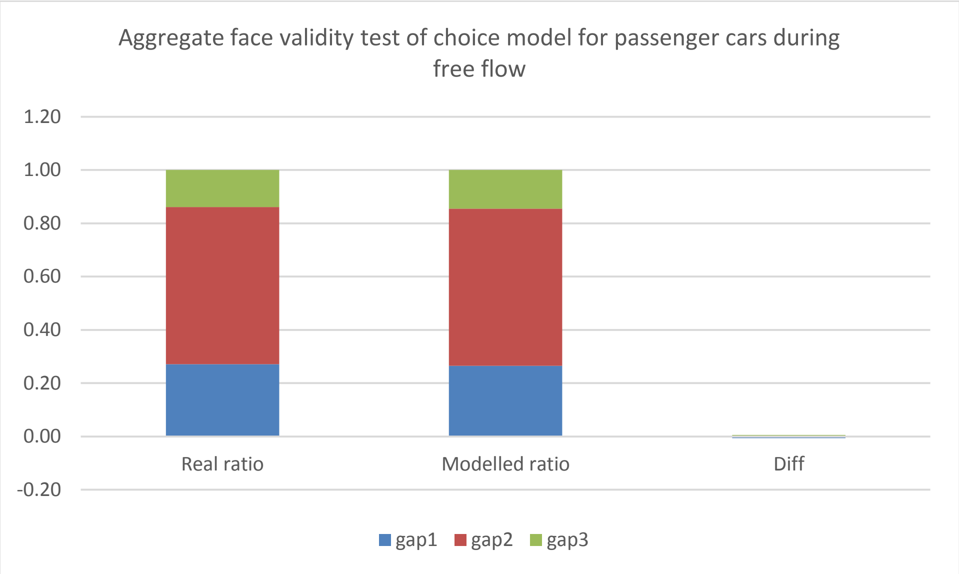


Figure 7.3 - Aggregate face validity test of discrete choice model for passenger cars in free flow.

The next check is the face validity of the discrete choice model per individual. For the discrete choice model for passenger cars in free flow, the face validity per individual is not good, see Table 7.4, and Figure 7.4. Gap2 performs best, but still differs by 35% in comparison with the empirical dataset. After that, gap1 is performing the best with a difference of 60%, and the performance of gap3 is weakest with a difference of 72% in comparison with the empirical dataset.

Table 7.4 - Ratio of results of the face validity test of the discrete choice model of passenger cars in free flow per gap.

		Empirical	Discrete choice model			Difference		
		Dataset	Gap1	Gap2	Gap3	Gap1	Gap2	Gap3
Emp. Data	Gap1	1.00	0.40	0.50	0.10	-0.60	+0.50	+0.10
	Gap2	1.00	0.22	0.65	0.13	+0.22	-0.35	+0.13
	Gap3	1.00	0.23	0.50	0.28	+0.23	+0.50	-0.72

In case of passenger cars in free flow, gap2 has the most observations, gap1 and gap3 have the least observations. Also, this case follows that the number of observations has an influence on the face validity of the discrete choice model. So it can be expected that the model would perform better if more observations are present.

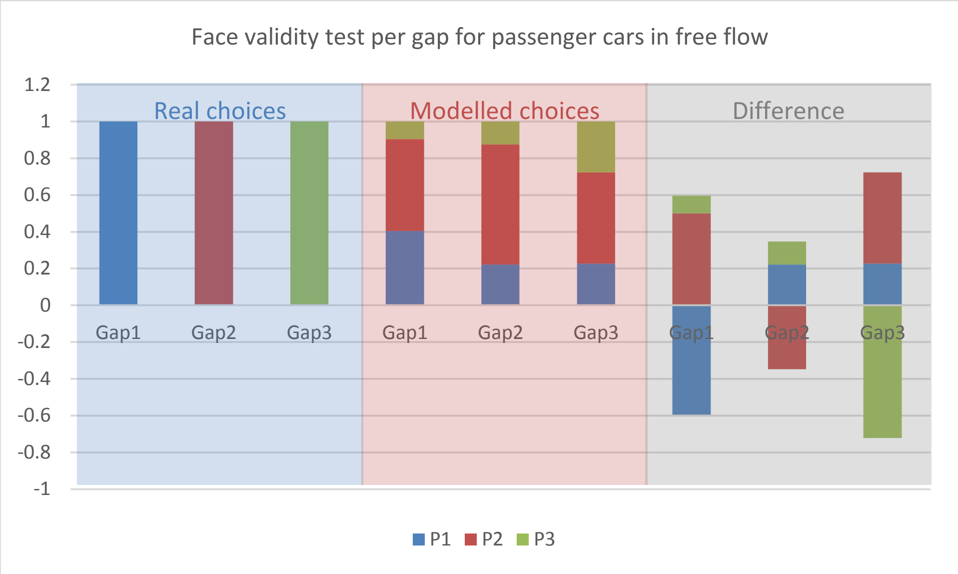


Figure 7.4 - Ratio face validity test of the passenger cars in free flow choice model per gap, first the real data, second the modelled results of the choice model, and third the differences.

7.4 Face validation - model for passenger cars in congestion

The last face validation checks the discrete choice model of passenger cars in congestion. The results of these runs are shown in Table 7.5 and Figure 7.5. This discrete choice model's aggregate face validity is not as good as the other two discrete choice models. In this case, larger differences occur between the gap choice distribution of the empirical dataset and the gap distribution of the modelled choices. For gap2, 4% less choices are modelled in comparison with the empirical dataset. In case of gap3 the discrete choice model modelled 10% more choices. For gap4 the choice model modelled 6% less choices. With a maximum difference of 10% the face validity is still acceptable.

Table 7.5 - Aggregate face validity test of discrete choice model for passenger cars during congestion.

	Empirical Dataset	Choice Model	Difference
Gap2	0.68	0.64	-0.04
Gap3	0.24	0.34	+0.10
Gap4	0.08	0.02	-0.06

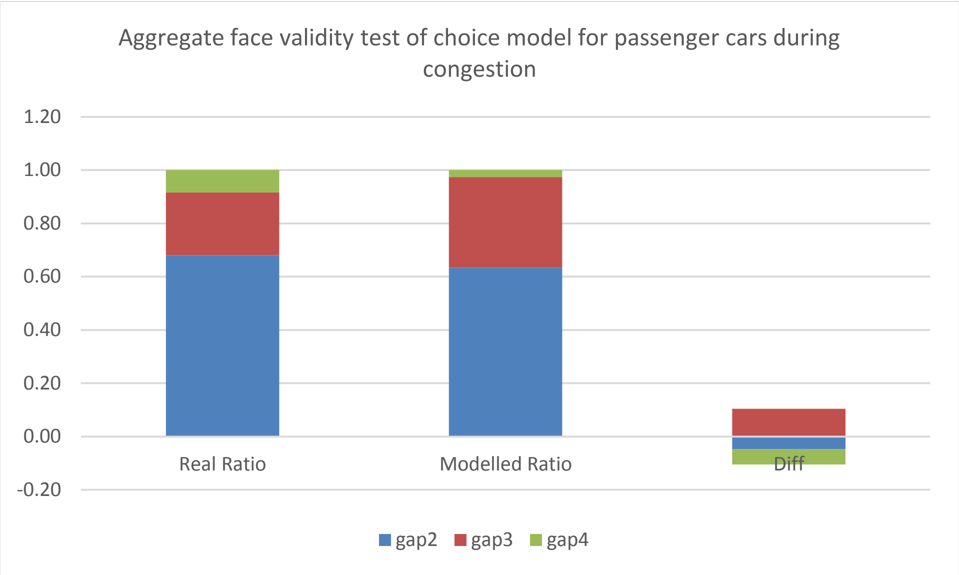


Figure 7.5 - Aggregate face validity test of discrete choice model for passenger cars during congestion.

The next part of the face validation is the face validity check per individual. In this case, face validity is not good, see Table 7.6, and Figure 7.6. In this case gap2 performs best with a difference of 26% in comparison with the empirical dataset. After that, gap3 performs best with a difference of 40%. Lastly, gap4 performs the weakest and has a difference of 94% in comparison with the empirical dataset.

Table 7.6 - Ratio of results of the face validity test of the discrete choice model of passenger cars during congestion per gap.

		Empirical Dataset	Discrete choice model			Difference		
			Gap2	Gap3	Gap4	Gap2	Gap3	Gap4
Emp. Data	Gap2	1.00	0.74	0.25	0.01	-0.26	+0.25	+0.01
	Gap3	1.00	0.38	0.60	0.02	+0.38	-0.40	+0.02
	Gap4	1.00	0.55	0.39	0.06	+0.55	+0.39	-0.94

In the case of passenger cars during congestion, the face validity performance has the same order as the number of observations. Gap4 has the least observations and the worst face validity. Gap2 has the most observations and had the best face validity. So for this model as well, it would be expected that the model performs better if more observations are assessed.

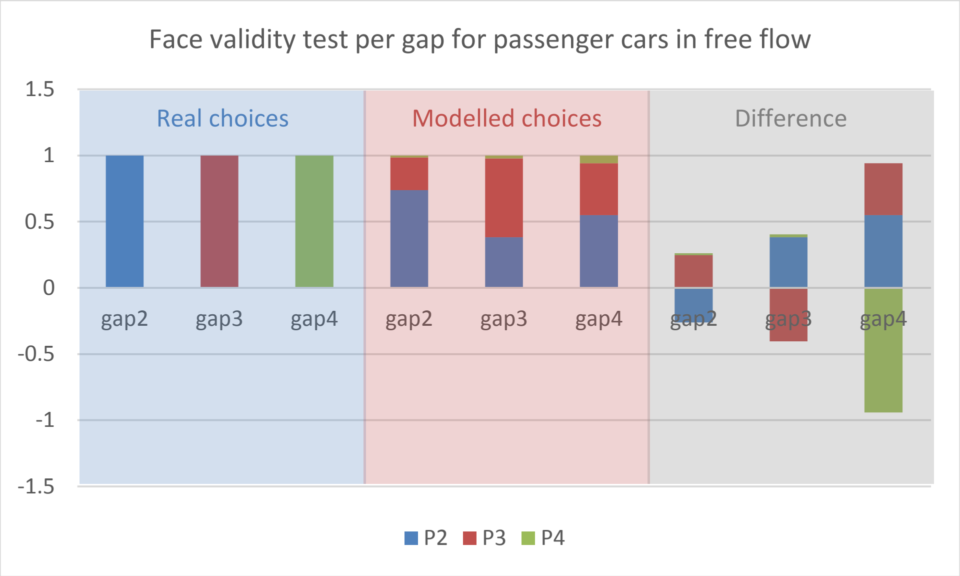


Figure 7.6 - Ratio face validity test of the passenger cars during congestion choice model per gap, first the real data, second the modelled results of the choice model, and third the differences.

7.5 CONCLUSION OF FACE VALIDATION OF DISCRETE CHOICE MODELS

In this chapter the face validity of the three discrete choice models is checked. This face validity check is done on two aspects, an aggregate face validity check and an individual face validity check. The best way to perform a face validation is to use a different empirical dataset than the dataset used for estimating the choice model. In this case there was no other empirical dataset available. Therefore, the same dataset is used as for the estimation of the discrete choice models to perform the face validation.

The aggregate face validity of the three choice models is good. Only the model of passenger cars during congestion has some small differences in comparison with the empirical dataset, but its maximum difference, 10%, is still acceptable. The individual face validity was not as good as the aggregate face validity. For all three discrete choice models there are big differences in gap distribution if the results is compared per gap choice of the empirical dataset. This means the model generally models the right gap choice distribution, but some of the drivers who choose a gap in the discrete choice model are not the same drivers as in the empirical dataset. In all three models, the individual check with the least observations performs the worst and the individual check with the highest amount of observations performs the best.

From the face validation it is clear the models of trucks and passenger cars in free flow perform the best in general. These two models have almost no differences (1% or less) when compared with the empirical dataset. The face validity of the choice model for passenger cars during congestion performs good, but in this case a difference of 10% occurs in comparison with the empirical dataset. The individual face validity of the models was not as good as the aggregate face validity. In this case the choice model for trucks performs better than the other two discrete choice models. The performance of these two models was equal in the individual face validation. Thus, overall, the model of trucks performs best. The discrete choice model for passenger car in free flow is performing second best and the discrete choice model for passenger cars during congestion performs third best.

The next chapter consist of the final conclusion. It consist of the main findings of the research, main conclusion answering the main research question and the sub questions, the recommendations of the research, and some suggestions for further research.

8 Conclusions and recommendations

The final chapter presents the conclusions of this master thesis research. These conclusions are underpinned by the main findings of the research. This chapter also gives recommendations for application and future research on this topic. Using the main research question and the corresponding sub research questions mentioned in the introduction, the findings are realized.

The main conclusion of this master thesis research is:

The three discrete choice models presented in this master thesis research are accurate models to model actual observed merging behaviour on a freeway on-ramp. These models use several characteristics of merging behaviour. In the model of HGV's, the gap size and the distance towards a gap are present. In the model of passenger cars in free flow the gap size, distance towards gap, vehicle type of putative follower, and the vehicle type of the putative leader are factors to model the gap choice. To model passenger cars during congestion the factors gap size, distance towards the gap, and the vehicle type of the putative leader are present. These models are evaluating more than one gap at the time. Also more factors other than the gap size have an influence on the choice for a gap, where a gap acceptance model only evaluates one gap at the time and only the gap size is considered.

The first section recaps the main research question and the sub questions. In the next section this research's main findings are summarised. In the third section the conclusions of this research are given. After that, research applications are recommended. The last section is about future research options on this topic.

8.1 Research questions

The main question was:

How can merging behaviour on a freeway on-ramp be modelled so that it corresponds to actual observed merging behaviour?

To answer the main research question, a set of sub research questions have been answered:

1. *What kind of conceptual and mathematical models are available to predict merging behaviour on a freeway on-ramp?*
2. *What kind of models are used in simulation software to describe merging behaviour?*
3. *What is the merging behaviour on a freeway on-ramp according empirical data?*
4. *How performs a simulation tool in comparison with empirical data?*
5. *What is the gap choice behaviour according empirical data?*
6. *What is a significant discrete choice model to model the gap choice behaviour?*
7. *What is the validity of the discrete choice model?*

8.2 FINDINGS

Throughout the report, findings are made based on the sub research questions mentioned in the previous section. In this section the main findings throughout the report are summarized.

In literature about merging behaviour it is clear drivers have a different merging behaviour in different circumstances. The traffic states, geometric design, and weather all influence merging behaviour. During congestion, a driver is willing to overtake several vehicles on the adjacent lane before he merges. The presence of a truck in the adjacent lane also has an influence of merging behaviour. A driver wants to overtake a truck before they merge into the adjacent lane. The length of the acceleration lane has an influence on the merge location. With a short acceleration lane, half of a regular acceleration lane, a driver will merge about 50 meters earlier when compared with the merge location in a normal acceleration lane. If the acceleration lane is extended with 150m, drivers will merge about 43 meters later. During bad weather, like fog, drivers are merging with a different speed. In all cases the driver who wants to merge on the adjacent lane is not coming to a total standstill and always merges before the acceleration lane ends. The distribution of merge location in free flow is 53% in the begin of the lane, 33% in the middle of the lane, and 15% in the end of the lane. During congestion this distribution is 38% in the beginning of the lane, 32% at the middle of the lane, and 30% at the end of the acceleration lane.
The second part of the literature research about existing models, shows that most of the theoretical models are a development of Gipps (1986) model. This model is based on gap acceptance. In it, only one gap at a time is examined. The driver will change lane if the gap is large enough. Loot (2009) stated that this does not correspond with the actual merging behaviour. There are some newly developed models, but these are not used in simulation tools. The researched simulation tools (Aimsun, Corsim, Paramics, FOSIM, VISSIM) in this research all use a gap acceptance model for simulating merging behaviour. They only differ in how they approach the determining of the critical gap.

In the second part of this research an empirical data analysis is performed. From this analysis it was clear that the average speed of the shoulder lane and acceleration lane are comparable. The average speed between the middle lane and median lane are related as well. Furthermore the average speed during a merge movement is relatively low for passenger cars during free flow, an average of 88 km/h, with a speed limit of 120 km/h. From the analysis of acceleration and deceleration on the acceleration lane, it was clear that passenger cars do not accelerate or decelerate a lot, while trucks are accelerating, during the first 25 meters of the acceleration lane, to the corresponding speed of the adjacent lane before they have the desired merging speed. From gap analysis, it was clear that the presence of a truck on the adjacent lane relates to the merge location of a passenger car. Most drivers overtake the truck and merge at the last part of the acceleration lane onto the adjacent lane, 77% from 250m till 300m during free flow. During congestion, drivers are also willing to overtake other passenger cars.

From empirical analysis about gap choice behaviour it is clear that the choice for a gap is different for different traffic states and different vehicle types. During congestion, gaps further ahead from the merging vehicle are chosen more often and the gaps behind the merging car are chosen less often in comparison with free flow. In case of vehicle types, a truck has a smaller choice set in comparison with passenger cars.

A micro traffic simulation tool study is performed with the program FOSIM. In this study the simulation results and the empirical dataset are compared. It is clear that the results are not comparable. During congestion there is no observable interaction between the lanes according to the average speed. The average speed of the median lane is 102km/h, while the other lanes have an

average speed of 46km/h or lower. The merge locations of drivers are not comparable, e.g. in the simulation results during free flow 80% of the flow that entered the acceleration lane is already merged in the first 50 meters, while from empirical analysis 25% of the flow that entered the acceleration lane has merged in the first 50 meters. In the simulation runs, merging vehicles are coming to a total standstill. This is not the case in the empirical analysis.

With the input of the gap choice analysis, three discrete choice models are estimated: a model for trucks, passenger cars in free flow, and passenger cars during congestion. For trucks, there were too few observations to split the dataset in drivers driving in free flow and congestion. Therefore, only one choice model for trucks has been estimated. In all three models the parameters of gap size in seconds and the distance towards the gap are present. For passenger cars during congestion the vehicle type of the putative leader is also included in the model. For passenger cars in free flow the vehicle type of both putative follower and putative leader are present in the model.

The face validation of the three discrete choice models is performed on the model in general and per individual driver. From this validation it is clear that the models perform well in general, but per individual driver, the discrete choice models are not accurate.

8.3 Conclusions

With the main findings of this research summarized in the previous section, the conclusions of this research are underpinned.

From the findings it can be concluded that gap acceptance models do not simulate merging behaviour accurately. In these kinds of models only one gap at the time is evaluated. If the gap is larger than the critical gap, the merge will take place. Concluded from the findings, however, a driver who wants to merge is making a choice from a set of offered gaps. This choice depends on several factors, like vehicle type of putative leader and traffic state.
Furthermore, the behaviour on the merging lane between empirical analysis and the results of a microscopic traffic simulation tool using a gap acceptance model is not comparable. It can be concluded that the driving behaviour on the acceleration lane is not accurate: where in the model the drivers are slowing down and even come to a standstill on the acceleration lane, the exact opposite behaviour occurs in field observations. There, a driver has a speed comparable with the speed on the adjacent lane, is always able to merge, and does not come to a standstill at the end of the acceleration lane.
The use of the acceleration lane is not the same when a gap acceptance model is chosen. From the findings, it can be concluded that a driver chooses a gap further ahead and sometimes even two gaps further ahead. This mostly happens during congestion, but also during free flow. If this behaviour will be included in a model, the acceleration lane will automatically be used more and a driver will make a merge further on the acceleration lane, because the gap is further away.

This choice is modelled with a discrete choice model based on a multinomial logit. Because it is clear from the findings a different choice behaviour occurs for different traffic states and vehicles types, three choice models are estimated. A model for trucks, passenger cars during free flow and passenger cars during congestion. It can be concluded that the three models have characteristics corresponding actual observed merging behaviour. From the findings, it was clear a passenger car in free flow wants to merge in front of a HGV. This is reflected in the models with the parameter 'vehicle type of putative follower'. It was clear that during congestion driver wants to overtake both passenger cars and HGV's. Therefore, this parameter is not present in the model for passenger cars during congestion. It is clear that a driver does not want to merge behind a HGV. This parameter is present in both models for passenger cars.

From the validation it can be concluded that the three discrete choice models are generally accurate in order to model the same gap choice distribution as observed in the empirical dataset. From the individual validation it can be concluded that the model is not accurate. So the discrete choice model simulates the representative gap choice distribution, but per driver, the predicted gap and the actually observed gap are not the same. Therefore, the model will give a better results of the usage of the acceleration lane. More gaps further away than the gap closest to the driver will be chosen. To merge into this gap a driver needs to stay on the acceleration lane for a longer time and will merge later. This does not depend on individual car's behaviour and therefore it is concluded that the discrete choice models can be implemented in merging models. So the model can be used for simulation if the simulation results used for analysing do not depend on the behaviour of each individual driver. For analysis of individual driver behaviour it is still not accurate, but it is an improvement in comparison with a gap acceptance model.

8.4 Recommendations

Using the conclusions of the previous section, recommendations for further research are given. Recommendations are given for merging behaviour, modelling merging behaviour and for the micro simulation tool FOSIM.

Merging behaviour

To make the discrete choice models more generally applicable, it is recommended to collect additional datasets in different conditions. These conditions are an on-ramp with a positive slope, an on-ramp with an acceleration lane that is shorter than a normal acceleration lane, and an on-ramp with an acceleration lane that is extended in comparison with a normal acceleration lane. It has been found that merging behaviour does not only depend on the gap size. There are also other characteristics that influences the merging behaviour, like vehicle type of the putative leader of a gap. It is recommended not to ignore these characteristics for modelling merging behaviour.

Modelling merging behaviour – Discrete choice model

As gap acceptance models are found not to be accurate for simulating merging behaviour, it is recommended to use the discrete choice models presented in this research. However, attention should be given to the fact that the behaviour of merging can be different for other geometric designs of freeway on-ramps. The discrete choice models presented in this research are based on an on-ramp with a normal acceleration lane and a negative slope leading to the acceleration lane. Because it has been found that different merging behaviour occurs for different vehicle types and traffic states, it is recommended to use the three discrete choice model for the corresponding conditions as presented in this research. These three models simulate accurately the gap choice distribution for a simulation run when the results do not depend on individual driver behaviour.

Micro traffic simulation – FOSIM

It is recommenced to use the discrete choice models presented in this research to simulate the merging behaviour. There is a big difference in the usage of the acceleration lane in the simulation results when compared to the empirical dataset. From the FOSIM study is was also clear that the interaction between lanes was not accurate. It is recommended to change this. The interaction between lanes plays a part in merging behaviour. When there is no interaction, no cooperative lane changes are made. These lanes changes gives more opportunities to merge. In FOSIM, the driver on the merging lane came to a standstill. But from literature review and empirical analysis it has been found that these drivers are not coming to a standstill at the end of the acceleration lane. It is recommended to change this philosophy. A merging vehicle will always merge into the adjacent lane before the end of the acceleration lane. Therefore, the congestion will occur on the shoulder lane and not on the acceleration lane.

8.5 FUTURE RESEARCH

The last part of this chapter concerns future research. From the findings, conclusions and recommendations, future research on this topic is recommended. The future research topics are split up in merge behaviour, micro simulation tool FOSIM, and the choice model.

Merging behaviour

- This research is performed with one empirical dataset from a specific on-ramp. If some characteristics change, the merging behaviour can also change. Therefore, more detailed research can be done on merging behaviour with difference in geometric design. Research can be done on an extended acceleration lane, a shorter acceleration lane, and an acceleration lane where the road leading to this lane has a positive slope. With these research topics, the influence of the geometric design of the on-ramp and acceleration lane will be clear.

Modelling merging behaviour

- Only a face validation is performed in this research. Future research can be done on the validation of the discrete choice model with an independent dataset.
- The estimation of the choice model is performed with a dataset of one on-ramp and a specific geometric design. The geometric design factors can be modelled in future research for implementation in a generic merging model.
- The choice model is only a part of merging behaviour. It only models the choice behaviour of a driver. To use it for micro simulation, future research can be done for implementing the choice model in a merging model.

Micro traffic simulation tool – FOSIM

- During this research, the merging behaviour of FOSIM is analysed. When performing the simulation runs some problems with FOSIM occur, like the flow distribution of the lanes near congestion and the large differences between average speed per lanes. More research can be performed to investigate these problems.
- Further research can be performed for implementing the choice models estimated in this research.

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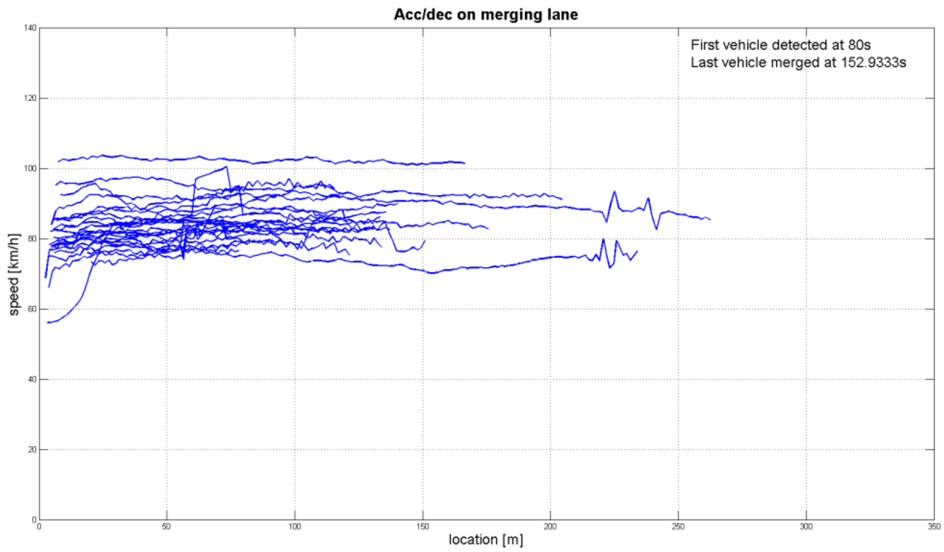
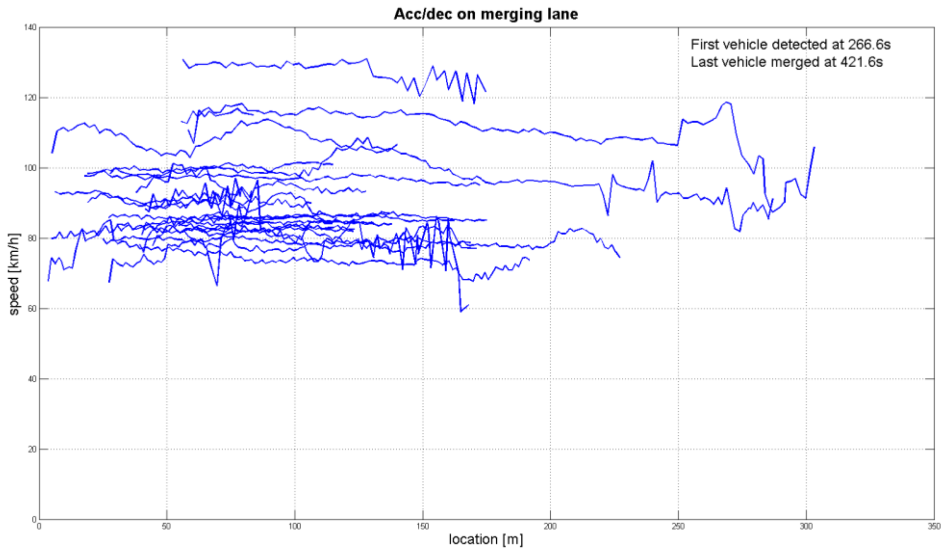
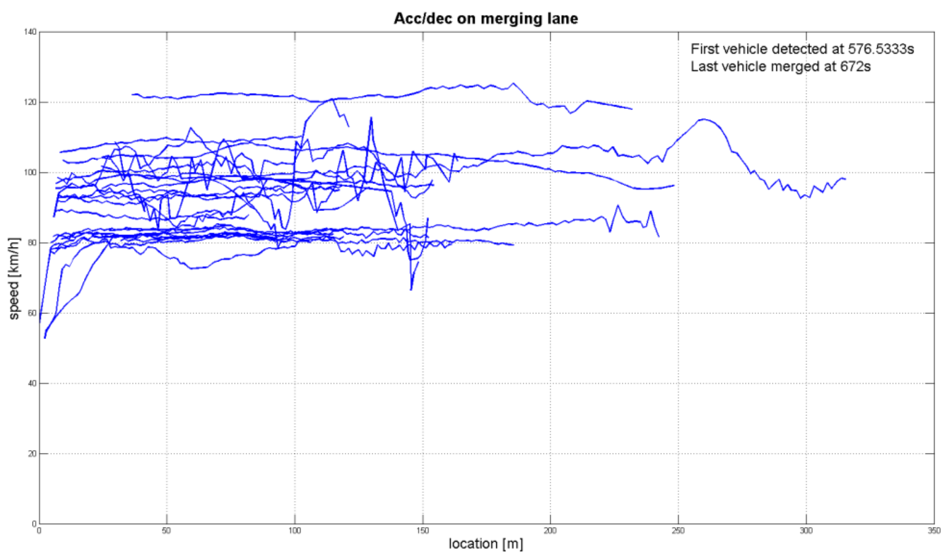
APPENDIX A

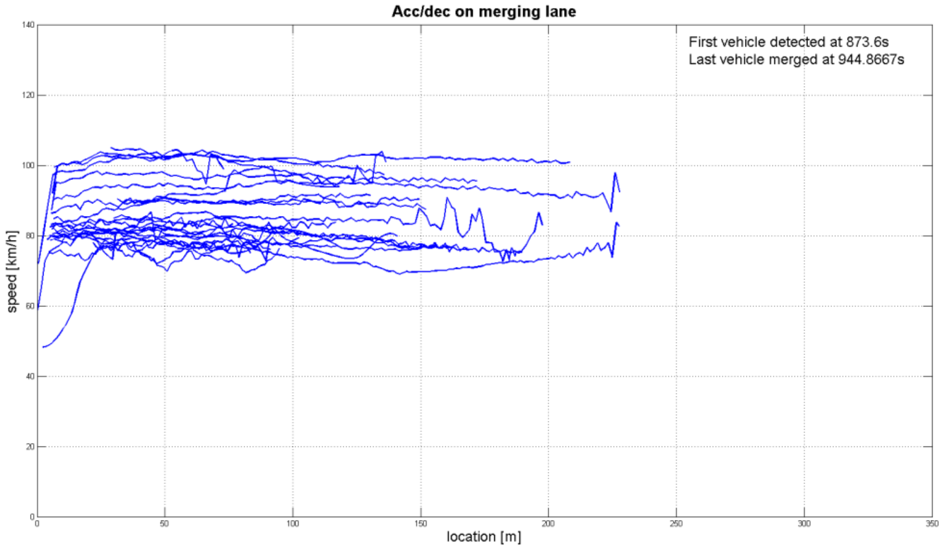
ACCELERATION AND DECELERATION GRAPHS

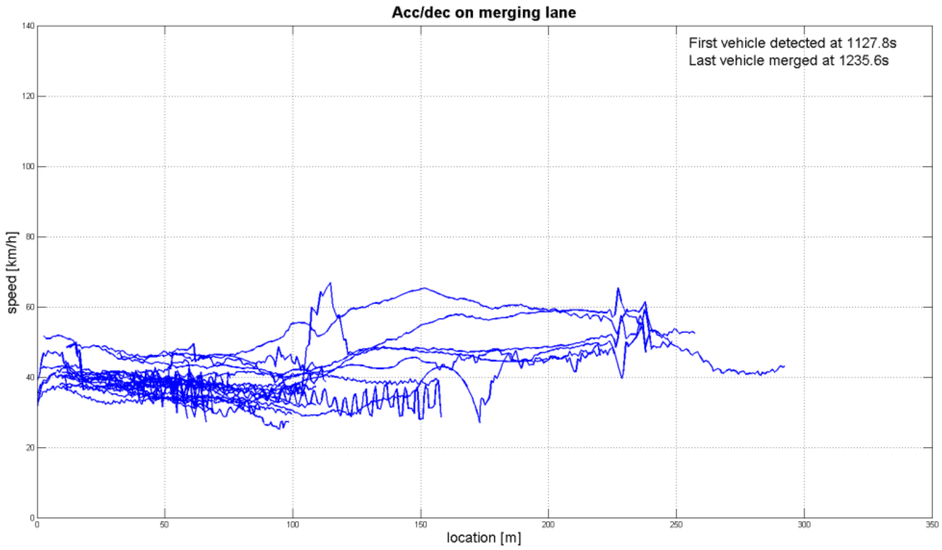
Nine acceleration and deceleration graphs of drivers driving on the acceleration lane. Per graph the speed in relation with the location on the acceleration lane is plotted in a set of 25 vehicles. For every graph the time when the first vehicle is detected and the time when the last vehicle has merged is mentioned.

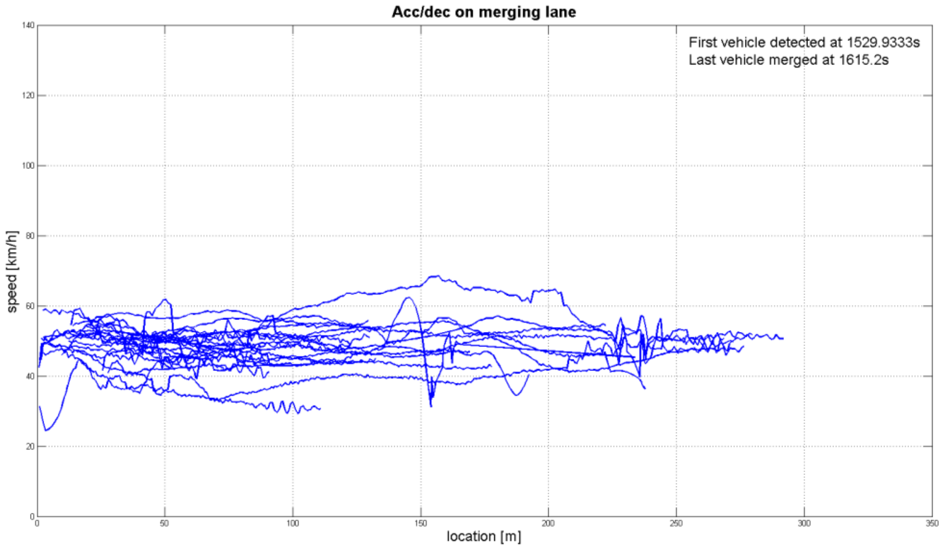

Acc/dec on merging lane
First vehicle detected at 80s
Last vehicle merged at 152.9333s
speed [km/h]
location [m]

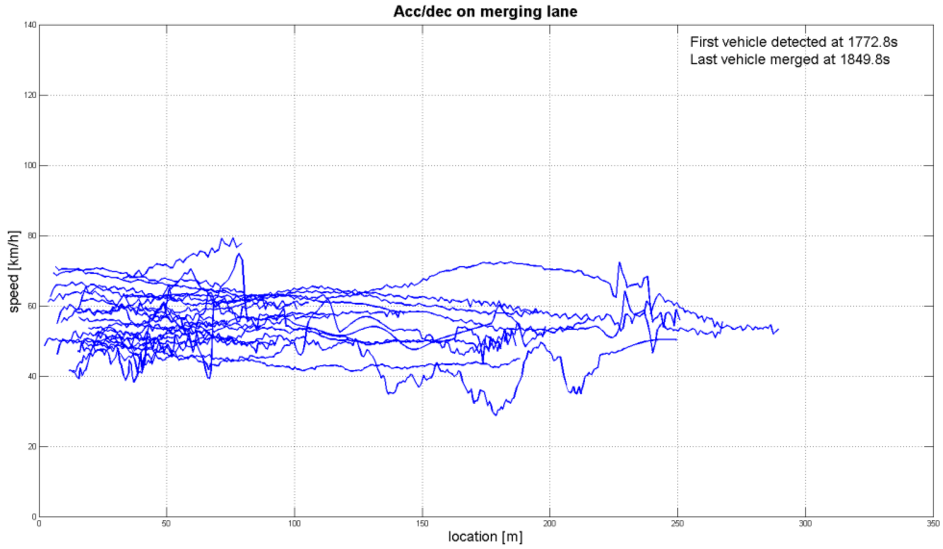

Acc/dec on merging lane
First vehicle detected at 266.6s
Last vehicle merged at 421.6s
speed [km/h]
location [m]

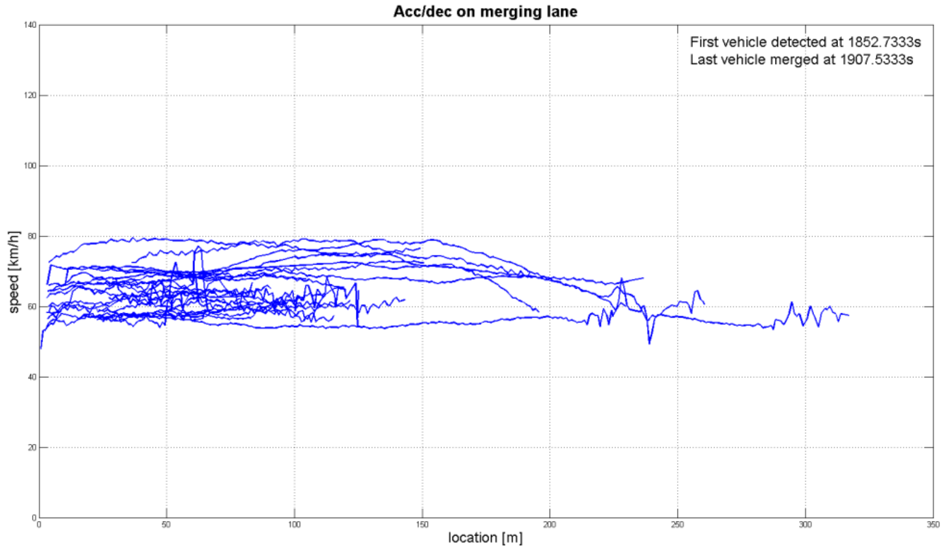

Acc/dec on merging lane
First vehicle detected at 576.5333s
Last vehicle merged at 672s
speed [km/h]
location [m]

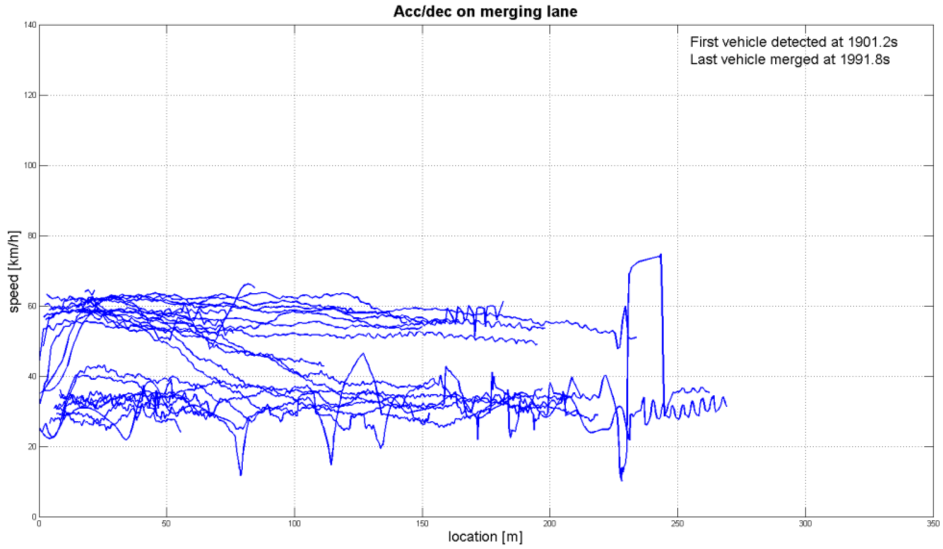

Acc/dec on merging lane
First vehicle detected at 873.6s
Last vehicle merged at 944.8667s
speed [km/h]
location [m]


Acc/dec on merging lane
First vehicle detected at 1127.8s
Last vehicle merged at 1235.6s
speed [km/h]
location [m]


Acc/dec on merging lane
First vehicle detected at 1529.9333s
Last vehicle merged at 1615.2s
speed [km/h]
location [m]


Acc/dec on merging lane
First vehicle detected at 1772.8s
Last vehicle merged at 1849.8s
speed [km/h]
location [m]


Acc/dec on merging lane
First vehicle detected at 1852.7333s
Last vehicle merged at 1907.5333s
speed [km/h]
location [m]

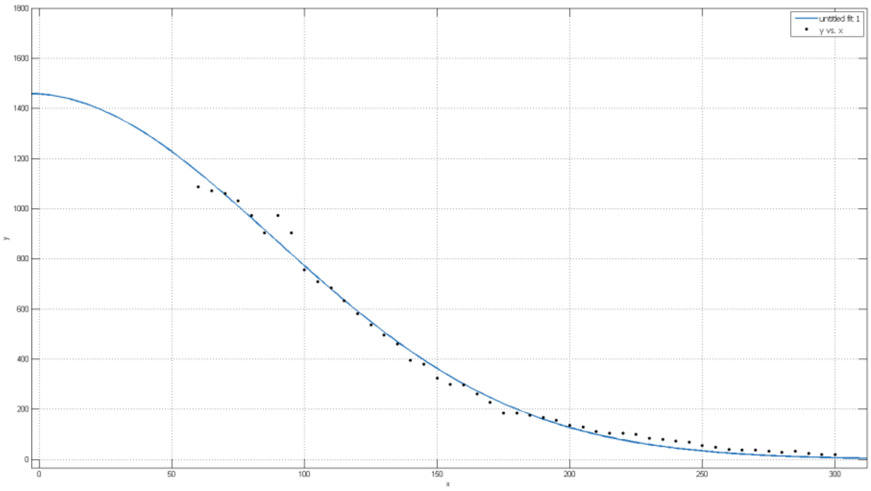

Acc/dec on merging lane
First vehicle detected at 1901.2s
Last vehicle merged at 1991.8s
speed [km/h]
location [m]

APPENDIX B

CURVE FITTING OF FLOW DISTRIBUTION ON THE ACCELERATION LANE

Graphs of the extrapolation using the curve fitting tool of Matlab of the flow distribution along the acceleration lane of the empirical dataset. The extrapolation is done on the flow during free flow traffic state and during congestion. Also the characteristics of the curve fitting are mentioned like the used fit type, standard error, rho-square, adjusted rho-square, etc.

Curve fitting of flow of the empirical dataset in free flow

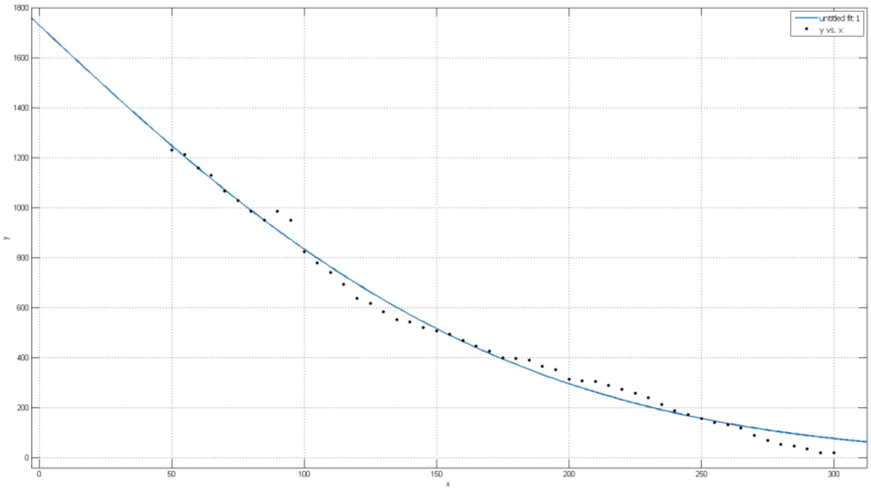


General model Gauss1:
f(x) = a1*exp(-((x-b1)/c1)^2)

Coefficients:
a1 = 1,459
b1 = -4.395
c1 = 130.8

Goodness of fit:
SSE: 39,410
R-square: 0.9934
Adjusted R-square: 0.9931
RMSE: 29.27

Curve fitting of flow of the empirical dataset in congestion

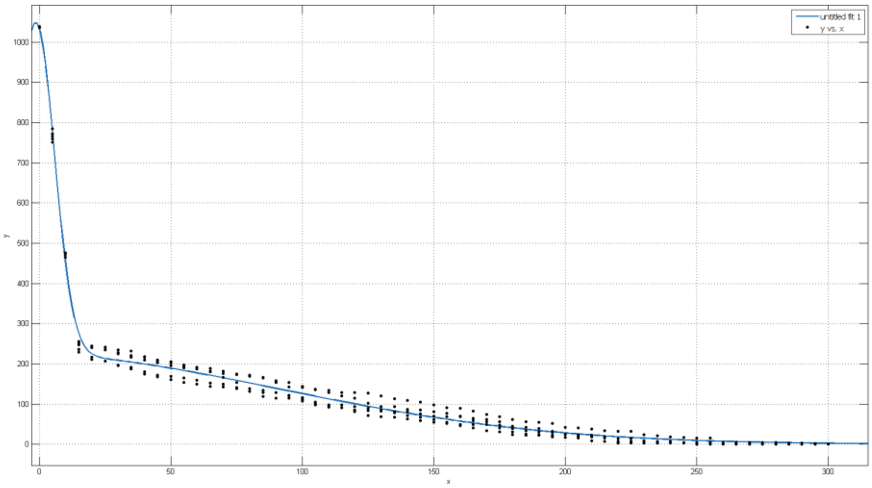


General model Gauss1:
f(x) = a1*exp(-((x-b1)/c1)^2)

Coefficients:
a1 = 2,972
b1 = -188.3
c1 = 255.8

Goodness of fit:
SSE: 58,350
R-square: 0.9908
Adjusted R-square: 0.9904
RMSE: 34.87

Curve fitting of flow of the FOSIM results in free flow



General model Gauss1:

f(x) = a1*exp(-((x-b1)/c1)^2)+a2*exp(-((x-b2)/c2)^2)

Coefficients:

a1 = 822.8 a2 = 288.2

b1 = -1.301 b2 = -14.44

c1 = 9.946 c2 = 148.4

Goodness of fit:

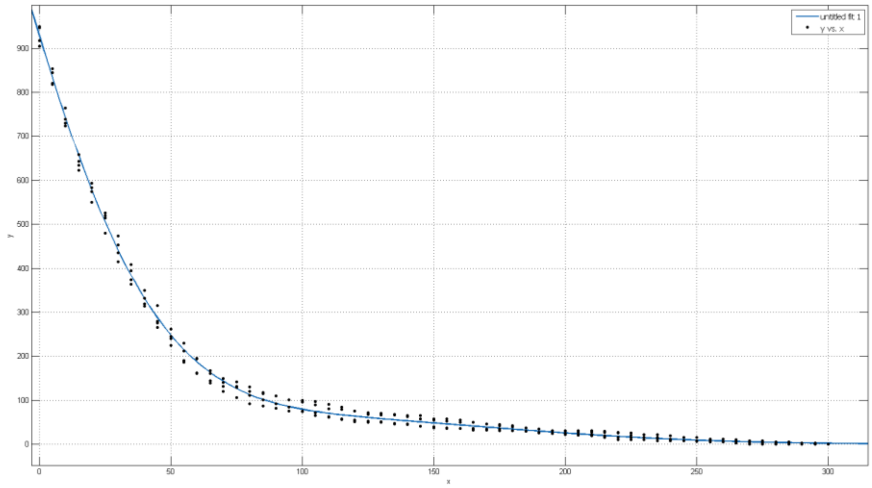
SSE: 63,630

R-square: 0.9929

Adjusted R-square: 0.9928

RMSE: 14.59

Curve fitting of flow of the FOSIM results in congestion



General model Gauss1:

f(x) = a1*exp(-((x-b1)/c1)^2)+a2*exp(-((x-b2)/c2)^2)

Coefficients:

a1 = 1,963 a2 = 60.55

b1 = -69.68 b2 = 94.15

c1 = 78.86 c2 = 114

Goodness of fit:

SSE: 36,270

R-square: 0.9974

Adjusted R-square: 0.9974

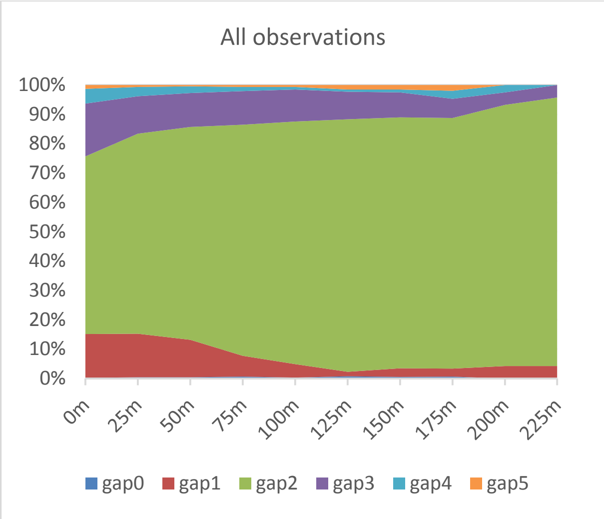
RMSE: 11.01

APPENDIX C

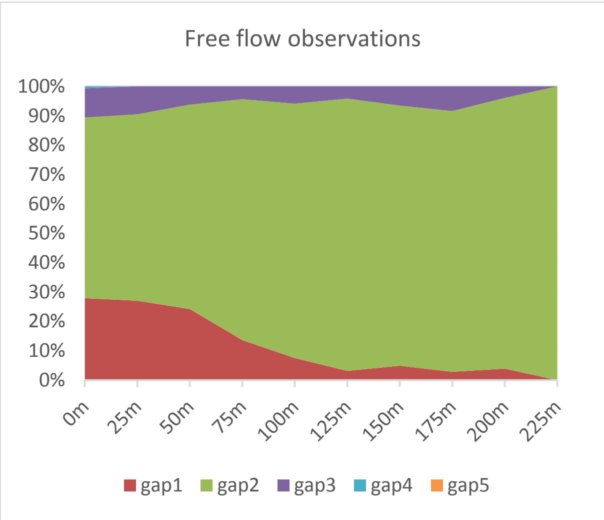
GRAPHS AND TABLES OF EMPIRICAL GAP CHOICE ANALYSIS

Graphs and the corresponding tables of the gap choice analysis with the empirical dataset. Frist the data about gap choice behaviour according to the location on the acceleration lane is showed. Secondly the data about gap choice behaviour in function of the time driving on the acceleration lane. Where at 0s the car is detected at the beginning of the acceleration lane. Lastly the data about gap choice behaviour in function of time before the merge manoeuvre happens. Where at 0s the vehicle merges into the adjacent lane.

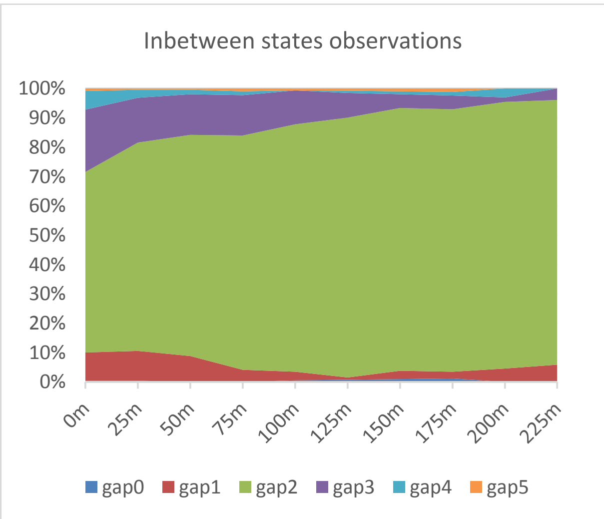
Data in function of the location driving on the acceleration lane



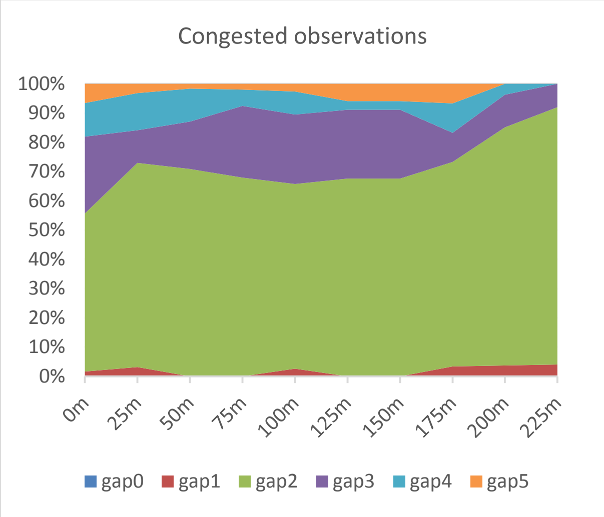
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0%	15%	61%	18%	5%	1%
25M	0%	15%	68%	13%	3%	1%
50M	0%	13%	73%	12%	2%	0%
75M	1%	7%	79%	11%	1%	1%
100M	0%	5%	83%	11%	1%	1%
125M	1%	1%	86%	9%	1%	1%
150M	1%	3%	86%	9%	1%	2%
175M	1%	3%	85%	7%	3%	2%
200M	0%	4%	89%	4%	3%	0%
225M	0%	4%	92%	4%	0%	0%



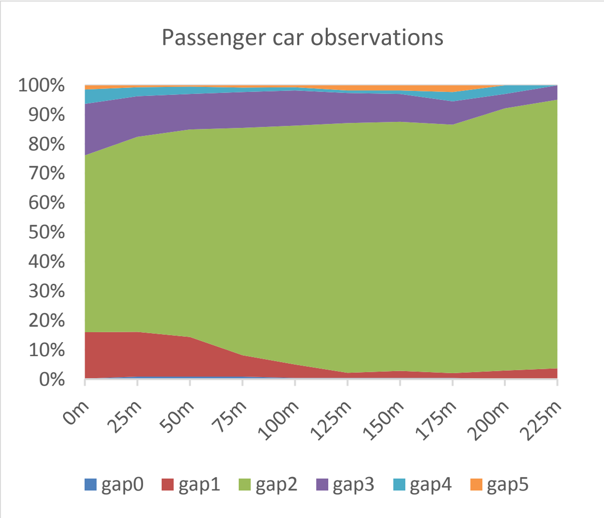
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0%	28%	61%	10%	1%	0%
25M	1%	27%	63%	9%	0%	0%
50M	1%	24%	69%	6%	0%	0%
75M	2%	13%	81%	4%	0%	0%
100M	0%	8%	87%	6%	0%	0%
125M	1%	3%	92%	4%	0%	0%
150M	0%	5%	89%	7%	0%	0%
175M	0%	3%	89%	8%	0%	0%
200M	0%	4%	92%	4%	0%	0%
225M	0%	0%	100%	0%	0%	0%



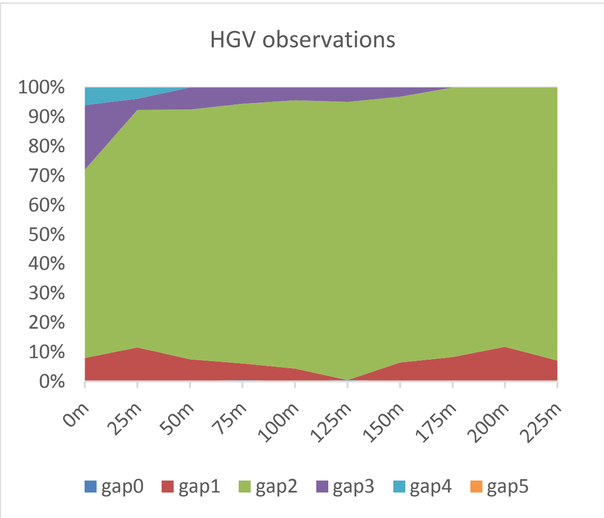
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0%	10%	62%	21%	6%	1%
25M	0%	10%	71%	15%	3%	0%
50M	0%	9%	75%	14%	2%	0%
75M	0%	4%	80%	14%	1%	1%
100M	1%	3%	84%	12%	0%	1%
125M	1%	1%	89%	8%	1%	1%
150M	1%	3%	90%	5%	1%	1%
175M	1%	2%	89%	5%	1%	1%
200M	0%	5%	91%	2%	3%	0%
225M	0%	6%	90%	4%	0%	0%



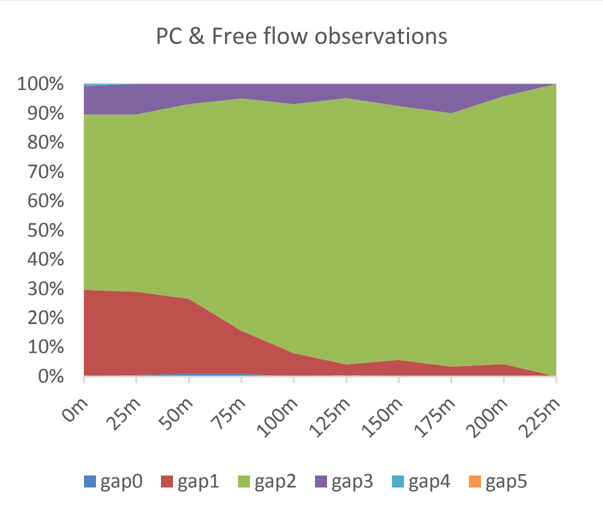
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0%	2%	54%	26%	11%	7%
25M	0%	3%	70%	11%	13%	3%
50M	0%	0%	71%	16%	11%	2%
75M	0%	0%	68%	25%	6%	2%
100M	0%	3%	63%	24%	8%	3%
125M	0%	0%	68%	24%	3%	6%
150M	0%	0%	68%	24%	3%	6%
175M	0%	3%	70%	10%	10%	7%
200M	0%	4%	81%	11%	4%	0%
225M	0%	4%	88%	8%	0%	0%



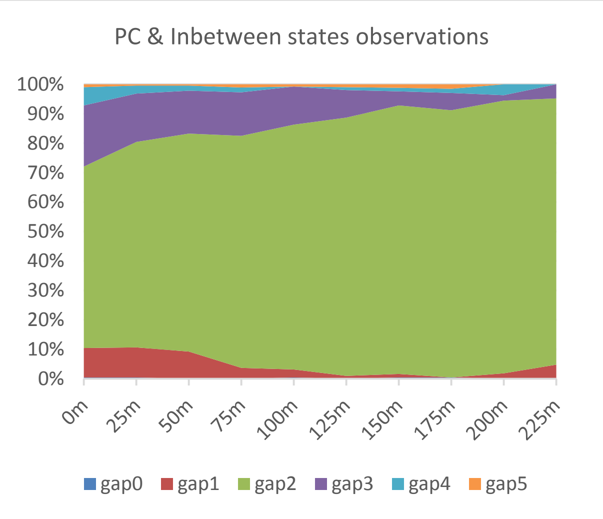
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.2%	15.8%	60.1%	17.5%	4.9%	1.5%
25M	0.9%	15.3%	66.7%	13.8%	3.1%	0.7%
50M	0.9%	13.5%	71.0%	12.1%	2.6%	0.5%
75M	0.9%	7.3%	77.5%	12.3%	1.6%	0.8%
100M	0.5%	4.6%	81.3%	12.0%	1.1%	0.7%
125M	0.5%	1.8%	85.0%	10.2%	0.9%	1.8%
150M	0.5%	2.4%	84.6%	9.5%	1.2%	1.8%
175M	0.5%	1.6%	84.3%	7.9%	3.1%	2.4%
200M	0.0%	2.9%	89.2%	4.9%	2.9%	0.0%
225M	0.0%	3.7%	91.4%	4.9%	0.0%	0.0%



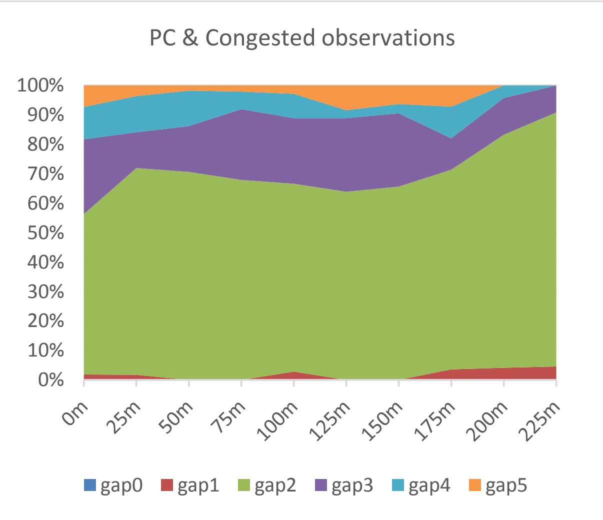
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.0%	8.0%	64.0%	22.0%	6.0%	0.0%
25M	0.0%	11.5%	80.8%	3.8%	3.8%	0.0%
50M	0.0%	7.5%	84.9%	7.5%	0.0%	0.0%
75M	0.5%	5.6%	87.0%	5.6%	0.0%	0.0%
100M	0.0%	4.3%	91.3%	4.3%	0.0%	0.0%
125M	0.5%	0.0%	92.7%	4.9%	0.0%	0.0%
150M	0.0%	6.5%	90.3%	3.2%	0.0%	0.0%
175M	0.0%	8.3%	91.7%	0.0%	0.0%	0.0%
200M	0.0%	11.8%	88.2%	0.0%	0.0%	0.0%
225M	0.0%	7.1%	92.9%	0.0%	0.0%	0.0%



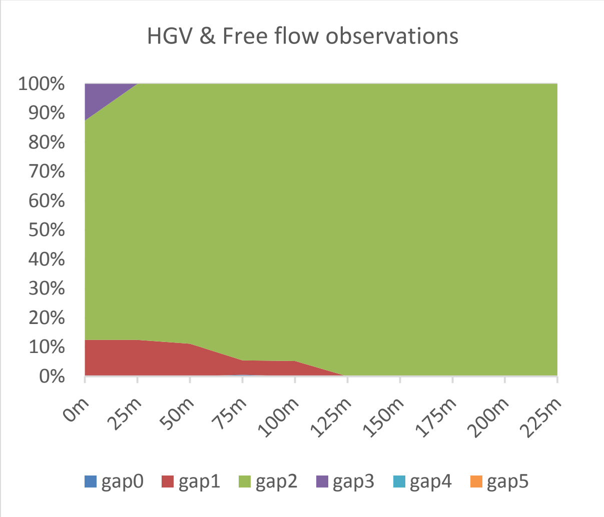
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.0%	29.7%	60.0%	9.7%	0.7%	0.0%
25M	0.5%	28.5%	60.4%	10.4%	0.0%	0.0%
50M	0.9%	25.5%	66.2%	6.9%	0.0%	0.0%
75M	0.9%	14.6%	79.2%	4.9%	0.0%	0.0%
100M	0.0%	7.9%	85.1%	6.9%	0.0%	0.0%
125M	0.5%	3.6%	90.5%	4.8%	0.0%	0.0%
150M	0.0%	5.7%	86.8%	7.5%	0.0%	0.0%
175M	0.0%	3.3%	86.7%	10.0%	0.0%	0.0%
200M	0.0%	4.2%	91.7%	4.2%	0.0%	0.0%
225M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%



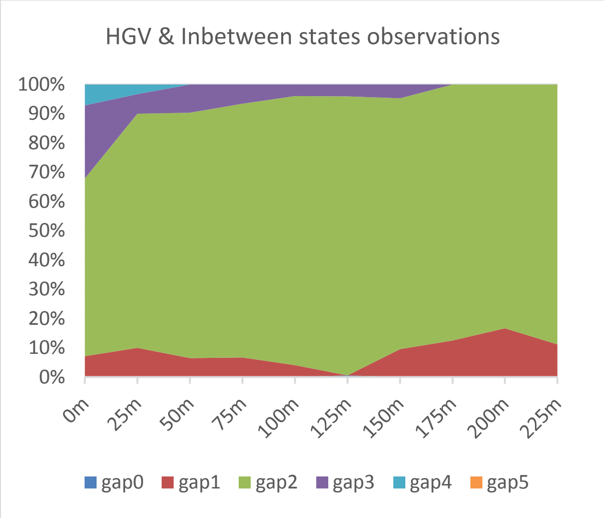
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.5%	10.0%	61.6%	20.9%	6.2%	0.9%
25M	0.5%	10.2%	69.8%	16.4%	2.7%	0.4%
50M	0.0%	9.2%	74.1%	14.5%	1.8%	0.4%
75M	0.0%	3.7%	78.8%	14.8%	1.6%	1.1%
100M	0.5%	2.7%	83.0%	12.9%	0.0%	0.7%
125M	0.0%	0.9%	87.7%	9.4%	0.9%	0.9%
150M	0.5%	1.2%	90.5%	4.8%	1.2%	1.2%
175M	0.5%	0.0%	89.9%	5.8%	1.4%	1.4%
200M	0.0%	1.9%	92.6%	1.9%	3.7%	0.0%
225M	0.0%	4.8%	90.5%	4.8%	0.0%	0.0%



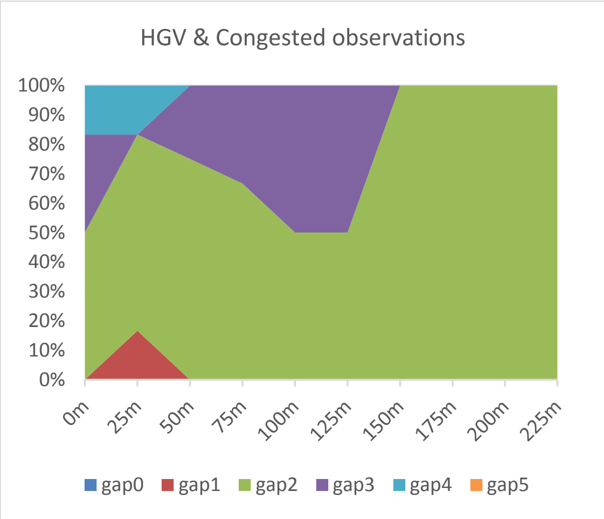
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.0%	1.8%	54.5%	25.5%	10.9%	7.3%
25M	0.0%	1.8%	70.2%	12.3%	12.3%	3.5%
50M	0.0%	0.0%	70.7%	15.5%	12.1%	1.7%
75M	0.0%	0.0%	68.0%	24.0%	6.0%	2.0%
100M	0.0%	2.8%	63.9%	22.2%	8.3%	2.8%
125M	0.0%	0.0%	63.9%	25.0%	2.8%	8.3%
150M	0.0%	0.0%	65.6%	25.0%	3.1%	6.3%
175M	0.0%	3.6%	67.9%	10.7%	10.7%	7.1%
200M	0.0%	4.2%	79.2%	12.5%	4.2%	0.0%
225M	0.0%	4.5%	86.4%	9.1%	0.0%	0.0%



	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.0%	12.5%	75.0%	12.5%	0.0%	0.0%
25M	0.0%	12.5%	87.5%	0.0%	0.0%	0.0%
50M	0.0%	11.1%	88.9%	0.0%	0.0%	0.0%
75M	0.5%	4.8%	90.5%	0.0%	0.0%	0.0%
100M	0.0%	5.3%	94.7%	0.0%	0.0%	0.0%
125M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
150M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
175M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
200M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
225M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

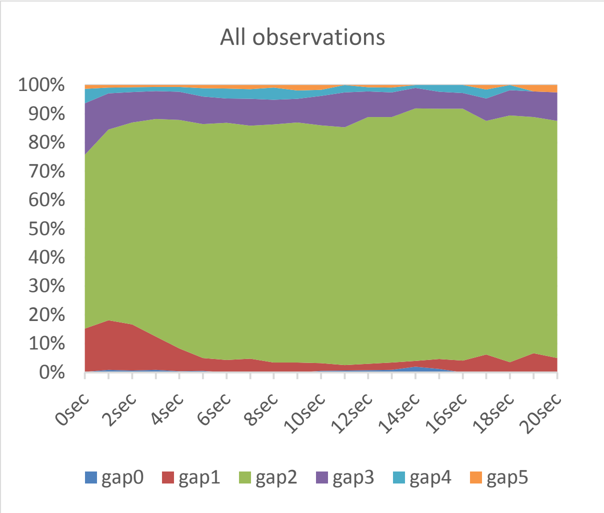


	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.0%	7.1%	60.7%	25.0%	7.1%	0.0%
25M	0.0%	10.0%	80.0%	6.7%	3.3%	0.0%
50M	0.0%	6.5%	83.9%	9.7%	0.0%	0.0%
75M	0.0%	6.7%	86.7%	6.7%	0.0%	0.0%
100M	0.0%	4.0%	92.0%	4.0%	0.0%	0.0%
125M	0.5%	0.0%	92.0%	4.0%	0.0%	0.0%
150M	0.0%	9.5%	85.7%	4.8%	0.0%	0.0%
175M	0.0%	12.5%	87.5%	0.0%	0.0%	0.0%
200M	0.0%	16.7%	83.3%	0.0%	0.0%	0.0%
225M	0.0%	11.1%	88.9%	0.0%	0.0%	0.0%

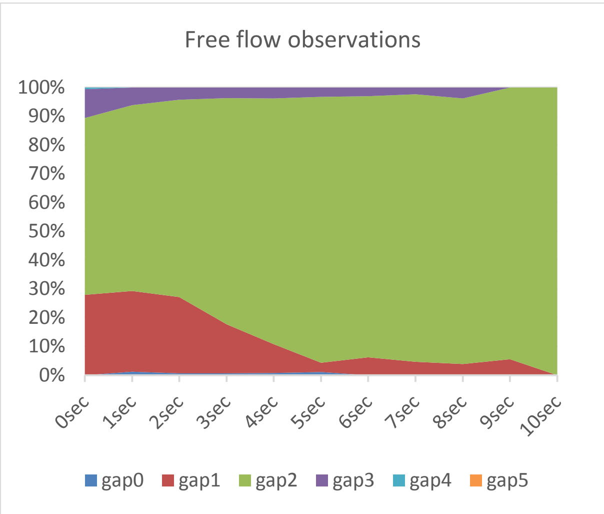


	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0M	0.0%	0.0%	50.0%	33.3%	16.7%	0.0%
25M	0.0%	16.7%	66.7%	0.0%	16.7%	0.0%
50M	0.0%	0.0%	75.0%	25.0%	0.0%	0.0%
75M	0.0%	0.0%	66.7%	33.3%	0.0%	0.0%
100M	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
125M	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
150M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
175M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
200M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
225M	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

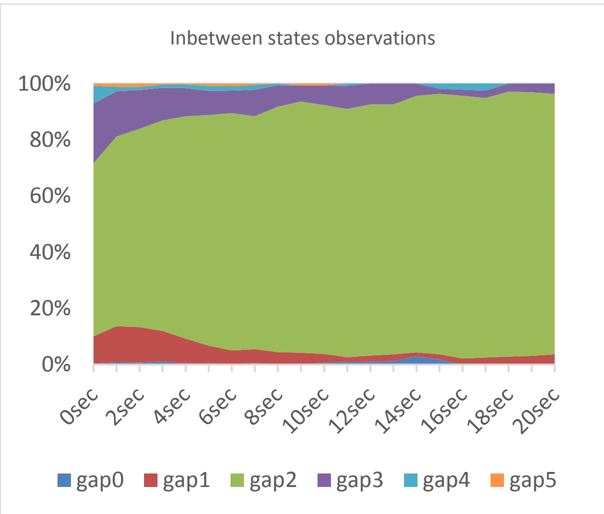
Data in function of the time driving on the acceleration lane



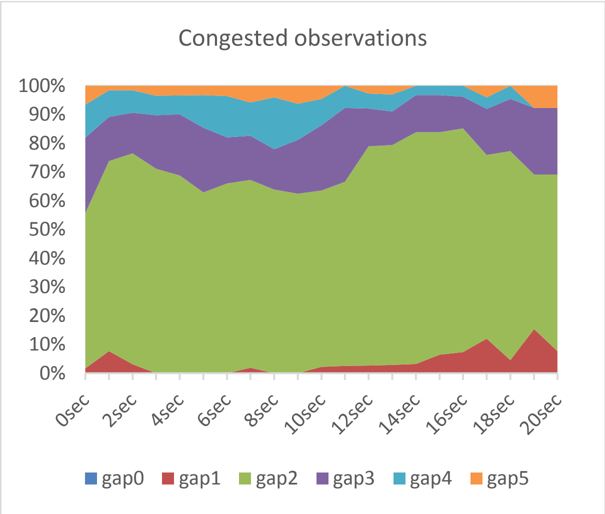
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	15%	61%	18%	5%	1%
2SEC	1%	16%	70%	11%	2%	1%
4SEC	0%	8%	80%	10%	2%	1%
6SEC	0%	4%	83%	8%	3%	1%
8SEC	0%	3%	83%	9%	4%	1%
10SEC	1%	3%	83%	10%	2%	2%
12SEC	1%	2%	86%	9%	1%	1%
14SEC	2%	2%	88%	7%	1%	0%
16SEC	0%	4%	88%	5%	3%	0%
18SEC	0%	4%	86%	9%	2%	0%
20SEC	0%	5%	83%	10%	0%	3%



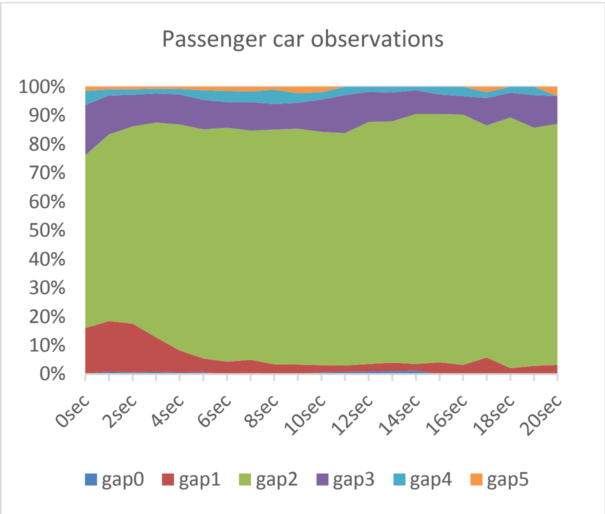
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	28%	61%	10%	1%	0%
1SEC	1%	28%	65%	6%	0%	0%
2SEC	1%	27%	69%	4%	0%	0%
3SEC	1%	17%	79%	4%	0%	0%
4SEC	1%	10%	85%	4%	0%	0%
5SEC	1%	3%	92%	3%	0%	0%
6SEC	0%	6%	91%	3%	0%	0%
7SEC	0%	5%	93%	2%	0%	0%
8SEC	0%	4%	92%	4%	0%	0%
9SEC	0%	6%	94%	0%	0%	0%
10SEC	0%	0%	100%	0%	0%	0%



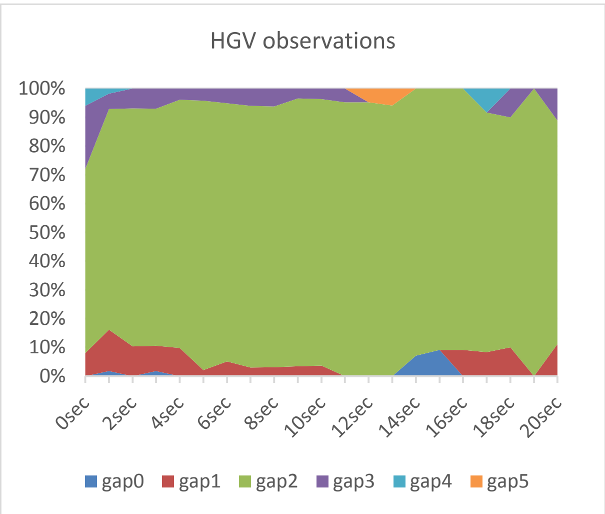
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	10%	62%	21%	6%	1%
2SEC	1%	13%	70%	14%	1%	1%
4SEC	0%	9%	79%	10%	1%	0%
6SEC	0%	5%	84%	8%	2%	1%
8SEC	0%	4%	87%	8%	1%	0%
10SEC	1%	3%	88%	7%	0%	1%
12SEC	1%	2%	89%	7%	0%	0%
14SEC	3%	1%	91%	4%	0%	0%
16SEC	0%	2%	93%	2%	2%	0%
18SEC	0%	3%	94%	3%	0%	0%
20SEC	0%	4%	93%	4%	0%	0%



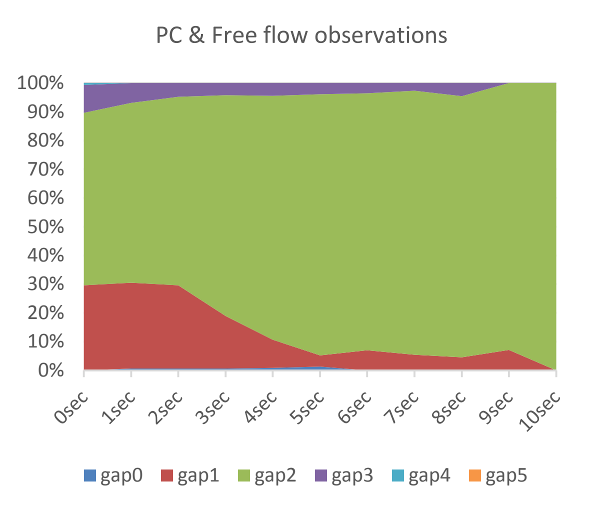
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	2%	54%	26%	11%	7%
2SEC	0%	3%	73%	14%	8%	2%
4SEC	0%	0%	69%	21%	7%	3%
6SEC	0%	0%	66%	16%	14%	4%
8SEC	0%	0%	64%	14%	18%	4%
10SEC	0%	2%	61%	23%	9%	5%
12SEC	0%	3%	76%	13%	5%	3%
14SEC	0%	3%	81%	13%	3%	0%
16SEC	0%	7%	78%	11%	4%	0%
18SEC	0%	5%	73%	18%	5%	0%
20SEC	0%	8%	62%	23%	0%	8%



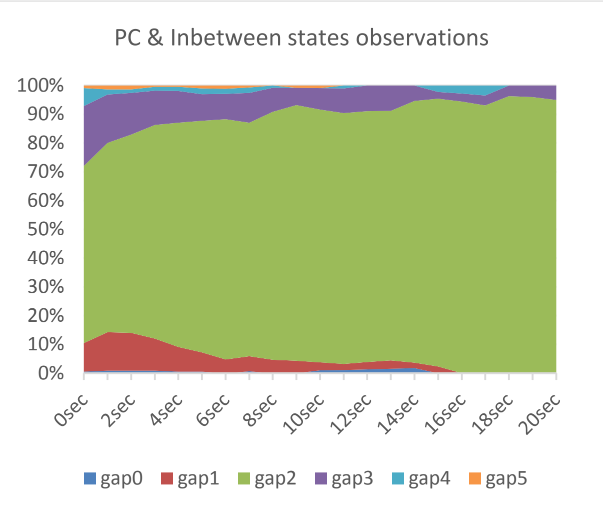
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	16%	60%	18%	5%	1%
2SEC	1%	17%	69%	11%	2%	1%
4SEC	1%	8%	79%	11%	2%	1%
6SEC	0%	4%	81%	9%	4%	1%
8SEC	0%	3%	82%	9%	5%	1%
10SEC	1%	3%	81%	11%	3%	2%
12SEC	1%	3%	84%	11%	2%	0%
14SEC	1%	2%	87%	8%	1%	0%
16SEC	0%	3%	87%	6%	3%	0%
18SEC	0%	2%	87%	9%	2%	0%
20SEC	0%	3%	84%	10%	0%	3%



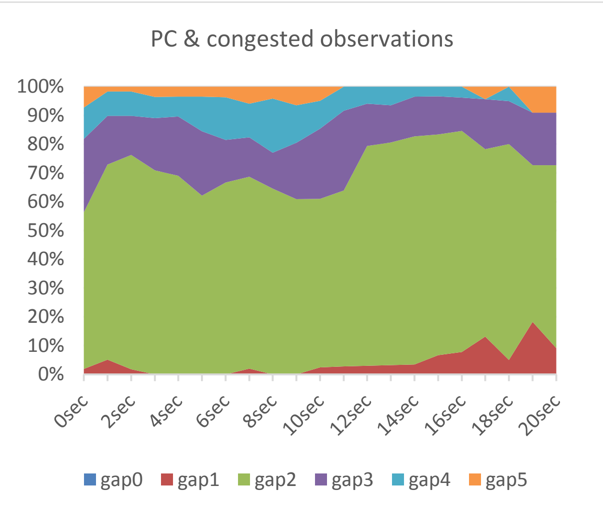
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	8%	64%	22%	6%	0%
2SEC	0%	10%	83%	7%	0%	0%
4SEC	0%	10%	86%	4%	0%	0%
6SEC	0%	5%	90%	5%	0%	0%
8SEC	0%	3%	91%	6%	0%	0%
10SEC	0%	4%	93%	4%	0%	0%
12SEC	0%	0%	95%	0%	0%	5%
14SEC	7%	0%	93%	0%	0%	0%
16SEC	0%	9%	91%	0%	0%	0%
18SEC	0%	10%	80%	10%	0%	0%
20SEC	0%	11%	78%	11%	0%	0%



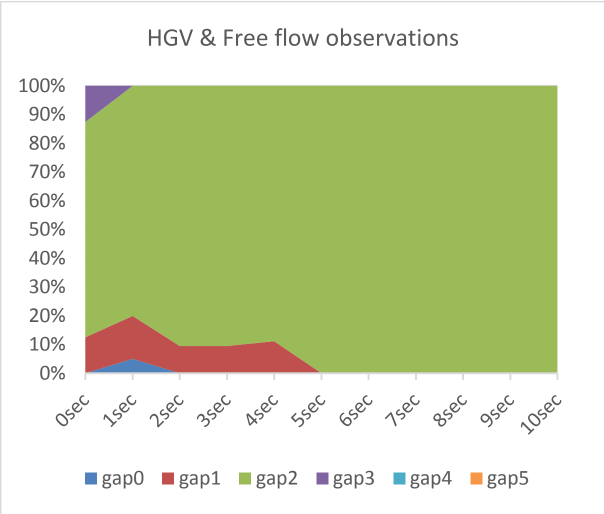
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	30%	60%	10%	1%	0%
1SEC	1%	30%	63%	7%	0%	0%
2SEC	1%	29%	66%	5%	0%	0%
3SEC	1%	18%	77%	4%	0%	0%
4SEC	1%	10%	85%	4%	0%	0%
5SEC	1%	4%	91%	4%	0%	0%
6SEC	0%	7%	89%	4%	0%	0%
7SEC	0%	5%	92%	3%	0%	0%
8SEC	0%	5%	91%	5%	0%	0%
9SEC	0%	7%	93%	0%	0%	0%
10SEC	0%	0%	100%	0%	0%	0%



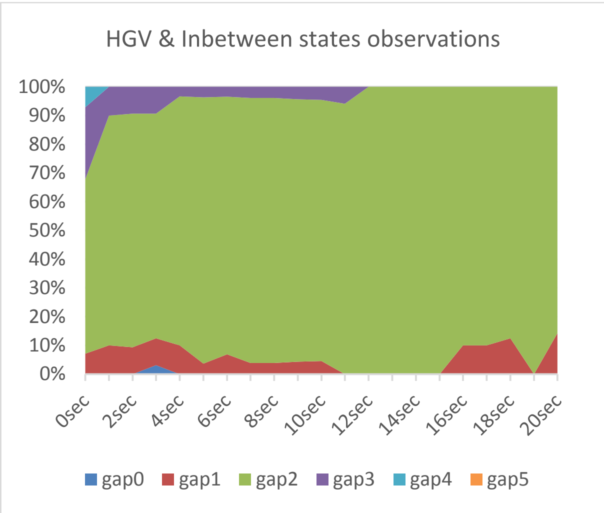
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	10%	62%	21%	6%	1%
2SEC	1%	13%	69%	14%	1%	1%
4SEC	0%	9%	78%	11%	1%	0%
6SEC	0%	5%	84%	9%	2%	1%
8SEC	0%	5%	86%	8%	1%	0%
10SEC	1%	3%	88%	7%	0%	1%
12SEC	1%	3%	87%	9%	0%	0%
14SEC	2%	2%	91%	5%	0%	0%
16SEC	0%	0%	94%	3%	3%	0%
18SEC	0%	0%	96%	4%	0%	0%
20SEC	0%	0%	95%	5%	0%	0%



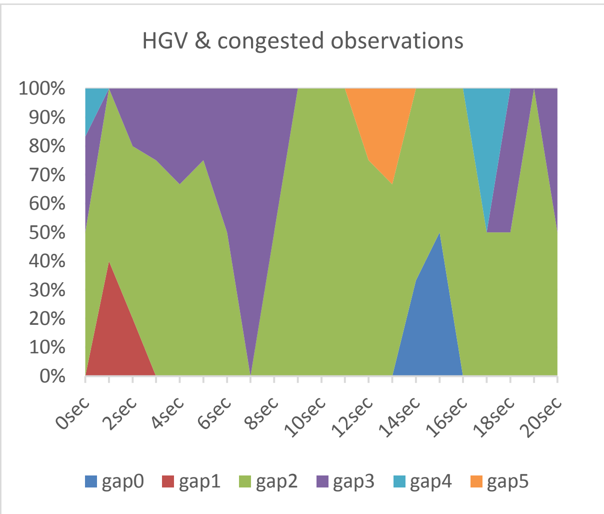
	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	2%	55%	25%	11%	7%
2SEC	0%	2%	75%	14%	8%	2%
4SEC	0%	0%	69%	21%	7%	3%
6SEC	0%	0%	67%	15%	15%	4%
8SEC	0%	0%	65%	13%	19%	4%
10SEC	0%	2%	59%	24%	10%	5%
12SEC	0%	3%	76%	15%	6%	0%
14SEC	0%	3%	79%	14%	3%	0%
16SEC	0%	8%	77%	12%	4%	0%
18SEC	0%	5%	75%	15%	5%	0%
20SEC	0%	9%	64%	18%	0%	9%



	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	13%	75%	13%	0%	0%
1SEC	5%	15%	80%	0%	0%	0%
2SEC	0%	10%	90%	0%	0%	0%
3SEC	0%	10%	90%	0%	0%	0%
4SEC	0%	11%	89%	0%	0%	0%
5SEC	0%	0%	100%	0%	0%	0%
6SEC	0%	0%	100%	0%	0%	0%
7SEC	0%	0%	100%	0%	0%	0%
8SEC	0%	0%	100%	0%	0%	0%
9SEC	0%	0%	100%	0%	0%	0%
10SEC	0%	0%	100%	0%	0%	0%

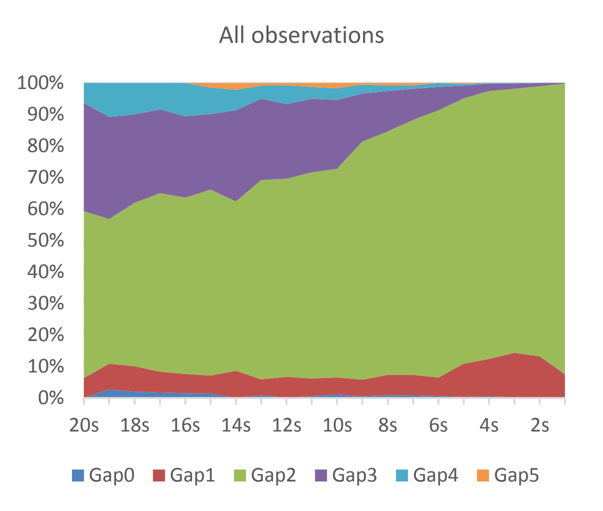


	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	7%	61%	25%	7%	0%
2SEC	0%	9%	81%	9%	0%	0%
4SEC	0%	10%	87%	3%	0%	0%
6SEC	0%	7%	90%	3%	0%	0%
8SEC	0%	4%	92%	4%	0%	0%
10SEC	0%	5%	91%	5%	0%	0%
12SEC	0%	0%	100%	0%	0%	0%
14SEC	0%	0%	100%	0%	0%	0%
16SEC	0%	10%	90%	0%	0%	0%
18SEC	0%	13%	88%	0%	0%	0%
20SEC	0%	14%	86%	0%	0%	0%

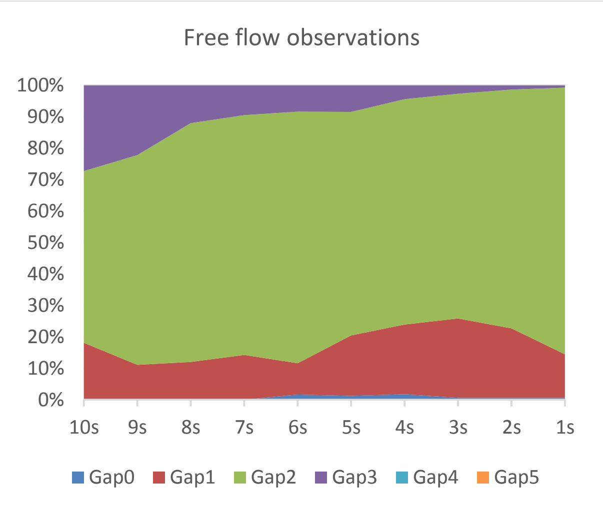


	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
0SEC	0%	0%	50%	33%	17%	0%
2SEC	0%	20%	60%	20%	0%	0%
4SEC	0%	0%	67%	33%	0%	0%
6SEC	0%	0%	50%	50%	0%	0%
8SEC	0%	0%	50%	50%	0%	0%
10SEC	0%	0%	100%	0%	0%	0%
12SEC	0%	0%	75%	0%	0%	25%
14SEC	33%	0%	67%	0%	0%	0%
16SEC	0%	0%	100%	0%	0%	0%
18SEC	0%	0%	50%	50%	0%	0%
20SEC	0%	0%	50%	50%	0%	0%

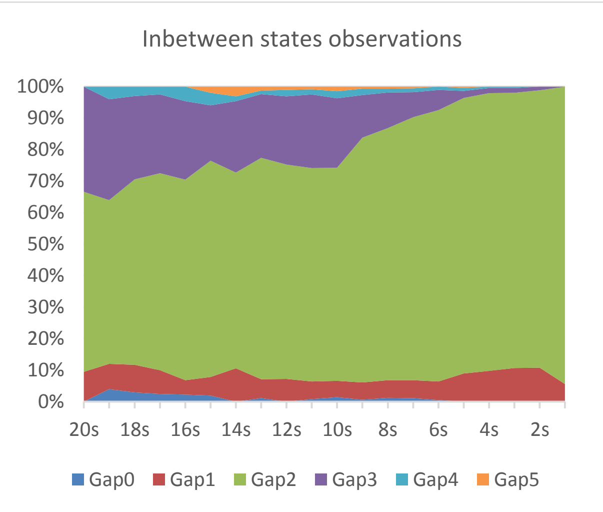
Data in function of time before the driver merges into the adjacent lane



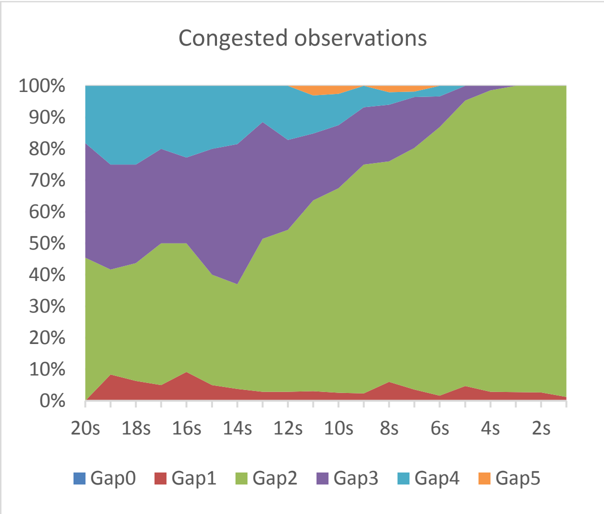
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	6.3%	53.1%	34.4%	6.3%	0.0%
18S	2.0%	8.0%	52.0%	28.0%	10.0%	0.0%
16S	1.5%	6.1%	56.1%	25.8%	10.6%	0.0%
14S	0.0%	8.6%	53.8%	29.0%	6.5%	2.2%
12S	0.0%	6.7%	63.0%	23.7%	5.9%	0.7%
10S	1.1%	5.3%	66.3%	21.9%	3.7%	1.6%
8S	0.9%	6.4%	77.4%	12.8%	1.7%	0.9%
6S	0.6%	5.9%	84.8%	7.4%	1.2%	0.0%
4S	0.5%	11.9%	85.0%	2.3%	0.2%	0.0%
2S	0.2%	13.0%	85.8%	1.0%	0.0%	0.0%



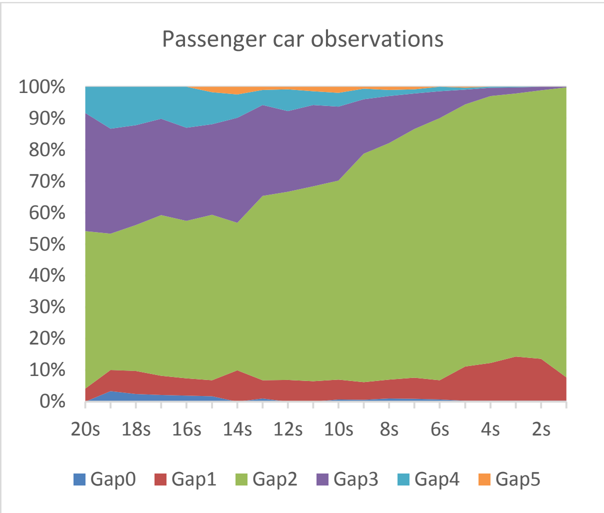
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
10S	0.0%	18.2%	54.5%	27.3%	0.0%	0.0%
9S	0.0%	11.1%	66.7%	22.2%	0.0%	0.0%
8S	0.0%	12.0%	76.0%	12.0%	0.0%	0.0%
7S	0.0%	14.3%	76.2%	9.5%	0.0%	0.0%
6S	1.7%	10.0%	80.0%	8.3%	0.0%	0.0%
5S	1.2%	19.3%	71.1%	8.4%	0.0%	0.0%
4S	1.8%	22.1%	71.7%	4.4%	0.0%	0.0%
3S	0.7%	25.2%	71.5%	2.6%	0.0%	0.0%
2S	0.7%	22.0%	76.0%	1.3%	0.0%	0.0%
1S	0.7%	13.8%	84.8%	0.7%	0.0%	0.0%



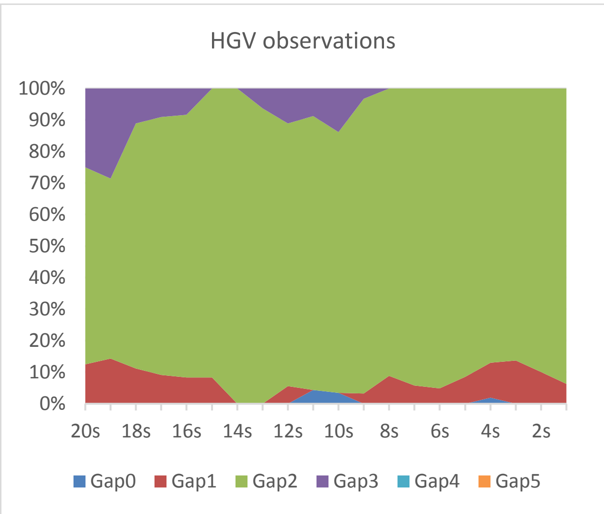
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	9.5%	57.1%	33.3%	0.0%	0.0%
18S	2.9%	8.8%	58.8%	26.5%	2.9%	0.0%
16S	2.3%	4.5%	63.6%	25.0%	4.5%	0.0%
14S	0.0%	10.6%	62.1%	22.7%	1.5%	3.0%
12S	0.0%	7.2%	68.0%	21.6%	2.1%	1.0%
10S	1.5%	5.1%	67.6%	22.1%	2.2%	1.5%
8S	1.3%	5.6%	80.0%	11.3%	1.3%	0.6%
6S	0.5%	5.9%	86.1%	6.4%	1.0%	0.0%
4S	0.0%	9.8%	88.2%	1.6%	0.4%	0.0%
2S	0.0%	10.8%	88.1%	1.2%	0.0%	0.0%



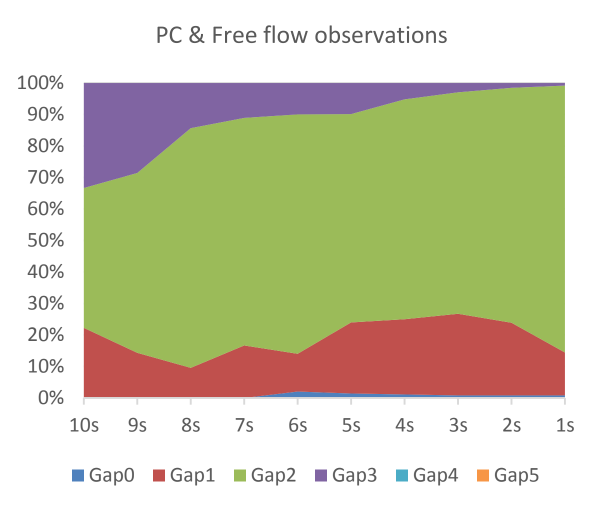
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	0.0%	45.5%	36.4%	18.2%	0.0%
18S	0.0%	6.3%	37.5%	31.3%	25.0%	0.0%
16S	0.0%	9.1%	40.9%	27.3%	22.7%	0.0%
14S	0.0%	3.7%	33.3%	44.4%	18.5%	0.0%
12S	0.0%	2.9%	51.4%	28.6%	17.1%	0.0%
10S	0.0%	2.5%	65.0%	20.0%	10.0%	2.5%
8S	0.0%	6.0%	70.0%	18.0%	4.0%	2.0%
6S	0.0%	1.6%	85.2%	9.8%	3.3%	0.0%
4S	0.0%	2.9%	95.7%	1.4%	0.0%	0.0%
2S	0.0%	2.7%	97.3%	0.0%	0.0%	0.0%



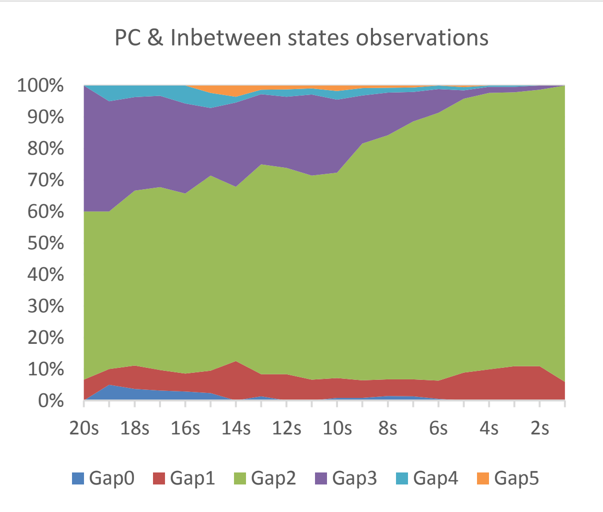
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	4.2%	50.0%	37.5%	8.3%	0.0%
18S	2.4%	7.3%	46.3%	31.7%	12.2%	0.0%
16S	1.9%	5.6%	50.0%	29.6%	13.0%	0.0%
14S	0.0%	9.9%	46.9%	33.3%	7.4%	2.5%
12S	0.0%	6.8%	59.8%	25.6%	6.8%	0.9%
10S	0.6%	6.3%	63.3%	23.4%	4.4%	1.9%
8S	1.0%	6.0%	75.1%	14.9%	2.0%	1.0%
6S	0.7%	6.0%	83.3%	8.5%	1.4%	0.0%
4S	0.3%	12.0%	84.8%	2.7%	0.3%	0.0%
2S	0.2%	13.3%	85.3%	1.1%	0.0%	0.0%



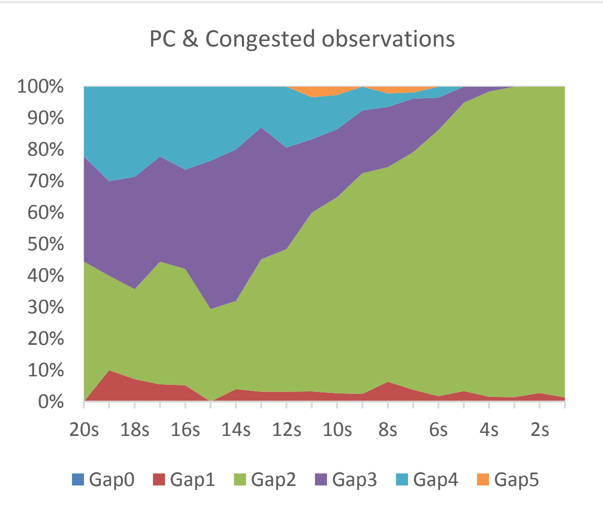
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	12.5%	62.5%	25.0%	0.0%	0.0%
18S	0.0%	11.1%	77.8%	11.1%	0.0%	0.0%
16S	0.0%	8.3%	83.3%	8.3%	0.0%	0.0%
14S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
12S	0.0%	5.6%	83.3%	11.1%	0.0%	0.0%
10S	3.4%	0.0%	82.8%	13.8%	0.0%	0.0%
8S	0.0%	8.8%	91.2%	0.0%	0.0%	0.0%
6S	0.0%	4.9%	95.1%	0.0%	0.0%	0.0%
4S	1.9%	11.1%	87.0%	0.0%	0.0%	0.0%
2S	0.0%	10.0%	90.0%	0.0%	0.0%	0.0%



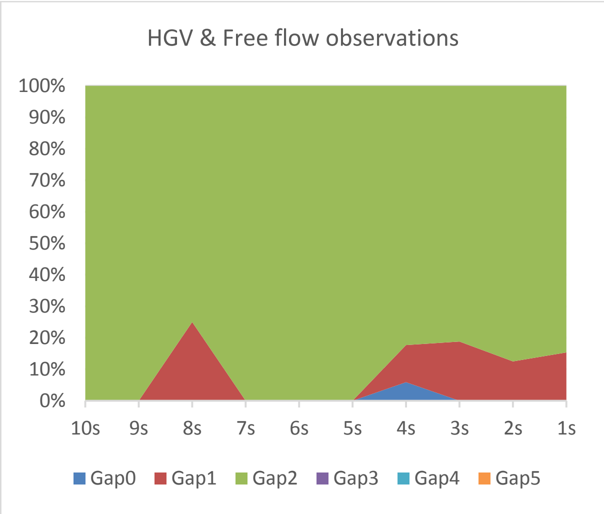
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
10S	0.0%	22.2%	44.4%	33.3%	0.0%	0.0%
9S	0.0%	14.3%	57.1%	28.6%	0.0%	0.0%
8S	0.0%	9.5%	76.2%	14.3%	0.0%	0.0%
7S	0.0%	16.7%	72.2%	11.1%	0.0%	0.0%
6S	2.0%	12.0%	76.0%	10.0%	0.0%	0.0%
5S	1.4%	22.5%	66.2%	9.9%	0.0%	0.0%
4S	1.0%	24.0%	69.8%	5.2%	0.0%	0.0%
3S	0.7%	25.9%	70.4%	3.0%	0.0%	0.0%
2S	0.7%	23.1%	74.6%	1.5%	0.0%	0.0%
1S	0.8%	13.6%	84.8%	0.8%	0.0%	0.0%



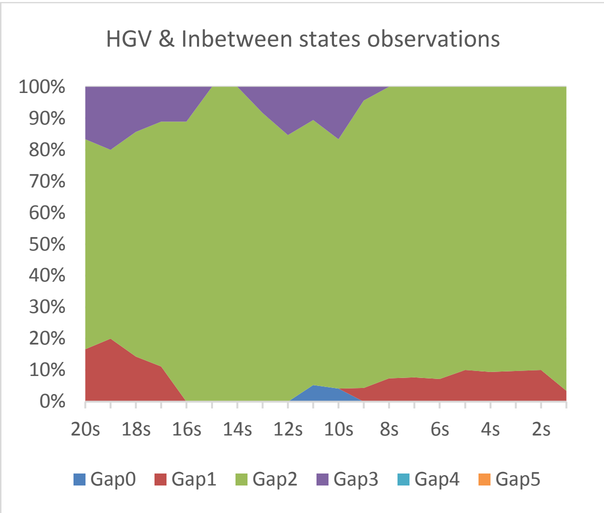
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	6.7%	53.3%	40.0%	0.0%	0.0%
18S	3.7%	7.4%	55.6%	29.6%	3.7%	0.0%
16S	2.9%	5.7%	57.1%	28.6%	5.7%	0.0%
14S	0.0%	12.5%	55.4%	26.8%	1.8%	3.6%
12S	0.0%	8.3%	65.5%	22.6%	2.4%	1.2%
10S	0.9%	6.3%	65.2%	23.2%	2.7%	1.8%
8S	1.5%	5.3%	77.4%	13.5%	1.5%	0.8%
6S	0.6%	5.7%	85.1%	7.5%	1.1%	0.0%
4S	0.0%	9.9%	87.8%	1.9%	0.5%	0.0%
2S	0.0%	10.9%	87.8%	1.3%	0.0%	0.0%



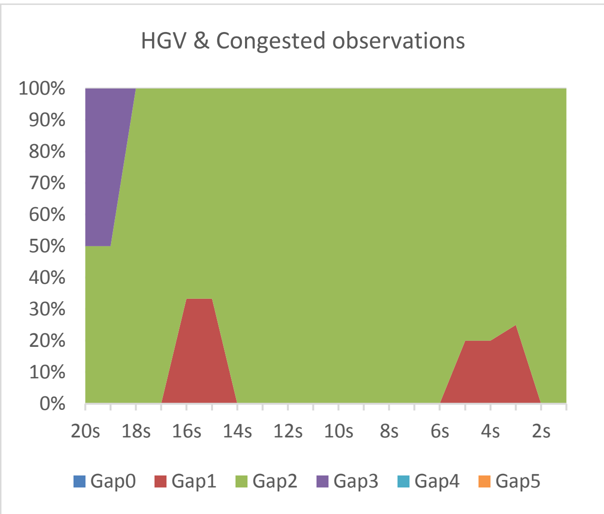
GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	0.0%	44.4%	33.3%	22.2%	0.0%
18S	0.0%	7.1%	28.6%	35.7%	28.6%	0.0%
16S	0.0%	5.3%	36.8%	31.6%	26.3%	0.0%
14S	0.0%	4.0%	28.0%	48.0%	20.0%	0.0%
12S	0.0%	3.2%	45.2%	32.3%	19.4%	0.0%
10S	0.0%	2.7%	62.2%	21.6%	10.8%	2.7%
8S	0.0%	6.4%	68.1%	19.1%	4.3%	2.1%
6S	0.0%	1.7%	84.5%	10.3%	3.4%	0.0%
4S	0.0%	1.5%	96.9%	1.5%	0.0%	0.0%
2S	0.0%	2.8%	97.2%	0.0%	0.0%	0.0%



GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
10S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
9S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
8S	0.0%	25.0%	75.0%	0.0%	0.0%	0.0%
7S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
6S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
5S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
4S	5.9%	11.8%	82.4%	0.0%	0.0%	0.0%
3S	0.0%	18.8%	81.3%	0.0%	0.0%	0.0%
2S	0.0%	12.5%	87.5%	0.0%	0.0%	0.0%
1S	0.0%	15.4%	84.6%	0.0%	0.0%	0.0%



GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	16.7%	66.7%	16.7%	0.0%	0.0%
18S	0.0%	14.3%	71.4%	14.3%	0.0%	0.0%
16S	0.0%	0.0%	88.9%	11.1%	0.0%	0.0%
14S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
12S	0.0%	0.0%	84.6%	15.4%	0.0%	0.0%
10S	4.2%	0.0%	79.2%	16.7%	0.0%	0.0%
8S	0.0%	7.4%	92.6%	0.0%	0.0%	0.0%
6S	0.0%	7.1%	92.9%	0.0%	0.0%	0.0%
4S	0.0%	9.4%	90.6%	0.0%	0.0%	0.0%
2S	0.0%	10.0%	90.0%	0.0%	0.0%	0.0%



GAP	GAP0	GAP1	GAP2	GAP3	GAP4	GAP5
20S	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
18S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
16S	0.0%	33.3%	66.7%	0.0%	0.0%	0.0%
14S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
12S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
10S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
8S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
6S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
4S	0.0%	20.0%	80.0%	0.0%	0.0%	0.0%
2S	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

Appendix D

Script for estimating choice model using BIOGEME

Example of a script for estimating a discrete choice model using BIOGEME. The script is from the estimated discrete choice model of gap choice of passenger cars in free flow presented in this master thesis research. In section [Choice] the identifier of the chosen alternative from the data file is provided. Each line in section [Beta] corresponds to a parameter used in the utility functions. These utility functions are described in section [Utilities]. In section [Expressions] all expressions appearing in the utility functions are defined. The used model type is specified in section [Model].

```
// Simple Binary Logit model for mode choice with generic coefficients
//Revealed preference data from Netherland
// Authors: G. Antonini, C.Choudhury, E. Frejinger, C. Gioia, M. Thémans

[Choice]
Gap_Choice

[Beta]
// Name Value  LowerBound UpperBound  status (0=variable, 1=fixed)
ASC_G1       0.0  -10000.0 10000.0  0
ASC_G2       0.0  -10000.0 10000.0  1
ASC_G3       0.0  -10000.0 10000.0  0
B_Gsize_s    0.0  -10000.0 10000.0  0
B_distgap    0.0  -10000.0 10000.0  0
B_VeTy_PF    0.0  -10000.0 10000.0  0
B_VeTy_PL    0.0  -10000.0 10000.0  0

[Utilities]
//
// Id Name  Avail  linear-in-parameter expression (beta1*x1 + beta2*x2
+ ... )
1 Gap1  one ASC_G1 * one +
            B_Gsize_s * G_Size_S_1 +
            B_distgap * Dist_Gap_1 +
            B_VeTy_PF * Veh_Foll_1 +
            B_VeTy_PL * Veh_Lead_1

2 Gap2  one ASC_G2 * one +
            B_Gsize_s * G_Size_S_2 +
            B_distgap * Dist_Gap_2 +
            B_VeTy_PF * Veh_Foll_2 +
            B_VeTy_PL * Veh_Lead_2

3 Gap3  one ASC_G3 * one +
            B_Gsize_s * G_Size_S_3 +
            B_distgap * Dist_Gap_3 +
            B_VeTy_PF * Veh_Foll_3 +
            B_VeTy_PL * Veh_Lead_3

[Expressions]
// Define here arithmetic expressions for name that are not directly
// available from the data
one = 1

[Model]
// Currently, only $MNL (multinomial logit), $NL (nested logit), $CNL
// (cross-nested logit) and $NGEV (Network GEV model) are valid keywords
$MNL
```