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Empirical Investigation of Strategy-Based Lane Change Choice

A driving experiment and questionnaire

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Preface

This thesis is the graduation work that concludes my Master programme Transport and Planning at the faculty of Civil Engineering of the Delft University of Technology. This research is conducted in association with ITS Edulab, which is a collaboration between Rijkswaterstaat and Delft University of Technology.

I want to thank all people that contributed to this thesis. First and most of all, I would like to express my gratitude to my daily supervisor Victor Knoop. His supportive advice and contagious enthusiasm helped me in completing this work. I enjoyed our bi-weekly meetings very much and it is a great honour for me that Victor initiated a scientific paper on my work.

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I also thank Ton Hendriks of the ANWB for his help and effort in spreading the survey, without his help I would never have received 1258 responses on the survey.

Marcus Jacob de Baat

Delft, August 2016

Summary

In practice, microscopic traffic simulation models are often used for the analysis and management of transport systems. These models simulate the movement of individual vehicles by using a car-following model for the longitudinal behaviour of drivers and lane change model for their lateral behaviour. However, current lane change models cannot simulate all driving behaviour that is seen in reality. Therefore, recent work has studied driving behaviour by means of driving experiments in combination with interviews to get insight in motives behind driving behaviour. This work revealed that drivers apply four different lane change strategies when driving on motorways:

1. **Speed leading**: Drivers settle for a speed and try to keep that speed. When they encounter a slower vehicle in front of them in the current lane they will change lanes so that they can maintain their speed.
2. **Speed leading with overtaking**: This strategy is almost similar as the 'speed leading' strategy. However, in this strategy drivers consider changing lanes when they encounter a slower predecessor as overtaking and will accelerate while doing so.
3. **Lane leading**: Drivers choose a lane based on their perceived relative driving speed and will adapt their speed to the vehicles in that lane.
4. **Traffic leading**: Drivers have no desired lane or speed but copy the speed of other drivers on the road, which could either be the faster or slower ones.

A model in which these four lane change models are incorporated cannot be used yet, since the lane change strategies need more quantification and the parameters require further calibration and validation. The main objective of this study is to quantify the use of the four lane change strategies by drivers on motorways. More specific, this study aims to reveal how many drivers apply each of the four lane change strategies, and what factors influence the distribution of drivers over these strategies. Based on this objective, the following main research question has been formulated:

"How do drivers apply strategy-based lane change behaviour on motorways?"

The research methodology to reach the objective includes a literature study, an interview-based field test and a video-based online questionnaire. The literature study concerned, firstly, factors that influence lane change behaviour, the conceptual working of current lane change models and appropriate methods to study lane change behaviour. Secondly, previous studies that applied driving experiments and interviews are discussed. The resulting insights have been used to set-up an appropriate field test. Thirdly, the literature study includes a discussion of previous work that used questionnaires to study driving behaviour, in which insight was gathered to develop an appropriate survey.

In total 34 drivers took part in the interview-based field study, which was held in February 2016. The driving study consisted of three components: the test drive, a background information survey and

an interview. First of all, participants had to drive in a camera-equipped car a predefined route that led over several motorways in the vicinity of Delft. Directly after the test-drive the participants were interviewed based on the video recordings of their trip. The aim of the interview was to reveal which lane change strategies a driver applies on the motorway, and their motives behind the application of the different lane change strategies. The video-based questionnaire was spread online via various channels and received in total 1258 valid responses from within the Netherlands. The questionnaire consisted of 14 traffic scenarios that were described by a short video of approximately 10 seconds, for which the respondents had to answer how they would behave at the end of the video clip in terms of their lane and speed choice. Several multiple choice answers were given, but respondents were also allowed to formulate their own answers.

The results show that most drivers, 90 to 95%, apply mainly one of the two speed leading strategies, meaning that they choose a speed and try to maintain that speed by changing lanes if necessary. About 5 to 10 % of the drivers prefer to drive in a specific lane and adapt their speed to their predecessors. However, the results show that in some situations significant shares of drivers change strategy. When drivers have to take an exit within a limited distance many drivers tend to stick to the shoulder lane and adapt their speed, while others only use the centre and shoulder lane, and only a few still drive according to the speed leading strategies. Furthermore, although drivers in the Netherlands need to keep right as much as possible unless they are overtaking, significant shares of drivers do not keep right. Not keeping right can be seen as lane leading driving behaviour. Additionally, 15 to 20% of the respondents would overtake another driver via its right side, while this is forbidden in the Netherlands. As last, about 83% of the drivers cooperate with a vehicle that wants to merge onto the main roadway, while the other 17% argues that the merging vehicle should adjust to them.

It should be noted that the results of this study do not present how often a driver applies a certain strategy. The scenarios that have been used in the questionnaire do not occur even frequently in reality. Furthermore, interviews and questionnaires are prone to socially desirable responses, which affect the reliability of the results. However, to what extent this occurs cannot be measured, since differences that have been found in the validation, in which the results from the driving experiment and questionnaire are compared, can have various explanations. Differences also occur because of for example the fact that drivers will not always react the same way in similar traffic situations.

Concluding, the results indicate that there are significant shares of drivers who choose a lane first and then choose a speed. Hence, modelling that all drivers base their lane choice on their speed choice is not correct. Lane change models can be improved by incorporating the four lane change strategies. However, this can mostly not be done by adjustment of parameters alone, and revision of the conceptual working is necessary. Furthermore, drivers often apply a combination of strategies, and the traffic situations show varying distributions of the respondents over the strategies.

Further research can be done into how often strategies are applied by drivers, and how strategy-based lane change behaviour is applied on motorways having more than three lanes. Furthermore, an explorative comparison has been made between on the one hand Dutch drivers and on the other hand Swiss and American drivers. This comparison revealed differences in driving behaviour between these nationalities. However, the sample sizes of the non-Dutch nationalities did not meet the requirements to draw conclusions for the population. Therefore, further research is necessary in terms of a more extensive international comparison to investigate differences in driving behaviour between nationalities with larger samples.

Samenvatting

In de praktijk worden microscopische simulatie modellen vaak gebruikt voor de analyse en het management van verkeerssystemen. Deze modellen simuleren de bewegingen van individuele voertuigen door gebruik van een auto-volg model voor het longitudinaal gedrag van bestuurders en een rijstrookwisselmodel voor het laterale gedrag. Huidige rijstrookwisselmodellen kunnen echter nog niet al het gedrag dat is waargenomen in de realiteit simuleren. Recent onderzoek aangetoond dat bestuurders op snelwegen vier verschillende rijstrookwissel strategiën toepassen, die luiden als volgt:

1. **Snelheid leidend**: Bestuurders bepalen hun wenssnelheid en proberen met die snelheid te blijven rijden. Als ze een langzamere bestuurder tegenkomen in hun huidige rijstrook dan zullen ze van rijstrook wisselen om hun snelheid te behouden.
2. **Snelheid leiden met snelheidsverhoging**: Deze strategie lijkt op de 'Snelheid leidend' strategie, echter bestuurders verhogen hun snelheid bij het inhalen van anderen.
3. **Rijstrook leidend**: Bestuurders kiezen een rijstrook op basis van hun relatieve snelheid en passen hun snelheid naar de andere voertuigen in die rijstrook aan.
4. **Verkeer leidend**: Bestuurders hebben geen voorkeur voor een rijstrook of snelheid, maar kopiëren de snelheid van hun medeweggebruikers. Dit kunnen enerzijds de langzamere bestuurders zijn maar anderzijds ook de snellere bestuurders.

Een simulatiemodel waarin deze vier strategiën zijn opgenomen kan nog niet toegepast worden in de praktijk, omdat de vier strategiën kwantificatie vereisen en de instellingen van de strategiën nog gekalibreerd en gevalideerd dienen te worden. Het voornaamste doel van dit onderzoek is om de toepassing van de vier strategiën door bestuurders op snelwegen te kwantificeren. Specifieker, hoeveel bestuurders elk van de vier strategieën toepassen, en welke factoren een invloed hebben op de distributie van bestuurders over deze strategiën. Daarop is de volgende onderzoeksvraag geformuleerd:

'Hoe passen bestuurders strategie-gebaseerd rijstrookwisselgedrag toe op autosnelwegen?'

De onderzoeksmethode om het doel te bereiken betreft een literatuurstudie, een veld test i.c.m. interviews en een online enquête. Literatuur over rijstrookwisselgedrag, rijonderzoeken en enquêtes om rijgedrag te onderzoeken worden besproken. Inzichten uit het literatuuronderzoek worden gebruikt om een geschikte veld test en enquête neer te zetten.

In totaal namen 34 bestuurders deel aan de veld test, welke in februari 2016 is gehouden. Het rijonderzoek bestond uit drie onderdelen: een proef rit, een achtergrond informatie enquête en een interview. Beginnend moesten de deelnemers in een met camera's uitgeruste personenauto een route rijden over een aantal snelwegen rond Delft. Direct na de proefrit werd het interview gehouden met ondersteuning van de camerabeelden. Het doel van het interview was om erachter te komen welke rijstrookwissel strategiën een bestuurder toepast, en wat de verschillende motieven zijn om deze strategiën toe te passen. De enquête is online verspreid via verschillende kanalen en heeft in totaal

1258 reacties ontvangen vanuit Nederland. De enquête bestond uit 14 verkeerssituaties die beschreven werden door een korte video, waarna de respondenten moesten aangeven wat zij zouden doen met betrekking tot hun rijstrook en snelheidskeuze. Verschillende meerkeuze antwoorden werden gegeven, maar respondenten kregen ook de optie hun eigen antwoord te formuleren.

De resultaten laten zien dat de meeste bestuurders, 90 tot 95%, een van de twee snelheid leidend strategiën toepassen, wat betekent dat zij een voorkeurssnelheid kiezen en proberen daarmee te blijven rijden door van rijstrook te wisselen als het nodig is. Ongeveer 5 tot 10% geeft aan eerst een rijstrook te kiezen en hun snelheid aan te passen aan andere bestuurders in die rijstrook. Echter, de resultaten geven ook weer dat er bepaalde verkeerssituaties zijn waarbij een significant aandeel van de bestuurders van strategie wisselt. Als bestuurders een afslag dienen te nemen binnen afzienbare afstand zijn er veel bestuurders die op de meest rechter rijstrook blijven rijden en hun snelheid aanpassen aan hun voorganger, tegelijkertijd zijn er ook mensen die enkel de middelste en rechter rijstrook gebruiken en slechts een klein deel rijdt volgens de snelheid leidend strategiën. Verder houdt een behoorlijk aandeel van de bestuurders niet rechts wanneer dat mogelijk is, ondanks dat de rechts rijden regel geld in Nederland. Niet rechts houden kan gezien worden als rijstrook lijdend gedrag. Daarbij is er ook het verbod op rechts inhalen van toepassing, maar 15 tot 20% geeft echter aan een andere bestuurders rechts in te halen. Als laatste punt, ongeveer 83% geeft aan medewerking te verlenen aan voertuigen op de invoegstrook door ruimte te creëren. De overige 17% vindt dat het invoegende voertuig zich aan hen moet aanpassen.

Er moet vermeld worden dat de resultaten niet laten zien hoe vaak een bestuurder een bepaalde strategie toe past. De verkeerssituaties die zijn opgenomen in de enquête zullen niet even vaak voorkomen in de praktijk. Interviews en enquêtes lokken verder sociaal wenselijke gedrag uit, wat invloed zal hebben op de betrouwbaarheid van de resultaten. Helaas is het niet mogelijk te bepalen in hoeverre dit is voorgekomen in deze enquête, omdat de verschillen die zijn gevonden in de validatie, waarin de resultaten van het rijonderzoek en de enquête met elkaar zijn vergeleken, uiteenlopende verklaringen kunnen hebben. Verschillen kunnen onder andere optreden doordat bestuurders nooit precies hetzelfde reageren in een zelfde situatie.

Concluderend, de resultaten laten zien dat niet-verwaarloosbare percentages van bestuurders eerst een rijstrook kiezen en dan hun snelheid. Om in modellen te veronderstellen dat alle bestuurders hun rijstrook kiezen op basis van hun snelheid is dus niet correct. Rijstrookwisselmodellen zouden verbeterd kunnen worden door de vier strategiën te implementeren. Echter, in de meeste gevallen zal dit niet gedaan kunnen worden door een eenvoudige aanpassing van instellingen, maar de conceptuele werking dient herzien te worden. Verder, bestuurders passen vaak een combinatie van strategiën toe, en resulteren de verkeerssituaties in verschillende distributies van de respondenten over de strategiën.

Verder onderzoek kan gedaan worden naar hoe vaak bestuurders de strategiën toepassen, en hoe strategie-gebaseerd rijstrookwisselgedrag wordt toegepast op snelwegen met meer dan drie rijstroken. In dit onderzoek is al een verkennende analyse gedaan naar verschillen tussen enerzijds Nederlandse en anderzijds Zwitserse en Amerikaanse bestuurders. Deze vergelijking heeft verschillen in rijgedrag tussen de nationaliteiten aangetoond. Echter, de steekproefgrootte van de niet-Nederlandse nationaliteit is niet groot genoeg om conclusies over de populatie te trekken. Daarom is meer onderzoek nodig in de vorm van een uitgebreidere vergelijking van rijgedrag tussen nationaliteiten met toereikende steekproefgroottes.

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Chapter 1

Introduction

Microscopic traffic simulation models are widely used in practice for the analysis and management of transport systems. For example, these models are used in the assessment of alternatives in road design, and traffic control measurements. Microscopic simulation models simulate the movement of individual vehicles, which have a particular position, speed and acceleration within the traffic system. To do so most microscopic models are split into two sub-models, a car-following model and a lane changing model. These two sub-models form the core of the modelling component. Many research has been done in car-following models, but less attention has been paid on lane changing models, although lane changes have a major influence on traffic operations. When drivers change lanes they create voids in traffic streams which results in underutilization of the road. The number of lane changes has a considerable impact on traffic flows on motorways (Mauch and Cassidy, 2002).

Despite all the effort researchers put into developing lane changing models, Keyvan-Ekbatani *et al.* (2015b) concludes that existing lane change models do not capture all phenomena seen in reality. For instance, current lane change models cannot simulate drivers that change lanes to a lane with a higher density than their initial lane (Keyvan-Ekbatani *et al.*, 2015a). Empirical analysis also showed that gap acceptance models are not able to model merge behaviour accurately (Daamen *et al.*, 2010). The ideal lane change model would capture all phenomena seen in reality. To come to such a model more research is still needed. A recent study revealed four different lane change strategies by means of a driving experiment combined with interviews to investigate the underlying motives of drivers for their shown driving behaviour (Knoop *et al.*, 2015). The four lane changing strategies for operations on motorways read as follows:

1. Speed leading: Drivers settle for a speed and try to keep that speed. When they encounter a slower vehicle in front of them in the current lane they will change lanes so that they can maintain their speed.
2. Speed leading with overtaking: This strategy is comparable with the speed leading strategy. However, in this strategy drivers increase their speed when they change lanes because of a slower predecessor, since they consider this as an overtaking manoeuvre.
3. Lane leading: Drivers choose a lane based on their perceived relative driving speed and will adapt their speed to the vehicles in that lane.
4. Traffic leading: Drivers have no desired lane or speed but copy the speed of other drivers on the road, which could either be the faster or slower ones.

Many lane changing models incorporate the heterogeneity of drivers by different parameter sets. However, the study by Keyvan-Ekbatani *et al.* (2015b) revealed that drivers apply several distinct

strategies which cannot be modelled by just using different parameter sets. A strategy-based lane change modelling approach might lead to a revolution in more realistic lane change models.

In Keyvan-Ekbatani *et al.* (2015a) the four lane change strategies have been implemented in the microscopic simulation model MOTUS, which makes use of the IDM+ car following model (Treiber *et al.*, 2000). However, this model cannot be used yet, since quantification of the lane change strategies and calibration and validation of the models parameters is required. Quantification is required in terms of finding a distribution of the drivers over the lane change strategies. However, one driver can behave according to more than one lane change strategy. Drivers do not consciously apply one of the strategies, but several factors consciously and unconsciously determine and affect the way people drive. Furthermore, several components of the lane change strategies need quantification, for example: the lowest speed for which drivers in the lane leading strategy do not change lane is stochastic with normal distribution of 90 km/h and a standard deviation of 5 km/h (Knoop *et al.*, 2015). This study will contribute to the quantification of strategy-based lane change behaviour, which is required before a model that includes the lane change strategies can be used in practice.

1.1 Research objective

This section describes the research objective of this study. First, the problem that led to this study is defined. Second, the objective of this research is described by means of the main research question. The main research question will be answered by answering several sub research questions.

1.1.1 Problem definition

Implementing the four lane change strategies revealed by Knoop *et al.* (2015) requires several steps, like finding distributions of drivers over the four lane change strategies and quantification of the several elements of the lane change strategies. As mentioned in the introduction already, people may behave according to multiple strategies, and they do not fully consciously make a lane change strategy choice. Several factors influence and/or determine the driving behaviour of drivers. The main problem this study will address concerns the lane change strategy choice of drivers. In more detail, this study will investigate how drivers are distributed over the four lane change strategies for various traffic situations and what factors might influence their behaviour.

1.1.2 Main research question

To get more insight in the lane change strategy choice of drivers and the factors that affect this choice, this study tries to answer the following research question:

How do drivers apply strategy-based lane change behaviour on motorways?

1.1.3 Sub research questions

To answer the main research question, several sub research questions need to be answered. Some sub research questions relate to the lane change behaviour of drivers, while other sub research questions relate to the research approach. The sub research questions have been formulated for each part of the research approach which is described in the next section.

1.2 Research approach

The research approach that has been set-up to answer the main and sub research questions will be briefly discussed in this section. This research contains the following components:

I Literature study

II Driving experiment with interviews

III Online survey on lane change behaviour

Every component will be described in the following subsections. For each method the sub research questions that will be answered are formulated, while a brief description and goal of each method is given. Figure 1.1 presents an overview of the structure of the research approach. Insight gathered in the literature study helps to set-up and execute both the driving experiment and the questionnaire. Gathered insight in the driving experiment on its turn is input for the questionnaire as well.

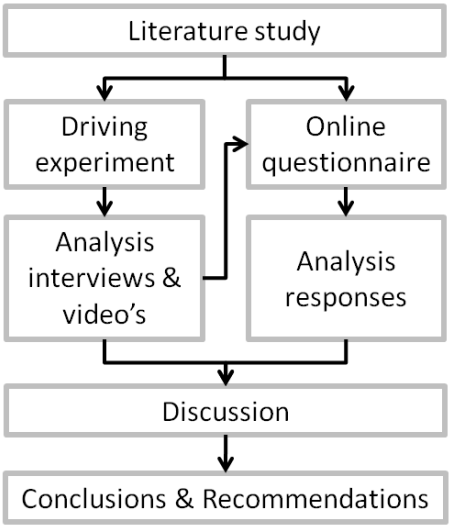


Figure 1.1 – Flow diagram of the components of the research approach

I. Literature study
The literature study is split into three sections, namely: lane change behaviour, driving experiments and driver behaviour questionnaires. In each section one or more of the following sub research questions will be answered:

1. How do existing lane change theories describe lane change behaviour?
2. What factors influence lane change behaviour?
3. What methods exists to study lane change behaviour, and what are their advantages and disadvantages?
4. What lessons can be learned from previous studies that used driving experiments?
5. To what extent do participants of a driving field test show naturalistic driving behaviour?
6. How well can drivers describe their own driving behaviour?
7. What lessons can be learned from previous studies that used questionnaires to study driving behaviour?

8. How valid are results from a questionnaire to study driving behaviour?

In the first section of the literature study, the lane change behaviour part, the modelling mechanisms of existing lane change models will be discussed to gain insight in lane change behaviour. Furthermore, literature has been studied concerning factors that influence lane change behaviour. Several theories have been found which give a theoretical framework for influencing factors of driving behaviour, while empirical studies are presented that found actual prove for influencing factors of driving behaviour. The second section of the literature study focusses on driving experiments. Studies from the past that used instrumented vehicles, interviews or focus groups to study driving behaviour are described, from which several lessons can be learned. This is both useful for the set-up of the experiment as well as the evaluation of the suitability and validity of a driving experiment in combination with an interview to study driving behaviour. The third section of the literature study investigates the experience of past research that used questionnaires to study driving behaviour. Furthermore, studies are discussed that assess the validity of such questionnaires. This is useful for the set-up of the online questionnaire and understanding the validity of self-reported behaviour via questionnaires.

Summarizing, the goals of the literature study are:

- To gain insight in the working mechanisms of existing lane change models
- To gain insight in factors influencing lane change behaviour
- To gain insight in an appropriate set-up and the validity of driving experiments to study driving behaviour
- To gain insight in an appropriate set-up and the validity of questionnaires to study driving behaviour

II. Driving study
The driving experiment will answer the following sub research questions. The research question concerning the influencing factors will be answered by a combination of literature study and the driving experiment.

- What factors influence the lane change behaviour of drivers?
- What are the triggers for drivers to apply a certain lane change strategy?
- How are drivers distributed over the lane change strategies?

To examine the underlying motives of drivers for their driving behaviour a driving experiment has been conducted. In this driving experiment several participants drove a predefined route which has been recorded by video cameras. The shown behaviour has been discussed afterwards in an interview with the help of the video recordings. Factors that influence lane change behaviour are tried to be revealed, as well as characteristics of each driver's lane change behaviour and the (unconscious) lane change strategy choice in several driving conditions. The video recordings from the test drives of the participants in this experiment are subsequently used in the online questionnaire, which is introduced in the next section.

Concluding, the goals of the driving experiment are:

- To gain insight in the factors that influence or determine the lane change strategy choice of drivers

- To gain a sample of the distribution of drivers over the different lane change strategies
- To collect video material from which video clips will be constructed for the online questionnaire

III. Questionnaire
The online survey will answer the following sub research questions, which have partially been answered by the results from the driving experiment with interviews:

1. What factors influence the lane change behaviour of drivers?
2. What are the triggers for drivers to change their lane change strategy?
3. When do drivers change their lane change strategy?
4. How are drivers distributed over the lane change strategies?

Due to practical reasons the number of participants and the duration of the field experiment is limited. Therefore, the driving experiment will be followed up by an online survey. Several insights that have been acquired in the driving experiment can be evaluated on a much larger group of people by means of an online survey. In the survey video clips of particular traffic situations have been shown to the respondents, after which they had to respond what they would do in that situation in terms of speed and lane choice. Varying traffic conditions have been shown, which combined give useful insight in strategy-based lane change behaviour. Some scenarios are followed up by questions concerning the motive of a driver to show particular driving behaviour. The participants of the driving experiment are invited to fill in the online survey, in order to assess, to some extent, the validity of the self-reported behaviour from the questionnaires.

The goals of the online questionnaire are:

- To gain insight in the distribution of drivers over the four lane change strategies
- To gain insight in the factors that influence the lane change strategy choice on a larger scale

IV. Conclusions and Recommendations
The last part of the research approach includes a recap of the main findings of the driving experiment and online questionnaire combined. Overall conclusions are thus presented in this section, which are followed up by a discussion of these results and this study, which follow on their turn in recommendations for practice and further research.

1.3 Relevance of the research

This study contributes to the improvement of the performance and development of lane changing models that are incorporated in microscopic simulation packages. Existing lane change models are not able to accurately model lane change behaviour as seen in reality. New insight in lane change behaviour has been obtained by the work of Keyvan-Ekbatani *et al.* (2015b), that revealed four general lane change strategies that are applied by drivers on motorways. This study continues the work of Keyvan-Ekbatani *et al.* (2015b) by studying when and why drivers apply a particular strategy, which is necessary to know before these lane change strategies can be implemented in a microscopic simulation package.

Although nowadays many studies focus on automated driving, the human factor in driving will stay an important factor in simulation models until the last manual car is replaced by an automated vehicle, which will take many years to happen. Until that moment simulation models need to account for human behaviour. The implementation of the four lane change strategies can contribute to improve the realism and thus the performance of these simulation models.

Furthermore, there have no studies (of which the author is aware) been done that used videos of traffic situations to investigate driving behaviour. Although a questionnaire is not new, the set-up of the survey in this study with videos describing traffic situations is new. The experience gained through this study concerning video-based questionnaires to study driving behaviour can be used for further research.

1.4 Thesis outline

This report is split into four parts that correspond with the four components of the research approach. An overview of the chapters in relation to the research approach is given in figure 1.2. The first part concerns the literature study which consists of three chapters. Chapter 2 includes a literature study on lane change behaviour, chapter 3 discusses literature concerning driving experiments, and chapter 4 concerns literature in relation to questionnaires. The second part of this report includes the set-up of the driving experiment in chapter 5 and its results in chapter 6. The third part concerns the online questionnaire, on which chapter 7 discusses the set-up, chapter 8 presents a validation of the results, chapter 9 describes the main results, and chapter 10 gives an additional analysis in terms of an international comparison. The fourth part of this report concerns the discussion(chapter 11) and conclusions (chapter 12).

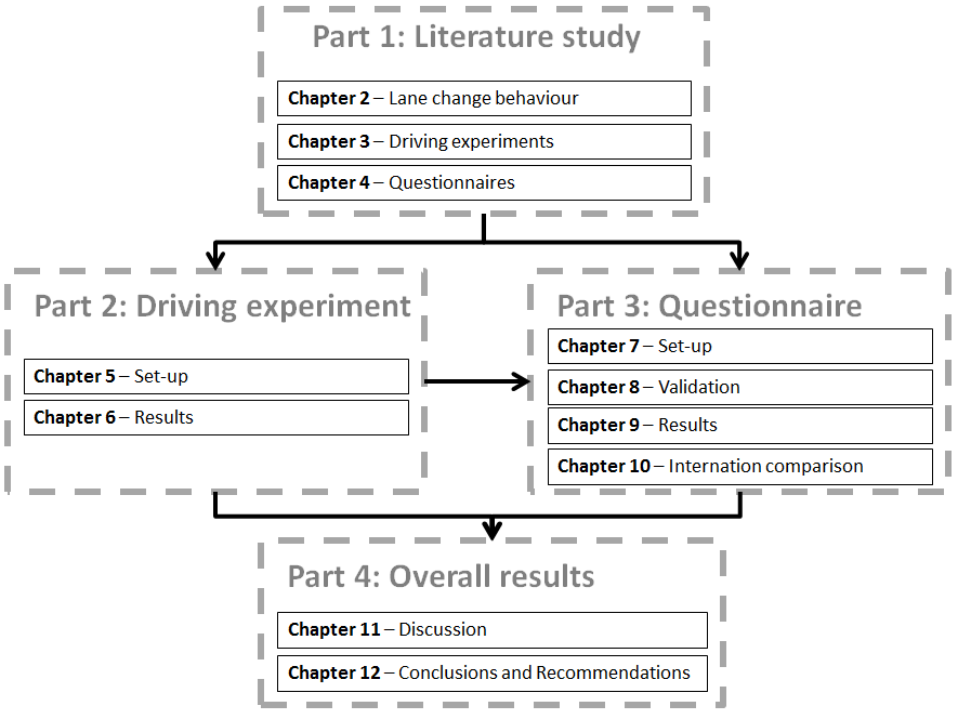


Figure 1.2 – Overview of thesis outline

Part I

Literature study

Chapter 2

Lane change behaviour

This chapter concerns the literature study on lane changing behaviour and will answer the following sub-research questions:

- How do existing lane change theories describe lane change behaviour?
- What factors influence lane change behaviour?
- What methods exists to study lane change behaviour, and what are their advantages and disadvantages?

Microscopic simulation models use a longitudinal (car-following) and a lateral (lane change) model to simulate the movement of vehicles on motorways. Many different lane change models exist, which can help to get more insight in lane change behaviour and how this is currently modelled.

The answer to the first sub research question is helpful in answering the second sub research question, since the mechanisms of existing lane change theories give useful insight in lane change behaviour. Section 2.1 elaborates on the working of existing lane change models, section 2.2 describes factors that influence lane change behaviour, while section 2.3 describes different methodologies and their advantages and disadvantages to study driving behaviour. Each section is reviewed by conclusions at the end of each section.

When referred to a lane in this report, the naming as illustrated in figure 2.1 is used.

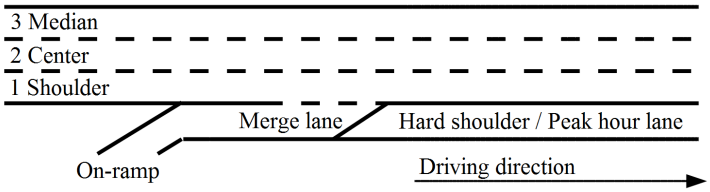


Figure 2.1 – Naming of lanes

2.1 Existing lane change models

Over the years several models have been developed to simulate the lane change behaviour of drivers on motorways. These models can be distinguished by the way they classify lane changes and their main modelling mechanisms.

2.1.1 Classification of lane changes

After Gipps (1986) introduced its lane change theory, many lane changing models distinguish between mandatory and discretionary lane changes (Ahmed, 1999; Wei *et al.*, 2000; Laval and Daganzo, 2006; Kesting *et al.*, 2007; Choudhury, 2007). Mandatory lane changes are performed when a driver must change lanes to follow a certain route (e.g. changing lane to an off-ramp to exit the motorway). Discretionary lane changes are performed by drivers to improve their driving conditions (e.g. when a driver encounters a slower vehicle and change lanes to maintain its desired speed) or the driving conditions of other drivers (e.g. courtesy lane changes when another vehicle wants to merge from an on-ramp). Wei *et al.* (2000) distinguish mandatory and discretionary lane changes, but also introduces a third type, namely the pre-emptive lane change. This is a lane change performed by a driver to get in the correct lane for an upcoming manoeuvre after the next intersection, while this lane change is not mandatory for a driver to follow its route.

Hidas (2002) concluded that Gipps lane change theory does not account for lane changes in congested traffic situations, since according to the rules of Gipps theory a lane change occurs without interference with vehicles in the destination lane. A new lane change model was introduced that distinguishes free, forced and co-operative lane changes (Hidas, 2002, 2005). Free lane changes occur in free flow traffic situations in which a driver can change lanes without interference with other drivers. In forced lane changes a subject vehicle force a following vehicle to make space in the target lane. While co-operative lane changes concerns following vehicles that adapt their speed to make room for the subject vehicle to change lanes.

Schakel *et al.* (2012) noticed that most lane change models classify lane changes by the reason for which they are executed, like mandatory and discretionary lane changes. Schakel, however, introduced a lane changing model that classifies lane changes by the way they are prepared and performed in three categories, namely: free lane changes, synchronized lane changes and cooperative lane changes. Which lane change type is performed is determined by the level of desire to change lanes. This desire consists of desire to follow a route, to gain speed and to keep right. When desire is low, no lane change will be performed. If little desire exists a free lane change is executed that requires no preparation. For a higher desire the subject vehicle is willing to synchronize its speed with vehicles from the target lane. In cooperative lane changes a potential following vehicle will follow the potential lane changer and thereby creating a gap.

2.1.2 Main mechanism of existing lane change models

One of the first lane change theories was developed by Gipps (1986). He formulated a decision model for urban driving situations that decides whether or not drivers will change lanes. The decision to change lanes follows from the answers on the following questions formulated by Gipps:

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

The following factors are considered most important by Gipps that influence drivers to change lanes:

- Whether it is physically possible and safe to change lanes: if there is an unacceptable risk of a collision a driver will not change lanes

- The location of permanent obstructions: drivers try to avoid being trapped behind obstructions by choosing lanes that will give them free way
- The presence of transit lanes: transit lanes are lanes were only public transport vehicles are allowed
- The driver's intended turning movement: driving behaviour is affected by the distance of the driver to the point where he is planning to make a turning movement
- The presence of heavy vehicles: drivers try to avoid being trapped behind a heavy vehicle, due to their lower accelerations
- Speed: when drivers encounter a slower vehicle on the same lane in front of them they tend to change lanes to maintain their desired speed

According to Gipps' model a lane change is performed when a driver cannot drive with its desired speed in the current lane, the speed in the adjacent lane is more desirable than the speed in the current lane and there is a sufficiently large gap in the adjacent lane. The two considerations that determine the driving behaviour in Gipps model are the driver's desired speed and the correct lane to make an intended turning manoeuvre (Gipps, 1986).

Kesting *et al.* (2007) formulated the lane change model called MOBIL. Kesting describes a lane change model as a multi-step process that contains a strategic level, a tactical level and an operational level. The strategic level concerns the route choice of drivers, which influences the lane choice. The tactical stage concerns the preparation and initiation of a lane change manoeuvre by acceleration, deceleration or the cooperation of other vehicles. The operational stage concerns the actual decisions of drivers to change lanes, which is often modelled by a gap-acceptance model. In a gap acceptance model the available gaps in the adjacent lane are compared with the critical gap of the driver. The critical gap depends on its term on the relative speeds of the subject vehicles with those of vehicles in the adjacent lanes. In MOBIL the decision to change lanes is determined by the utilities of the lanes based on the possible acceleration and the risks related to lane changes. Thus, the only incentive to change lanes is speed. Furthermore, MOBIL included politeness as a factor that expresses the conflict of a lane change on the acceleration of other drivers. This factor can vary to both describe aggressive drivers as more cooperative drivers (Kesting *et al.*, 2007).

Choudhury (2007) presented a complete framework that captures the whole decision process of lane changing, in which decisions are interdependent and often unobservable. Choudhury pointed out that changes in circumstances over time may lead to an update of an initially chosen plan, which all of the lane change models in that time ignored. Separate models are used in this framework for motorway lane selection, motorway merging, and for urban lane selection. The motorway lane selection model, which is relevant for this study, consists of a target lane model and a gap acceptance model. The target lane model determines the utility per lane based on lane attributes, neighbouring vehicle attributes and path-plan variables. The gap acceptance model determines if a lane change is possible by considering the available gaps in the adjacent lanes. Lane attributes are in general the speed of a lane, the density of a lane, the traffic composition on a lane and the percentage of trucks on a lane. Sometimes lanes have lane-specific attributes in their utility, for example, an exclusive lane will have a high disutility for vehicles which are not allowed on that lane induced by a variable concerning the lane-ban. Neighbouring vehicle attributes concern the speed, relative position and type of the surrounding vehicles, which may affect the decision to change lanes. The path-plan variables related to a drivers pre-defined destination and schedule. Such a variable is for example

the distance to a certain point where the vehicle needs to be on a particular lane to continue its route to the destination. The smaller this distance is, the higher the desire will be to change lanes. The framework of Choudhury is quite comprehensive, but Daamen *et al.* (2010) concluded that not all phenomena observed in reality are covered by the model. The first is that cooperative lane changes are not modelled, which can result in an underestimation of the number of lane changes. The second is that drivers do not accelerate towards a target gap. As third that the effect of lane changes on the traffic state is not included in the model (Daamen *et al.*, 2010).

Toledo noticed that a rigid behaviour structure exists when lane changes are classified into mandatory and discretionary lane changes. This distinction in lane change types, for example, does not allow the overtaking of vehicles on the shoulder lane just before an off-ramp that a subject vehicle needs to use to continue its route. Toledo, therefore, developed an integrated lane change model that combined mandatory and discretionary lane changes in one framework (Toledo *et al.*, 2003). Furthermore, Toledo integrated this lane change model with a car-following model, while most other lane change models assume and model that acceleration and lane changing behaviour is done separately Toledo *et al.* (2007). In reality drivers make short-term plans to accomplish their objectives, while incorporating both their acceleration as lane changing behaviour. For example, drivers might adjust their acceleration to facilitate a desired lane change. The integrated model of Toledo consists of four sub-models, namely the target lane choice model, the gap acceptance model, the target gap model and the acceleration model. The target lane choice model uses utility per lane to determine if a lane change is desired. The utility per lane is determined by explanatory variables that are classified by Toledo in four categories:

- Neighbourhood variables: These variables describe those that are in the direct surroundings of the subject vehicle like, the presence and actions of other vehicles, geometry elements, signals and signs, and police presence.
- Path plan variables: It is assumed that drivers have selected a destination, path and desired arrival time. These decisions make drivers change lanes to follow a certain path. Variables are for example the distance to a point where de driver needs to be in a specific lane to follow its route.
- Network knowledge and experience: These variables captures the preferences and considerations of drivers based on their network knowledge and experience. For example, some drivers prefer not to use the shoulder lane to avoid interaction with merging traffic.
- Driving style and capabilities: These variables capture the aggressiveness of drivers and vehicle characteristics, like acceleration and deceleration.

The gap acceptance model determines if an adjacent gap in the target lane is acceptable or not. If this adjacent gap is acceptable, in other words the gap is larger than the driver's critical gap on that moment, a driver will change lanes without considering other gaps in the target lane. If the gap is not acceptable, the driver will try to find another gap in the target lane, which is modelled by the target gap choice model. This sub model will determine the utility of other available gaps, based on the size of the gap and speeds of surrounding vehicles, which results in a short-term plan to accomplish the desired lane change. The acceleration model on its turn determines the necessary acceleration of a driver to accomplish its short term goal and short term plan. Three acceleration cases are considered in this model: stay in the lane acceleration, acceleration during a lane change and target lane acceleration (Toledo *et al.*, 2003, 2007).

Wei *et al.* (2000), on the other hand, describes a lane change model which is built up from a decision model, a condition model and a manoeuvring model. The decision model concerns the route and lane choice that depends on the current lane type and driving conditions in the current lane and the adjacent lanes. The condition model describes the conditions in which lane changes are accepted. The manoeuvring model on its turn describes the actual vehicle's speed and the duration of a lane change.

Schakel *et al.* (2012) proposed on its turn a lane change model with relaxation and synchronization called LMRS. Schakel points out that most of the first class lane change models apply simple gap acceptance model based on distance and speed difference, while a second class of lane change models accounts for the fact that drivers sometimes accept smaller gaps, but while applying a larger acceptable deceleration. In reality, drivers apply small decelerations and accept smaller headways for merging traffic for a short time (Daamen *et al.*, 2010), which is called relaxation. Furthermore, the model of Schakel also accounts for synchronization which is the phenomena that drivers prepare for a lane change by adapting their speed and align with a gap in the adjacent lane. Schakel assumes that drivers desire to change lanes with the incentives to gain speed, to follow a certain route and to keep right if possible.

2.1.3 Conclusions

Several lane change models have been discussed throughout the previous section. These models differ from each other on their classification of lane changes and/or their main modelling principles. Three ways to classify lane changes have been found:

- Classification into mandatory or discretionary lane changes: This classification is used in most models that were reviewed and followed from the theory of Gipps (1986).
- Classification into free, forced and co-operative lane changes: This classification was introduced by Hidas (2002), because the first classification could not account for lane changes in congested situations. The classes are distinguished based on the possible interaction between a subject and following vehicle.
- Classification info free, synchronized and co-operative lane changes: This classification was developed by Schakel *et al.* (2012), and is based on the way lane changes are prepared and performed and the underlying desire to make a lane change.

These classifications give already a first insight in lane change behaviour. There are different reasons to execute a lane change, during lane changes there can be different levels of interference with other drivers and lane changes are differently prepared and performed.

Many of the reviewed models use utility maximization with speed as incentive to determine the desire of a lane change. Several models incorporate some sort of politeness or co-operative behaviour to account for the phenomena that some drivers adapt their speed or change lanes to make space for other vehicles. Furthermore, several researchers pointed out that there is not such a rigid separation of lane change behaviour and acceleration behaviour, but that these behaviours are very intertwined and depended of each other, for which is not accounted for by most models. Other phenomena that have been noticed by researchers and modelled in lane change models are: relaxation, synchronization, and critical gaps based on relative speed. All lane change models found only use one lane change model that mainly use speed as incentive to change lanes for discretionary lane changes. However, Knoop *et al.* (2015) found four different lane change strategies that are applied by drivers on motorways, of which two do not have speed as incentive to change lanes. The models that do

use speed as incentive to change lanes determine the desire and decision of a lane change on several explanatory variables like the presence and actions of other vehicles, the distance to a point were the subject vehicle needs to be in a specific lane, the aggressiveness of drivers and vehicle characteristics. These variables are thus already part of the answer to the research question "What factors influence the lane change behaviour of drivers?", more on this research question will be discussed in section 2.2.

The sub research question "How do existing lane change theories describe lane change behaviour?" has been answered throughout the previous section. Not all lane change models that exists have been discussed here and will not be discussed here, but it is believed that the most influential lane change models and theories over the years are discussed. The previous section has on the one hand shown the relevance of the development and improvement of new lane change models, since all existing models still miss the power to model all phenomena seen in reality. On the other hand, answering this research question resulted in useful insight in possible ways to classify lane changes and phenomena of lane change behaviour seen in reality. This insight might be of use in the set-up of the driving experiment and questionnaire.

2.2 Influencing factors

This section tries to answer the second research question: "What factors influence the lane change behaviour of drivers?". Reviewing the mechanism of existing lane change models revealed several factors that affect lane change behaviour. Also in the field of traffic safety and psychology, theories concerning driving behaviour have been formulated. Theories help us to understand human behaviour. Human factors are in two ways incorporated in driving, namely driving skills and driving style (Elander *et al.*, 1993). Driving skills refer to the ability of drivers to maintain control of the vehicle and respond adequately to traffic situation, and can also be called driving performance. It can be expected that driving skills will improve with experience and training. Driving style refers to the way drivers choose to drive, and thus includes their speed choice and headway. Driving style can also be called driving behaviour and is influenced by motives, personal characteristics and attitudes (Elander *et al.*, 1993). Factors influencing driving behaviour are tried to be found be reviewing driving behaviour theories and these will be underpinned by presenting evidence of influencing factors from empirical studies.

2.2.1 Theories on driving behaviour

Michon (1984) classified behaviour in traffic intro three different levels of skills and control: strategical (planning), tactical (manoeuvring) and operational (control). The distinction is made at how conscious certain actions are executed and in what time magnitude these actions are performed. The hierarchical structure of the road user task by Michon (1984) is illustrated in figure 2.2. On the strategic level decisions are made concerning general plans like destination choice, mode choice, route choice and departure time choice. This level is characterized by a long time constant. The manoeuvring level includes controlled actions to negotiate the prevailing circumstances, like for example the interaction with other vehicles, obstacle avoidance, gap acceptance, turning and overtaking. Drivers take some time for these actions in the magnitude of seconds to prevent any errors. At the control level automatic actions are performed like for example pushing the gas pedal, shifting gears, steer the car to follow the lane and braking. All these actions are performed within milliseconds (Michon, 1984).
Lane changes take place at the manoeuvring level of Michon's hierarchical structure of the road user

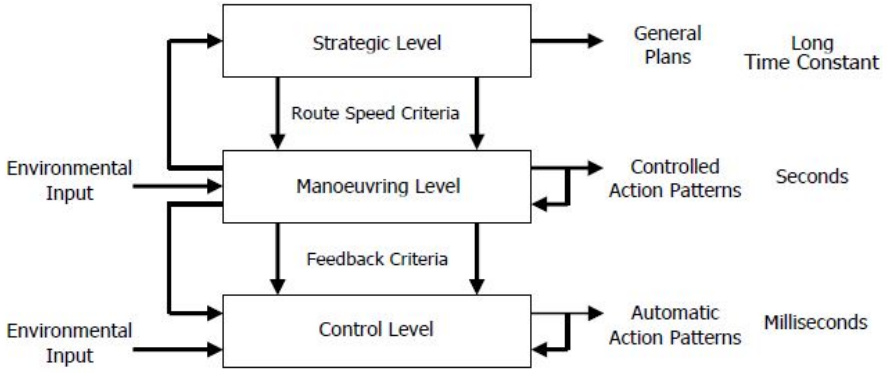


Figure 2.2 – Hierarchical structure of the road user task by Michon (1984)

task. These are controlled actions that are performed in a time span of seconds. The more one drives the more actions will be made automatic and the more routine will be built up. At some point a lot of actions and interactions with other road users will be performed automatically without much of our attention. However, there should be noted that there are large differences between individuals, and even within one individual over time, due to its mental and physical state for example. Individuals can be very unpredictable on their actions, which can be performed either conscious or on the automatic pilot (Brookhuis, 2007).

An often cited model for conditions that influence driving behaviour is the one of Lonero (1995). According to Lonero an intricate and interdependent set of congenital, experiential and environmental influences determine driving behaviour. The model of Lonero is presented in figure 2.3.

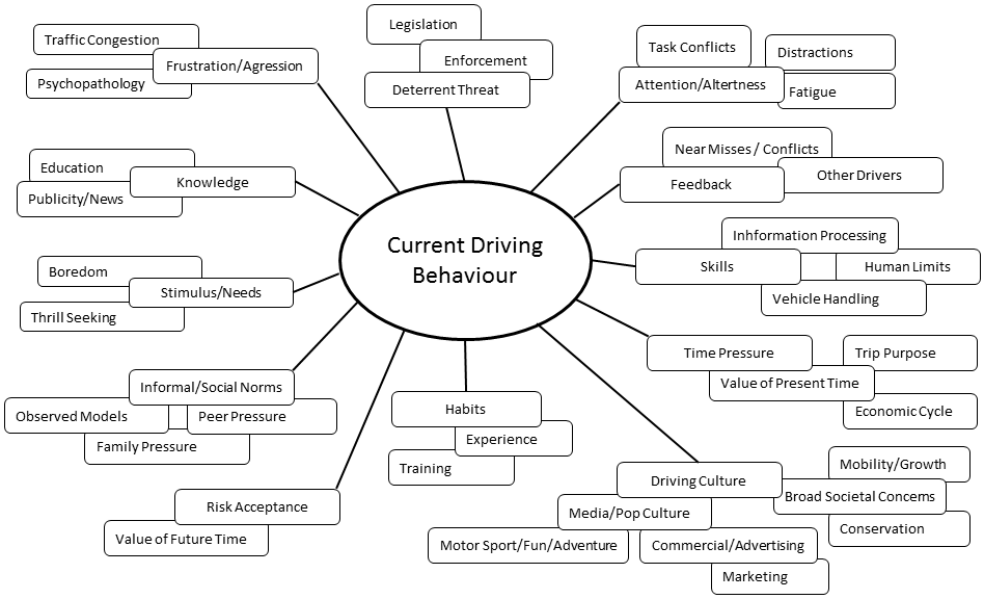


Figure 2.3 – Conditions influencing driver behaviour (Lonero, 1995)

The model of Lonero reveals several conditions that affect human driving behaviour. This model

looks at driving behaviour from the way how driving behaviour can be changed, while there are theories on driving behaviour that have a different point of view or describe a different aspect of driving behaviour. The following aspects can be distinguished to characterize theories on driving behaviour:

- Perceptual, attentional aspects
- Social and motivational aspects
- Task performance & errors

A well-known model in the field of traffic safety is the task-capability interface model of Fuller that describes the task performance & errors aspect of human driving behaviour. An adapted version of Fullers' task-capability model (Fuller, 2005) is presented in figure 2.4.

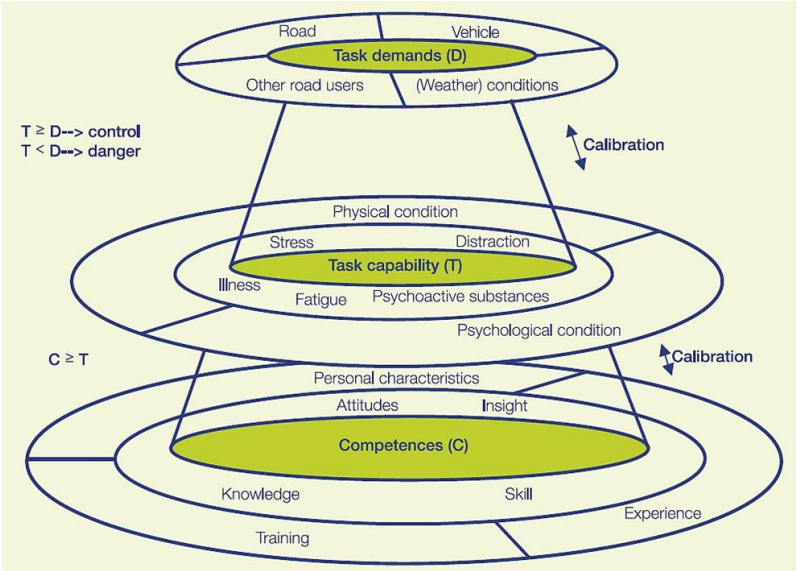


Figure 2.4 – Adapted from Fullers' task-capability model (Fuller, 2005)

Task performance of drivers is not really of interest in this study, but the model of Fuller gives useful insight in how several factors can have effect on driving behaviour. The model describes the interactions between the task demands, task capabilities and competences, which are all determined by specific factors. The model implies that when task demands transcend the task capabilities a driver is not able to perform the task in full control and safely, which may lead to errors and accidents.

Zaidel stated that every driver is influenced by the social environment which consists of other road users, general social norms and formal traffic rules. Four ways have been defined by Zaidel that influence driving behaviour (Zaidel, 1992; Björklund, 2005):

1. **Others' as a source of information.** When drivers share a common driving culture the behaviour of others can be helpful to understand the required behaviour, however, misunderstandings can also occur. For example, when a predecessor is slowing down, this might raise the attention of a driver so it can appropriately response on an upcoming situation.
2. **Communication with others.** Communication with other drivers help to understand each other's actions and intentions, and thereby reduce misunderstanding, frustration and conflicts. Communication may even induce co-operative behaviour.

3. **Others as a reference group.** Social norms / informal traffic rules are the summary representation of the opinions of others. However, only to some extent drivers share common norms and informal rules, since norms are not defined clearly and are accepted by one as their one opinion of the collective expressions.

4. **Imitation of others.** People also act according to other ones behaviour without any communication between them or direct instructions to do so. For example, a driver who parks his car in a narrow street with parking on one side only at the opposite side of the parking with his near wheels on the sidewalk, and thereby blocking half the street, will soon be imitated by other drivers that will park their car just like that.

Another theory on driving behaviour, but from the field of transport and traffic modelling, is Daganzo's theory of slugs and rabbits. This traffic model gives a theoretical explanation on how drivers are affected by the traffic intensity (Daganzo, 2002a,b). Two types of drivers are distinguished in this theory, namely slugs and rabbits. Slugs are slow and less aggressive drivers, while rabbits are fast and aggressive drivers. When intensities are rather low the slugs and the rabbits are separated into a so-called two-pipe regime. Slugs are driving with a relative low speed on the shoulder lane, while the rabbits are driving with a relative high speed on the other lanes. For situations were intensities are high and speeds decrease the two-pipe regime will transfer to a one-pipe regime, where the rabbits will also make use of the shoulder lane. Thus, for different traffic intensities rabbits might choose other lanes.

2.2.2 Empirical studies

Driving behaviour comprises, among others, of longitudinal and lateral behaviour, planning and talking. Hagenzieker and Brookhuis (2010) state that this behaviour is altered by experience, surroundings, presence of passengers and for example in-vehicle devices, which leads to an increase or decrease of the driving quality. However, it is very hard to determine to what extent changes occur. Hagenzieker and Brookhuis (2010) give as example: a navigation system can lead to both a visual as a cognitive distraction for drivers from the driving task, and influences the driving performance. Empirical studies can give useful insight in the factors that influence driving behaviour. Several empirical studies are presented here.

Research has found that the more one drives the more frequent one violates traffic rules, and thus experience affects (or determines) driving behaviour (Aberg and Rimmo, 1998; Blockey and Hartley, 1995). Research also showed cross-cultural differences in driving behaviour (Özkan *et al.*, 2006). Driving style and behaviour is thus determined and affected by both personal characteristics, like gender, age and driven mileage, as well as the traffic culture in a country.

As seen in the task-capability model of Fuller, a person's task capacity is (among others) determined by distraction. Distraction takes up a certain amount of attention from the driver which cannot be used anymore for the driving task itself. This might result in errors and lapses. Furthermore, distraction is also incorporated in Lonero's model as an influencing condition that makes up a person's driving behaviour. Distraction has many appearances, for example: advertisement signs along the road, using a smartphone while driving or a thought that occupies one's mind. Distraction can also be caused by other occupants in the vehicle, who will take up some of the driver's attention when they speak with each other (Young *et al.*, 2008). Evans found in 1983 shorter headways for drivers with no passengers, indicating that the presence of passengers affects driving behaviour (Evans and Wasielewski, 1983).

Driving behaviour is affected by the type of vehicle. A study into driving behaviour showed that drivers of a 4wheel-drive car show more risky behaviour than small car users. Four wheel drivers, in general, exceed the speed limit, they commit more violations, errors and lapses, they drive faster and they report a lower seat belt usage than small car drivers (Bener *et al.*, 2008a). However, it should be noted that this study was carried out on drivers in Qatar and to what extent this phenomena is applicable on Dutch drivers is not known, although Horswill and Coster (2002) found a similar relationship between vehicle performance and risky driving behaviour for drivers in the UK. Results from Horswill and Coster (2002) even indicates a bi-directional relationship, such that drivers who drive more risky will choose faster cars, and that better vehicle performance will result in more risky behaviour.

Already acknowledged for a long time is the fact that people change their behaviour based on the perceived probability and severity of harm. For example, people will walk more carefully when the ground is wet or icy than when it is dry (Evans, 1991). The same has been found for drivers, who lower their speed and increase their headway in rainy weather conditions (Hogema, 1996).

Lane flow distribution is a measurable effect of lane choice by drivers. A study by Knoop *et al.* (2010) has found that the lane flow distribution differs for various speed limits and the presence of an on-ramp. The study concludes that just upstream of an on-ramp a significantly lower fraction of the drivers is using the shoulder lane in comparison with a road section without an on-ramp. Furthermore, the empirical study showed that in situations with a speed limit of 120 km/h the shoulder lane is underutilized, while in situations with a speed limit of 60 km/h the flow in the shoulder lane increases.

At some motorways in the Netherlands the maximum speed has been lowered a few years back to 80 km/h in combination with the implementation of average speed checks. An evaluation study revealed that these measurements have led to a lower utilization of the median lane and an higher utilization of the shoulder lane (Harms, 2006). Furthermore, this study concluded that not the lower speed limit on itself led to this change in driving behaviour, but the combination of the lower speed limit with average speed checks influences driving behaviour. A study on the effects of average speed checks on Belgium roads concluded that due to average speed checks the median lane is less utilized, drivers are shifted to the centre lane and average speeds are lower (Akkermans, 2014). It is expected that Belgium drivers are comparable with Dutch drivers, and thus that this effect of average speed checks on driving behaviour is comparable for the Dutch case.

A study to the performance of plus and rush-hour lanes in the Netherlands found that the occupation and mean speeds of rush-hour lanes are substantially lower than a regular hard shoulder lane of a 3-lane motorway (Beentjes, 2012). A plus-lane is defined as a lane on the left side of a motorway which is opened for traffic when high intensities are reached, a rush-hour lanes is defined as a hard shoulder lane on the right side of a motorway that is opened for traffic when high intensities are reached (Van Vliet, 2003). The study by Beentjes (2012) found an underutilization of plus-lanes at low intensities, but a higher utilization of plus-lanes at high intensities in comparison with regular median lanes. Also a small difference in average speeds was found between plus lanes and regular median lanes. This study thus indicated that road sections with a plus or peak-hour lane have influence on the driving behaviour.

2.2.3 Conclusions

Several theories on driving behaviour have been discussed to gain insight in factors that influence this behaviour. However, all these theories and factors together will probably only describe a very little part of the complex beings that humans are. Much more can be written here concerning human behaviour in traffic, but that is not the aim of this study. The most relevant factors are identified for both answering the research questions as well as setting up a proper methodology to study driving behaviour.

Human factors are in two ways incorporated in driving: driving skills and driving style. Skills refer to the ability of drivers to maintain control over the car and to adequately respond to traffic situation. Driving style is the way people choose to drive and is influence by motives, personal characteristics and attitudes (Elander *et al.*, 1993). The driving task can be classified into three different levels: strategic, manoeuvring and control (Michon, 1984). Lane change behaviour takes place at the manoeuvring level, which is characterized by a timespan of seconds and as controlled actions. However, the more one drives the more actions will be done automatic without much of our attention. Furthermore, there are huge differences between individuals and even within one individual concerning their driving behaviour.

The model of Lonero (1995) describes a set of congenital, experiential and environmental influences that determine driver behaviour, for instance: knowledge, skills, habits, social norms, driving culture, time pressure and attention. Driving behaviour is according to the task-capability model of Fuller (2005) determined by one's task capabilities and competences. Task capabilities are determined by the physical and psychological condition of a driver, while competences are determined by training, experience and personal characteristics. The theory of Zaidel (1992) focused more on the influences on driving behaviour by the social environment, consisting of other road users, general social norms and formal traffic rules. The slugs and rabbits theory of Daganzo (2002a,b) gives a theoretical explanation on how drivers are affected by traffic intensities.

These theories give a good insight in the factors that play a role in the determination of human driving behaviour. However, to what extent factors have influence does not become clear from these theories. Therefore, studies with empirical evidence for factors influencing driving behaviour have also been reviewed. Experience, the presence of other occupants, type of vehicle, weather conditions, speed limit, the presence of an on-ramp, average speed checks and the presence of plus or peak hour-lanes have shown in empirical studies to influence driving behaviour. The factors found in theories and by empirical study together answer the sub research question "What factors influence the lane change behaviour of drivers?. You could easily think of more factors that influence human behaviour that are not discussed here. Human behaviour is very complex and cannot be discussed completely here. The factors found throughout the previous section will be used to set-up an appropriate driving experiment to study driving behaviour. Furthermore, this obtained insight in driving behaviour will be helpful in the driving experiment and questionnaire to find out how, when and why drivers apply a certain lane change strategy.

2.3 Methods to study driving behaviour

Several methods exists which can be used to study driving behaviour. Hagenzieker and Brookhuis (2010) state that driving behaviour have been studied predominately in three ways: by interviews and questionnaires to ask people to describe or report their behaviour, by means of post hoc data

like police reports and crash data, and by observing the actual driving behaviour itself. Drawbacks of interviews and questionnaires are the fact that people might not be able to accurately report their own behaviour, or might give socially desirable answers. Post hoc data is an indirect observation of driving behaviour which lacks accuracy and underlying motives of behaviour (Hagenzieker and Brookhuis, 2010).

2.3.1 Direct observations

Direct observations of driving behaviour can be further differentiated in three methods, which were compared by Hagenzieker and Brookhuis (2010) in more detail: driving simulators, field studies and naturalistic driving observations. Driving simulators exist already quite some time and in various classes, from cheap and static simulators to more expensive and dynamic simulators. All simulators try to create a safe environment which can be fully controlled to study driving behaviour. However, simulators are still being questioned on how well they can resemble real traffic situations.

Field studies make use of real, sometimes instrumented, cars to study driving behaviour on the public road or a test track. The clear advantage of field studies is the high realism of the driving conditions. However, field studies have several disadvantages too. Instruments are installed in the car to record several driving variables for analysis purposes, or otherwise mostly observers are present in the car to examine the participants driving behaviour. The presence of observers could make participants to show socially desirable driving behaviour, although Turetschek (2009) claims that participants forget the presence of the observers in 15 minutes. Another disadvantage of observers could be their subjective judgement, caused by their experience, fatigue and attention. Furthermore, in a field test the experimental conditions cannot be controlled fully, like the weather and traffic intensities on the road. Finally, field tests are also often bounded by the available resources, like the car or the test track owned by the research institution.

In naturalistic driving observations drivers are observed in their own cars for a relatively longer period than in simulators or field tests. Cars are often equipped with all kinds of sensors and instruments to record several driving variables, which can be used to analyse driving habits and driving style. However, drawbacks of this method are the high costs to execute such a study, the sample of participants is often small and non-representative, and it is hard to analyse drivers' thoughts and motives for their behaviour (Hagenzieker and Brookhuis, 2010). All three methods of direct observations of driving behaviour have limitations concerning behavioural validity, experimental strength and observatory reliability. For this study this insight in the different methods is useful to underpin the choice of the appropriate research methodology.

2.3.2 Ecological validity

Figure 2.5 has been adapted from Glendon (2007), which investigated driving violations. The figure gives an overview of empirical analysis methods to study driving behaviour, ranked according to their ecological validity.

A differentiation between the methods can be made to which extent data is collected in real-time. Furthermore, Glendon (2007) also distinguishes on-road and in-vehicle observations in methods with observers present (direct) and methods that use instruments to observe driving behaviour (indirect).

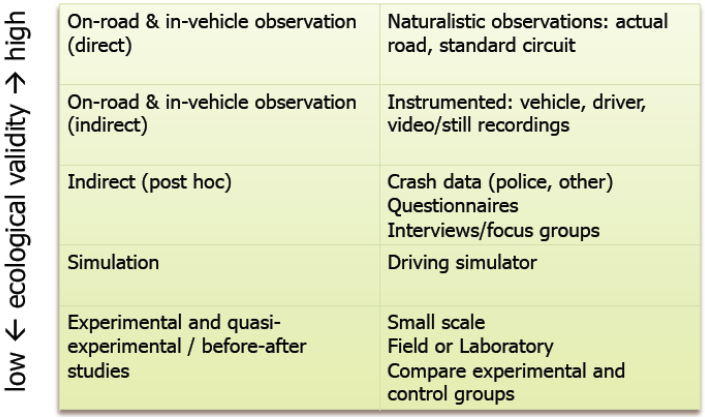


Figure 2.5 – Methods to study driving behaviour, adapted from (Glendon, 2007)

2.3.3 Conclusions

There are several ways to classify methods to study driving behaviour, of which two were presented in the previous section. Hagenzieker and Brookhuis (2010) distinguishes three predominant ways: interviews and questionnaires, post hoc data and direct observations. This last category can be further split into driving simulators studies, field studies and naturalistic driving observations. All these methods have their own advantages and disadvantages. Glendon (2007) summarized these methods based on their ecological validity in a table. The sub-research question "How can lane change behaviour be studied?" is thus answered. The acquired insight in the different methods and their advantages and disadvantages will be used to comment on the used methods in this study.

There can be some discussion on where to categorize the methods applied in this study. The driving study is an direct real time in-vehicle observation of driving behaviour by means of video recordings, which can be classified in the category with the highest ecological validity. However, in the driving study the participants need to drive a predefined route, which requires a relative short time, in a car which is not their own car. These components can be classified in the second highest group based on the ecological validity. Observing participants over a longer time in their own car would have resulted in a better observation of their naturalistic driving behaviour. The behaviour observed during the driving experiment is only a snapshot of their complete behaviour, which is a set of different driving styles. The interview that will be conducted after the participants have driven the route is an indirect method to study driving behaviour. Although in combination with the driving experiment the validity of the interview is believed to be higher than a regular interview in which driving behaviour is discussed, since concrete traffic situations can be recalled and discussed that occurred in the driving experiment.

The questionnaire to examine the actions of drivers on certain traffic situation is also an indirect method to study driving behaviour. Participants namely need to state what they should do in a particular traffic situation, however, self-reported behaviour is biased by socially desirable behaviour and self-depiction. To increase the validity of the questionnaire video clips from real traffic situations are used in the questions. There are several advantages of using questionnaires compared to other methods to study driving behaviour, namely: large amounts of data can be collected and analysed in a short time with low costs (Lajunen and Summala, 2003). Furthermore, in some cases questionnaires also allow to study aspects of driving behaviour which are difficult or impossible to

study with other methods, such as observations and interviews. These aspects include for example measurements of driving style among many different traffic situations, on which observations only would result in a few observations during a single trip, while questionnaires can be made such that much more information can be obtained (Lajunen and Summala, 2003). This advantage is mainly applicable when self-reported behaviour or self-reported driving style is studied with for example the Driving Behaviour Questionnaire(DBQ) or the Driving Style Questionnaire(DSQ).

Chapter 3

Driving experiments

This chapter describes the literature study concerning driving experiments. The following sub research questions will be answered throughout the chapter:

- What lessons can be learned from previous studies into driving behaviour that used driving experiments?
- To what extent do participants of a driving field test show naturalistic driving behaviour?
- How well can drivers describe their own driving behaviour?

Section 3.1 refers to previous studies that have used driving experiments to study driving behaviour, and what lessons can be learned from these studies. Section 3.2 describes how driving behaviour might be affected by the experimental set-up, and thus to what extent drivers show naturalistic driving behaviour in field tests. Section 3.3 presents a first discussion on the validity of self-reported driving behaviour. The chapter ends with section 3.4 that gives a brief recap of the main findings throughout the chapter.

3.1 Driving experiments in previous studies

This section answers the first sub research question stated above: "What lessons can be learned from previous studies into driving behaviour that used driving experiments?". Many studies in the past have used driving experiments to study driving behaviour. Often instrumented vehicles have been used to measure variables like speed, steering angle, headway and the use of turn signals (Brackstone *et al.*, 1998; Dingus *et al.*, 2006; Kondyli and Elefteriadou, 2012). These studies were performed to collect data for calibration and estimations purposes of gap acceptance and car-following models. Driving experiments with instrumented vehicles have also been done to study the workload of drivers (Chang *et al.*, 2001) or to examine safety issues (Hanowski *et al.*, 2006).

Only two studies are known that conducted driving experiments in combination with interviews to get insight in the underlying motives of driving behaviour: one study performed by Knoop *et al.* (2015) and one study by Kondyli and Elefteriadou (2012). In the study by Knoop *et al.* (2015) 10 participants drove a pre-defined route over a Dutch motorway that took approximately 25 minutes to complete. A Toyota Prius was used that was equipped with three video cameras to record the front situation, back situation and speed display of the vehicle. The aim of the study was to investigate hidden strategies related to lane changing behaviour by means of a combination of stated and revealed preference (Knoop *et al.*, 2015). The study points out several aspects that are important in

a driving experiment. The number of participants was small and the sample was not representative for the population, but the study still gives a good starting point for the identification of strategies. To not affect the driving behaviour of the participants, they are told as least as possible concerning the aim of the study. Interviewing the participants after driving has also been a conscious choice so that participants would show their naturalistic driving behaviour better. In the interview participants were asked a mix of prepared and open questions related to their test-drive experience. Three groups of prepared questions were asked, namely questions related to the background of the participants, questions related to general driving behaviour of the participants and questions related to the driving experiment. The interview started with the question to what extend they drove as their normal driving behaviour. Furthermore, they encountered that some participants were not familiar with or aware of peak hour lanes.

Kondyli studied driving behaviour at merging areas by in-vehicle observations during driving experiments (Kondyli and Elefteriadou, 2012). 31 drivers participated in the experiment and drove a predefined route over a motorway in Florida that took approximately one hour to complete. An observer was present in the vehicle during the complete driving experiment. While driving participants had to comment on their driving behaviour and thinking process. Participants were also asked to report cooperative driving behaviour of other drivers when they would merge onto the motorway. However, several researchers have argued that the presence of an observer inside the vehicle affects driving behaviour (Lee *et al.*, 2004). Participants tend to show socially desired behaviour when they are aware their behaviour is being observed. Participants were recruited via the internet and local organizations. Candidates had to fill in some of their demographic characteristics, which were used for pre-screening: gender, age group, race, driving experience, occupation, driving frequency, hours per week, peak/non peak and vehicle ownership. These demographic variables were used to select a diverse group of participants. They aimed at 60 participants to participate in the experiment, however, many participants did not appear at the scheduled meetings. Finally, all participants had to fill in a background survey form that included 7 multiple-choice questions concerning their driving style. The questions referred to:

- the participants' desired speed in good visibility and a speed limit of 110 km/h;
- lane-changing habits;
- how aggressive they consider themselves;
- how aggressive their friend/family consider them;
- when and where they typically merge onto the motorway;
- how they react to a vehicle on the merging lane when they would drive on the shoulder lane;
- and whether they plan extra time in their trip to account for possible delays.

The video recordings of the test-drives were used to estimate parameters concerning distances and speeds when participants merged onto the motorway. Observations on the merging process resulted in the formulation of a five step merging process, which incorporates speed adjustment decisions, gap choice and gap acceptance. Merges during the driving experiments were categorized as either free, cooperative or forced merges. Merges onto the motorway were compared based on speed and merging position for ramps with a parallel design and a taper design. Furthermore, qualitative and quantitative factors from the observed behaviour during the driving experiment were used to categorize the participants into three driver behaviour types: aggressive, average and conservative drivers.

This categorization was based on previous research (Kondyli and Elefteriadou, 2009). The qualitative factor is the level of 'selfishness' of a participant during the driving test. Aggressive drivers will not yield for vehicle on the on-ramp, dislike they are being cut off, and it is very likely that they force other vehicles to decelerate. On the other hand, conservative drivers mainly act as a response to other road users, will yield for vehicles on the on-ramp and hesitate when they merge onto the motorway. Average drivers take both their own status as the impact of their actions on other drivers into account. The quantitative factors to categorize all participants are the number of performed discretionary lane changes in light traffic conditions and desired speeds. The desired speed of participants was determined based on driven speeds in free-flow and non car-following conditions during the driving experiment. A sample of the driver behaviour analysis is given in table 3.1. Observations from the field test and responses from the background survey form are compared.

Table 3.1 – Sample of driver behaviour analysis from Kondyli and Elefteriadou (2012)

ID	Field Observations			Background survey responses			
	DLC	Desired Speed (km/h)	Driver Type	Lane Change	Travel Speed (km/h)	Driver Type	Driver Type by Friends
10	7	124	Aggressive	Very often	120 to 130	Somewhat aggressive	Somewhat aggressive
23	4	109	Average	Very often	110 to 120	Somewhat conservative	Very conservative
17	0	97	Conservative	Sometimes	<100	Very conservative	Very conservative

A study by Boyce used an instrumented vehicle in combination with a questionnaire to examine relationships between personal characteristics and several driving behaviours (Boyce and Geller, 2002). In this study 61 participants conducted a personality questionnaire and drove a predefined route that took about 45 minutes to complete in an instrumented vehicle that measured several variables and recorded the driving trial. Furthermore, after the test drive each participants had to fill in another questionnaire concerning risk-taking. The researchers misled the participants from the real aim of the experiment by presenting another study objective, so that the participants would show naturalistic driving behaviour while not being affected by the study goal. Before the experiment was conducted each of the driving licenses of the participants were checked, participants had to conduct a hearing and vision test and each of the participants had to read and sign informed consent documents, in which the objective of the study was described to be an investigation of way-finding strategies.

The experiment conducted in the current study has also resemblance with focus group discussions concerning driving behaviour. Focus group discussions are useful to collect relevant information. Already in 1930 the first focus group discussions were applied when social scientists wanted to have open discussions instead of close-ended interviews (Krueger *et al.*, 2000). Kondyli and Elefteriadou (2009) studied merging behaviour at motorways by means of focus group discussions. Participants had to discuss and indicate their thinking process during a merging manoeuvre from on on-ramp to a motorway. They used focus groups since observations on driver behaviour are usually external observations but these give no information on the thinking process of drivers. Kondyli and Elefteriadou (2009) states that focus groups help to understand the drivers thinking process and the factors

that affect their behaviour, upon this is accurately modelled in simulation models.

Focus group discussions have also been used to collect information on lane changing from drivers to be included in lane change models (Sun and Elefteriadou, 2011). Several scenarios for lane changing on urban streets were presented and discussed in focus groups. Researchers tried to determine the likelihood of initiating lane changes for each scenario. Focus group discussions were used in this study since traditional vehicle data do not provide information on the thinking and decision-making process of drivers during lane-change manoeuvres. All participants of the focus group discussions were classified into a certain driver type based on their background information, like age and gender. The researches formulated four different driver types based on the responses of the participants, these four are presented in table 3.2. For each driver type a likelihood was then determined, as well as factors that are of importance to make a lane change. Factors, as congestion level and speed differences, were relevant for all scenarios. They furthermore found that there is a variability of driver behaviour for the lag vehicle during lane changes. Drivers of type A and B typically cooperate and make space so the subject vehicle can change lanes, where drivers of type C and D typically do not cooperate and increase or maintain their speed.

Table 3.2 – Driver types distinguished by Sun and Elefteriadou (2011)

Driver Type	Desiring Speed Advantage	Risk Taking	Consideration of Consequence	Selfishness
A	No	No	No	No
B	Sometimes	No	Yes, always	No
C	Yes, always	Sometimes	Sometimes	Yes, always
D	Yes, always	Yes, always	No	Yes, always

Other studies that used focus groups, studied for example the quality of service of motorways (Hall *et al.*, 2001; Hostovsky and Hall, 2003) and the driving behaviour of Chinese drivers on urban roads (Li *et al.*, 2014b). However, as Sun and Elefteriadou (2011) points out, there are some big differences in focus group discussions and questionnaires or interviews. Focus group discussions involve many people at the same time which encourages more critical thinking. Also due to group interaction greater insight can be obtained in the participants thinking and beliefs.

3.2 Naturalistic driving during a field-test

This section answers the sub research question "To what extent do participants of a field test show naturalistic driving behaviour?". In a driving experiment it is important that participants show naturalistic driving behaviour as best as possible. However, due to several factors participants might behave differently which will affect the validity of the results.

Previous studies mentioned that the presence of an observer influences the driving behaviour of participants, and will result in less naturalistic behaviour (Lee *et al.*, 2004; Dingus *et al.*, 2006). One study found that drivers show safer behaviour when they are being observed by monitoring systems (Hickman and Geller, 2005). The duration of experiments has also been mentioned, since driving behaviour of people is a set of driving styles affected by for example their mood and traffic conditions, of which only a small part can be observed during a short driving experiment. An experiment with a relatively short duration can give insight in driving behaviour, but will not include a range of

behaviours that represent naturalistic driving behaviour (Lee *et al.*, 2004).

Furthermore, instructions or clarifying the aim of an experiment could also lead that people do not drive as they would normally do. When participants are told that the study focuses on lane change behaviour, they might behave very conscious concerning their lane choice. One study mislead participants from the real aim of the study by pretending the study had a different topic (Boyce and Geller, 2002). However, ethically seen this method can be questioned, and even by pretending the study has a different aim, drivers might still adapt their driving behaviour due to the experimental nature of the test drive. Several other studies, therefore, gave no instructions beforehand of the driving experiment (Dingus *et al.*, 2006; Knoop *et al.*, 2015).

3.3 Validity of self-reported behaviour in interviews

In this study the experiment combined with an interview is a qualitative investigation of lane change behaviour. In contrast to the study by Lee *et al.* (2004) and Dingus *et al.* (2006) no instrumented vehicle is used to record data of certain variables. In the interview questions related to the shown behaviour during the field test and hypothetical situations have been discussed. However, it is important to know how well a person can describe its own behaviour, will the interview give some valid information of the participants driving behaviour?

Brookhuis (2005) described that driving behaviour is to some extent performed on the "auto-pilot" by drivers, and it is thus arguable how well people can describe their behaviour which is partly done unconscious. According to Michon (1984) changing lanes takes place at the manoeuvring level of the driving task, and this level is characterized by controlled action patterns. Experience will increase the number of actions that are performed automatically, experienced drivers will thus perform more of their actions, like changing lanes, on the auto-pilot in comparison with novice drivers. When actions are done automatically, describing and motivating these actions at a later stage could be hard for a person. This could make self-reported behaviour less valid. However, there should be noted that there are large differences between individuals, and that on these grounds the validity of self-reported behaviour in the current driving experiment cannot be assessed.

The interview in this study is somewhat comparable with a focus group discussion. In a focus group discussion it is important that the moderator, who conducts the research, creates a comfortable environment for the participants that is non-evaluative and non-threatening. The quality of the results from a focus group rely heavily on how well the moderator conducts the discussion. The moderator can choose different levels of directiveness, the use of discussion aids and intimacy (Stewart and Shamdasani, 2014). In marketing studies respondents, for example, sample a certain product, which is used as aid to stimulate discussion . In the current study, the test drive can be seen as a discussion aid that helps the discussion concerning a participants' lane change behaviour. However, the question 'how well what people say they do correspond with what they actually do' is still unanswered. This questions is, on the other hand, also of relevance to assess the validity of a questionnaire to study driving behaviour. Section 4.2 will elaborate more on the validity of self-reported behaviour.

3.4 Conclusions

Several studies have been found that conducted driving experiments. Only two of these studies applied test drives in combination with interviews as data collection method to study underlying

motives of driving behaviour, namely the studies by Knoop *et al.* (2015) and by Kondyli and Elefteriadou (2012). Several lessons have been learned that are taken into account in setting up an appropriate driving experiment:

1. Minimize information on the goal of the study beforehand to not affect a participants driving behaviour.
2. Interviewing the participants afterwards instead of during the test drive will result in more naturalistic driving behaviour of the participants;
3. Participants tend to show socially desirable behaviour when they are aware their behaviour is being observed, therefore it is better to let the participants drive on their own without any other car passengers present in the vehicle;
4. Participants in the study by Keyvan-Ekbatani *et al.* (2015b) could easily recap most of the test drive that took 25 minutes to complete;
5. Prepare pre-defined questions for the interview, but also hypothetical traffic situations can be used during the interview to get insight in the driving behaviour of a participant;
6. The sample of participants in a driving experiment will not be representative for the population due to the limited number of participants that can participate, however it gives a good starting point for the questionnaire;
7. Participants in the study by Kondyli and Elefteriadou (2012) had to fill in a background survey form on which they were categorized into driver types, which can add an extra dimension to the results.

Like focus group discussions, interviews are useful to get insight in the thinking process of drivers and the factors that affect their behaviour. Although focus groups will encourage more critical thinking than one-to-one interviews, external observations of someone's driving behaviour do not give information on motives and thoughts of a drivers, and thus interviews are necessary.

Driving behaviour is a set of driving styles which can (probably) not all be observed in a driving experiment with a short duration. However, the aim of the driving study is to get insight in motives behind driving behaviour. Participants need to be able to recap most parts of the test drive, and thus an experiment with a long duration is not suitable. The driving experiment will thus only show a fraction of the total set of driving styles of a participant. Furthermore, changing lanes is executed on the manoeuvring level of the driving task. Dependent of someone's experience level, actions on this level are (partially) performed automatically by a driver. This could make it harder for a driver to fully explain its driving behaviour.

The success of the interview lies heavily with the moderator. The video of the test drive is on the other hand a useful discussion aid which will help the moderator to get a better view of the driving behaviour of the interviewee. The insight that is gained concerning driving experiments and interviews throughout this chapter is used to set-up an appropriate driving experiment which is described in chapter 5.

Chapter 4

Questionnaires

This chapters describes the performed literature study on questionnaires concerning driving behaviour and answers the following sub research questions:

- What are the lessons learned in previous studies that used questionnaires to study driving behaviour?
- How suitable and valid is a questionnaire to study driving behaviour?

First, section 4.1 presents a review of previous studies that used questionnaires to study driving behaviour. Second, section 4.2 describes to what extent self-reported behaviour through a questionnaire is valid for the actual driving behaviour. This chapter finishes with section 4.3 which contains a brief recap of the main findings and how these are used in the current study.

4.1 Questionnaires in previous studies

Questionnaires to study driver behaviour have been widely used in the field of traffic safety and accident analysis. Reason *et al.* (1990) developed the Driver Behaviour Questionnaire (DBQ) that have been used many times since then (Bener *et al.*, 2008a,b; De Winter and Dodou, 2010; Li *et al.*, 2014a). The DBQ is based on a theoretical taxonomy of aberrant behaviours and is a tool for measuring self-reported driving style and the analysis of the relationship between driving behaviour and accident involvement (Reason *et al.*, 1990). There exists several forms of the DBQ, on which multiple evaluation studies have been done to assess their performance (Lajunen *et al.*, 2004; Özkan *et al.*, 2006).

The original DBQ distinguishes five classes of aberrant behaviour and consists of three sections. The first section concerns questions regarding occupation, marital status, age groups, capacity of car, number of years the person had been driving, the average annual mileage, whether or not he or she commuted regularly, mileage to and from work, and finally the frequency of motorway use. The second section contains 50 behavioural actions related to errors and violations. Participants were asked to point out on a five-point category scale, ranging from 0 (*never*) to 5 (*nearly all the time*), how often they committed each of the 50 actions. The 50 actions are discriminated to their nature in five categories (slip, lapse, mistake, unintended violation, deliberate violation) and to the posed thread to other road users. The third section contains five self-reported questions concerning their driving-behaviour, for example how safe a driver they would rate themselves. The set-up of the DBQ allows for statistical analysis, and this way differences have been found between, for example, men

and woman concerning the number of violations made.

Some examples of the application of a DBQ to study driving behaviour:

1. Bener *et al.* (2008a) used a DBQ to study the impact of driving a four-wheel car on driving behaviour.
2. Parker *et al.* (1995) made a questionnaire that was adapted from the original DBQ to study the frequency of fast driving.
3. Davey *et al.* (2007) used the DBQ to examine on-road behaviour among professional drivers concerning errors and violations.

Several other forms of questionnaires exists that have been used in driving related studies, namely Driving Style Questionnaire, Driver Attitude Questionnaire, Decision Making Questionnaire, Cognitive Failures Questionnaire, Propensity of Angry Driving Scale, Driver Perception of Pressure, Driving and Riding Avoidance Scale, and Sensation Seeking Scale (De Winter and Dodou, 2010). The Driving Style Questionnaire (DSQ) has been used to examine a relationship between behavioural variables, like speed, headway and seat belt use, with risky driving behaviour or accident involvement (e.g. West *et al.* (1992)).

Although many forms exists of the DBQ, a questionnaire has never, to the best of the author's knowledge, been used to ask people to their actions concerning speed and lane choice in particular traffic situations by means of video clips from traffic situations. The study by De Craen *et al.* (2008) used pictures of traffic situations to identify novice, unsafe and overconfident drivers. Several traffic situations were shown to the participants via two almost identical photographs. One of these photographs contained an extra element that increased the traffic complexity. The participants had to report the speed they would drive in that particular traffic situation. The study found that novice drivers performed worse than experienced drivers, meaning that they did not adapt their speed to the complexity of the traffic situation. The results from this test were evaluated by on-road driving assessments and a driver behaviour questionnaires, and concluded that this method is effective to measure speed adaptation to traffic situations.

4.2 Validity of self-reported behaviour in questionnaires

Questionnaires have been used on a large scale in research to study driving behaviour, while the validity of these questionnaires has been argued regularly. It is important to know how valid self-reported behaviour is, since there can be quite a difference between what drivers say they do and what they actually do. Self-reports can be validated with objective measurements, which has been done in several studies. One of the first to compare self-reported behaviour with observations was West *et al.* (1992). In a study they let 48 drivers answer questions related to their driving style and drive a pre-defined route under observation. A good agreement was found between observers judgement and self-reports of speed, attentiveness and carefulness.

Zhao studied the relationship between results from the DBQ and driver behaviour variables, like speed, acceleration, lane choice and several others. He found that drivers with high violation scores in the DBQ showed higher speeds, poorer lateral control, more lane changes and drove more often in the median lane than drivers with low violation scores in the DBQ (Zhao *et al.*, 2012). The results of this study do not assess the validity of self-reported behaviour, but have shown that there is a relationship on the answers given in the DBQ by participants and their actual driving behaviour on

the roads.

A study by Staplin found big errors in self-reports of older adults concerning their annual and weekly kilometres driven (Staplin *et al.*, 2003). Blanchard underpinned these findings in 2010, by concluding that older drivers forget a significant number of trips they made (Blanchard *et al.*, 2010). They furthermore concluded that self-reports of older drivers for some driving style variables, like frequency of driving in city, or at night, were quite consistent with observations. In another study by Staplin was found that drivers with a low annual mileage tend to overestimate their annual mileage, while drivers with a high annual mileage tend to underestimate their annual mileage (Staplin *et al.*, 2008). Other studies found that drivers forget approximately one-third of accidents in which they were involved each year (Maycock *et al.*, 1991), while up to 80% of near-accidents were missed in self-reports(Chapman and Underwood, 2000). Several studies also found that people tend to overestimate their driving capabilities (Svenson, 1981; Groeger and Grande, 1996).

Lajunen and Summala (2003) underpin that questionnaires have advantages above other methods and that they allow for the collection and analysis of large amounts of data in a relatively short time for low costs. However, people tend to give socially desirable responses to questionnaires which affect the reliability. In psychology literature two types of socially desirable responses are distinguished, namely impression management and self-deception. The first refers to the tendency of people to give socially desirable answers to others, while the second is defined as the biased but subjectively honest self-description. Lajunen and Summala (2003) studied the effect of social desirability on DBQ answers by comparing the DBQ answers from a public and private setting, and concluded that there was not a large difference in the DBQ answers from the public and private setting. They note that the reliability of the DBQ answers depends largely on the anonymity of the respondents and the techniques that are applies to reduce social desirable responses (Lajunen and Summala, 2003).

A meta-analysis by De Winter and Dodou (2010) on Driver Behaviour Questionnaires showed that errors and violations are positively correlated with self-reported accident involvement, and that objective accident data is not necessarily more valid than self-reported accident involvement, since both data sources are subject to biases. Reason *et al.* (1990) already pointed out that the DBQ is "several stages removed from the actuality of what goes on behind the wheel". As another limitation of the DBQ, Bjørnskau and Sagberg (2005) remarked that it is hard for drivers to remember unconscious errors because they are unconscious.

4.3 Conclusions

Questionnaires have been widely used to study driving behaviour, of which the Driver Behaviour Questionnaire (DBQ) is one of the most applied forms. The DBQ contains several statements on which respondents need to respond to what extent they agree on a five-point category scale. These type of questionnaires concern driving behaviour in general by only presenting statements with respect to someone's driving style, while the questionnaire of the current study presents explicit traffic situations via videos, which makes these questionnaires different. However, no study, of which the author was aware, used videos of traffic situations to study driving behaviour before. One study was found that used photographs that showed a traffic situation to identify novice, unsafe and overconfident drivers. The method was found to be effective to measure speed adaptation in traffic situations (De Craen *et al.*, 2008). The set-up of this survey has resemblance with the questionnaire developed in the current study. However, besides speed adaptation also someone's lane choice is measured

in the current survey, which results in more degrees of freedom in the multiple choice answers, which might lead into a larger deviation of self-reported behaviour from someone's actual driving behaviour.

The validity of self-reported behaviour through questionnaires is debated regularly. Several studies (West *et al.*, 1992; Zhao *et al.*, 2012; Staplin *et al.*, 2003; Maycock *et al.*, 1991) have been discussed that give insight in the validity of self-reported behaviour. Some of these found a good agreement between self-reported and objective measurements of their driving behaviour, while some others found large errors in self-reported behaviour. Lajunen and Summala (2003) concluded that the reliability of the questionnaire results depends largely on the anonymity and the techniques to reduce socially desirable behaviour. Nevertheless, errors are expected in the outcome which can be limited to some extent by the set-up of the questionnaire.

Although self-reported behaviour shows errors and people tend to give socially desirable responses, surveys allow for the collection of large amount of data in a relatively short time and low costs, which makes questionnaires preferable over other methods. Despite several factors that affect the validity of self-reported behaviour or the results from the questionnaire, an online questionnaire is the most applicable method to get insight in driving behaviour of a large number of drivers. It is furthermore believed that the videos that are included in the survey will increase the realism of the driving behaviour that is asked for. Other methods, like simulator studies or interviews, are too time and money consuming to collect the required information of a large amount of drivers.

The limitations and the validity of self-reported behaviour needs to be taken into account in the interpretation of the results from the questionnaire in chapter 9. Furthermore, to decrease the tendency of respondents to give socially desirable answers their anonymity in the questionnaire needs to be ensured. This will be taken into account in the set-up of the survey, which is described in chapter 7.

Part II

Driving study

Chapter 5

Driving study

This chapter discusses the set-up of the driving experiment. Decisions made concerning the methodology will be underpinned with insights gained in the literature study. The first section describes the recruitment of the participants, the second section describes the set-up of the test drive, the third section describes the set-up of the interview and the fourth section describes the background information form.

5.1 Participants

In total 34 participants have been recruited via flyers and social media posts. An online application form was created in Google Forms, which allowed the participants to pick a day and timeslot. Participants have not been pre-screened, but the recruitment of the participants took place at three different locations, which resulted in more diversity in the background of the participants than if only one location was used. The three locations were as follows:

- University of Technology, Delft
- Rijkswaterstaat, Rijswijk
- Gardening centre, The Hague

There should be mentioned that at Rijkswaterstaat recruitment took place at a department that involved traffic engineering. These participants are thus expected to be more informed and aware of traffic rules, the motorways included in the route and the traffic system in general.

The recruitment of participants started approximately one month before the execution of the driving experiment. About one week before the driving experiment took place all participants received an informed consent form via e-mail which can be found in appendix A.1. In this form the participants were informed about the goal, the methodology, the route, and other practical information of the driving experiment. In literature was found that participants could (un)consciously change their driving behaviour when they are aware of the aim of the experiment. However, it is not ethically right to not inform the participants at all on the goal of this study. Therefore the description of the aim of the driving experiment has been kept a bit vague:

"This study aims to get more insight in human behaviour on motorways, which is valuable information to improve and develop simulation models of motorway traffic."

The driving study was held on 8 days between the 1st of and the 10th of February 2016. For each participant one and a half hour was scheduled to complete the route and interview. All participants received a gift card of 20 euro for their participation in the experiment. Since human participants are involved in the experiment approval by the Ethics Committee was required. The application to conduct this study has been approved on 11-12-2015, before any participants took part in the experiment.

5.2 Test drive

The participants drove a 2013 Toyota Prius which has been equipped with three cameras (of which example images are displayed in figure 5.1):

- one camera to capture the traffic situation in front of the vehicle;
- one camera to capture the traffic situation behind the vehicle;
- one camera to capture the driver inside the vehicle during driving.

Figure 5.1 – Examples of video material from front, back and interior cam

The camera that registered the traffic situation in front of the vehicle was equipped with GPS. This way the actual speed of the vehicle has been displayed in the video. Another GPS-receiver was placed in the car to track the car during the driving experiment. For each participant a log-file and a speed-time graph are created automatically based on the information from this GPS-receiver. In this log-file 0 to 8 times per minute the location and the speed of the vehicles is registered. The speed graphs give a quick and clear view on the trip of each participant. Congestion, a bridge opening or a traffic light can be easily recognized in these graphs. Several examples of these speed profiles are found in appendix A.4.

The participants drove on their own, since in the literature study it was found that other occupants or observers will affect ones driving behaviour. Furthermore, one study (Hickman and Geller, 2005) concluded that a driver adapts his driving behaviour when he is being monitored by an observation system. Although the cameras in the car are not comparable with the observation system from that study, participants could still notice they are observed by the presence of the cameras in the car, which might lead to adapted driving behaviour.

Naturalistic driving behaviour is a set of driving styles and can be best observed over a longer period (Lee *et al.*, 2004). However, participants are not expected to be able to recap in detail their motives and decisions in traffic situations of quite some time ago. Since the participants' driving behaviour is discussed afterwards on the basis of the video recordings, participants will drive for only a short time period, so they are better able to recap the traffic situations and the motives for their behaviour. In the study by Knoop *et al.* (2015) participants had to drive a trip of 14 kilometres which took on

average 25 minutes to complete. The researchers stated that the participants were very well able to recap all the traffic situations they encountered and the decisions they made.

The route that participants had to drive in the driving experiment is illustrated in figure 5.2 and leads over the A13, A20 and A4. The A13 is a three-lane motorway, which has a speed limit of 100 km/h from junction 'Ypenburg' to on-ramp 'Berkel en Rodenrijs' and a speed limit of 80 km/h in combination with average speed checks from the on-ramp 'Berkel en Rodenrijs' to the junction 'Kleinpolderplein'. The A20 is also a three-lane motorway and has a speed limit of 100 km/h from junction 'Kleinpolderplein' to junction 'Kethelplein'. Just after junction 'Kleinpolderplein' on the A20 is a bridge located named 'Giessenbrug'. The bridge opens several times per day to let ships pass the A20 and is operated between 09:00 - 15:30 hour. The A4 has three lanes from junction 'Kethelplei'n to on-ramp 'Delft-zuid', two lanes from 'Delft-zuid' to 'Den Haag-zuid' and three lanes from 'Den Haag-zuid' to junction 'Ypenburg'.

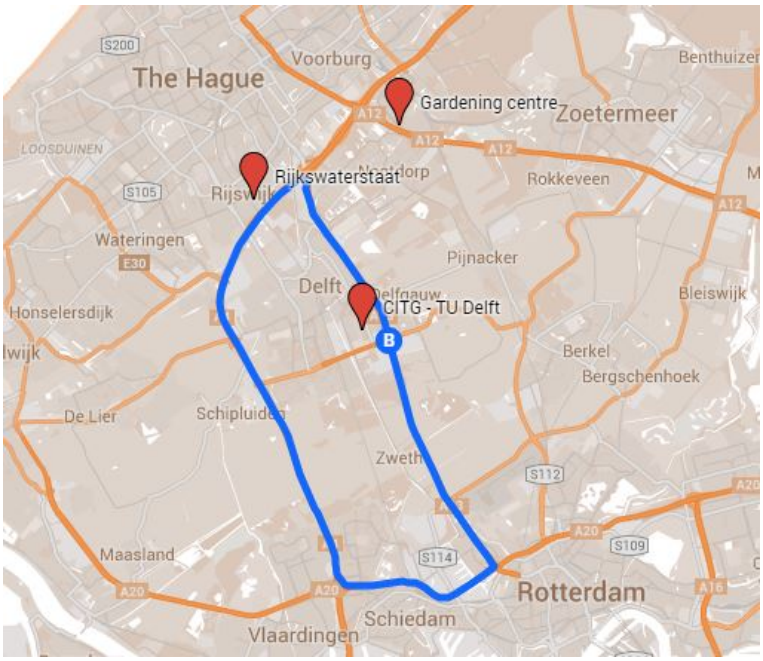


Figure 5.2 – Map indicating the main route over the motorways and the three different starting locations (source: Google Maps)

Three different starting locations have been used in the driving experiment to get a sufficient number of participants and to ensure a variety in backgrounds of participants. The main route that leads over the A13, A20 and A4 is easily accessible from these locations within a short amount of time. The first starting location is the Civil Engineering faculty of the TU Delft on the Stevinweg, the second location is the Rijkswaterstaat office on the Lange Kleiweg in Rijswijk, and the third location is a gardening centre on the Donau in The Hague. The three starting locations are indicated on the map in figure 5.2. The route that starts and ends at the TU Delft is approximately 36 kilometres and takes around 29 minutes to complete. The route starting and ending at Rijkswaterstaat is in total approximately 37 kilometres and takes around 30 minutes to complete. The route starting at the gardening centre is approximately 45 kilometres and takes around 35 minutes to complete. The three routes are illustrated in figure 5.3.

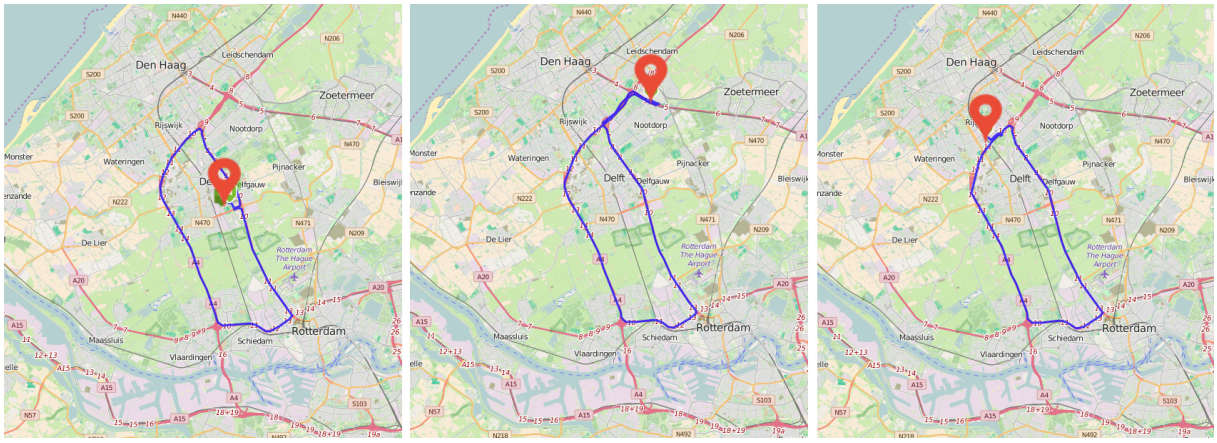


Figure 5.3 – Route per starting location (source: OpenStreetMap)

5.3 Interview

The aim of this study is to get more insight in the lane change driving behaviour of drivers on motorways. An interview is a useful method to really get the personal thoughts and opinion from the participants concerning their driving style, this has been acknowledged by the studies of Kondyli and Elefteriadou (2012) and Keyvan-Ekbatani *et al.* (2015b). After the participants return from driving the route, an interview is held concerning their driving style. This interview is semi-structured and consists of two parts, a general part concerning their driving style and one part concerning their test drive.

Beforehand a protocol has been developed that described the set-up of the interviews and the main questions, to contribute to the success of these sessions. This protocol follows the guidelines from other studies that used qualitative methods like interviews and focus group meetings (Kidd and Parshall, 2000; Tsapi, 2015). From these studies is learned that questions need to be short and to the point, one-dimensional, unambiguously worded and open-ended. The success of an interview thus weigh heavily on the researchers' performance.

Each interview was introduced by the researcher explaining the ground rules for the conversation, which read as follows:

1. I want you to do the talking; speak freely about your thoughts and motivations.
2. Tell your own thoughts and motivations; every ones thoughts are important for this study.
3. Everything you say is confidential; you will not be judged on your driving style or your compliance with traffic rules.
4. The interview will be recorded if the interviewee agrees, so the researcher can recall the whole conversation.

The first part of the interview consisted of some general pre-defined questions concerning the participants driving style, driving experience and the test drive, namely:

- To what extent did you just drive as you would normally drive?

- To what extent are you familiar with the motorways of the route?
- How often do you drive on these roads?
- To what extent did you have to make use of the navigation system to follow the route?
- To what extent did you have to get used to the car?
- What is according to you the aim of this study?
- How would you describe your own driving style on motorways?
- Is there a specific lane where you often drive?
- How fast would you drive on a 3-lane motorway with a speed limit of 100 km/h without speed checks?
- Do you make use of driver assistance systems, such as cruise control? If yes, how often and when do you use these systems?

After the above stated questions the researcher explained the aim of this study in more detail and introduced the interviewee to the four lane change strategies revealed by Keyvan-Ekbatani *et al.* (2015b). A brief explanation of each strategy was given to the participants, which is found in table 5.1. Thereafter the following questions were asked:

- In what strategy or strategies do you recognize yourself?
- (If interviewee answered multiple strategies) When would you apply which strategy? And why?

Table 5.1 – Description of the four lane change strategies given to participants

Strategy	Description
1: Speed leading	In this strategy you have a certain desired speed. If you encounter a slower predecessor you will change lanes to overtake the vehicle. If later on your initial lane is empty you will change back.
2: Speed leading with overtaking	In this strategy you also have a certain desired speed which you try to maintain, and you will also change lanes when you encounter a slower predecessor to overtake it. However in contrast to strategy 1 you will increase your speed during overtaking. This way the overtaking manoeuvre takes less time, so you will hinder other drivers less.
3: Lane leading	In this strategy you feel comfortable in a certain lane in which you will stay driving. You adapt your speed to your predecessor in the same lane.
4: Traffic leading	In this strategy you do not have a preference for a speed or lane, but you will adapt your speed to that of other drivers on the road.

The second part of the interview consisted of looking back the videos from the test drive. The interviewee was asked to comment on their own driving actions concerning their lane choice, speed choice and underlying motives for their behaviour. At moments the researcher noticed interesting topics for discussion, open-ended questions were asked to the interviewee. The video of the cam that recorded the situation in the front of the vehicle was used to start the discussion. If the interviewee mentioned any interesting events that happened behind the vehicle, the video of the back cam would be replayed. The videos were replayed on a higher speed to shorten the duration of the

interview. Several times during an interview the video would be paused to calmly discuss a certain topic.

Each interview ended with some concluding questions to check if all topics were discussed and the participants said everything he wanted, namely:

- To what extent would you drive the route in your own car similar to what we just saw on the videos?
- To what extent was the test drive representative for your driving style?
- Are there any characteristics of your driving style not discussed in the interview?

5.4 Background information form

As last part of the driving study each participant filled in a background information form. In this form questions were asked concerning personal characteristics, driving experience and driving style. This form is found in appendix A.2.

The questions concerning personal characteristics and driving experience are stated to check how representative the group of participants is for the complete population of car drivers. The questions related to their driving style come from the multidimensional Driving Style Questionnaire by Taubman-Ben-Ari *et al.* (2004). In this study eight different driving styles have been revealed, which are found in the left column of table 5.2.The multidimensional driving style inventory which has been used to reveal the different driving styles consisted of 44 items which participants had to rate to what extent that item fitted their feelings, thoughts and behaviour on a 6-point scale. The aim of this study is not concerned with distinguishing driving styles of drivers, however it could give some explorative insight in the driving style of a participant. Therefore not all 44 items are included in the background information form, but only one item per driving style. In the study by Taubman-Ben-Ari *et al.* (2004) a loading factor is presented for each item that indicates the variance it explains. The item with the highest loading factor per driving style is selected for the background information form, unless the item was not relevant on motorways, see table 5.2.

Table 5.2 – The 8 driving styles from Taubman-Ben-Ari *et al.* (2004) and corresponding items

Driving style	Item	Loading
Dissociative	"I intend to switch on the windscreen wipers, but switch on the lights instead"	0.70
Anxious	"I feel nervous while driving"	0.75
Risky	"I enjoy the excitement of dangerous driving"	0.83
Angry	"I swear at other drivers"	0.72
High-velocity	"In a traffic jam, I think about ways to get through the traffic faster"	0.72
Distress-reduction	"I use muscle relaxation techniques while driving"	0.73
Patient	"I base my behaviour on the motto 'better safe than sorry'"	0.52
Careful	"I tend to drive cautiously"	0.56

5.5 Analysis methods

This section will elaborate on the analysis methods that have been used to extract the main findings from all the information and data that is collected in the driving experiment. The output of the driving experiment consists of video material of each participants test drive, an audio recording of each interview held with the participants and the background information forms the participants had to fill in.

5.5.1 Processing of the interviews

The analysis of the interviews is partly based on the thematic analysis which is often used in the field of psychology. Qualitative analysis methods can be very diverse, complex and nuanced (Holloway and Todres, 2003), but thematic analysis is the fundamental method for qualitative analysis according to Braun and Clarke (2006). The definition of thematic analysis is formulated by Braun and Clarke (2006) as follows:

"Thematic analysis (TA) is a method for identifying and analysing patterns of meaning in a data set."

A theme according to Joffe (2012) refers to a specific pattern of meaning found in the data. A theme can either be drawn from a theoretical idea, which is called termed deductive, or from the raw data itself, which is called termed inductive. A thematic analysis can be performed with the help of software packages using complex coding frame. For this study a more simple adapted version of the thematic analysis is done in which the responses of each interviewee are sorted and structured in themes. Part of these themes follow directly from the pre-defined questions while some themes follow from the raw data. Each interview except one has been held in Dutch, so the raw thematic analysis table has been made in Dutch. From this raw thematic analysis table the main findings will be summarized per theme in chapter 6.3.

5.5.2 Use of the video material

The video material is watched back during each interviews with the participants. In each interview interesting traffic situations have been discussed, and have been put in a list of potential relevant traffic situation for the online questionnaire. This way a long list of interesting traffic scenarios has been created.

If during the set-up of the questionnaire it appeared that there was no appropriate video clip in the initial list to describe a certain traffic scenario, the video material has been searched for additional video clips that are suitable for the intended traffic situation. Besides the use of video clips for the questionnaire, the video material has not been further analysed.

5.5.3 Use of the background information form

The personal characteristics of the participants that have been gathered via the background information form will be used to get insight in the representativeness of the sample. The distribution of the participants over age and gender will be compared with distribution of age and gender of the total population of drivers in the Netherlands. The 'driving experience' and the 'driving style' parts from the background information form will not be used any further. These parts were included in the form so the researcher had some first insight in a participants driving behaviour at the beginning of the interview.

Chapter 6

Findings from the test-drive

In this chapter the findings from the test-drive and interviews are presented. First, section 6.1 will describe the sample of participants. Second, section 6.2 discusses the execution of the field test. Third, section 6.3 presents the major part of this chapter, namely the results of the interviews. In this section an overview is given of the findings per theme which were found relevant. As last, this chapter ends with section 6.4 briefly concluding on the main findings of this chapter.

6.1 Background of participants

Several characteristics of the group of participants of the driving experiment have been summarized in graphs in appendix A.5, these include the distribution of drivers over age, gender, occupation, driving frequency and years of holding a driving license. To compare the sample of drivers that took part in the experiment some graphs on the complete population are shown in appendix A.6.

Although the aim was to get a mixed group of participants by assigning three starting locations for the test drive, students, 20 to 29 years and men are still overrepresented in the sample. However, there is some spread of the participants over the different age groups, the driving frequency and the number of years someone holds a driving license. Nevertheless, the group of participants that works full-time and the group that drives 5-7 days per week are the highest in number per category.

The background information form participants filled after the test-drive included several statements to assess their driving style. From a Driving Style Inventory Questionnaire seven statements were used to get some directions of one's driving style. The initial Driving Style Inventory Questionnaire consisted of 44 items, and for only 7 items it was not possible to categorize drivers into the driving styles. However, it gives some insight in how they drive. The responses on the 7 items are found in appendix A.7.

Remarkably only a few participants totally agree with the statement that they tend to drive cautiously, most answered they somewhat agree, while a few disagree. Most people do not use muscle relaxation techniques, which was an item for the distress-reduction driving style. Only 1 participants agrees somewhat with the dissociate driving style item, which state you sometimes switch on the lights instead of the windscreen wipers. Most people would base their behaviour on the motto 'better safe than sorry', while a few disagree with this statement which belongs to the patient driving style. Almost everyone responded they do not enjoy dangerous driving. Furthermore, most responded also that they do not feel nervous while driving, which was as expected since drivers voluntarily participated in this driving experiment. If a person feels nervous while driving, according to the

driving style questionnaire of Taubman-Ben-Ari *et al.* (2004) that person fits the anxious driving style. People who are anxious to drive are not expected to sing up voluntarily to participate for a driving study, and are thus not represented by the sample of participants.

6.2 Test drive

This section describes the traffic conditions participants encountered during the test drive, it shows some information that was extracted from the speed profiles created of the gps log file and it gives a brief description of the execution of the experiment.

6.2.1 Meta data: Traffic conditions

Figure 6.1 shows the speed-contour plot of the complete route for Monday 1 February 2016. The yellow zone in the figure indicates the 80 km zone that starts on the A13 near Overschie, and shortly after the route continues over the A20 the 80 km zone ends. Several other speed-contour plots and intensity-contour plots of various days the driving experiment was held can be found in appendix A.3. Unfortunately, some induction loop data was missing for the Tuesday and Thursday the experiment was executed, since these days are normally most crowded. Overall there was not much congestion during the execution of the driving experiment. Several speed and intensity diagrams for particular sections along the route are also presented in appendix A.3. From these figures can be concluded that the A13 is the most crowded section of the route with a flow of roughly 5000 vehicles per hour in peak hours and roughly 3500 vehicles per hour in off-peak hours during daytime. The A20 has a flow of roughly 4500 vehicles per hour in the evening peak and roughly 2500 vehicles per hour in off-peak hours during daytime. The A4 has on average the lowest flow with roughly 2500 vehicles per hour in peak hours and 1250 vehicles per hour in off-peak hours during daytime. Note that the new section of the A4, the Ketheltunnel, has partly four lanes, while the presented flows are over the complete roadway. Densities on the new section of the A4 are thus low.

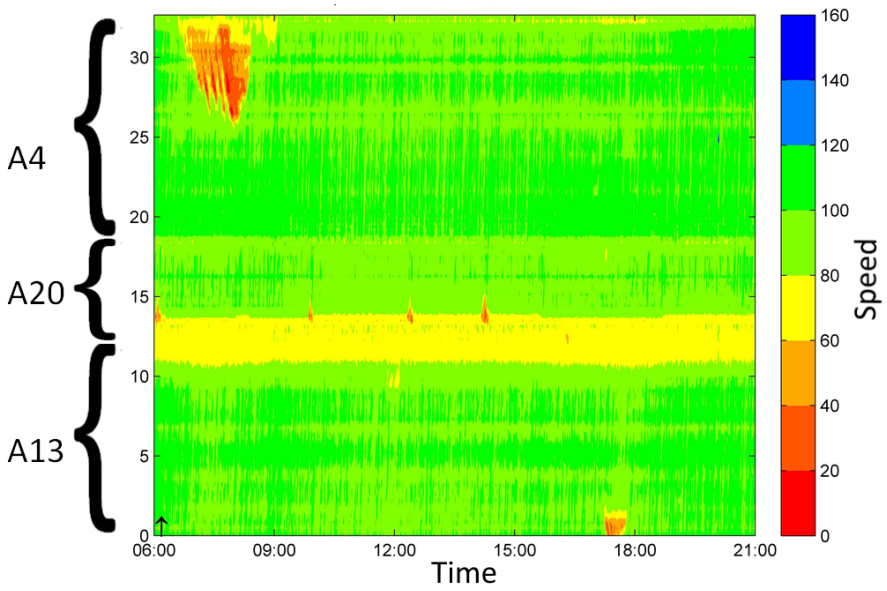


Figure 6.1 – Speed contour plot of complete route for Monday 1 February 2016

6.2.2 Meta data: Speed profiles

Several speed profiles of participants from the driving study are found in appendix A.4. These speed profiles already give some information on the trip of each participant, one example is presented in figure 6.2. The 80 km zone on the A13 can be clearly distinguished in this profile by a temporarily lower speed of 80 km/h in comparison with the rest of the plot. The bridge in the A20 opened several times during the execution of the driving experiment, which is clearly visible in one of the speed contour-plots in appendix A.4. Only two participants encountered a bridge opening, which caused them to stand in a queue for a few minutes. Most participants drove during off-peak hours (09:30 - 16:30 hour). Two participants drove in the morning peak hour (08:00 - 09:00), while three participants drove during evening peak hours (16:30 - 19:00 hours).The speed profile of one of the participants that drove in the morning peak is also presented in appendix A.4 in which congestion is clearly visible.

Figure 6.2 – Example speed profile of one participants test drive

6.2.3 Execution

Before the start of the test-drive all participants were asked if they knew the route and if they wanted to use the navigation system. When participants knew the route, most of the time the navigation system was not turned on to ensure naturalistic driving behaviour, since they would normally also not use the navigation system. Although each participant either used the navigation system or said they knew the route, three participants drove wrong. One participant that used the navigation system took a wrong exit, another participant that also used the navigation system missed an exit, while the third participant who said he was familiar with the route took a wrong exit. In the interviews with these participants, they were asked if their mistake affected their driving behaviour. All three responded it did not affect their driving behaviour.

6.3 Interviews

This section presents the main findings from the interviews with the participants of the driving experiment. These findings form the most important results of the driving study and have been structured per theme.

6.3.1 Familiarity with route

Afterwards all participants were asked how familiar they were with the route. Most participants were familiar with the A13 and 'old' section of the A4, but less or not familiar with the A20 and 'new'

section of the A4. Three starting locations have been used to ensure different background of the participants in the driving experiment. The participants that started from the TU Delft quite often commented that the connection road between the A20 and A4 and the connection road between the A4 and A13 were unfamiliar for them. The new section of the A4 just opened in December 2015, while the driving experiment took place in the first weeks of February of 2016, so indeed it was expected that not many participants had driven over the new section of the A4.

Many participants commented that the familiarity with the road has significant effect on their driving behaviour. Several participants stated that when they were unfamiliar with a certain road section where they had to make a direction decision they would decrease their speed to create some extra time to find the route they had to follow. Furthermore, some participants would increase their speed drastically when they drove on a familiar road section, as a motive behind this behaviour most answer they know where the speed checks were located on that section. One participant stated he always drives faster on a particular section of the route, since normally when he drives there it is early in the morning when traffic intensities are very low.

Participants would also overtake more often on road that was familiar to them, since they knew better what was coming at what distance. The participants that started from the TU Delft, often mentioned the off-ramp on the A13 to Delft which is relatively long. This made them driving for a longer time on the median or centre lane to overtake a few extra vehicles, instead of driving already in the shoulder lane just before the off ramp would start. In generally some people were more willing to overtake other vehicles just before an off-ramp they had to take, when they were familiar with that particular off-ramp. Some participants that started from the gardening centre encountered some heavy traffic on the A4 near Rijswijk, and where they took the parallel roadway to drive around the bottleneck. Colonna *et al.* (2016) studies the effect of route familiarity on speed choice, and indeed it seems that the speed choice of drivers goes up when they got more familiar with a route.

6.3.2 Navigation

A navigation system will influence one's driving behaviour, therefore each participant was asked in advance of the test-drive if he knew the route by hard or if the navigation system should be turned on. 21 of 34 participants drove with the navigation system turned on, although some of them responded afterwards that they did not use it. Some participants commented on the beeps of the navigation system when the drove to the 80 km zone on the A13, it gives a warning that there are speed checks. The navigation system also displays the local speed limit, which was remarked by several participants as useful. Some find the navigation relaxed, since they have to think less for themselves, while one participant remarked that the navigation system distracted him. Several participants had to get used to this type of navigation, since they use a different version or brand themselves, which could give more instructions for example. Most participants only use navigation when they drive unfamiliar routes, although a few mentioned they use it all the time, just for fun or to see their time of arrival.

"I definitely used the navigation system. I like using navigation systems since I do not have to pay attention myself and this way I drive definitely the correct route."

6.3.3 Vehicle

Various answers were given on the question if the participant had to get used to the vehicle. Most participants indicated they had to get used to the vehicle indeed, but that it did not affect their driving

behaviour significantly. While some said the vehicle had a good acceleration, others said the vehicle was heavy and slow. A few mentioned the car was much bigger than they were used to, while others complained about the poor visibility through the rear window. Furthermore, some mentioned that the speedometer showed the speed pontifical in their sight which felt confronting. One participant mentioned he drove slower because the deviation of the speedometer of the car with the actual speed was unknown, while a substantial number said they drove slower since it was not their own car.

Literature had already shown that the vehicle type has effect on one's driving behaviour (Bener *et al.*, 2008a). Several participants mentioned this effect as well. One participant regularly drove in an old car, with which you did not felt comfortable driving over 100 km/h because of the noise and vibrations the car would generate at those speeds. Therefore he would keep to the shoulder lane and adjust his speed to his predecessor. On the other hand, several participants mentioned they would drive (unconsciously) faster in a more sporty vehicle, which was found in literature to affect one's driving behaviour.

"I really didn't like the car, it reacted very slow after you press the gas pedal and it accelerates slow. Not my type of car."

6.3.4 Experimental set-up

Each participant was furthermore asked what in his opinion was the aim of this study. Although the provided information on the study's aim was tried to kept to a minimum, many participants could describe the goal roughly, which could have affected one's driving behaviour. However, ethically seen some information on the goal had to be provided. On the other hand, most participants mentioned that this did not affect their driving behaviour. Only a few stated that they were driving more conscious or were questioning if they would have done some of their actions normally as well. One participant even mentioned that he was thinking during an action if it was good or bad in terms of the experiment. Another participant mentioned he had to show socially desirable behaviour because he was watched by the cameras in the car. Several other participants said they had no clue on the goal of the driving study.

"In general I drove as how I would normally have driven, but I had the feeling I had to drive more neatly, since the test drive was being recorded."

6.3.5 Driving style

In the interview the participants were asked to describe their own driving style. Some found it hard to come to an answer, since it was not clear on what aspects they had to describe their driving style. But it was curious to see what people would respond to such an open question. Most participants find themselves smooth and safe drivers, several call them average drivers, while a few declare themselves very good drivers. The background form included a question on one's own perception of its driving skill in comparison with an average driver. About 50 percent of the participants found themselves average drivers, while the other 50 percent found themselves better drivers than the average driver. No one said he drove worse than the average driver.

"I am a smooth driver, always driving a bit faster than the speed limit"

6.3.6 Speed choice on a 100km/h motorway

The speed participants stated they would drive on a three lane motorway with a speed limit of 100 km/h and no speed checks varied quite a lot. In table 6.1 a summary is given of all the answers participants gave. Although some participants stated they would drive 120 or 130 km/h on such a road, most of them drove during the experiment with a lower speed than that. Almost half of the participants stated they would drive 110 km/h, 10 percent above the speed limit.

Furthermore, several participants stated their speed choice fluctuated and depended on some variables. A few, for example, said the region influence their speed choice. Within the Randstad they would drive much slower than outside the Randstad. Or in the port area of Rotterdam speeds would also go up, since a lot of other drivers would speed as well or they would not expect speed checks. As already describe a few paragraphs back the type of vehicle has a large effect as well on the speed choice.

One participant also noted that he is not checking the speedometer of the car all the time, so that he is not always aware of his own speed. Some others said their speed choice depended on their mood. After a long day of work they would drive more aggressive, and would speed more, while when they were tired or did not want to drive at that moment they would drive slower. However, there was one participant who state he always uses cruise control while driving, and never would speed. Concluding, someone's preferred speed can be very stochastic and can depend on many factors, like for example region, mood and type of vehicle.

Table 6.1 – A summary of all speeds stated by participants they would drive on a 100 km/h motorway

Stated speed	Frequency
100	4
100-105	1
100-130	1
103	2
104-106	1
105	3
108-110	1
110	14
110-120	2
115	1
120	2
130	1

6.3.7 Driver assistance systems

Only one participant used the cruise control system during the driving experiment. On forehand of the test drive nothing was said on the cruise control, only if participants themselves asked. The Toyota Prius that was used for the experiment has adaptive cruise control, which is still a relatively new system, so most cars will still have the traditional cruise control system. About a third of the partici-

pants mentioned that at some point they wanted to turn on the cruise control system, but either they could not find it or could not figure out how it works they did not use it in the end. These participants thus show a deviation of their naturalistic driving behaviour.

A few participants stated they would always drive using cruise control, no matter what the situation was. But most participants only use cruise control when densities are low, so they would not have to intervene in the system very often. Several said they use cruise control to be sure they do not speed or they would not drive to slow. Also a substantial number of participants only use cruise control when they are on holidays. No other driver assistance systems were mentioned by participants. However, a few participants mentioned to use smart-phone applications, like Flitsmeister and Waze, that indicate the presence of speed checks. One person actually brought a holder to the experiment so he could use Flitsmeister on his smart phone during the test drive, since he always uses Flitsmeister while driving.

"I never use cruise control, it's not installed in my own car either."

6.3.8 Lane change strategies

All four lane change strategies were briefly described to the participants by the interviewee, according to the descriptions in table 5.1. The participants were asked to indicate in which strategy they belonged. Each strategy is referred to with a number:

- Strategy 1 = Speed leading
- Strategy 2 = Speed leading with overtaking
- Strategy 3 = Lane leading
- Strategy 4 = Traffic leading

Almost all participants indicate they drive in first instance according to strategy 1 or 2. Only a few initially responded they would drive according to strategy 3, however, later on they made comments that could place them in strategy 1 or 2. For example, one participants responded he would drive according to strategy 3 in his 'old' car, since it was not pleasant to drive above 100 km/h with this car. Another participant stated that he sometimes drives in a Mercedes Sprinter bus with a trailer, which accelerate very slow so that it is not easy to overtake other vehicles. Only one participant stated that he would drive in his own car according to strategy 3, because that felt comfortable. He would adapt his speed to his predecessor. However, if the speed dropped too much below his preference speed he would change lanes. That person furthermore commented that he was a proponent of the 'keep your lane' system, in which you are supposed to stick to you lane as much as possible while overtaking is allowed via the left and the right side.

People will not show a constant driving style or always react the same, many people actually drive according to multiple strategies. In the interviews strategy 3 and 4 were always mentioned in combination with strategy 1 or 2. But when would people apply strategy 3 or 4 instead of 1 or 2? And when would someone drive according to strategy 1 and when to strategy 2?
Based on all comments in the interview the strategies applied by each participant were determined, of which on overview can be found in table 6.2. The participants do not uniformly use all strategies indicated in the table, and even a small comment given in the interview could have led to assigning a strategy to a participant. For example driver 1: initially he stated he drives according strategy 1 and 2. However, later in the interview he made the following comment:

Table 6.2 – Overview of applied strategies for each participants based on comments during the interview

	Strategy					Strategy			
Participant	1	2	3	4	Participant	1	2	3	4
1	x	x	x	x	18	x	x	x	
2		x		x	19	x	x	x	
3	x	x	x	x	20	x	x		x
4	x	x	x	x	21	x	x		x
5		x	x		22	x	x	x	
6	x		x		23	x	x		
7		x			24	x			
8	x	x		x	25	x	x		x
9	x	x	x		26	x	x	x	
10	x	x			27		x	x	x
11	x	x	x	x	28	x	x		x
12		x	x	x	29	x	x	x	
13	x	x	x		30	x			x
14	x		x		31		x	x	x
15	x	x		x	32	x	x		
16		x	x		33	x	x		x
17	x	x			34	x	x		x

"When it is quite crowded on the road, I just keep to my current lane. In the end your it does not really matter for your travel time if you would have changed lane all the time or not."

Based on that single comment also strategy 3 was assigned to this participant. Later on he said the following:

"Normally I drive 110 on the speedometer of my car, unless it is crowded than I will adjust my speed"

Based on that comment also strategy 4 was assigned to him. However, the participant did not show these strategies during the test drive. That was of course expected, since people apply different strategies with various motives and for different conditions, which not all occurred during a test drive of only half an hour.

An overview of the frequency of each strategy combination that was found for the participants of the driving experiment is presented in table 6.3, which followed from table 6.2. Based on comments throughout the interviews with the participants, 79% does sometimes behave according to strategy 1, while 88% says to drive (partly) according to strategy 2. The lane leading and traffic leading strategies are applied by a smaller share, respectively 53% and 50%. Furthermore, the table also shows the combinations of strategies applied by the participants. About 53% of the participants show a combination of three strategies. A combination of Speed leading, Speed leading with Overtaking and Traffic leading is applied by most participants. Note that this table does not indicate how often

participants apply a certain strategy. The percentages only indicate how many participants apply these strategies, based on comments in the interview, and has not been necessarily observed in the test drive.

Table 6.3 – Overview of occurrence of strategy combinations among driving experiment participants

Number of strategies	Strategies				Number of participants	Number of participants
	Speed leading	Speed leading with overtaking	Lane leading	Traffic leading		
1	x				1	2 (6%)
		x			1	
2	x		x		2	10 (29%)
	x			x	1	
	x	x			4	
		x		x	1	
		x	x		2	
3		x	x	x	3	18 (53%)
	x	x	x		7	
	x	x		x	8	
4	x	x	x	x	4	4 (12%)
Number of drivers	27 (79%)	30 (88%)	18 (53%)	17 (50%)	34 (100%)	34 (100%)

6.3.9 Strategy 1 vs strategy 2

Strategy 1 and 2 have large similarities. What makes drivers choose strategy 1 or strategy 2? Some participants would always increase their speed when they overtake another vehicle, while the behaviour of many depended on the situation. Several frequently heard situations that influence a participant's choice between strategy 1 or 2 are:

- When participants would encounter a slower predecessor, but at the same time a faster driver was approaching from behind, they would increase their speed to overtake their predecessor. While in the same situation but without the faster driver from behind, some of the participants would keep their speed constant to overtake the slower predecessor. People tend to do this to minimize them hindering the faster driver by faster making space.
- Several participants further commented that they would increase their speed when overtaking when the speed difference with their predecessor was small, since otherwise the overtaking manoeuvre would take a long time. However, some participants also commented that this was also related with their current speed. If they were already driving quite some kilometres per hour above the speed limit, and even though the speed difference with the predecessor was small, they would not speed in that situation.
- The application of either strategy 1 or strategy 2 also depends for several people on the use of cruise control. Most of the cruise control users state that they would drive according to strategy

1 if cruise control was turned on, while if cruise control was turned off they would drive according to strategy 2. A single participant indicated otherwise by stating he also increases his speed when he uses cruise control.

- A lot of participants indicated traffic intensities also played a role in the application of either strategy 1 or strategy 2. Most participants say they in generally would apply strategy 1 when intensities were low, while they would apply strategy 2 when intensities were high. The idea behind this behaviour was that in conditions with low intensities there would often be enough space for other vehicles to overtake them, while in conditions with high traffic volumes they wanted to minimize their hinder to other drivers. However, a few participants stated the effect of intensities on their strategy choice the other way around. In conditions with low intensities they would apply strategy 2, while in conditions with high intensities they would apply strategy 1.

However, there were also some participants who stated they would always drive according to strategy 1 or always according to strategy 2, and they would not let their behaviour be affected by others. One participants did not want to risk a fine because he would speed due to another driver. While another participant stated he learned during his driving lessons that you need to increase your speed when you would overtake another vehicle. Several others mentioned that when they decided that they wanted to overtake someone, they ensured that would actually happen by increasing their speed.

"If I see faster drivers are approaching from behind I will increase my speed when I am planning to overtake, since I do not want to hinder the faster drivers that much. "

6.3.10 Strategy 3: Lane leading

An often heard motive to drive according to strategy 3 is the traffic intensity. When the crowdedness on the road goes up, several people tend to keep more and more in their current lane and to accept lower speeds. Speed is of less importance for them in busy traffic conditions, while comfort and steady driving were getting more important.

Other motives to apply strategy 3 exists as well of course. One participant had to drive only a short distance over a motorway during peak hours on his home-work trip, during which he would only use the shoulder lane, since by changing lanes he would not gain much travel time and it required much effort during peak hour to change lanes. Another participant had a similar argumentation to apply strategy 3 on a certain section of this trip, which was a relative short motorway section between two junctions with high traffic intensities in peak hours. It requires too much effort to change lanes in that situation while he had to follow a certain route. One participant also mentioned that he would unconsciously drive according to strategy 3 since he was not always aware of the fact he adapted his speed to its predecessor, which in some case would drive slower or faster than his own preference speed. Strategy 3 is also often applied by people who are approaching an exit they need to take to follow their route. Their route requires them to take the exit, and to not miss the exit people will ensure they drive in the shoulder lane at some distance from the start of the exit and thereby accept lower speeds. This was often seen on the video recordings of the test drives.

Strategy 3 was several time also associated with drivers that unnecessary keep driving left. Traffic rules in the Netherlands say that you have to keep right as much as possible. Several participants showed aversion to this strategy, and said they were annoyed by these drivers. Although you can indeed categorize unnecessary left drivers in this third strategy, the lane leading strategy captures more than this behaviour alone. For example, someone who would only drive on the shoulder lane

and adapt his speed to the traffic in that lane.

Some of the participants who showed aversion to strategy 3, later mentioned they do not strictly obey to the keep right rule. You could even argue that people who do not keep strictly right if possible also follow strategy 3. Many participants would not change to the shoulder lane when there were driving trucks on the shoulder lane up ahead, or when a motorway section contained many on- and off ramps on a short distance even though no traffic was present on the merging lanes. However, these people would still overtake a slower predecessor, while one of the typical characteristics of strategy 3 is the adaptation of one's speed to its predecessor in that lane. So you could say that these people drive conditionally as strategy 3, or is it a complete different and new strategy?

"During congestion I just choose a lane and stick to that lane,
unless another lane is obviously faster. "

6.3.11 Strategy 4: Traffic leading

Like in the case of strategy 3, some participants responded they would drive according to strategy 4 when intensities were high on the road. In this strategy people do not have a preference for speed or lane but base their behaviour on that of others. On an empty road you cannot drive according to strategy 4, since there no other vehicles around to base your behaviour on.

It is further important to make a clear distinction between strategy 3 and 4 to understand to which strategy people actually belong. In strategy 3 drivers have a preference or feel comfortable in a certain lane, while in strategy 4 there is not such a preference. Strategy 4 consists more of driving behaviour that is influenced by other drivers on the road. A driver of strategy 4 could for instance drive much faster than his preference speed when a faster driver is present. Other typical behaviour that belongs to strategy 4 is the phenomena that people choose their speed such that they go with the flow, which on that moment will differ from their preferred speed, while they do not really have a preferred lane.

Besides the traffic intensities, participants mentioned that they wanted to go with the flow, and thus apply strategy 4. Some argued they apply strategy 4 since it feels more comfortable to drive with the flow than driving with your own speed, or they want to contribute to a stable traffic stream. Others argued that it feels safer to go with the flow. A few participants noted that you are forced to drive according to strategy 4 when traffic intensities are high.

During the interview some participants were also asked what they would do if all other drivers would drive much faster than you and the speed limit. Several participants responded this would not affect their speed choice, while some admit they would increase their speed because of the other drivers. A few times also the relative speed was mentioned. Some drivers, or maybe even all drivers, use their relative speed with drivers around them to determine their own speed. Unconscious of their exact own speed, they would go with the flow based on their perceived speed, determined with their relative speed. Finally, one participant that drove regularly using cruise control said he noticed when other drivers used cruise control as well, and that he would sometimes get behind such a driver and would synchronize his speed, since that felt comfortable. He thus basis his own speed on that of another driver without having a preference for a lane, which is typically strategy 4 behaviour.

"If everyone is driving 80 km/h when 100 km/h is allowed,
than I will also drive 80 km/h, maybe I missed something."

6.3.12 Speed during test drive

Although many participants reacted with a single speed on the question how fast they would drive on a three lane motorway with a speed limit of 100 km per hour, someone's desired speed is often stochastic and affected by many factors. An simple example is rain, while a participant would drive 110 km/h in dry and clear weather conditions, there is a high chance he will lower is desired speed when there is heavy rain and bad vision. Road characteristics like lane width also influences someone's speed choice (Martens *et al.*, 1997). Most participants indeed showed a lower speed during the test drive than they stated they would drive on a 3-lane motorway with a speed limit of 100 km/h.

The speedometer of most vehicles show a speed that deviates from the actual speed. In this case, the Toyota Prius displayed a speed that lay about 8 km/h above the GPS speed when driving around 100 km/h. Many participants are aware of this difference and account for this, although some participants were not aware. The participants that drove with the navigation system turned on, were able to compare the speedometer and the GPS speed on the navigation system. Some participants thus found out the exact deviation of the speedometer. However, not everyone used the navigation system or did not notice the displayed speed, so they would account too less for the deviation than they would normally do. Since if their own car deviates 5 km/h and the speedometer of the Toyota Prius deviates 8 km/h, while they always drive 110 km/h on the speedometer, they end up driving slower than they normally do.

As seen in the plots of the induction loop data the intensities on the A4 were quite often relatively low, which made some people to increase their speed. Several participants admit they would drive faster on an empty road. However, several people were also aware of the recent speed checks by the police that made them kept them from increasing their speed. Some people also commented that the speed limit on the A4 was not in accordance with the road geometry, and thus that the road geometry make people drive faster, while several also commented that the 80 km zone on the A13 was justifiable so that you are automatically driving the appropriate speed there.

The section of the A20 that was included in the route contained some curvature and several bridges, which make that section a bit windy and bumpy. One participant commented that on this section he always lowers its speed because of the road geometry. As already mention a couple of times before participants were not always aware of their speed. Multiple participants said they sometimes noticed they unconsciously drove faster than they wanted to, so when they noticed they would lower their speed. Finally, a few participants based their speed on the performance of their vehicle. There is often an optimal speed at which the fuel consumption is most efficient. Some would therefore even drive much slower than the speed limits on road with a speed limit of 120 or 130 km/h.

"I determine my speed on basis of the geometry of the road, I believe people can quite well assess an appropriate speed themselves."

6.3.13 Predecessor

Many people will change lanes when their predecessor drives too slow and there are possibilities to overtake the vehicle, as in correspondence with strategy 1 and 2. But several people also mentioned they would change lanes when their predecessor is blocking their view, like a truck or high van.

6.3.14 Keep right rule

Many people state they drive right as much as possible. However, in some cases several people make exemptions to do so, of which some have already been discussed in the paragraph of strategy 3. The following motive were heard to not obey to the keep right rule:

- The presence of trucks on the shoulder lane;
- The shoulder lane is meant for trucks;
- It's not comfortable to change lanes many times;
- The presence of on- and off ramps, with or without vehicles riding on the merging lanes, to allow (possible) vehicles on the ramps to merge onto the roadway;
- The traffic flow on the shoulder lane can be irregular because of merging vehicles, which is not comfortable;
- The gap to the predecessor on the shoulder lane is too small.

"If you can stay on the shoulder lane for at least 10 seconds, I will change back to the shoulder lane. But if I have to change lanes within 10 seconds, I will stay in my current lane."

6.3.15 Overtake via right side

About the same number of participants answered they would overtake other via their right side as the ones who answered they would not overtake other drivers via their right side. Several say they do not like it, but that it occasionally just happens when a vehicle is driving for a long time unnecessary on the centre or median lane. A few responded they would definitely overtake others, also to show those drivers that there is space on the shoulder lane and they should change lanes. Some even stated that would cut off these drivers a bit to make a statement. Some participants encountered a truck during the driving experiment that was driving on the median lane of a connection road, in that scenario they would not overtake the truck via the right. If the truck driver would not see them and perhaps decide to change to the shoulder lane, the participants argued that they would come of worst. Many stated one of their main frustrations on motorways are drivers that unnecessarily stick to the median lane.

6.3.16 Speed checks

Differences in the way how people approach an average speed check section have been noticed. Most participants were aware of the average speed checks on the A13 near Schiedam, only a few stated that they did not know it. Some participants would release their foot of the gas pedal the moment they would see the traffic sign indicating the lower speed limit of 80 km/h. While a significant number would release the gas pedal when they passed the first sign indicating the speed limit of 80. And a few participants stated they knew exactly where the cameras are located, so from that moment they tried to drive a bit over 80 km/h. Several participants were aware of all the margins they have concerning their speed before they get fined, and really tried to drive as fast as possible within these boundaries. Some also used a smart phone application or their navigation system to determine their average speed over the section that was controlled by the system.

"I read in the newspaper many drivers got fined on the new A4, so I pay more attention on my speed there. "

6.3.17 Merging vehicles

Almost everyone stated they would make space for merging vehicles by changing lanes, of which some would do so by increasing or decreasing their speed. Several participants stated they would only make space for merging vehicles if they themselves did not have to decrease their own speed. Furthermore, one participant stated he would only make space if the merging vehicle would indicate that he wants to merge by using its blinker. As motive behind this cooperative lane change behaviour some stated they also appreciate it when others create space for them to merge onto the main roadway. During the experiment one participant lowered his speed to allow another vehicle merge, since he had to take an off-ramp up ahead and did not want to change lanes anymore.

6.3.18 Faster driver from behind

An often heard motive for drivers to apply strategy 2 is the presence of a faster driver behind them. Where some drivers always increase their speed during overtaking, others would only do so when a faster driver is approaching from behind. However, a substantial number of participants also indicated they would not change their speed because of a faster driver behind them. They did not want to risk a fine because they would speed due to another driver, or they would not let their behaviour be affected by other drivers. Several participants mentioned it depends on the attitude of the driver that approaches them from behind how they would react. If they would drive aggressive (high speed and short following distance) they would either lower their speed or take much more time to change lanes. On the other hand, a lot of participants would just change lanes when possible and give space for the faster driver from behind.

6.4 Conclusions

The aim of the driving study was to get insight in how drivers apply the four different lane change strategies. From the interviews several motives to apply a certain strategy have been discovered. For each participant a clear view on their driving behaviour and their application of the strategies has been gained. Many participants follow in principal one of the two speed leading strategies. However, some participants switch to the lane leading or traffic leading strategy when they are triggered by for example high traffic densities, a different mood or when they approach an off-ramp which they have to take to follow their route. Often reoccurring themes during the interviews were the keep right rule, which required drivers to drive in the shoulder lane unless they are overtaking, and the ban on right overtaking. Participants showed some characterizing differences on these themes, which are not described by the four lane change strategies. Nevertheless, there were also some participants who felt comfortable in keeping a lane as much as possible and tend to minimize lane changes in general.

Some interesting triggers have been identified that make people choose a certain strategy. These triggers will be taken into account in the set-up of the questionnaire, and include for example the presence of a faster driver in the back, a small speed difference with a predecessor, a vehicle that unnecessarily drives in the median lane or a certain route a driver needs to follow.

As final point, driving behaviour is very stochastic and drivers apply different strategies sequentially of which some only for a short time. Furthermore, it is arguable how well people can describe their own driving behaviour. Several studies mention this as weakness of self-reported behaviour, and since many findings presented throughout this chapter come from self-reported behaviour it is important to bear this in mind.

Part III

Questionnaire

Chapter 7

Questionnaire based study

In this chapter the set-up of the online questionnaire is discussed. First, the goal of the questionnaire is made clear. Second, the actual content of the survey is presented and explained. Third, some insight in the practical set-up of the survey is given. Fourth, an overview of the distribution channels are presented. Fifth and last, the data analysis method which is used to investigate the strategy-based lane change behaviour of the respondents is outlined.

7.1 Goal of questionnaire

Insight in strategy-based lane change behaviour, which has been obtained via the driving experiment, can be tested on a much larger group of drivers via a questionnaire. The aim of the questionnaire is to quantify strategy-based lane change behaviour. The questionnaire tries to find which strategy drivers would apply in various traffic situations that have been found relevant in the driving study. The results of the survey are used to answer the following sub-research questions:

- How are drivers distributed over the lane change strategies?
- What are triggers for drivers to change their lane change strategy?

Since many drivers can be reached by an online questionnaire, it is also an useful tool to analyse possible correlations between driver characteristics and strategy-based lane change behaviour. Interesting characteristics are age, gender, driving frequency and driving experience.

- How does strategy-based lane change behaviour correlate with age, gender, driving frequency and driving experience?

Strategy-based lane change behaviour is studied to improve lane change models that are incorporated in microscopic simulation packages. Worldwide there are a few leading software packages that are used. It is therefore very useful to understand how the findings from Dutch drivers concerning strategy-based lane change behaviour are applicable for other countries. For this purpose the following research question has been formulated:

- How different is strategy-based lane change behaviour of drivers from various countries?

7.2 Content

To answer the research questions the correct traffic situations need to be captured in videos. However, before these videos can be made the desired traffic situations need to be known.

First of all, the characteristics of each strategy that are found in table 7.1 help to make a clear distinction between the strategies. The only difference between strategy 1 and 2 is the speed increase while overtaking of drivers in strategy 2. This can be used to identify lane change behaviour of strategy 1 or 2. This can easily be grasped in the multiple choice answers by differentiating to overtaking a slower predecessor with constant speed or overtaking a slower predecessor while increasing your speed. The characterizing difference between the speed leading strategies and the lane leading strategy is the overtaking of a slower predecessor or the adjustment of your speed to that predecessor. This can easily be grasp in a scenario in which you encounter a slower predecessor, after which you can choose to adjust your speed (strategy 3), overtake it with constant speed (strategy 1) or overtake it while increasing your speed (strategy 2). The fourth strategy is a bit harder to grasp, since driving behaviour that falls into this strategy has not such a clear appearance as behaviour from strategy 1, 2 or 3 and can be very different. However, what really distinguishes strategy 4 from the other strategies is that a drivers does not have a desired speed or lane and that it's behaviour is determined of influence by other drivers on the road. Several participants from the driving experiment stated that they preferred to drive along with the traffic flow, which means they would synchronize their speed with vehicles around them to contribute to a more steady traffic flow in terms of speed. Other typical strategy 4 behaviour is that some drivers could be triggered by a faster driver on the road to increase their speed above their desired speed. Opposite, several drivers also tend to drive slower than the speed limit when everyone else drivers slower than the speed limit, they argued that there might be something going on of which they are not aware on that moment.

Table 7.1 – Characteristics of each strategy by Knoop *et al.* (2015)

Strategy	Characteristics
1: Speed leading	- Settle for a speed and keep it - Change to left if slower driver ahead - Change to right if lane is empty
2: Speed leading with overtaking	- Settle for a speed and keep it while at the right - Change to left if slower driver ahead - When overtaking, increase speed
3: Lane leading	- Settle for a lane - Adapt speed to the vehicles in that lane - Speeds will be higher than in the lane right of the chosen lane
4: Traffic leading	- No desired lane or speed - Hidden ideas on relative speed, e.g. joining the faster ones or slower ones - Remarkably, relative faster drivers may drive (absolutely) faster in busier conditions, since there is a higher probability of finding someone with a high desired speed

Besides the differences in lane change behaviour based on the nature of the four strategies, there are some other elements that distinguishes driver's lane change behaviours. This includes the compliance to the keep right rule. The drivers from the driving experiment had various thoughts on this rule which was reflected in their lane choice. Several people were really strict in keeping right, while other drivers did not comply to the keep right rule due to various reasons which were described in chapter 6. Not complying to the keep right rule can be seen as strategy 3 behaviour. However, drivers

according to lane keeping behaviour would adjust their speed to their predecessor. The drivers that not strictly keep right would mostly still overtake another vehicle in that lane, which thus differs from strategy 3 behaviour. So does this behaviour indeed fall in strategy 3 in combination with one of the speed leading strategies, or is it a new strategy? Nevertheless, drivers act differently, and so it is an interesting element of driving behaviour to include in the questionnaire.

The keep right rule furthermore states that overtaking is only allowed via the left side, passing via the right side is only allowed during congestion or when block marks are present. However, in cases that drivers drove on the median or centre lane while there was space to go to the shoulder lane, several people said they would overtake those drivers via their right side. Drivers can thus be distinguished based on their actions in case of another driver that unnecessary drives in the median lane.

In literature lane changes are often distinguished in 2 or 3 categories. After the introduction of the lane change theory of Gipps (1986), many models distinguishes between mandatory and discretionary lane changes. Mandatory lane changes are performed when a driver must change lanes to follow his route, while discretionary lane changes are done by a driver to improve its driving conditions or the driving conditions of others. In some studies discretionary lane changes are split in voluntary and courtesy lane changes, and together with mandatory lane changes that makes 3 categories. Drivers tend to make space for vehicles on the on-ramp to merge onto the main roadway, besides a courtesy lane change drivers can also increase or decrease their speed to create a gap. Many drivers in the driving experiment indicated they were willing to make space for merging vehicles. However, some drivers indicated that they would not do this if they themselves would come of worse, meaning they had to decrease their own speed. One participant furthermore indicated he would only cooperate if the merging vehicle would indicate with its blinker that he wanted to merge. There is thus some variance in the way how people react to vehicles on the on-ramp, and is thus of interest to include in the questionnaire.

Table 7.2 – Categorization of traffic scenarios

Theme	Description
Strategy 1,2,3	Scenarios to determine if a respondent drives according to strategy 1,2 or 3.
Strategy 4	Scenarios to determine if a respondent drives according to strategy 4.
Keep right rule	Scenarios to determine if a respondent strictly obeys to the keep right rule.
Overtaking via right	Scenarios to determine if a respondent would overtake another driver via its right side.
Courtesy lane change	Scenarios to determine if a respondent would make a courtesy lane change to create space for a merging vehicle

The questionnaire needs to contain various traffic scenarios to get all of the previously described insight in one's driving behaviour. The scenarios have been categorised as presented in table 7.2. Each theme will include different scenarios, since there are many variables that can vary. However, to reach a great number of drivers that are willing to fill in the questionnaire, the questionnaire cannot be too long. A critical selection of scenarios has been made. Per theme several scenarios are formulated based on the gained insight from the driving experiment, and in which drivers showed different behaviour. More scenarios can easily be thought of. However, besides the length of the

questionnaire also the video material is limited, meaning that there might not be appropriate video footage from the driving experiment that describes the intended traffic scenario.

The questionnaire is found and discussed in more detail in appendix B, while a brief overview of the scenarios is included in appendix B.9[1]. The survey is divided in three categories, namely:

1. Traffic scenarios
2. Keep your lane system
3. Personal characteristics

The traffic scenarios part contains all video questions. Each traffic scenario is introduced by an embedded YouTube video, which a respondent needs to play before answering the question. The second part of the questionnaire concerns the respondents' opinion on the lane keeping system and was included on request of the ANWB (Dutch Motorist Association). The ANWB has been approached to distribute the questionnaire via their newsletter, in return this topic was included in the survey. The third part of the questionnaire consists of questions related to personal characteristics like age, driving frequency and the number of years holding a driving license. These questions were asked last since it is believed that in this way more people would complete the questionnaire. If a respondent finished the first two categories and would see that the third category consists of personal detail questions which do not require much time to fill in, the chance that the respondent will complete the questionnaire is expected to be higher.

7.2.1 Three versions

Since the Netherlands also inhabits non-Dutch speakers who drive a car the Dutch questionnaire has been translated in English. In the driving study participated for example an Italian who lived and worked in the Netherlands. Three different versions have been made of the online questionnaire:

1. **Dutch** version to spread **within** the Netherlands
2. **English** version to spread **within** the Netherlands
3. **English** version to spread **outside** the Netherlands

The English version that has been spread outside the Netherlands, hereafter referred to as the International version, has been set-up to allow for the cross-cultural analysis of driving behaviour. This version is a bit different from the English version that has been spread inside the Netherlands since not all questions were relevant for people living outside the Netherlands. The differences are as follows:

- The whole section concerning the respondents' opinion on the Keep your lane system has been removed in the International version. It is not of interest to ask people from outside the Netherlands if the 'Keep your lane' system should be applied in the Netherlands.
- The gift card is omitted for international respondents due to practical reasons.
- International respondents will not be asked in which provinces they regularly drive, since it is outside the scope of this study to analyse possible differences between people from the Paris region or the Bordeaux region.

[1] Readers of the hardcopy version of this report can unfold the pages of appendix B.9, which presents a brief overview of all scenarios

7.2.2 Flow diagram

As seen in the driving experiment people have varying desired speed. It would be therefore not correct to show every respondent the same video containing one particular speed. For example, showing a respondent with a desired speed of 120 km/h a video of a traffic situation in which you are driving 100 km/h. You can expect this respondent will answer to increase his speed. However, this is because he has a higher desired speed than the video displays and not because he drives according to strategy 2 for example. So it is important that the speed in the videos somewhat correspond to the desired speed of the respondent.

Figure 7.1 – Question concerning the participants' desired speed

This issue has been solved by implementing three categories based on the preferred speed of respondents. At the beginning of the questionnaire each respondent is shown the question in figure 7.1 and asked what their preferred speed is on a three lane motorway with a speed limit of 100 km/h. Based on this answer they are redirected to one of the three categories ('slow', 'average', 'fast'). Table 7.3 presents the categorization of the three categories and their speeds shown in the videos of the scenarios. Each of the three categories will consist of the same scenarios, but the videos will be tweaked a bit when necessary. The 'own speed' which is displayed in the video differs between the three categories, and the speed at which the video is played is modified a bit to make the video more realistic. A flow diagram that shows all divergence points in and paths through the questionnaire is found in appendix B.

Table 7.3 – Categorization of respondents into three categories

Desired speed	Category	Speed in scenarios
<103 km/h	'Slow' driver	∼100 km/h
103 - 110 km/h	'Average' driver	∼107 km/h
>110 km/h	'Fast' driver	∼115 km/h

7.2.3 Scenarios

From the videos of the driving experiment relevant clips have been taken out that could be used in the questionnaire, 13 videos and 1 image have been selected to be used in the questionnaire. The aim of each video, its contents and the corresponding pre-defined multiple choice answers are described in appendix B.2 to clarify the actual questionnaire. The scenarios are discussed in the order they have been put in the final version of the questionnaire, the order of the scenarios is shuffled to prevent clusters of videos with the same theme.

Five themes have been formulated which are covered by 14 scenarios. The theme and aim of each scenario is found in table 7.4. Scenario 7 belongs to two themes. Initially the video was included to analyse the keep right behaviour of drivers, while the video also includes a faster driver from behind which could induce strategy 4 driving behaviour.

Table 7.4 – Theme and research question per scenario

Scenario	Theme	Scenario question
1	Right overtaking	Would the respondent overtake another vehicle via its right side, while there is the possibility to overtake via the left side?
2	Strategy 1,2,3	Would the respondent overtake a slower predecessor (person car), or adjust its speed and keep lane?
3	Strategy 1,2,3	If the respondent would overtake a slightly slower predecessor, would he do this according to strategy 1 or 2?
4	Strategy 1,2,3	Is a respondent during congestion trying to get in the fastest lane, or will he keep lane
5	Right overtaking	Would the respondent overtake another vehicle via its right side, when there is no possibility to overtake via the left side?
6	Strategy 1,2,3	If the respondent has to take the 2nd exit from where he entered the motorway (3000 metres), what strategy will he apply?
7	Keep right/Strategy 4	Does a respondent keep strictly right, or is this decision affected by the presence of other vehicles?
8	Keep right	Does a respondent keep strictly right, when there are not much other vehicles around?
9	Strategy 1,2,3	Would a respondent overtake a slower predecessor (truck), or adjust its speed and keep lane?
10	Keep right	How strict would a respondent obey to the keep right rule, when there are other vehicles around?
11	Strategy 4	Would a respondent increase its speed above its own desired speed and the speed limit when all other drivers do so?
12	Courtesy lane change	Would a respondent cooperate with a driver on the on-ramp that wants to merge?
13	Strategy 1,2,3	If a respondent has to take the exit 600 metres up ahead, would he overtake a truck just before the off-ramp?
14	Keep right	Would a respondent keep right when the peak hour lane is opened?

7.3 Practical set-up

In this section some practical manners are discussed like the choice of the used survey tool, the construction of the videos of the traffic scenarios and the distribution of the final questionnaire.

The questionnaire has been set-up in the survey tool called Typeform. It is a commercially exploited online survey package, and has been used because it allows unlimited responses and easy forwarding of respondents based on previously given answers.

The videos that describe the traffic scenarios have been made with video editing software Adobe Premier Pro. This software package allowed a large range of adjustment tools to make the videos more clear, for example colour improvement, speed adjustment and dynamic zoom functions. Image of the raw video footage and edited video footage for scenario 2 are presented in figure 7.2.

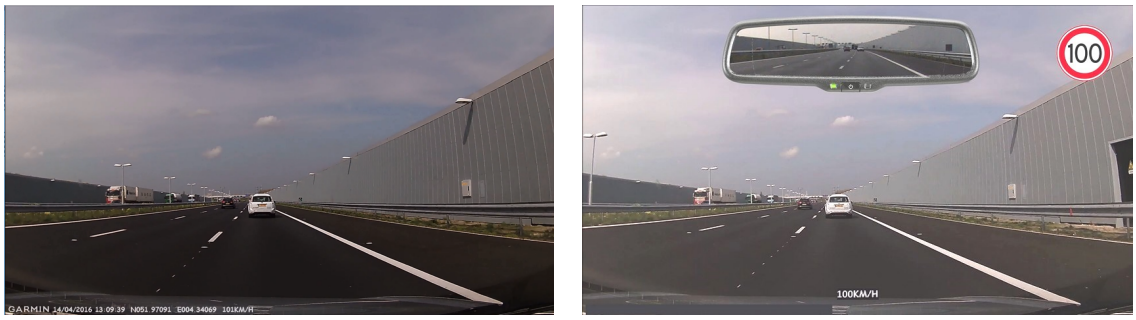


Figure 7.2 – Images of the raw video footage and edited video footage of scenario 2

7.4 Questionnaire distribution

As mentioned earlier in this chapter the Dutch Motorist Association was willing to cooperate in this project by distributing the survey with their 'followers'. Over a period of time the questionnaire was promoted several times via multiple e-mail newsletters and a news item on their website.

The questionnaire was furthermore distributed via social media in the author's own network, on various TU Delft and transport analysis related Facebook groups and on traffic related Dutch web forum. The questionnaire has also been promoted via internal emails among Rijkswaterstaat employees. Furthermore, each respondent was asked at the end of the questionnaire to share a link to the survey on their own social media accounts.

All participants from the driving experiment have been asked to fill in the questionnaire. They were furthermore requested to fill in their e-mail address in the end, in order to link their response on the questionnaire with the information gained in the driving study. This allows a small scale evaluation of the questionnaire.

To boost the response rate one gift card of 50 euro is given away to one respondent that is chosen randomly among all respondents living in the Netherlands that filled in their e-mail address at the end of the questionnaire.

For respondents from outside the Netherlands a separate version was made of the questionnaire. This was an exact copy of the English version that was spread in the Netherlands for non-Dutch speaking inhabitants, except for category two, which contained questions related to one's opinion on the keep your lane system. The international version of this survey has been posted on several social media groups and more importantly is spread by researchers in the traffic and transport analysis field from Switzerland, the United States of America and France.

7.5 Data analysis method

First of all, the validity of the questionnaire results will be assessed (chapter 8). Does the questionnaire actually give the intended results from which the correct conclusions can be drawn? The participants from the driving experiment have been invited to fill in the questionnaire and are asked to leave their email address in the comment box at the end of the questionnaire so there response can be linked with the findings from the driving experiment. After the coupling of the data is done, the data is anonymized. The participants' questionnaire responses can then be compared with the findings from the driving experiment, which is used as assessment of the validity of the questionnaire results. The results gathered in the driving experiment are elaborate, and the comparison is done to check if the same conclusions can be drawn for a participant based on the driving experiment results as the questionnaire results.

After the validation the actual data analysis is done, which is presented in chapter 9. To understand the sample of respondents better at first a demographic data analysis is done. Descriptive statistics that describe the background of the respondents are presented, which are compared with data from the population to assess the representability of the sample (section 9.2). The distributions of the respondents over the several multiple choice answers does already give a clear result on the differences in driving behaviour and the application of the four lane change strategies. Therefore the response on each scenario are discussed and interpreted (section 9.3).

Thereafter, a cross-question analysis is done which analyses the response of individuals over multiple questions. Since, do drivers consistently behave the same way or apply the same strategy all the time? And if not, are there any combinations of strategies that stand out? The cross-question analysis is done for scenarios of three themes: 'Strategy 1,2,3', 'Keep right behaviour' and 'Right overtaking behaviour'. This analysis is found in section 9.4.

As found in the literature study, there are many factors that influence or determines one's driving behaviour, including personal characteristics. Therefore, several hypotheses are formulated and assessed using statistical tests. These hypotheses contribute to a better understanding of either the sample of respondents, or the factors that influence driving behaviour, and in particular strategy-based lane change behaviour. In section 7.5.1 statistical tests that can be used on the data set are described and discussed. In section 7.5.2 hypotheses are formulated and the appropriate statistical tests selected. Since the meaning of the p value, which is extensively used in hypothesis testing, is often misinterpreted, the meaning of p values is discussed in section 7.5.3.

Furthermore, the data analysis continues with a brief discussion of the respondents' opinion on the 'Keep your lane' system is included in section 9.6.

So far, all analysis focused on the sample which was retrieved from within the Netherlands. All results that follow from these analyses are thus applicable for the Dutch case only. As a separate

analysis a comparison will be made between responses from the international and Dutch questionnaire. This is done to assess the transferability of the findings based on the Dutch case to other countries, while cultural differences are searched for that might need further research.

Part III of this report ends with chapter 10 that concerns the comparison of questionnaire results between different nationalities. Responses from the international survey are compared with responses from the Dutch survey. This is thus a between-subjects study design of an independent variable (nationality) and one dependent variable (responses on scenarios). Both variables have a nominal scale, and thus the Pearson's Chi-square test and Cramer's V test are run to evaluate the relationship between nationality and driving behaviour as questioned in each of the scenarios. This international comparison is done to assess the transferability of the results from the Dutch sample to other countries, while some first directions in possible cultural differences are given.

7.5.1 Choice of statistical tests

To select the appropriate data analysis method it is useful to know what level of measurement the information has. The most common used classification distinguishes four levels (Field, 2013), namely:

- nominal: no order, no measuring unit, no fixed origin;
- ordinal: order, no measuring unit, no fixed origin;
- interval: order, measuring unit, arbitrary origin;
- ratio: fixed origin;

The data gathered via the questionnaire have different classification levels. Age, desired speed, average weekly mileage, years holding a driving license are collected as ratio variables. The opinion of respondents on various aspects of the 'Keep your lane' system are measured via likert scales and are thus ordinal variables, just like driving frequency. Nationality and occupation are clearly nominal variables. The responses on each scenario are also nominal variables, since the multiple choice answers do not have any order or measuring unit. Age, average weekly mileage and years holding a driving license will be used to divide the sample in subgroups to check on differences between these subgroups, which means these ratio variables are converted into ordinal variables. Table 7.5 gives an overview of the appropriate visualizations, independence tests and measures of association for comparing a mix of nominal and ordinal variables. These tests can be done on contingency tables of two variables. Contingency tables (or cross tabulations) present the counts of the joint distributions of the variables.

Pearson's Chi-square test

Independence tests are done to check if there is a significant relationship between the two variables. This test can for example be used to see if respondents from different age groups have reacted similar on the questions, or if age possibly shows an association with driving behaviour. The Pearson Chi-square test is used to evaluate the cross tabulation results of Nominal vs Nominal variables and Nominal vs Ordinal variables. This test compares the observed frequencies in a cross tabulation with the expected frequencies that are determined using the row and column totals of a cross tabulation. The squared difference between the observed and expected frequencies is then used as the test statistic. Using the Pearson Chi-square test possible relationships between personal characteristics and driving behaviour can be tested on statistical significance. However, it is important to bear in mind that a statistical correlation of two variables is not evidence for a causal relationship. Furthermore, when doing the Chi-square test two important assumptions are made (Field, 2013):

Table 7.5 – Overview of applicable statistical tests for comparing nominal and ordinal variables (adapted from CIE4831 (2014))

Row variable	Column variable	
	Nominal	Ordinal
Nominal	Clustered bar-graph Pearson's Chi-square Phi (ϕ) or Cramer's V	Clustered bar-graph Pearson's Chi-square Phi (ϕ) or Cramer's V
Ordinal	-	Scatter plot or clustered bar chart Linear Chi-square Spearman's Rho or Kendall's Tau

- Independence of data. The variables that are being tested needs to be independent, which means that each respondent, item or entity can only belong to one cell of the contingency table.
- The expected frequencies needs to be higher than 5. However, in large contingency tables it is allowed to have 20% of the expected frequencies below 5, but none may be lower than 1.

A significant relationship exists between two variables when the Pearson Chi-square test value is bigger than the critical value from the Chi-square distribution, which can be found in Field (2013) with the help of the degrees of freedom. The degrees of freedom of a contingency table in case of the Pearson's Chi-square test is the multiplication of the number of rows and columns minus one.

The Pearson's Chi square is also recommended to be used for testing the association between an ordinal and nominal variable. However, the Pearson's Chi square test neglects the order of the ordinal variable, and thus there is some loss of statistical power (Agresti, 1996). For nominal variables that are dichotomous an alternative test can be done that is called the Mantel-Haenszel linear-by-linear association chi-squared test, which is the Linear Chi-squared test as referred in table 7.5. The order of a variable that has only two categories does not matter, and thus in that case a nominal variable can be treated as an ordinal variable, so the order of the true ordinal variable does not have to be neglected.

Cramer's V measure of association

The Pearson Chi-square test does not say anything on the strength of the relationship between the tested variables. Therefore an additional test needs to be done. For a contingency table greater than 2x2 Field (2013) recommends to use Cramer's V effect size test. Cramer's V coefficient is a value between 0 (representing no relationship) and 1 (perfect relationship). How to interpret the values in between is found in table 7.6 and is based on the degrees of freedom, which is for Cramer's V test statistic defined as the minimum of either the number of columns or rows minus one. For 2x2 contingency tables a more elaborate interpretation of Cramer's V is given by Rea and Parker (2014) and is presented in table 7.7.

Table 7.6 – Interpretation of effect size Cramer's V according to Cohen (2013)

Degrees of freedom	Small effect	Medium effect	Large effect
1	0.1	0.3	0.5
2	0.07	0.21	0.35
3	0.06	0.17	0.29
4	0.05	0.15	0.25
5	0.05	0.13	0.22

Table 7.7 – Interpretation of effect size Cramer's V according to Rea and Parker (2014)

Values	Interpretation of effect size
0.00 and under 0.10	Negligible association
0.10 and under 0.20	Weak association
0.20 and under 0.40	Moderate association
0.40 and under 0.60	Relatively strong association
0.60 and under 0.80	Strong association
0.80 and under 1.00	Very strong association

Linear Chi-square test

If the categories of a variable do have an order as in the ordinal variables, linear chi-square tests can be done which actually take the order of a variables categories into account. There are several tests that can do this, but the statistical analysis software package SPSS applies standard the Mantel-Haenszel linear-by-linear association. This tests gives a chi-squared statistic with one degree of freedom, and tests the null hypothesis that the two variables do not show a relationship against the alternative that they actually do have a relationship.

The requirements to run the Mantel-Haenszel test of trend read as follows:

- Both variables are ordinal.
- The Mantel-Haenszel test of trend is used to test if a linear association exists, but not whether the association is linear. So if this test is used, it is assumed that the relationship is expected to be linear.

Goodman and Kruskal's gamma

The linear Chi-square test does not say anything on the size of the association between two variables, but only if it exists. There are several tests that can measure the size of the association, and include Gamma, Spearman's correlation and Kendall's Tau-b. While these three test are all non-parametric measures of strength, in case the data includes many tied ranks the Goodman and Kruskal's gamma is recommended (Laerd-Statistics, 2016). The interpretation of Goodman and Kruskal's gamma according to Gau (2016) is presented in table 7.8. The assumptions that needs to be met to apply the Goodman and Kruskal's gamma read as follows:

- The two variables should be measured on an ordinal scale.

- The relationship between the two variables must be monotonic, which can be checked by a scatter plot. Figure 7.3 elaborates more on monotonic relationships.

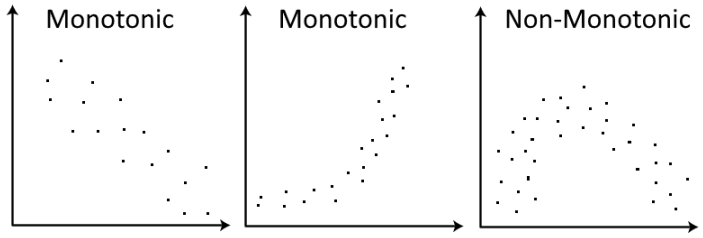


Figure 7.3 – Example of monotonic and non-monotonic relationships between two variables (Laerd-Statistics, 2016)

Table 7.8 – Interpretation of Gamma to assess the strength of an association.

Value of gamma	Strength of association
0 to $\pm$ 0.19	Weak
$\pm$ 0.20 to $\pm$ 0.39	Moderate
$\pm$ 0.40 to $\pm$ 0.59	Strong
$\pm$ 0.60 to $\pm$ 1.00	Very strong

7.5.2 Hypothesis testing

The aim of the questionnaire is to see how the respondents are distributed over the lane change strategies, and what factors possibly could make them shift from one strategy to another. Furthermore, it is important to understand the sample of respondents, since certain sub-groups might show different behaviour. Driving behaviour is influenced by personal characteristics, training and experience, as can be seen in Fuller's task-capability model in figure 2.4. A particular sub-group that shows deviating driving behaviour will affect the results if this sub-groups is overrepresented in the sample. To understand the sample of respondents better the following alternative hypotheses have been formulated that will be assessed with the previously described statistical tests :

h_1^a : *Older drivers have a lower desired speed than younger drivers.*
h_1^b : *Frequent drivers have a higher desired speed than infrequent drivers.*
h_1^c : *Inexperienced drivers have a higher desired speed than experienced drivers.*
h_1^d : *Drivers with high average weekly mileages have a higher desired speed than drivers with low average weekly mileages.*

All four hypotheses concern two variables that were initially measured in the questionnaire on a ratio scale. Although relationships between two ratio variables can be tested with the Pearson's product-moment correlation test, this test is not used. The Pearson's product-moment correlation test assumes a linear relationship between the two variables that are tested, which can be checked using scatter plots. However, it is expected that these scatter plots show very spread results, and there are for

example no data point expected for desired speed variable below 80 km/h, and thus not a clear linear relationship will exist. But if for example the speed variable is converted to an ordinal variable, this linear relationship can be ensured, which allows for the application of the Mantel-Haenszel linear-by-linear association test.

Furthermore, to assess whether sub-groups responded differently on the questions a broad analysis is done by comparing the responses given by these sub-groups on each question. If and how personal characteristics are related to driving behaviour are revealed by these analyses. The Pearson's Chi-square test and the Cramer's V measure of association will be run, since the multiple choice answers have a nominal level while the sub-groups are categorized on an ordinal level. All open answers will be neglected, since the Pearson's Chi-square test assumes independent categories for each variable, while open answers might show similarities with the pre-defined answers. The following sub-group analyses will be done:

1. **Age.** The sample of respondents will be split into several categories. For each question will be checked if these categories show a different response. For example, this analysis will show if senior drivers more often answered 'A' in question 1 than young adult drivers, which could indicate a significant difference in driving behaviour based on age.

2. **Desired speed.** The questionnaire contained three speed branches over which respondents are distributed based on their desired speed. An analysis will be done to assess if any differences can be found in the responses from the three speed branches, that categories respondents in 'Slow', 'Average' or 'Fast' drivers.

3. **Driving frequency.** In the driving experiment a participant commented that during the weekends he experienced many frustrations because of other drivers. He believed that commuters who drive a car every working day drive different than the drivers who only occasionally drive during the weekends. Therefore an analysis is done to check whether frequent drivers show different behaviour than infrequent drivers, by comparing their responses on each scenario.

4. **Driving experience.** Another personal characteristic that could result in different responses is driving experience in terms of number of years holding a driving license. As underpinned by Vlakveld (2005) and Fuller (2005) driving behaviour depends on skill which is achieved by experience. So the question that will be answered is: Do novice drivers respond similar as experienced drivers for the various traffic situations?

7.5.3 Meaning of *p* values

The Chi-square tests that are used in this study produce test-statistics, which are compared with critical values of the chi-square distribution, that on their turn correspond with a p value. This value is used to draw conclusions. However, the p value is often wrongly used and misinterpreted (Colquhoun, 2014; Sellke *et al.*, 2001). Therefore, a short explanation of the p value and its meaning is presented here.

In this study statistical tests are used to determine if there exist effects or differences between variables and/or groups. The p value determines how well the sample data agrees with the null hypothesis, which states that there is no difference or effect on population level. A high p value means that based on the sample data the null hypothesis is probably true, while a low p value suggests that there is sufficient proof that the null hypothesis is not true for the population. The definition of the p value according to Field (2013) is:

"p is the probability of observing results as extreme (or more) as observed, if the null hypothesis (H0) is true."

Colquhoun (2014) writes that the most commonly made mistakes are to interpret p as the error rate or the probability of making a Type I error, which means rejecting the null hypothesis while in fact the null hypothesis is true. Paraphrasing Colquhoun (2014), the following statement can be made if the significance test results in $p = 0.05$:

"If there were actually no effect (if the true difference between means were zero) then the probability of observing a value for the difference equal to, or greater than, that actually observed would be p = 0.05. In other words there is a 5% chance of seeing a difference at least as big as we have done, by chance alone."

The p value should thus not be misinterpreted with the error rate. Although the error rate depends on several assumptions which can differ per study, Sellke *et al.* (2001) made estimations of typical error rates, which are presented in table 7.9, for some often used p values for precise null hypothesis testing.

Table 7.9 – Typical error rates for some p values(Sellke *et al.*, 2001)

p value	Probability of incorrectly rejecting a true null hypothesis
0.05	At least 23% (and typically close to 50%)
0.01	At least 7% (and typically close to 15%)

There is a tendency to conclude that results are significant if the produced p value is lower than 0.05. However, studies with similar p values, can have different error rates, and thus do not provide the same strong evidence for the alternative hypothesis. Colquhoun (2014) recommends to never use the word 'significant', since this is arbitrary, the error rate is more important. Furthermore, he states that a p value of 0.05 means the results are 'worth another look', while only a p value of 0.001 is low enough to claim a discovery of something. Another recommendation is the use of effect size, since the p value does not say anything about the size, for which in this study either Cramer's V test or Goodman and Kruskal's gamma test is performed.

Concluding, a value of $p<0.05$ means that there is a chance of 5% of observing the same difference or bigger by coincidence, while there is a chance of at least 23% a true null hypothesis is rejected. Furthermore, determination of the effect size is important, since only checking if a difference is 'significant' does not say anything about its true meaning (Colquhoun, 2014). Nevertheless, in this study a $p<0.05$ is used as threshold to distinguish between 'significant' and 'non-significant' differences, although this could imply an error rate of at least 23% and typically close to 50%. On the other hand, the strength of the association (effect size) is used to draw conclusions.

Chapter 8

Validation of questionnaire

Two comparisons will be made in this section to validate the results from the questionnaire. The first one is a comparison of the behaviour of participants in the driving experiment with their response in the questionnaire for videos that were taken from their test drive. For example, the video of scenario 1 was actually taken out of the field test video material of participant 'x'. It is thus known for sure how participant 'x' reacted in that situation on that moment. This comparison is found in section 8.1 The second comparison to validate the results from the questionnaire involves a more general comparison between the driving experiment and questionnaire. For example, based on the interview with participant 'z' was concluded he drives according to strategy 1 and 3, which will be compared with the strategies found in the questionnaire. This comparison is found in section 8.2. Almost every question included the option to give an open answer, which has been used by respondents that could not find themselves in one of the pre-defined multiple-choice answers. Checking these open answers sometimes give valuable information on how respondents perceived a question and it's corresponding video. Furthermore, several respondents used the comment box at the end of the questionnaire to give feedback, of which some can be used to assess the validity of the questionnaire. Therefore the open answers and comments which affect the validity of the questionnaire are discussed in section 8.3. This chapter ends with some general conclusions on the validity of the questionnaire in section 8.4.

8.1 Video-based validation

In total 7 of in total 13 videos have been linked to a survey response, for which the comparison with the shown behaviour in the driving experiment is shown in table 8.1. Three of the videos could not be linked with a participants from the driving study, since not all participants filled in the questionnaire or could not be identified through their email address in the questionnaire. Furthermore, three videos have been recorded by the author himself after the field tests, to collect appropriate video footage of particular traffic situations which could not be found in the available videos from the driving experiment.
In four out of seven scenarios the response in the questionnaire was exactly the same as the shown behaviour in the driving experiment. However, in three out of seven scenarios the person responded differently in the questionnaire. There can be varying explanations for this, although it is not possible to state which explanation is applicable for each case, which read as follows:

- In the videos distances and speed are harder to estimate than in reality. Therefore a person could interpret the situation differently than during the actual test-drive.

- The videos have a duration of about 10 seconds, which is in some cases too short to really show the actual traffic conditions and traffic situations. In the comment box at the end of the questionnaire, a few respondents noted that it was sometimes hard to estimate the traffic density, which affects their driving behaviour they said.

- When a person fills in the questionnaire he is very aware of his behaviour, however on the road people might be less aware of their own behaviour. In the driving study several times participants mentioned they were not aware of their speed at certain moments, or did not have an explanation for their shown behaviour.

- In the questionnaire a person has unlimited time to overlook the traffic situation and to make a well-though decision, although each respondent was asked in the introduction not to think too long.

- As seen in the literature study in section 2.2, driving behaviour is affected by a person's condition. Different moods of participants in the driving experiment and while filling in the questionnaire, could also lead to differences.

8.2 Interview-based validation

A second validation of the questionnaire has been done using the findings of the interviews. Comparisons between the questionnaire and interview findings are presented in figures 8.2, 8.3 and 8.4. Each table shows a comparison between results from the driving experiment and results from the questionnaire for all participants from the driving experiment that could have been identified.

There is quite a good correspondence between the desired speeds reported in the driving experiment and the questionnaire. Some respondents gave a varying desired speed in the questionnaire than in the interview, although it is questionable if in both situations the respondents accounted for the deviation of the speedometer of the vehicle. Several participants for example stated they would drive a certain speed on the speedometer of the car, while their true speed is about 5 - 10 km/h lower. So participants might responded with a corrected speed in the interview of the driving experiment, but their true speed in the questionnaire. Overall seen, 12 of 25 respondents (48%) reported the same desired speed in the questionnaire as in the driving experiment. There were 10 (40%) respondents that gave a different desired speed with a difference between 1 and 5 km/h, 2 respondents gave responses with a difference of 10 km/h and 1 respondent gave a 20 km/h deviating response.

The comparison of the strategies found by the driving experiment and strategies applied in the questionnaire show varying correspondence. For about 12 participants quite a good correspondence is found, while for the other 13 there is deviation. For example participant number 7 indicated in the interview he drives strictly according to strategy 2, while in scenario 9 and 13 he responded with strategy 1 driving behaviour. On the other hand, a good match was found for participant 5 who stated to drive according to strategy 2 and 3 in the interview, which has also been concluded based on his response in the questionnaire. Overall seen, of the 147 strategies that have been identified in the questionnaire 127 (86%) were in line with the findings from the interviews. Thus, 20 (14%) strategies were not in line with the strategies revealed in the driving experiment, which means in 20 cases a respondent showed a different strategy in the questionnaire than the strategies that were revealed by the interviews.

Also for right overtaking behaviour a comparison is made between what people said during the interview and how they responded in the questionnaire. This comparison shows varying correspondence as well. Some participants that stated they would never overtake via the right, did indeed not overtake the vehicles via their right in the two scenarios of the questionnaire. However, one participant who stated never to overtake others via their right side, did overtake the vehicle in scenario 5 via its right side. Overall seen, a good correspondence was found for about 9 participants. For 10 participants the comparison could not be made because right overtaking behaviour was not discussed in the interview. While for 6 participants deviating results were found.

A good correspondence was found for cooperative behaviour with vehicles on the merging lane between the interviews and the questionnaire. Most participants state they would change lanes, and actually did too in the questionnaire. The participant that stated he would not change lanes or cooperate with the merging vehicle if he did not use its indicator, indeed gave the same response in the questionnaire. For all 17 out of 25 respondents for which the comparison could be made a correspondence was found between the driving experiment and questionnaire results.

As last, a comparison was also made for obeying to the keep right rule. In scenario 7 a truck was driving on the shoulder lane up ahead, while in scenario 8 the respondents had a completely empty road in front of them after passing a truck on the shoulder lane. Scenario 10 involved a two-lane motorway where a faster driver was approaching from behind and truck were driving on the shoulder lane. Scenario 14 concerned the situation with the opened peak hour lane. The results show varying compliance between the findings of the driving experiment and the questionnaire. However, is very subjective if a certain gap on the shoulder lane is large enough for a driver or not. Some participants stated in the interview they would not keep right if a truck was driving up ahead on the shoulder lane. But how far is up ahead? This cannot be concluded, so how well 'keeping right' behaviour from the questionnaire correspond with the statements from the interview cannot be concluded.

8.3 Comments from respondents

The validity of the questionnaire involves also the correct interpretation of the scenarios. Via the open answer option which was available in most of the questions, respondents mentioned in some cases that the scenario was not clear enough.

In scenario 5 many respondents mentioned that the direction they had to follow was not clear, and so they could not answer the question. The video showed the on-ramp near Nootdorp on the A12 in the direction of the Hague, just before junction Prins Clausplein. The on-ramp continues as the shoulder lane of a two-lane connection road. The respondents were supposed to follow the connection road, which was tried to made clear in the introduction of the questionnaire. However, the pre-defined multiple choice answers also indicated the direction a respondent had to follow, since there were no options in which you would change to the main roadway. So it is believed that most respondents did understand the intended traffic situation correctly. In scenario 6 some respondents stated the distance to the exit was unclear, while it was presented in the video. In the last comment box a few respondents mentioned they did not see all videos, since the videos did not function in their browser or they did not know how to play the videos. It is not possible to find out if a respondent saw the video or not. In scenario 13 a participant mentioned it was hard to assess based on the video if it was possible to overtake the truck in time before the off-ramp.

Furthermore, the comment box at the end of the questionnaire give also insight in how people per-

ceived the videos and questions. There were many positive comments of people who enjoyed filling in the questionnaire. There were also many who used the comment box to describe their frustration they experience on motorways, while others gave their opinion on the 'keep your lane' system. But of course also some comments concerning the questions or videos that were unclear were given:

- 'In a few questions the predefined multiple choice answers did not display the answer I was looking for, namely changing lanes and just slightly increase your speed.'
- 'I found the speed limit of 100 km/h and the speed of the car confusing. I would drive exactly with the applicable speed limit.'
- 'I found it difficult to fill in the questionnaire. In practice I would sometime overtake another vehicle via its right side, but in the shown traffic situations I found it harder to do so.'
- 'I never drive 107 km/h where 100 km/h is allowed, I always drive 103 or 104 km/h.
- 'I did not understood the videos, I based my answer on the text and photo.'
- 'There were some situations which required a more extensive explanation in my opinion, I think the answers do not represent my actual actions completely correct.'
- 'The questionnaire induces socially desirable responses.'

8.4 Conclusions

The validation of the results have been done in three ways: a video-based comparison, an interview-based comparison and a discussion of comments respondents gave at the end of the questionnaire. The video-based comparison showed that in 4 out of 7 scenarios an exact correspondence was found, while there was a deviating results for the other 3 scenarios. A varying correspondence have been found in the interview-based comparison for the different themes, 86% of the strategies found in the questionnaire for participants of the driving study correspond with the strategies found in the interviews, while 88% of the desired speeds given in the experiment and questionnaire gave a correspondence with a difference less or equal to 5 km/h. A full correspondence was found for the results concerning courtesy behaviour between the experiment and questionnaire.

In the literature several drawbacks of a questionnaire and self-reported behaviour were found, which could explain part of the deviating results of the driving experiment and the questionnaire. Furthermore, driving behaviour is stochastic. As formulated by Lee *et al.* (2004) naturalistic driving behaviour is a set of driving styles, which thus could also explain some of the found deviation. As last, interviews as well as questionnaires are prone to socially desirable answers, which influence the validity of the results, although the effect has not been assessed. It is hard to quantify the validity of the questionnaire in terms of representability for naturalistic driving behaviour of the respondents, and it is unknown how 'big' a drivers set of driving styles is. In other words, how much has been observed of someone's driving behaviour via the questionnaire? Nevertheless, reasonable correspondence is found between the questionnaire and driving experiment, but of course drivers do not react completely similar to a traffic situation every time.

Table 8.1 – Comparison of answers in questionnaire and shown behaviour in driving experiment

Scenario	Theme	Answer in questionnaire	Shown behaviour in driving experiment
1	Right overtaking	E) I change two lanes to the left and will pass the black car with a constant speed of about 100 km/h	B) I continue driving on this lane, I adjust my speed and will stay behind the black car
2	Strategy 1,2,3	-	-
3	Strategy 1,2,3	-	-
4	Strategy 1,2,3	A) I stay in the current lane	A) I stay in the current lane
5	Right overtaking	A) I continue driving on this lane and will adapt my speed so I stay behind the black car	A) I continue driving on this lane and will adapt my speed so I stay behind the black car
6	Strategy 1,2,3	-	-
7	Keep right	-	-
8	Keep right	-	-
9	Strategy 1,2,3	B) When the car behind me passed me, I will change lanes and keep my speed constant at about 100 km/h	E) I will change one lane to the left immediately, while increasing my speed well above 100 km/h
10	Keep right	-	-
11	Strategy 4	A) I keep my speed constant at about 107 km/h	A) I keep my speed constant at about 107 km/h
12	Courtesy lane change	C) I continue driving on this lane with my current speed	C) I continue driving on this lane with my current speed
13	Strategy 1,2,3	B) I continue driving on this lane and increase my speed (far) above 100 km/h, after I pass the truck I will change one lane to the right to take the off-ramp	C) I change one lane to the right and adjust my speed to the truck and eventually take the off-ramp up ahead

Table 8.2 – Comparison of applied strategies and desired speeds for participants from the driving experiment with their responses in the questionnaire

Participant	Applied strategies								Desired speed	
	Driving experiment	Questionnaire							Driving experiment	Questionnaire
		Sc 2	Sc 3	Sc 4	Sc 6	Sc 9	Sc 11	Sc 13		
1	1,2,3,4	1	1	3/4	1/2	1	-	2	110	110
3	1,2,3,4	1	1	3/4	1/2	1	-	2	103	104
4	1,2,3,4	1	1	3/4	3*	1	-	3	104-106	100
5	2,3	2	NA	3/4	1/2	2	-	2	110-120	110
6	1,3	1	1	1/2	3*	2	-	3	110	110
7	2	2	NA	1/2	3*	1	-	1	108-110	105
8	1,2,4	1	2	3/4	1/2	1	-	2	110	110
9	1,2,3	1	1	3/4	3*	1	-	3	100	102
10	1,2	1	2	3/4	3*	1	-	1	110	110
11	1,2,3,4	1	1	3/4	3*	1	-	2	110	100
12	2,3,4	1	2	3/4	1/2	1	4	3	110	110
13	1,2,3	1	1	3/4	1/2	1	-	3	110	105
14	1,3	1	2	3/4	1/2	1	4	3	100	102
15	1,2,4	1	2	3/4	3	1	-	2	100-105	105
16	2,3	other	NA	3/4	3	1	-	2	100	105
18	1,2,3	1	2	1/2	3*	2	4	3	110	110
19	1,2,3	1	2	3/4	3*	1	-	2	110	105
20	1,2,4	2	NA	3/4	3*	2	-	3	110	110
22	1,2,3	1	2	3/4	1/2	2	4	2	115	110
23	1,2	1	2	1/2	1/2	2	-	2	100-130	125
24	1	1	1	3/4	other	1	-	1	103	100
25	1,2,4	2	NA	3/4	1/2	2	-	3	120	100
27	2,3,4	1	1	3/4	1/2	1	-	1	110-120	105
29	1,2,3	1	2	3/4	1/2	1	-	2	110	110
33	1,2,4	1	1	1/2	1/2	1	-	2	130	130

Table 8.3 – Comparison of right overtaking and cooperative driving behaviour for participants from the driving experiment with their responses in the questionnaire

Participant	Overtaking via right?			Cooperative behaviour?	
	Driving experiment	Questionnaire		Driving experiment	Questionnaire
		Sc 1	Sc 5		Sc 12
1	-	No	No	Yes	Lane change
3	Sometimes	Yes	No	Yes	Lane change
4	In principal not, but it happens sometimes	No	No	Yes	Lane change
5	Yes, to show them there is space on the right side	No	No	Yes	Lane change
6	-	No	No	Yes	Lane change
7	Never	No	Yes	-	Lane change
8	-	No	No	Yes	Lane change
9	-	No	No	Yes	Lane change
10	-	Yes	No	Yes	Lane change
11	Do not like right overtaking, only if someone is driving really slow	No	No	Yes	Lane change
12	-	Yes	No	-	Lane change
13	Yes, especially at peak hour lanes I want to show others there is space on the right side	Yes	Yes	-	Lane change
14	-	No	Yes	-	Lane change
15	Never	No	No	Yes	Lane change
16	Rarely	No	No	Yes	Lane change
18	Never	No	No	-	Lane change
19	Sometimes you can not avoid right overtaking another driver	No	No	Yes	Lane change
20	-	No	No	Yes	Lane change
22	Yes, for example at a weaving section where drivers drive slower when they want to merge onto the other roadway	No	No	-	Lane change
23	Yes	Yes	Yes	-	Lane change
24	-	No	No	Yes	other
25	Yes	No	No	Yes	Lane change
27	Yes, definitly	No	No	Only if they use indicator	No
29	-	No	No	Yes	Lane change
33	Yes, sometimes. I also want to show them there is space on the right side	No	No	-	No

Table 8.4 – Comparison of keep right behaviour for participants from the driving experiment with their response in the questionnaire

Participant	Strictly keeping right?				
	Driving experiment	Questionnaire			
		Sc 7	Sc 8	Sc 10	Sc 14
1	Always	No	Yes	Yes	Yes
3	-	No	Yes	No	Yes
4	-	No	Yes	No	Yes
5	Yes, except when truck up ahead on right lane	Yes	No	No	Yes
6	-	Yes	Yes	Yes	No
7	Not always worth the effort	Yes	Yes	No	Yes
8	Yes, except when slower traffic up ahead on right lane	No	Yes	No	No
9	Not always, ff density is low and others can overtake me	No	Yes	Yes	Yes
10	-	No	Yes	Yes	Yes
11	I try to prevent driving on the rightmost lane between two trucks, since I heard a driver has once been sandwiched by two trucks	No	Yes	Yes	Yes
12	Not if a truck is driving on the shoulder lane up ahead	Yes	Yes	No	Yes
13	Yes, it is annoying if drivers do not keep strictly right	No	Yes	Yes	Yes
14	Not always, since you can get stuck at the shoulder lane between other traffic	Yes	Yes	No	No
15	Not always, for example when on-ramps are present and when I drive faster than the vehicles on the shoulder lane	No	Yes	Yes	No
16	-	No	Yes	Yes	Yes
18	Yes, but not when slower vehicles on the shoulder lane	No	Yes	No	No
19	Not strictly, the shoulder lane is for trucks and I do not want to change constantly to the left and right	No	No	Yes	Yes
20	Yes, even when I see a truck on the shoulder lane, which sometimes results in me being stuck on the shoulder lane	Yes	Yes	No	Yes
22	Not strictly, when I think traffic is driving slower on the right lane I will not keep striclty right.	Yes	Yes	Yes	Yes
23	No, my speed is mostly much higher than that of the vehicles on the shoulder lane, and thus I will overtake those vehicles within several seconds. Furthermore, on the centre lane you have more options to go to.	Yes	No	No	No
24	-	Yes	Yes	other	Yes
25	Yes, if possible	Yes	Yes	Yes	No
27	-	No	Yes	Yes	Yes
29	Not always, especially when you could get stuck between slow traffic on the shoulder lane	Yes	Yes	Yes	No
33	Not always, I base this decision on my relative speed with other drivers. I try to prevent getting stuck on the shoulder lane between slow traffic.	Yes	Yes	Yes	Yes

Chapter 9

Questionnaire Results

In this chapter the results from the online questionnaire are discussed. Section 9.1 gives a brief description of the data set. Then a demographic analysis of the respondents is presented in section 9.2. Third, an overview of the responses for each question is presented and interpreted in section 9.3. Section 9.4 presents a cross-question analysis of the responses over multiple questions with the same theme. An analysis to assess whether demographic characteristics show a relationship with driving behaviour is done in section 9.5. A brief discussion of the results and interpretations of part 2 of the questionnaire concerning the 'Keep your lane' system is given in section 9.6. This chapter ends with conclusions on the main findings that were presented throughout the chapter, and are found in section 9.7.

9.1 Data set

Over a period of 3 weeks 1,248 responses were collected via the Dutch version and 22 responses via the English version that was spread in the Netherlands. However, only 10 out of 22 responses from the English version were taken further into account, since 12 respondents either did not live or had ever driven in the Netherlands. On the other hand these 12 responses can be combined with the responses from the international version, on which 179 people respondent. After downloading the dataset from the survey tool it has been anonymized by removing email addresses and other directly identifiable data from the data file.

A first analysis of the full dataset shows that over all questions of part 1, which concerned the 14 traffic scenarios, 1,249 unique combinations of answers have been given by 1,258 respondents from the Dutch version. There is thus a very large spread in the answers. However, if the questions concerning the motives are neglected, there is less spread (which is obvious when less questions are taken into account). Without the 'motive' questions 1,143 unique response sets were found, while the most frequent given combination of answers occurred only 9 times. Hence, the results show a very large spread. Note that throughout this chapter the 1,258 responses that were collected from the national surveys are used. The responses from the international survey are first used in the international comparison that is found in chapter 10.

9.2 Demographic data analysis

In appendix B.3 several s and tables are presented showing the demographic characteristics of the group of respondents. In this section an analysis is done to understand the sample of respondents,

based on their background characteristics. If and how personal characteristics influence lane change behaviour will be analysed in section 9.5.5.

9.2.1 Age

The youngest respondent was 17 years old, while the oldest respondent was 92 years old. As can be seen in the distribution of the respondents over the several age groups in figure 9.1, there is a peak in the 25 - 29 years old group. Furthermore, drivers with an age of 50 years and older are overrepresented in the sample, while people between 30 and 49 years are underrepresented. In figures A.33 and A.34 in appendix A.6 some information of the population of drivers in the Netherlands is presented. In these figures the graph has more of a bell shape, with a peak around the 40 to 50 years group.

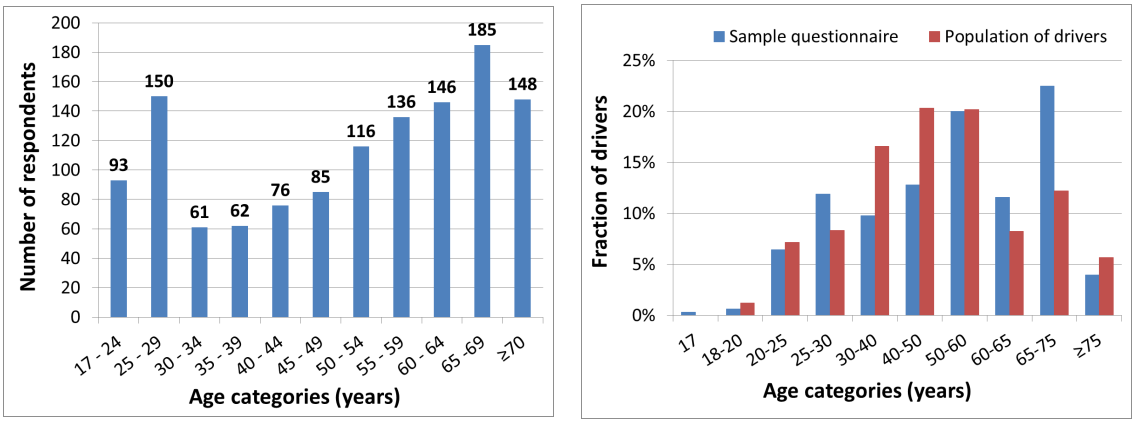


Figure 9.1 – Distribution of respondents over age and comparison of sample and population

9.2.2 Gender

Unfortunately, the gender of each respondent is not known, since there was accidentally no question on this included in the questionnaire. It is thus not possible to evaluate the representativeness of the sample concerning gender. However, based on CBS Statline data some insight has been achieved on the expected differences based on gender concerning travel behaviour. As can be seen in s A.33 and A.34 a smaller percentage of women per age group possess a driving license and women tend to drive as car driver less kilometres per day on average. For example: men in the age between 40 and 50 years travelled on average about 34 km per day as car driver, while women in this same age group travelled on average about 18 km per day as car driver.

9.2.3 Occupation

The largest share (51%) of the respondents works more than 30 hours per week. Of all respondents 9% are students, which are a thus overrepresented. Also because about 50% of the students indicated to drive only once per week or less. Many respondents were 65 years or older, which results in a high share of retired people in the sample, namely 29%. The share of retired people in the complete population of the Netherlands in 2014 was about 18% (CBS-Statline, 2016a). The group of retired people is thus overrepresented in the sample. Retired people make on average per person per day as a car driver less trips, travel less far and for a shorter time period. In 2014 an average retired person

travelled 9.57 km per day as car driver, while a person that works more than 30 hours per week travelled on average 32.24 km per day as car driver (CBS-Statline, 2016c).

9.2.4 Education level

Of the 1258 respondents 61% has completed a study on bachelor level or higher, which are commonly referred to as the high educated people. In the first quarter of 2016 about 29% (CBS-Statline, 2016b) of the population in the Netherlands older than 15 years old completed higher education, and thus high educated people are overrepresented in the sample. Higher educated people make on average more and longer trips than lower educated people. In 2014 higher educated people travelled on average 28.62 km per day as a car driver, in comparison with lower educated people that travelled 9.55 km per day on average as a car driver (CBS-Statline, 2016c).

9.2.5 Other demographics

Nearly all of the respondents (98%) are Dutch. Only 22 respondents have other nationalities, but do live and drive in the Netherlands. There are five provinces which stand out in the question concerning the provincens in which respondents regularly drive, namely Zuid-Holland, Utrecht, Noord-Holland, Gelderland and Noord-Brabant. The other provinces occur much less in the dataset. About 50% of the respondents drives a car on average 5 to 7 days per week, while only 6% of the respondents state they drive less than 1 day per week. Furthermore, 12 participants said they do not drive any more.

The average mileage per week on motorways varies a lot, however it is expected that this question was not understood correctly by all participants. There were 53 respondents who filled in an average mileage on motorways per week above 4,000 kilometres, some even noted a mileage of 10,000 or 65,000 kilometres per week. These respondents probably thought of their yearly mileage. It is also expected that not all participants reported their mileage on motorways but their total mileage. The information is thus not really trustworthy.

More than half (56%) of the respondents stated they would drive with a speed between 100 and 104 km/h on a motorway with a speed limit of 100 km/h. Peaks were seen for the speeds 100, 105, 110, 115, 120 and 130 km/h. The highest reported speed was, surprisingly, 157 km/h. Would this respondent really drive with a speed of 157 km/h on the motorway in the picture, or did he misinterpret the question? It is hard to tell, since no motives for the reported speed were asked.

9.3 Frequency distributions

The first results of the questionnaire consists of the frequencies of the multiple choice answer per scenario, since most of the multiple choice answers directly relate to a certain strategy or behavioural characteristic. In this section a brief summary of the main findings will be presented, while a more thorough analysis of the responses on each scenario and its interpretation is presented in appendix B.4. Each scenario is separately discussed together with possible corresponding follow-up questions, and a brief overview of the most occurring open answers is given.

Each multiple-choice answer per scenario relates to one or two of the four lane change strategies or to a driving behaviour characteristic. Table 9.1 shows the distribution of the respondents over the lane change strategies for 7 scenarios. Scenario 2, in which the respondents encountered a slower predecessor on the shoulder lane of a three lane motorway, shows that 77% of the respondents adapts

Table 9.1 – Distribution of respondents over the lane change strategies per scenario

Scenario	Theme	Lane change strategy							Other answers
		1	2	3	4	1/2	3/4	3*	
2	Strategy 1,2,3	77%	10%	12%	1%	-	-	-	0%
3	Strategy 1,2,3	56%	43%	-	-	-	-	-	1%
4	Strategy 1,2,3	-	-	-	-	27%	73%	-	0%
6	Strategy 1,2,3	-	-	44%	-	28%	-	27%	1%
9	Strategy 1,2,3	85%	11%	3%	-	-	-	-	1%
11	Strategy 4	-	-	-	12%	87%	-	-	1%
13	Strategy 1,2,3	20%	18%	61%	-	-	-	-	1%

a strategy 1 driving behaviour when they encounter a slower predecessor. These strategy 1 drivers were also the only ones that got to see scenario 3. So 43% of the initial strategy 2 drivers of scenario 2 would apply strategy 2 behaviour in scenario 3, which described a situation where the speed differences became very low with the vehicle you wanted to overtake.

The results of scenario 4 shows that 27% of the respondents would change to the fastest lane during congestion, while 73% would continue on their initial lane. The speed leading strategies have speed as the most important incentive to change lanes, so while there is a faster lane, in congestion more people tend to stick to their lane.

Following a route also seems to affect the strategy based lane change behaviour of the respondents. In scenario 6 44% of the respondents would continue in the initial lane and adapt their speed (strategy 3 behaviour) and 27% would conditionally apply strategy 3 behaviour if they have to take the off-ramp that is located 3000 metres up ahead, while in scenario 2 only 12% of the respondents would show strategy 3 behaviour. Also in scenario 13 were the respondents asked to take the off-ramp, only this time 600 metres up ahead with a truck in front of them. Again it seems that more people adapt a strategy 3 driving behaviour in this scenario, while only 20% would stick to strategy 1 driving behaviour.

Scenario 9 described a situation where the respondent encountered a slow truck, and the results indicate that less people apply strategy 3 and more people apply strategy 1 in comparison with scenario 1, in which the respondent encountered a slower person car. In case of scenario 11 about 12% of the respondents show strategy 4 behaviour when all other vehicles drive much faster than themselves.

Table 9.2 shows how many respondents would keep right in the four different scenario that were presented. The results of scenario 7 deviates from the other three scenarios concerning keep right behaviour. In scenario 7 a faster driver was approaching from behind and a truck was driving up ahead on the shoulder lane, while the respondents themselves were driving in the centre lane on a three lane motorway. Scenario 8 was almost similar as scenario 7, except for the truck and faster vehicle from behind that were not present. Scenario 10 presented a two lane motorway, while just as scenario 7, a faster driver was approaching from behind and a truck was driving on the shoulder lane up ahead. More people tend to change to the shoulder lane, of which 71% indicated to do so because of the faster driver. As last, only 73% of the respondents would keep right when a peak hour lane

Table 9.2 – Keep right behaviour of respondents

Scenario	Theme	Changing to shoulder lane?		Other answers
		Yes	No	
7	Keep right/Strategy 4	57%	42%	1%
8	Keep right	88%	12%	0%
10	Keep right	76%	23%	1%
14	Keep right	73%	25%	2%

was opened, while in scenario 8 88% of the respondents would keep right, which were comparable situation since no other vehicles were around.

Table 9.3 – Right overtaking behaviour of respondents

Scenario	Theme	Right overtaking?	
		Yes	No
1	Right overtaking	20%	80%
5	Right overtaking	16%	84%

How many respondents would overtake via the right side in the two scenarios that were included in the questionnaire is found in table 9.3. Both scenarios have comparable shares. However, in scenario 1 respondents has the possibility to overtake the vehicle that was driving unnecessarily left via its left side, while respondents did not have this possibility in scenario 5. On the other hand, in scenario 5 you entered the motorway and the merging lane continued as a regular lane of a connection road of a junction, in which respondents might see the unnecessarily left driving in this case of another vehicle as less annoying. However, motives behind someone's decision have not been asked, so no conclusions can be made on this.

Table 9.4 – Cooperative driving behaviour of respondents

Scenario	Theme	Cooperative behaviour?			Other answers
		Yes		No	
		Lane change	Speed adjustment		
12	Courtesy lane change	72%	11%	16%	1%

Finally, 72% of the respondents, as can be seen in table 9.4, indicated they would change lanes when they encounter a vehicle on the merging lane. Another 11% would adjust their speed (accelerating or decelerating) to make space for the vehicle to merge onto the roadway, while 16% would not cooperate with the vehicle on the on-ramp.

9.4 Theme analysis

So far only results per scenario have been shown, while the response of an individual over multiple scenario can give relevant insight in strategy-based lane change behaviour. In this section the behaviour of respondents over multiple questions will be analysed for the videos that concerned 'Overtaking via right' behaviour, 'Right keeping behaviour' and 'Strategy 1,2,3'.

9.4.1 Overtake via right

The questionnaire included two scenarios concerning right overtaking behaviour, scenario 1 and 5. These scenarios described a situation in which another vehicle kept driving unnecessarily on the left, in one situation there was also the possibility to overtake this vehicle via its left side. Table 9.5 shows the cross tabulation of the responses on scenario 1 and 5. Scenario 1 presents a four lane motorway where a car is driving on the second lane from the left, there is space to overtake the vehicle via its left or right side. Scenario 5 describes a situation in which you just entered the motorway and are approaching a connection road of a junction that you need to follow, while a car is driving on the second lane from the right and there is space for that vehicle to keep right.

Table 9.5 – Cross-tabulation of scenario 1 and 5

			Scenario 5				Tot.
			Right overtaking	No right overtaking	Strategy 3	Other	
Scenario 1	Right overtaking	% of Total	7%	4%	8%	1%	21%
	Left overtaking	% of Total	6%	11%	21%	1%	40%
	Strategy 3	% of Total	2%	10%	26%	1%	39%
	Other	% of Total	0%	0%	1%	0%	1%
Total		% of Total	16%	25%	56%	3%	100%

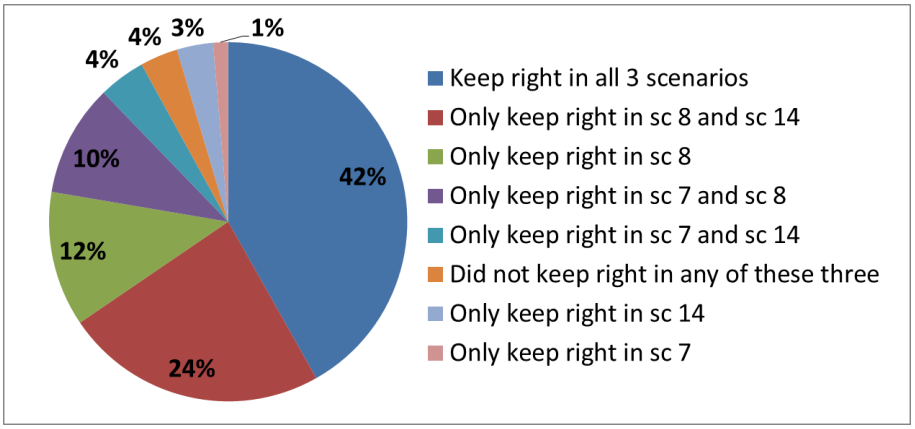
About 7% of the respondents stated they would overtake the vehicle via its right side in both scenarios, while in scenario 1 in total 21% of the respondents would overtake the vehicle via its right and in scenario 5 16% of the respondents would overtake the vehicle via its right. There are thus quite some people that show varying behaviour for these two scenarios. Approximately 26% of the respondents showed strategy 3 driving behaviour in both scenarios, which means they would stay in their initial lane and adapt their speed.

About 29% of the respondents indicated they would overtake another vehicle via its right side in either scenario 1, scenario 5 or both. Thus, 71% would not overtake the other vehicle in these situations. It is hard to generalize these results, since there is not very consistent behaviour concerning right overtaking and it thus really depends on the situation. Up front it was expected that more people would overtake the vehicle via its right side in scenario 5 than in scenario 1, since in scenario 1 there was the possibility to overtake via the left side. Other motives than the availability of left overtaking manoeuvres will probably play a role in the decision to overtake via the right or not. However, these have not been investigated in this study.

9.4.2 Keep right

Three scenarios concerning 'Keep right' behaviour were included in the questionnaire, scenario 7, 8 and 14. Scenario 7 showed a three lane motorway in which you were overtaking a truck via the centre lane, while a faster driver was approaching from behind. 723 (57%) of the respondents indicated they would change to the shoulder lane in that scenario. Scenario 8 described a situation of a three lane motorway where there was almost no other vehicle in front of you, for which 1104 (87%) of the respondents indicated they would change to the shoulder lane. In scenario 14 the peak hour lane was opened. 918 (73%) of the respondents stated they would drive on the peak hour lane.

Table 9.6 – 'Keep right' behaviour seen over three scenarios



Interesting to see is how each individual reacted on the three scenarios, so how strict would someone keep right? Figure 9.6 shows the answers over the three scenarios combined. About 42% of the respondents would keep right in all three scenarios, while 4% would not keep right in any. Furthermore, 24% of the respondents only keep right in scenario 8 and 14, while in scenario 7 they would continue in the initial lane. In scenario 7 there was another slow vehicle driving on the shoulder lane, and there was the possibility for other drivers to overtake the respondent. About 12% of the respondents only changed to the shoulder lane in scenario 8, and would thus not use the peak hour lane in scenario 14. This is quite surprising since in both scenarios there are no other vehicles in front of you, and after you pass the truck on the shoulder lane there is plenty of room to keep right. Another 10% of the respondents only keep right in scenario 7 and 8, but not in scenario 14. There are thus quite some people who do not use the peak hour lane, while they would use the rightmost lane on a motorway without a peak hour lane.

9.4.3 Strategy 1,2,3

In total 6 scenarios were included to distinguish strategy 1, 2 and 3 driving behaviour, namely scenario 2, 3, 4, 6, 9 and 13. However, scenario 3 was a following-up question for the respondents who showed strategy 1 behaviour in scenario 2. Scenario 3 will therefore be neglected. Due to the large sample of respondents and the wide variety of answer combinations there is a large spread in the given answers on these scenarios. Therefore a first analysis is done over only three scenarios. Scenario 4 and 6 are neglected initially since not all multiple choice answers do allow a clear distinction in the four lane change strategies.

44 unique combinations of answers were found for scenarios 2, 9 and 13. Most of these combinations had a very low frequency, only some occurred more frequent. Table 9.7 shows the five most

occurring answer combinations in the response on scenarios 2, 9 and 13. In the table the answers indicate the strategy. So the most occurring combination of answers is given by 41.1% of the respondents, and would thus overtake the slower person car and truck with a constant speed in respectively scenario 2 and 9, while they would not overtake the truck just before the off-ramp. The second most occurring combination concerns strict strategy 1 driving behaviour, and is similar as the most occurring combination except for the fact that these respondents state they would overtake the truck just before the off-ramp. The third most occurring combination concerns respondents that also would overtake the slower car and truck in scenario 2 and 9, but they would overtake the truck while increasing their speed just before the off-ramp in scenario 13.

Furthermore, about 9% of the respondents would not overtake the slower person car in front of them (scenario 2) but they would overtake the slower truck in front of them (scenario 9). Most of these people would furthermore not overtake the truck just before the off-ramp, this groups corresponds with the fourth most occurring answer combination.

Table 9.7 – Top 5 of answer combination for scenario 2, 9 and 13

Combination of answers			Frequency	Percentage
Sc. 2	Sc. 9	Sc. 13		
1	1	3	517	41.10%
1	1	1	186	14.79%
1	1	2	141	11.21%
3	1	3	85	6.76%
2	1	3	44	3.50%

In table 9.8 the number of respondents are presented who apply strictly strategy 1, 2 or 3. Where strategy 1 is applied by a significant share of the sample, strategy 2 and 3 are not strictly applied by a substantial number. Only 9 people showed strategy 2 behaviour in all three scenarios that are considered, while only 6 respondents showed strategy 3 behaviour. It shows that strategy 2 and strategy 3 are not really strategies which are applied by a lot of people on itself, many people will apply strategy 1 and in some situations they would change to a different strategy.

Table 9.8 – Frequencies of answer combinations for applying strictly strategy 1,2 or 3

Combination of answers			Frequency	Percentage
Sc. 2	Sc. 9	Sc. 13		
1	1	1	186	14.79%
2	2	2	9	0.72%
3	3	3	6	0.48%

The results over five scenarios combined gives a wide spread of the responses, 139 combinations of strategies have been found. However, the top 20 combinations account for 72.6% of the sample. The top 5 combinations are presented in table 9.9 which together account for 40.1% of the sample. The most occurring combination corresponds with respondents who apply mostly strategy 1 behaviour, but would keep their lane when they have to take the exit 3000 metres up ahead in scenario 6

and they would not overtake the truck just before the off-ramp in scenario 13. The second and third most occurring combination over these five scenarios are almost similar as the most occurring combination, except for the behaviour in scenario 6, in which some only would use the shoulder and centre lane, while others would use the lane in which they can drive with their preferred speed.

Table 9.9 – Top 5 of answer combination for scenario 2, 4, 6, 9 and 13

Combination of answers					Frequency	Percentage
Sc. 2	Sc. 4	Sc. 6	Sc. 9	Sc 13		
1	1/2	3	1	3	216	17.17%
1	1/2	3/4	1	3	91	7.23%
1	1/2	1/2	1	3	80	6.36%
1	1/2	1/2	1	1	61	4.85%
1	3/4	3	1	3	57	4.53%

The number of respondents that strictly apply strategy 1, 2 or 3 are shown in table 9.10. Again there are almost no respondents who strictly show strategy 2 or 3 behaviour, while on the other hand almost 5% of the respondents would behave according to strategy 1. About 95% of the respondents thus shows a combination of multiple strategies over these 5 scenarios.

Table 9.10 – Frequencies of answer combinations for applying strictly strategy 1,2 or 3

Combination of answers					Frequency	Percentage
Sc. 2	Sc. 4	Sc. 6	Sc. 9	Sc 13		
1	1/2	1/2	1	1	61	4.85%
2	1/2	1/2	2	2	2	0.16%
3	3/4	3/4	3	3	1	0.08%

Table B.10 in the appendix shows the combination of strategies respondents have shown over the 7 scenarios that concerned either 'strategy 1,2,3' or 'strategy 4' behaviour. A total distribution of respondents over the strategies is presented in table 9.11. It shows that strategy 1 is applied by almost every respondent. But more importantly about 74% of the respondents stated to drive according to strategy 3 behaviour in at least one of these seven scenarios.

Table 9.11 – Number of participants per strategy seen over the seven questions that concerned the lane-change strategies

	Strategies						
	1	2	3	4	1/2	3/4	3*
Number of participants	1211	665	931	11	1220	336	341
Percentage of participants	96%	53%	74%	13%	82%	27%	27%

9.5 Hypothesis testing

In this section the hypotheses formulated in 7.5.2 will be tested and the sub-group analyses are presented.

9.5.1 Older drivers have a lower desired speed than younger drivers

Age has been categorized in bins of 5 years (except for the first bin 17-24 years), while the self-reported desired speed has been divided into 5 categories. Both classifications can be observed in figure 9.2.

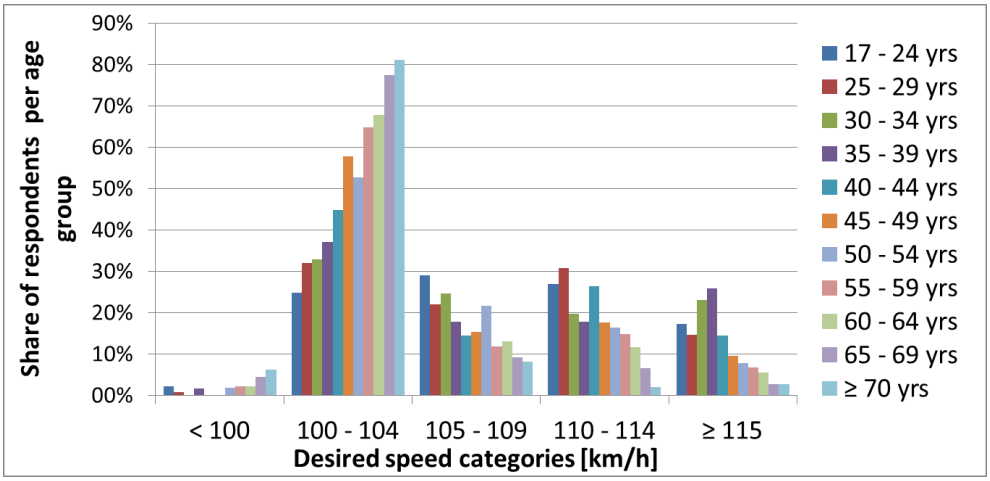


Figure 9.2 – Histogram of distribution of participants per age group over the speed categories

The clustered bar histogram in figure 9.2 gives insight in the relationship between age and desired speed. More than 80% of the respondents with an age of 70 years or older noted they would drive with a speed between 100 and 104 km/h, while only 25% of the 17 - 24 years old would drive with such a speed.

A Mantel-Haenszel test of trend was run to determine whether a linear association exists between age and desired speed. Age was scored from 1 to 11, indicating the age groups, while speed was scored from 1 to 5. The test showed a statistically significant linear association between age and desired speed, $\chi^2(1) = 193.591, p < 0.0005$. Meaning there is a chance of 0.05% of finding an as least as big difference by chance alone. Goodman and Kruskal's gamma indicates a negative and strong association between age and desired speed (G=-0.436).

Conclusion: the alternative hypothesis is accepted. There is a statistically significant association between age and desired speed, indicating that an increase in age shows a decrease in desired speed. And thus that older drivers tend to have more often a lower desired speed than younger drivers.

9.5.2 Frequent drivers have a higher desired speed than infrequent drivers

Two driving frequency groups have been distinguished in this case, namely frequent drivers (3 days per week or more) and infrequent drivers (less than 3 days per week). About 75% of the sample is considered a frequent driver, while 25% is an infrequent driver.

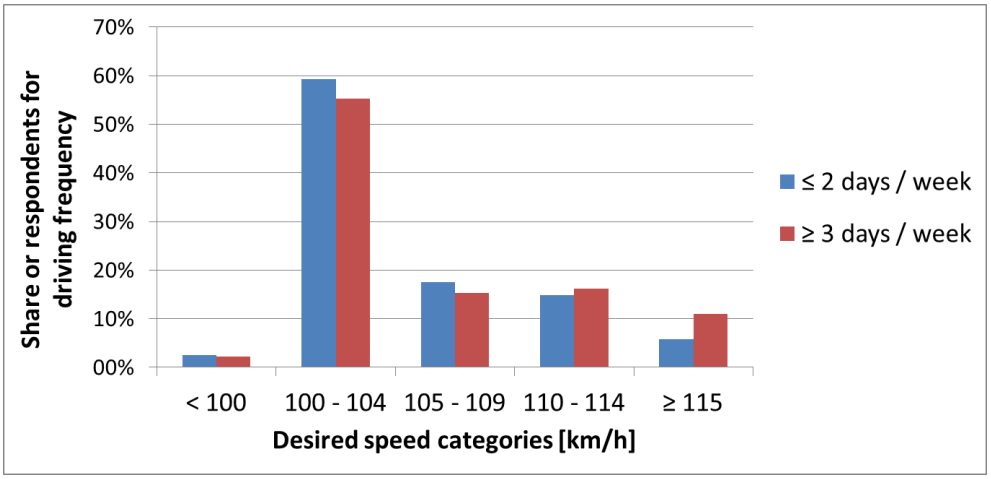


Figure 9.3 – Histogram of distribution of participants per driving frequency groups over the speed categories

The Mantel-Haenszel test of trend was run to determine whether a linear association exists between driving frequency and desired speed, as shown in figure 9.3. Desired speed was scored from 1 to 5, while driving frequency was scored 1 to 2, indicating infrequent and frequent drivers. The test showed a statistically significant linear association between driving frequency and desired speed, $\chi^2(1) = 5.421, p < 0.020$. Meaning, there is a 2% chance of finding an as least as big difference by chance alone. Goodman and Kruskal's gamma indicates a positive, but weak, association between driving frequency and desired speed (G=0.109).

Conclusion: the alternative hypothesis is partially accepted, there is a statistically significant association between driving frequency and desired speed. However, the association has been found weak, indicating only a small difference in desired speed for frequent and infrequent drivers.

9.5.3 Inexperienced drivers have a higher desired speed than experienced drivers

In figure 9.4 the distribution of respondents per driving experience group over the desired speed groups is presented. The figure shows on first sight a similar relationship as the comparison of speed and age.
The Mantel-Haenszel test of trend was run to determine whether a linear association exists between driving experience and desired speed. Driving experience was score from 1 to 11, indicating the different groups of years holding a driving license. The test showed a statistically significant linear association between driving experience and desired speed, $\chi^2(1) = 156.392, p < 0.0005$. Meaning there is a chance of 0.05% of finding an as least as big difference by chance alone. Goodman and Kruskal's gamma indicates a negative and moderate association between driving experience and desired speed (G=-0.387).

Conclusion: the alternative hypothesis is accepted. There is a statistically significant association between driving experience and desired speed with a negative, moderate effect, indicating that an increase in years holding a driving license shows a decrease in desired speed. This indicates that inexperienced drivers tend to have more often a relatively high desired speed in comparison with inexperienced drivers.

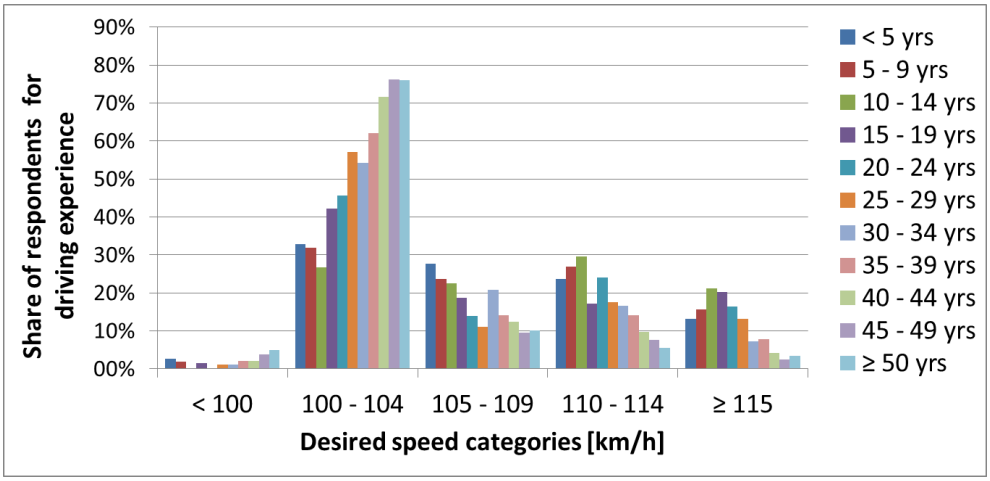


Figure 9.4 – Histogram of distribution of participants per 'number of years driving license' group over the speed categories

9.5.4 Drivers with high weekly mileages have a higher desired speed than drivers with low weekly mileages

Driving frequency expressed in terms of the average days per week a respondent drives a car is a bit arbitrary, since even if a respondent only drives 5 minutes per day he is classified as frequent driver. Furthermore, the years holding a driving license is also arbitrary as measure for driving experience, since a respondent could have a driving license for ten years while actually never driving. Therefore also the average weekly mileage is used to analyse the sample. Figure 9.5 present the clustered bar plot of the distribution of the weekly mileage groups over the desired speed groups.

The Mantel-Haenszel test of trend was run to determine whether a linear association exists between average weekly mileage and desired speed. Desired speed was scored from 1 to 5, while average weekly mileage was scored 1 to 8 indicating the eight different mileage groups. The test showed a statistically significant linear association between driving frequency and desired speed, $\chi^2(1) = 17.165, p < 0.0005$. Meaning there is a chance of 0.05% of finding an as least as big difference by chance alone. Goodman and Kruskal's gamma indicates a positive, but weak association between driving frequency and desired speed (G=0.096).
Conclusion: the alternative hypothesis is rejected. There is a statistically significant association between driving frequency and desired speed. However, the association is found weak by the gamma test, indicating a negligible difference in desired speed for the different weekly mileage groups. Visually analysing figure 9.5 shows only a linear association for the highest speed category. Additionally, it can be argued if the mileage data is reliable, since some respondents filled in their annual mileage instead of their weekly mileage.

9.5.5 Sub-group analysis

To analyse whether personal characteristics have a relationship with driving behaviour cross-tabulations have been created per scenario for four variables. The answers of each of these sub-groups have been compared for each scenario by means of cross-tabulations, a Chi-square test and a Cramer's V effect size test. The results of the statistical tests can be found in appendix B.6. One of the assumptions of the Chi-square test is that the items of each variable are independent. However, several respondents

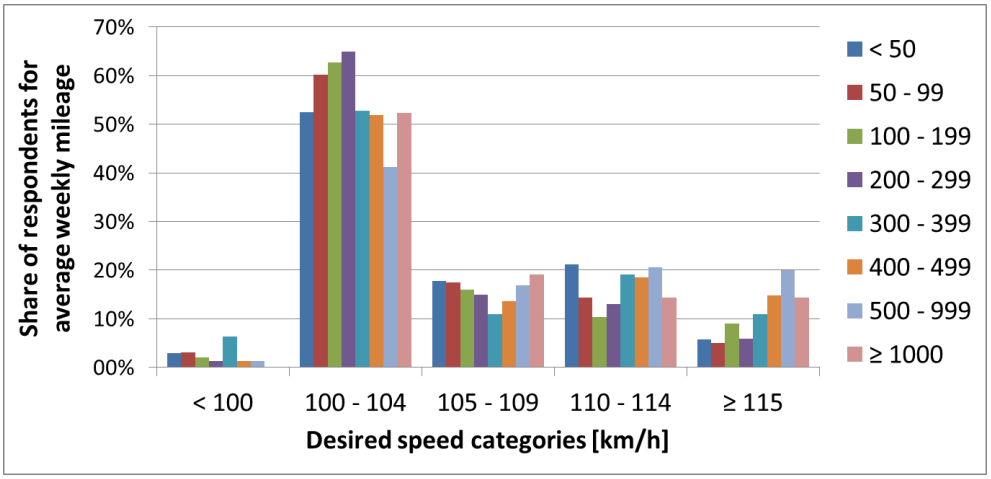


Figure 9.5 – Histogram of distribution of participants per average weekly mileage groups over the speed categories

gave sometimes an open answer which was quite similar as one of the multiple choice answers, so it is arguable if these items are independent. Therefore the open answers have been removed from the data on which the tests have been done. Table B.11 in the appendix shows the sub-groups that have been distinguished.

The results of the Chi-square test in appendix B.6 indicate in many cases a significant relationship between the sub-group and the answers given in the scenarios. However, the Cramer's V test shows often that the association is either small or negligible. One medium size association has been found, namely for age and the responses on scenario 6. The cross-tabulation to interpret the direction of the relationship is found in figure 9.12. Scenario 6 describes the traffic situation in which the respondent enters the motorway and needs to take the second exit from that point which is 3000 metres up ahead. As can be seen in the cross tabulation about 60% of the seniors indicated they would stay in the initial lane until they reach the exit. Of the young adults only 26.3% gave this answer, while an average of 44% was expected. The opposite can be seen for answer C, for which an average of 28.5% was expected per age group when there would be not relationship, while 37% of the young adults and 14.8% of the seniors gave this answer.
A significant relationship exists between age and the behaviour in scenario 6 $\chi^2(4) = 109.757$, p<0.001. Meaning there is a chance of 0.1% of finding an as least as big difference by chance alone. Cramer's V test statistic (0.210,df*=2) indicates a medium association between these two variables. The direction of the relationship can be withdrawn from table 9.12. Seniors tend to keep their lane more often when they have to take the off-ramp 3000 metres from where they entered the motorway, while more young adults tend to drive in the lane in which they can drive with their desired speed.

9.6 Lane keeping system

Part two of the questionnaire concerned the opinion of the respondent on the 'Keep your lane' principle. This system is an alternative for the rule which is currently applicable in the Netherlands, which says that the road users must drive on the rightmost lane as much as possible, unless they are overtaking.

Table 9.12 – Cross-tabulation of scenario 6 and age groups

Scenario 6		Age groups			Total
		Young adult	Adult	Senior	
A) I continue in this lane and will adapt my speed to my predecessor	Count	64	200	285	549
	Expected Count	107	233	209	549
	% within Age groups	26%	38%	60%	44%
B) I change between this lane and one lane left of it, and will adapt my speed to my predecessor	Count	89	133	119	341
	Expected Count	67	145	130	341
	% within Age groups	37%	25%	25%	27%
C) I will drive in the lane in which I can drive with my desired speed	Count	90	195	70	355
	Expected Count	69	151	135	355
	% within Age groups	37%	37%	15%	29%

The responses on each statement are found in appendix B.8. About 68% of the respondents is familiar with the keep your lane system. A majority of the people believes the keep your lane system will result in a steadier traffic flow. Furthermore, a large share of the respondents does not really know if the 'Keep your lane' system would results in less congestion than the 'Keep right' rule. While there is a spread opinion on the traffic safety effects and whether or not the system should be implemented in the Netherlands.

Note that, as some respondents also commented in the comment box at the end of the questionnaire, it is hard for the average person, but also traffic experts, to assess the effect of the 'Keep your lane' system on the traffic flow, congestion severity and traffic safety. There can thus no conclusions be drawn on the actual effect of the 'Keep your lane' system based on these results. These results only show the opinion of the respondents on the expected or believed effects of the system. Finally, the opinion of the respondents does not show a clear answer in whether the 'Keep your lane' system should be implemented in the Netherlands, there are both supporters as opponents of this idea.

9.7 Conclusions

This chapter presented the results of the questionnaire, which has been filled in by 1258 respondents from within the Netherlands. One of the most import findings is the distribution of the drivers over the four lane change strategies, which is presented in figures 9.1 and 9.11. Most drivers (about 90 to 95%) have a desired speed in mind, and try to maintain that speed by changing lanes if necessary. The other 5 to 10% choose a lane and stick to that lane while adjusting their speed to their predecessor. However, most drivers apply a combination of strategies. The cross-question analysis shows there are almost no drivers who consequent apply the same strategy. However, it is not possible to conclude how often a driver applies a certain strategy based on these results, since the traffic situations that were included in the questionnaire will not occur even frequently in reality.

Several scenarios have resulted in a major shift of drivers from the speed leading strategies to the lane or traffic leading strategies. These scenarios include the situation of severe congestion in which most drivers want to go with the flow and wnat to minimize their lane changes, but also the situation in which drives need to follow a route. If drivers enter a motorway and need to take the second exit

which lays 3000 meters up ahead, about 44% of the drivers indicate to keep to the shoulder lane. This was also found in the interviews of the driving experiment. Drivers found it hard to estimate how far it was to the exit, and (initially) kept driving in the shoulder lane. Also many drivers (61%) would not overtake a truck just before an off-ramp but they would change to the shoulder lane and adjust their speed to the predecessor.

Furthermore, about 80% of the drivers overtakes other vehicles with a constant speed, although 43% of these drivers shift to strategy 2, meaning they would increase speed, when the speed difference with the overtaken vehicle becomes very small. A share of 12% would also increase its speed when all other drivers drive much faster than themselves and the speed limit, which corresponds with strategy 4 behaviour, and was also often heard in the interviews by terms of 'going with the flow'.

The hypothesis testing showed that young drivers drive faster than older drivers, that there is not much of a difference in desired speed between frequent and infrequent drivers, and mileage does not show a significant relationship with desired speed. Furthermore, especially senior drivers will keep to the shoulder lane when they need to take the exit 3000 metres up ahead, while younger drivers more often choose the lane in which they can drive with their desired speed.

The theme-analysis showed that about 29% (16+21-7) of the drivers do not hesitate overtaking other vehicles via their right side now and then, although this is forbidden in the Netherlands. About 75 to 80% of the drivers keeps right when they can, only when a truck is driving up ahead on the shoulder lane and there are possibilities for other drivers to overtake them much less drivers (57%) keep right.

Several respondents found it hard to assess the effect of the 'Keep your lane' system on traffic safety, congestion severity and traffic flow stability. Even for traffic experts it is hard to assess this system. The results concerning the 'Keep your lane' system thus only reflect the public opinion, and do not have to represent the true effect of the 'Keep your lane' system. Most participants believe the system will result in a steadier traffic flow, but are less confident the system can reduce congestion severity. Furthermore, the public opinion is very spread whether or not the system should be implemented in the Netherlands.

Chapter 10

International comparison

The international questionnaire has been filled in by 179 people with 22 different nationalities. Appendix B.7 presents graphs and tables related to the characteristics of this sample. The nationality with the highest response are the Swiss with 59 respondents, second is the USA with 40 respondents. These numbers, unfortunately, do not meet the minimum required sample size of 384, given a confidence level of 95% and a confidence interval of 5%, and thus no statistically underpinned conclusions on the populations can be drawn. However, these samples can be used as an explorative study that can give insight in possible difference between countries or cultures. A comparison of the Swiss and Dutch samples is made in section 10.1, and a comparison between the American and Dutch samples is made in section 10.2. This chapter ends with conclusions in section 10.3.

10.1 Swiss versus Dutch drivers

In this section a comparison is made between Swiss and Dutch drivers. There were in total 59 Swiss respondents and 1235 Dutch respondents. In the literature study is found that legislation, enforcement, social norms and driving culture can influence driving behaviour. Therefore a short discussion is done concerning the legislation and enforcement in both Switzerland as in the Netherlands. Thereafter a comparison will be made concerning the driving behaviour of Dutch and Swiss drivers using the questionnaire responses. In appendix B.7 graphs are presented that show the distribution of Swiss respondents over the age groups, lane choice and speed choice.

10.1.1 Traffic rules

The 'Keep right' rule is applicable in both the Netherlands and Switzerland, and thus overtaking via the right is in both countries not allowed. Furthermore, the maximum speed limit on Swiss motorways is 120 km/h, while in the Netherlands 130 km/h is applicable. However, the speed limit of 130 km/h currently applies for 61% of the motorways while the other 39% of the motorways has lower speed limits like 120/100/80 km/h.

Switzerland is known for its heavy punishment of traffic offenders. Driving over 30 km/h above the speed limit on motorways is punished with a minimum disqualification from driving of one month, while in the Netherlands a driver is suspended from driving from 50 km/h and more above the speed limit. Besides disqualification from driving speed offenders are subject to traffic fines. Speeding 30 km/h above the speed limit results in a fine of 333 euro in Switzerland and 276 euro in the Netherlands. However, traffic fines for speed offenders above 35 km/h are in Switzerland, contrary to the Netherlands, based upon a driver's taxable income and wealth.

10.1.2 Differences in driving behaviour

The responses of both samples are compared by means of cross-tabulations, chi-square tests and Cramer's V tests, since both the responses and nationality are ordinal variables. Cross-tabulations are used to determine the possible relationship between the nationality and the driving behaviour in each scenario. So for each question a test is done to check if Swiss and Dutch drivers responded differently. In appendix B.7 two tables are presented that give an overview of the Chi-Square test and Cramer's V test results for each scenario. The results of the Chi-square tests show that in four scenarios Dutch and Swiss drivers responded significantly different. However, the Cramer's V test statistic reveals that these differences have a small of negligible size.

In 8 out of 14 scenarios the conditions to execute the Chi-square tests were not met. Therefore, the multiple choice answers that are similar of nature were combined. For instance, in scenario 10 the four MC-answers have been aggregated to two categories, namely keep right behaviour and keep lane behaviour. This way the expected counts per cell of the contingency tables go up, so the conditions of the Chi-square test are met. However, the results show again that there is a significant difference between Dutch and Swiss, but that these differences have negligible sizes.

Table 10.1 – Comparison of responses of Dutch and Swiss drivers for scenario 3,5 and 13

Scenario	Scenario question	Response	Nationality	
			Dutch	Swiss
3	If you overtake a slower predecessor (person car), would you do this according to strategy 1 or 2?	Strategy 1	56%	73%
		Strategy 2	43%	27%
5	Would you overtake another vehicle via its right side, when there is no possibility to overtake via the left side?	Yes	16%	7%
		No	84%	93%
13	If you have to take the exit 600 metres up ahead, would you overtake a truck just before the off-ramp?	Yes, with constant speed	20%	12%
		Yes, with speed increase	19%	3%
		No	61%	85%

Table 10.1 presents an overview of the responses that showed a small size difference for Dutch and Swiss drivers. These results show that Swiss drivers tend to increase their speed less often when they overtake a slower predecessor in comparison with Dutch drivers. Furthermore, less Swiss drivers overtake another vehicle via their right side than Dutch drivers. This is observed in both scenarios that concerned right overtaking behaviour, although in only one scenario this difference was found significant different by the Chi-square test. Furthermore, only 15% of the Swiss respondents would overtake the truck just before the off-ramp, while 39% of the Dutch respondents would do so. This could be caused by the typical length of the merging lanes of off-ramps in Switzerland and the Netherlands. The design guidelines for merging lanes of off-ramps in the Netherlands recommend a total length of 250 metres inclusive the wedge-shaped section. Whereas a quick look into the Swiss motorways learns that the merging lanes of off-ramps have lengths of 150 to 170 metres.

A further comparison can be made concerning speed choice, which is found in figure 10.1. The mean speed of Swiss respondents is 104.1 km/h, while the mean speed of Dutch respondents is 104.5 km/h. Q-Q plots show that the desired speed distributions of both Dutch as Swiss drivers

are positively skewed, and thus not normally distributed. The independent sample t-test cannot be done since this test assumes that the dependent variable is normally distributed. Therefore, the non-parametric Mann-Whitney test is used to check if the median desired speeds of Dutch and Swiss drivers are significantly different. The results of the test show no significant difference in the median values (U=36, z=0.208, p=0.835). However, some statistical power is lost due to the large difference in sample sizes and it is hard to check whether all assumptions of the Mann-Whitney test are met. Conclusion: although Switzerland has higher punishments for speed offenders than the Netherlands no difference has been found in the desired speed distributions between these two nationalities.

The last comparison between Dutch and Swiss drivers concerns the lane choice on an empty three lane motorway. Figure 10.1 presents a comparison of the lane choice for the samples. Lane choice can be seen as an ordinal variable, since the three lanes have an order. Furthermore, since the variable nationality has only two categories in this case the Mantel-Haenszel test of trend is used to test if there is a significant difference between Dutch and Swiss drivers concerning lane choice. The Mantel-Haenszel test showed a statistically significant association between nationality and lane choice, $\chi^2(1) = 37.232, p < 0.0005$. Goodman and Kruskal's gamma indicate a very strong association between being either Dutch or Swiss and the chosen lane, (G=0.794).

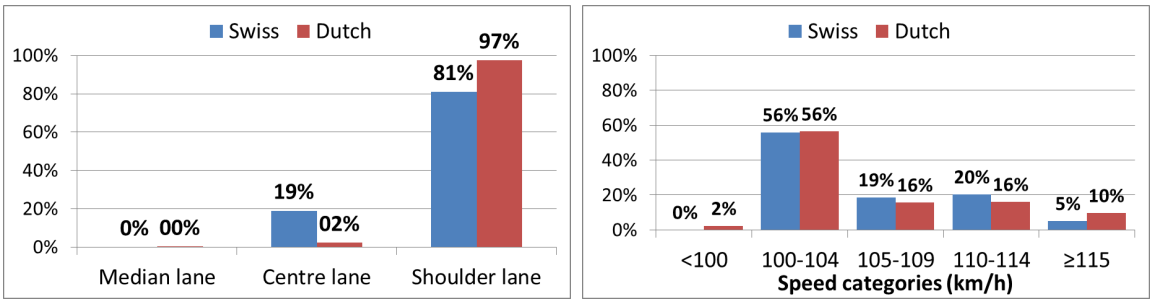


Figure 10.1 – Lane choice (left) and speed choice (right) of Swiss and Dutch respondents

10.2 American versus Dutch drivers

In this section the samples of American drivers(n=40) and Dutch drivers(n=1235) are compared. Again a comparison is made between legislation and enforcement on motorways in the US and in the Netherlands. In appendix B.7 graphs are presented that show the distribution of American respondents over the age groups, lane choice and speed choice.

10.2.1 Traffic rules

First of all, in the US speed is expressed in miles per hour, while in the Netherlands kilometres per hour is used as measuring unit. This does probably not influence driving behaviour, but all speeds in the questionnaire were expressed in km/h. American respondents were asked to give their answer in km/h, but were helped by presenting the conversion of 100 km/h to mph in the introduction. Nevertheless, several American respondents reacted it was quite hard to do the conversion themselves during the questionnaire. This will affect the reliability of their results.

Each state in the US has its own laws, which results in differences between states concerning traffic rules. When there is more than one lane for the same direction all states allow vehicles to use the

left lane for overtaking. In addition, most states prohibit the use of the left lane by slow vehicles. In a few states the use of the left lane is **only** allowed for passing or turning left, which resembles the keep right rule. Furthermore, many states follow the Uniform Vehicle Code which requires relatively slow drivers to keep right. But there are no rules concerning lane choice if a driver is going with the flow or drives with the normal speed. This resembles somewhat the 'lane keeping' system, although the Uniform Vehicle Code do not require keeping a lane as much as possible. Furthermore, in most states it is common that vehicles using the left lane must yield to vehicles on the adjacent lane that want to overtake. Only a few states do not require any vehicles to keep right and permit the use of the left lane in any traffic conditions. Additionally to the rules concerning lane choice, most states allow overtaking via the left and the right, although a few states have exemptions on this (MIT, 2015a).

In most states of the US the minimum age for driving a car unaccompanied is 16 years, while in the Netherlands this is 18 years. Further, maximum speed limits vary between 60 and 85 mph, although most states have a maximum speed limit of 70, 75 or 80 mph, which corresponds with respectively 112, 121, 129 km/h. Fines and penalties for speeding also differ per state. Several states use a point system, and regulations allow for a license suspension of 90 days for 26 mph (42 km/h) over the speed limit. It is hard to give a brief overview of all legislations that apply in the different states, but MIT (2015b) gives a complete overview. Concluding, there are some major differences in legislation between the American and Dutch motorways, which will cause large differences in driving behaviour of American and Dutch respondents.

10.2.2 Differences in driving behaviour

The responses of both samples on each scenario are compared by means of cross-tabulations, chi-square tests and Cramer's V tests. An overview of the results is presented in appendix B.7. In 6 out of 14 scenarios the conditions of the Chi-square test were met by using the initial multiple-choice answers as stated in the questionnaire. For 3 scenarios a small but significant difference was found between Dutch and American respondents, for 2 a negligible difference was found and for 1 scenario there was no difference at all. For 6 other scenarios the multiple-choice answers were aggregated, so the cross-tabulations has less cells and the chance is higher the conditions of the Chi-square test are met. The results for these cross-tabulations are also presented in appendix B.7 and reveal a moderate size difference for scenario 1 and 8.

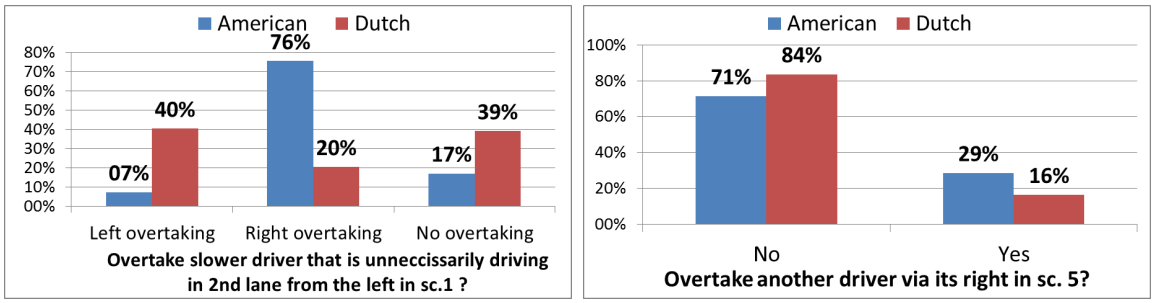


Figure 10.2 – Responses of American and Dutch respondents for scenario 1(left) and 5(right)

As seen in figure 10.2 American respondents tend to overtake more often another driver via its right side than Dutch drivers, although the size of this difference varies strongly between the two scenarios. In scenario 1 76% of the Americans overtake via the right while this is only 29% in scenario 5. The traffic rules that apply in both countries are a logical explanations for the major differences that have been found concerning right overtaking behaviour, in most states in the US overtaking is

allowed via the left and the right, while in the Netherlands right overtaking is forbidden.

Figure 10.3 reveals the large difference in the response on scenario 8 for American and Dutch drivers. The graph shows that most American respondents would keep their lane, while most Dutch respondents would change lanes, again obviously caused by the difference in traffic rules. Figure 10.3 shows that much more American respondents than Dutch respondents would increase their speed when surrounding drivers have a much higher speed than themselves, which is strategy 4 "Traffic leading" behaviour.

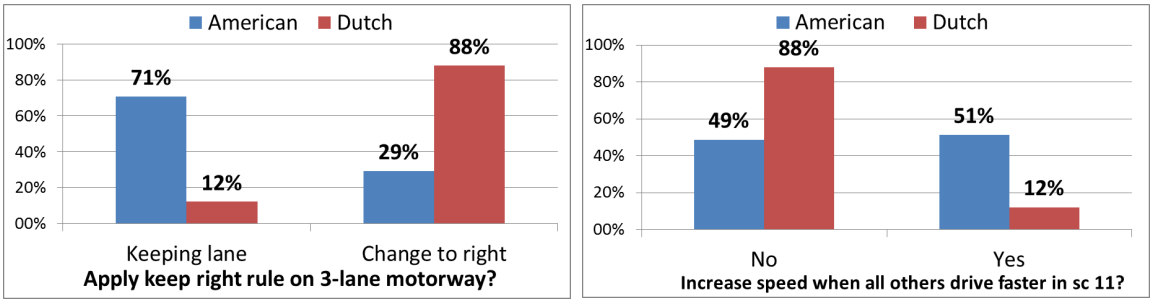


Figure 10.3 – Responses of American and Dutch respondents for scenario 8(left) and 11(right)

A further comparison between the two samples can be made concerning lane and speed choice, which can be found in figure 10.4. The lane choice of American and Dutch respondents differs a lot, 70% of the American would drive in the centre lane while 97% of the Dutch would drive in the shoulder lane. A Mantel-Haenszel test is performed and reveals a highly significant difference in lane choice between Dutch and American drivers, $\chi^2(1) = 469.141, p < 0.0005$. Goodman and Kruskal's gamma indicate a very strong association between being either Dutch or American and the chosen lane, (G=0.983). However, the assumption that the relationship between the two variables is monotonic is violated, although from the graph alone it is already quite clear difference exists.

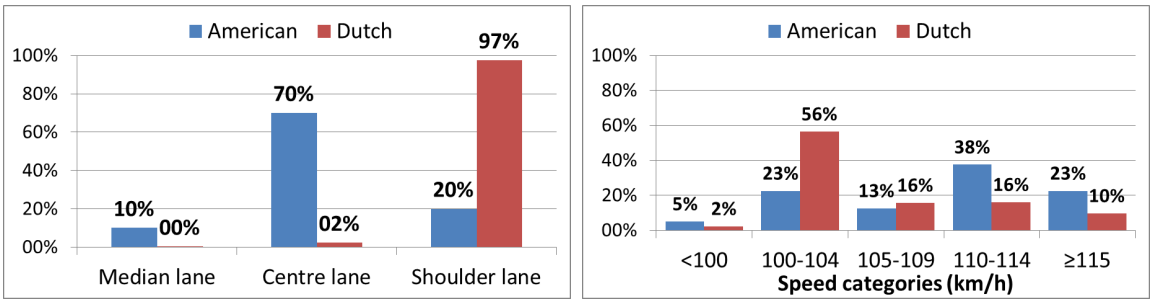


Figure 10.4 – Lane choice (left) and speed choice (right) of American and Dutch respondents

The mean speed of American respondents is 109.1 km/h, while the mean speed of Dutch respondents is 104.5 km/h. A Mann-Whitney test is performed to test if the median speed of American and Dutch respondents is different. The results of the test reveal that the median speeds of American (median=110 km/h) and Dutch (median=100 km/h) respondents are significantly different (U=33, z=4.055, p=0.0005). However, again due to the large difference in sample size it is hard to check if all assumptions of the Mann-Whitney test are met, but the current samples indicate that there is a difference. Conclusion: as seen in figure 10.4 American respondents have a higher desired speed on an empty 3-lane motorway than Dutch respondents.

10.3 Conclusions

A brief comparison revealed several differences in the traffic system between Switzerland and the Netherlands, although most aspects that were considered showed large similarities. Fines and punishments for traffic offenders are higher in Switzerland than the Netherlands, which could explain the fact that less Swiss than Dutch respondents would overtake another driver via its right side, since overtaking via the right is not allowed in both countries. Furthermore, possibly due to shorter deceleration lanes at off-ramps in Switzerland, Swiss respondents tend to less often overtake a truck just before an on-ramp in comparison with Dutch drivers. As last difference found was the application of either strategy 1 or 2 in case of an slower predecessor, Swiss drivers tend to overtake the vehicle more often with a constant speed instead of an increasing speed in comparison with Dutch drivers.

The traffic systems of the US and the Netherlands are very different. Differences have been found concerning age allowed to drive solely, rules concerning lane choice and overtaking legislations. Large differences were found in the responses of American and Dutch drivers. Much larger shares of the American respondents than Dutch respondents would overtake another vehicles via its right side, which is in most states of the US allowed. Furthermore, American drivers do not keep right as often as Dutch drivers, which is not surprising since in most states drivers do not have to keep right. About 70% of the American drivers responded to drive in the centre lane of an empty 3-lane motorway, while 97% of the Dutch keeps right. American drivers would more often than Dutch drivers increase their speed when all surrounding vehicles drive much faster than themselves and the speed limit. It was also found that American drivers have higher desired speeds than Dutch drivers.

Part IV

Discussion and Conclusions

Chapter 11

Discussion

In this chapter drawbacks of the methodology and limitations of the results are discussed. Several have already been discussed in previous chapters, but are repeated here to have a clear overview. First, drawbacks concerning the results of the driving experiment are discussed in section 11.1. Then a discussion of the questionnaire and its results is found in section 11.2, while the interpretation of the traffic situations is separately discussed in section 11.3.

11.1 Discussion of driving experiment

The results from the driving experiment have been discussed in chapter 6. From these main findings factors that make participants change strategy have been identified. A driver can namely behave according to multiple strategies, which has indeed been revealed by the driving experiment, as can be seen in table 12.1. Only two participants drive strictly according to one particular strategy. Not all strategies that are applied by participants have actually been observed during the test drive. Based on comments participants gave during the interviews strategies were assigned to them. However, it could easily be that not someone's full driving behaviour has been discussed in the interview, even though at the end of each interview the participant was asked if his driving behaviour needed more explanation and if everything concerning his driving style has been said.

Furthermore, the results shown in table 12.1 do not show how often a participant applies a certain strategy. This could not have been concluded from the interviews or the field tests, since how often a participant drives according to which strategy has not been discussed. Furthermore, to assign a strategy to a participant you need to know his motives. It is thus not possible to categories someone's driving behaviour into the four lane change strategies on the basis of external observations. On the other hand, it is arguable how well a person could indicate how often he drives according to each of the strategies, so even if this was discussed in the interviews the results might be arbitrary.

In the interviews each of the participants was introduced to the lane change strategies, after which they had to indicate in which strategies they recognized themselves. The strategies that respondents answered themselves do not completely correspond with the results of table 12.1, since some participants were assigned additional strategies based on other comments during the interview, although they did not indicate they drive with that strategy themselves when asked. However, lane change behaviour takes place at the manoeuvring level of Michon's hierarchical structure of the road user task. With increasing driving experience these actions are more and more performed automatically. And how well can drivers described tasks they do automatically? One participant of the driving experiment mentioned that he sometimes drive unconsciously according to strategy 3. There are

probably more drivers that have this, and perhaps even participants from the driving experiment that did not mention this in the interview and respondents that did not answered with strategy 3 driving behaviour in any of the scenarios. This would mean the percentage of drivers that drive according to strategy 3 sometimes is too low. Moreover, people might have shown (unconsciously) socially desirable behaviour in the field test. One participant even admitted he drove different than normally since he knew he was being recorded. Furthermore, in interviews people tend to give socially desirable answers too, which can be distinguished into two types: impression management and self-deception.

Nevertheless, the overview of the combination of strategies give useful insight in how strategies are applied. There were no participants in the field study that strictly drove according to strategy 3 and 4, while there were drivers who only applied strategy 1 or strategy 2. However, most participants drove in under-saturated conditions during the driving experiment, while many participants stated in the interview that they tend to drive according to strategy 3 or strategy 4 when traffic densities are high. The few participants that drove during peak-hours did show and respond more often according strategy 3 or strategy 4 driving behaviour. You could argue if participants would respond the same if the conditions during the test drive were differently, since the test drive was the major discussion point. How aware are participants of their own driving behaviour in saturated conditions when they just drove in under-saturated conditions? Would participants thus that drove outside peak-hours give the same responses if they would have driven in peak-hours? Or would they also show and respond more often according to strategy 3 and/or strategy 4 behaviour?

11.2 Discussion of questionnaire

Driving behaviour knows many aspects, of which many could be discussed in the interviews of the driving experiment. However, the length of the questionnaire is limited if large numbers of participants are required. Short questionnaires in general receive more responses than long questionnaires. The number of traffic scenarios presented has been limited to 14, which resulted in an average time to complete of 19 minutes. This is already quite long for a survey. So, because of the limited scenarios that could be included it is arguable to what extent a driver's set of driving styles is captured by this questionnaire. Although the most relevant traffic scenarios from the driving experiment were selected, more and other traffic scenarios for which a respondent might show deviating strategy-based lane change behaviour can be easily thought of.

Table 11.1 – Number of participants per strategy seen over the seven questions that concerned the lane change strategies

	Strategies						
	1	2	3	4	1/2	3/4	3*
Number of participants	1211	665	931	11	1220	336	341
Percentage of participants	96%	53%	74%	13%	82%	27%	27%

An overview of how many respondents applied a certain strategy seen over the seven questions that concerned lane change strategies is presented in table 11.1. In several questions not all multiple choice answers could be assigned to one particular lane change strategy but correspondent to the actions of two lane change strategies. The percentage of respondents who applied strategy 2 in at least one of the scenarios could thus easily be higher than the 53%, which is listed in the table.

Nevertheless, the results show that 96% respondents responded at least once with strategy 1 driving behaviour, which is substantially higher than the 79% of the participants from the driving experiment that apply strategy 1. Is this difference caused by the fact that drivers find it hard to describe their own driving behaviour in interviews or that they are not fully aware of their own driving style?

The results from the questionnaire cannot be used, just like the results from the driving experiment, to indicate exactly how often a respondents would apply a certain lane change strategy. The traffic situations that were included might not all occur even frequent in reality. It is, furthermore, not known how respondents would react to traffic scenarios that deviate a bit from the traffic situations in the survey, since in traffic situation many variables that influence a person's driving behaviour can vary.

The number of participants that responded with strategy 4 behaviour is rather low, this is also caused by the fact that typical strategy 4 behaviour was reflected in only two multiple choice answers in two different scenarios. It was hard to grasp a traffic situation in which you were 'going with the flow' in a video, which is typical strategy 4 behaviour. If more videos were included that incorporated 'traffic leading' behaviour, the share of respondents that show strategy 4 behaviour is probably higher.

Furthermore, the appearance of strategy 4 behaviour can be very different, since some drivers drive along with the faster ones on the road, while other drivers would drive with the slower ones. In scenario 4 staying in your lane in a congested traffic situation while vehicles on the other lane are driving faster was considered as either strategy 3 or strategy 4 behaviour. However, this is arguable since how would someone that drives according to strategy 4 react in a situation as scenario 4? Strategy 4 behaviour could actually result in both actions that were presented in that scenario, namely staying in the initial lane or changing lanes. Many participants in the driving experiment stated such behaviour falls in strategy 4, since you do not prefer that lane but you just go with the flow of that particular lane.

Eight scenarios involved a three lane motorway, of which some included merging lanes on the right. Four scenarios involved a two lane motorway, of which some were connection roads. One scenario described a traffic situation on a four lane motorway, while the last scenario concerned a three lane motorway with an opened peak hour lane. How driving behaviour relates to the number of lanes has not been studied, so it is important to bear in mind that the results possibly do not apply for all motorway configurations and possibly relate to the number of lanes. Since, you can easily argue if drivers would keep right on a five lane motorway as strict as they do on a two lane motorway.

11.3 Interpretation of questions and videos

Via the open answers options in the questions and the comments box at the end of the questionnaire, several respondents made comments which have been used to assess how well the questionnaire represent that what was intended. For some questions the formulation of answers or the situation was a bit unclear for some people. To distinguish strategy 2 from strategy 1 one answer often included an overtaking manoeuvre with constant speed and one answer an overtaking manoeuvre with a speed (far/well) above the initial speed. However, some participants could not find themselves in these answers when they would increase their speed only a bit.

Furthermore, in scenario 5 it was unclear for several respondents which directions they had to follow, since the situation shows an on-ramp that continues as the right lane of a connection road. The

respondents asked if they had to follow the connection road or the main roadway, although in the introduction text of the survey respondents were told they have to go straight to follow their route, unless stated differently. Furthermore, based on the given multiple choice answers in scenario 5 you were also able to figure out the direction you had to go, so it is believed that most participants understood the situation correctly. However, it could be that other videos or multiple choice answers were misinterpreted as well, and if they did not realize the situation or multiple choice answers had to be interpreted differently, respondents would not comment on it. Did all respondents understand the multiple choice answers and traffic situation presented in scenario 6? Several respondents commented they did not know how far the 2nd exit was, although was shown during the video. So did these participants actually watch the video? Unfortunately, this cannot be verified, since YouTube has a flawed viewing count for embedded videos, so not all views are counted as a view.

Respondents have different desired speeds on a three-lane motorway with a speed limit of 100 km/h. Desired speeds reported by respondents varied between 90 and 157 km/h, although 95% of the values lay between 100 and 120 km/h. To let the speed in the videos correspond to some extent with the desired speed of the respondents, three branches with a characteristic speed were set-up in the survey. The speeds shown in the videos were 100, 107 and 115 km/h. The speed in the video thus does not always correspond exactly with a respondent's desired speed. This could induce respondents to answer consequently with strategy 2 driving behaviour, since they might feel they drive too slow in the videos. On the other hand, the desired speed was asked for a completely empty motorway, while a driver's desired speed can be stochastic as well, depending on the traffic situation. Only a few respondents commented on the speeds that were shown in the videos, so it is believed that most respondents understood the logic behind the shown speeds in the videos.

Chapter 12

Conclusions and Recommendations

This chapter discusses the main findings (section 12.1) of this study, the overall conclusions that can be drawn from the main findings (section 12.2), recommendations for practice (section 12.3) and recommendations for further research (section 12.4).

12.1 Main findings

In this study an interview-based driving experiment, in which 34 drivers participated, and an online questionnaire, which received 1258 responses, was held to obtain insight in strategy-based lane change behaviour of drivers on motorways. Based on the participants' own perception and comments they made throughout the interview strategies were assigned to each participant of the driving experiment, of which an overview is found in table 12.1. Every participant used at least one of the two speed leading strategies, while about half of the respondents also applied the lane leading or traffic leading strategy. There were no participants that only used the lane or traffic leading strategy.

Table 12.1 – Application of strategy combinations among driving experiment participants

Number of strategies	Strategies				Number of participants	Number of participants
	Speed leading	Speed leading with overtaking	Lane leading	Traffic leading		
1	x				1	2 (6%)
		x			1	
2	x		x		2	10 (29%)
	x			x	1	
	x	x			4	
		x		x	1	
		x	x		2	
3		x	x	x	3	18 (53%)
	x	x	x		7	
	x	x		x	8	
4	x	x	x	x	4	4 (12%)
Share	79%	88%	53%	50%	100%	100%

The interviews gave an insight in the application of the lane change strategies. Strategy 1 and 2 are very similar, so how do drivers apply them? The difference between the two strategies is that strategy 2 drivers will increase their speed when they overtake a slower predecessor. Several factors have been heard in the interviews that makes drivers increase their speed while overtaking. Some participants mentioned that the presence of a faster driver behind them would induce them to increase their speed when they overtake, most of them would do so not to hinder the faster driver too much. Furthermore, several participants also mentioned a small speed difference with the vehicle they overtook to apply strategy 2 instead of strategy 1, otherwise the overtaking manoeuvre would take too long. Another factor that was mentioned is cruise control, if they had cruise control turned on they would keep a constant speed while overtaking, but without cruise control they tend to increase their speed when overtaking. Traffic densities also played a role for several participants to either use strategy 1 or strategy 2 behaviour, during busy traffic conditions they want to minimize their hinder to other drivers by increasing their speed when overtaking, although the opposite was also mentioned.

Strategy 3 is more and more applied when traffic densities go up, since it feels more comfortable to keep a lane in busy conditions. Route-following, distance to exit or distance to junction have also been mentioned as motives to apply strategy 3. A participant also acknowledged that he sometimes drives unconsciously according to strategy 3. Some participants had an aversion to strategy 3 behaviour, they associated this strategy with driving unnecessary on the left, although in some cases they themselves did also not keep strictly to the right. Not keeping strictly right can be seen as strategy 3 behaviour. The traffic rules require drivers to keep to the shoulder lane unless they are overtaking, although drivers have different perceptions on how strict they have to obey to this rule.

Strategy 4 behaviour was often referred to by participants in the interviews as 'going with the flow'. Several participants mentioned they would drive along with the traffic flow when the traffic density is high, since this is more comfortable. Note that this is the same line of reasoning for applying strategy 3 in conditions with high densities. Contribute to a more stable traffic flow was also mentioned to apply the fourth strategy. A participant commented that you are forced to drive according to strategy 4 when the traffic density is high, since you can not always drive with your own desired speed when its crowded. This makes it also hard to distinguish the different strategies in saturated conditions, since the actions that follow from the four different strategies will be very similar when the traffic flow forces you to drive with a certain speed.

Table 12.2 – Distribution of respondents over the lane change strategies per scenario

Scenario	Theme	Lane change strategy							Other answers
		1	2	3	4	1/2	3/4	3*	
2	Strategy 1,2,3	77%	10%	12%	1%	-	-	-	0%
3	Strategy 1,2,3	56%	43%	-	-	-	-	-	1%
4	Strategy 1,2,3	-	-	-	-	27%	73%	-	0%
6	Strategy 1,2,3	-	-	44%	-	28%	-	27%	1%
9	Strategy 1,2,3	85%	11%	3%	-	-	-	-	1%
11	Strategy 4	-	-	-	12%	87%	-	-	1%
13	Strategy 1,2,3	20%	19%	61%	-	-	-	-	1%

The questions of the survey were categorized into five themes: 'Strategy 1,2,3', 'Strategy 4', 'Overtaking via right', 'Keep right rule' and 'Courtesy lane change'. The responses on the scenarios are presented in table 12.2 and table 12.3. The description of the traffic scenarios are found in appendix B.2 and B.9. The results of the strategies that concerned the strategy-based lane change behaviour is found in table 12.3. The questionnaire results confirm the findings from the driving experiment. Most people, about 90%, pick a speed they want to drive with, and then choose the appropriate lane. If they cannot maintain their speed due to slower predecessor they will change lanes. However, there are several traffic situations in which drivers tend to show more often lane leading or traffic leading behaviour. Limited distance to the off-ramp drivers need to take result in much more drivers sticking to a lane. Furthermore, the results showed that drivers apply many different combinations, almost no drivers showed strictly strategy 2 or 3 in the questionnaire, but there were some who consequently responded with strategy 1 behaviour.

The results of 'right keeping' behaviour, 'right overtaking' behaviour and 'cooperative' behaviour are presented in table 12.3. About 70 to 90% of the drivers changes to the rightmost lane when there is space. In case a truck is driving up ahead on the shoulder lane, and there are possibilities to be overtaken, 40% would not keep right, but stay in their lane. When comparing a regular shoulder lane and a peak hour lane, the use of the peak hour lane is 15% less. Although right overtaking another vehicle is not allowed, 15 to 20 % of the respondents indicated to do so when the vehicle is unnecessarily driving on the left. As last topic from table 12.3 is cooperative behaviour towards a vehicle that wants to merge onto the main roadway, 83% of the respondents would make space by mostly changing lanes or adjusting their speed. However, 16% of the respondents said the merging vehicle needs to adjust to them, so they would not adapt their speed or lane to cooperate.

Table 12.3 – Distribution of respondents to behaviour characteristics

Question	Theme	Changing to rightmost lane?	
		Yes	No
7	Keep right/Strategy 4	57%	42%
8	Keep right	88%	12%
10	Keep right	76%	23%
14	Keep right	73%	25%
Question	Theme	Right overtaking?	
		Yes	No
1	Right overtaking	20%	80%
5	Right overtaking	16%	84%
Question	Theme	Cooperative behaviour?	
		Yes	No
		Lane change / Speed adjustment	
12	Courtesy lane change	72% / 11%	16%

12.2 Conclusions

The aim of this study was to gain insight in strategy-based lane change behaviour of drivers on motorways, which is reflected in the main research question:

How do drivers apply strategy-based lane change behaviour on motorways?

The results have shown that every drivers applies at least one of the two speed leading strategies, which indicate that drivers have a desired speed, which they use to choose their lane. Many drivers have shown to apply a combination of strategies. The evaluation can even be interpreted as that drivers do not always respond similar to the same traffic situation, driving behaviour is stochastic. There have not been a combination of responses on the traffic scenarios which occurred often, there are thus also quite some differences in driving behaviour between people. Furthermore, there are no drivers who consequently only drive according to the lane leading or traffic leading strategy. These strategies tend to be applied more often in traffic situation with relatively high densities.

All participants from the driving experiment were able to identify their behaviour with one or more lane change strategies. No new strategies have been identified, since all behaviour that was discussed could have been categorized into the four lane change strategies. However, several combinations of strategies occurred relatively frequent. Quite often participants did not keep to the rightmost lane, but kept driving on the centre lane while there was space on the shoulder lane. This can be seen as lane leading behaviour. However, the moment these drivers encountered a slower predecessor they would change lanes and overtake it, which does not correspond with the lane leading strategy in which a driver would adapt its speed. This behaviour is not been labelled as a new strategy, since it can be modelled by a combination of the speed leading and lane leading strategy. So, these drivers apply a lane leading strategy on the centre lane till the moment they encounter a slower predecessor, then they would apply a speed leading strategy and overtake it. The opposite have also been observed in the driving experiment and questionnaire, namely that drivers apply a speed leading strategy on the shoulder lane. They would thus overtake a slower predecessor on this lane, but when they drive on the centre lane they show lane leading behaviour, since when they encountered a slower predecessor on the centre lane they would adjust their speed.

Strategy-based lane change behaviour can be used to improve microscopic simulation models. Many lane change models are based on the theory of Gipps (1986), which states that a lane change is performed when a driver cannot drive with its desired speed in the current lane. The results from this study have shown that in several traffic situations non negligible shares of drivers would not choose a desired speed and base their lane choice upon it but would stick to a lane and adapt their speed to the other vehicles in that lane. Lane change models that only consider speed as incentive to change lanes cannot incorporate the four lane change strategies by a simple adjustment of its parameters, but require a more complex revise of their decision model that concerns lane choice.

However, the integrated model of Toledo *et al.* (2007) uses a target lane choice model to determine if a lane change is desired, which calculates a utility per lane using multiple variables. These variables include already several of the factors that have been found to play a role in the 'choice' of one of the four lane change strategies, or can be used in setting up the lane leading and traffic leading strategies. Since the 'network knowledge and experience' category already includes a variable that can account for drivers who prefer not to drive in the shoulder lane to avoid interaction with merging traffic. Although this study did not concern the implementation of strategy-based lane change models, it seems that the model of Toledo already includes multiple variables that are relevant. Nevertheless,

also Toledo's model needs adaptations in terms of an extra sub-model that determines the 'lane change strategy choice'. Since drivers apply a combination of strategies, which cannot be modelled by an adjustment in parameters alone.

12.3 Recommendations for practice

Besides recommendations concerning improvements of current lane change model by incorporating strategy-based lane change behaviour, several other recommendations can be made as well.

In the field of traffic management knowledge on human behaviour is used in designing and evaluating traffic systems. Quantitative data and relationships are used to formulated a 'design road user', which is a road user that has certain skills that should be considered when traffic management measures are designed (Godthelp *et al.*, 2012). However, so far a 'design road user' is only described by skill and not on a tactical driving behaviour level, which includes the lane and speed choice. This study provides quantitative insight in drivers' lane and speed choice, which can be used to formulate a 'design road user' that can act as input in the design or application of traffic management tools.

The results have shown that drivers show varying compliance to the keep right rule. In case of the two-lane roadway of scenario 10 only 44% of the respondents would go the right to obey to the traffic rules. The rest of the respondents had either other reasons to go to the right or kept driving in the median lane. Quite often drivers stay in the left lane to prevent being stuck on the shoulder lane between slow traffic. This behaviour results in gaps in the traffic stream on the shoulder lane, and thus the utilization of the shoulder lane will be lower. If the median lane reaches its capacity, and (some) drivers do not keep strictly right the traffic flow can breakdown, while the capacity of the shoulder lane has not been reached yet. The recommendation for practice is thus to consider the fact that not all drivers keep strictly right, and thereby create gaps in the traffic stream, which results in a lower utilization of the shoulder lane. In case of a peak hour lane even less drivers keep strictly to the right most lane, this should thus be considered in practice, while this also leads to the question if measurements need to be taken to increase the utilization of these lanes.

The traffic rules concerning keeping right date from the time most motorways consisted of two lanes per direction. However, nowadays more and more motorways have three lanes or more and there are quite some differences in how people perceive the keep right rule on these multi-lane roadways. On the one hand there are drivers who always keep right, while on the other hand there are drivers that keep right until the second lane from the right, and there are also the 'lane keepers' that drive on the lane they prefer. Do we need to keep using the current keep right rule on multi-lane motorways? Or would adaptations of the rules or maybe even a complete different system, such as the 'Keep your lane' system, work better nowadays? The keep right rule causes frustrations among drivers and especially on motorways that have three lanes or more strictly obeying the keep right rule is not found necessary by all drivers and even hard to do sometimes. Thus, it is recommended to reconsider the keep right rule if it still fits the traffic system.

And what about the right overtaking ban, should this rule be reconsidered as well? Apparently 15 to 20 % of the participants would overtake another driver that is unnecessary driving on the left. In the 'Keep your lane' system drivers need to stick to a lane as much as possible, while overtaking via the left as the right is allowed. The respondents show a distributed opinion on whether this system should be applied in the Netherlands. A majority believes the system results in a steadier traffic flow, but that it cannot decrease congestion severity. This study has not investigated the effectiveness of

the 'Keep right' rule, but the results do show that significant shares of the drivers do not comply with the current rules. So why do we have rules when 15 to 20% shows to not follow these rules? Thus, it is recommended to either take measurements to increase compliance to the right overtaking ban (possibly by increasing compliance to the keep right rule), or to reconsider the right overtaking ban, especially on motorways that have three lanes or more on which obedience to the keep right rule decreases.

As last, the fact that not all drivers keep right should also be considered in designing road geometry. However, in some cases this is already done, for example at taper diverging points, often continuous lines are applied here that make it easier for traffic on the 2nd lane to take the exit.

12.4 Further research

The main findings of this study are applicable for Dutch drivers only. According to the framework of Lonero (1995) driving culture and informal rules influence driving behaviour, and thus differences can be expected in driving behaviour between countries and nationalities. An explorative comparison has been made between Swiss and Dutch drivers as well as between American and Dutch drivers. Although the sample sizes of the non-dutch nationalities are not large enough to draw conclusions on the population, these analysis already revealed several differences in driving behaviour between these nationalities. However, more research is needed with larger samples to investigate how drivers in other countries apply strategy-based lane change behaviour.

Furthermore, more research can be done to investigate how often drivers apply a certain strategy. Although the results from this study give some insight in how often a strategy is applied by participants, the scenarios of the questionnaire do not occur even frequently in reality, so the results cannot be used as frequency distribution of the strategies.

Most participants in the driving experiment drove during under-saturated traffic conditions, how the participants would drive in saturated have been discussed during the interviews, although self-reported behaviour is not always very trustworthy. Most of the scenarios from the questionnaire involved also under-saturated traffic conditions, while from the driving experiment and from the one scenario that did concern a saturated traffic condition it is known that many drivers change strategy when traffic densities increase. The field test has shown to be a very useful discussion aid in the interviews which also increases the trustworthiness of self-reported behaviour since it can (partially) be observed in the video. Future research can thus be done on strategy-based lane change behaviour in saturated traffic conditions by using field studies that have been found very useful.

The route that participants drove in the driving experiment consisted mostly of three-lane motorway sections, and for a two small sections of two lanes and four lanes. However, the four lane section, the Ketheltunnel, has relatively low traffic densities and is thus not very representative for other four lane motorways. Most scenarios presented in the questionnaire therefore also concerned a two- or three-lane motorway. How the results found by this study are applicable for motorways that have four lanes or more is unknown. Further research is needed to investigate how strategy-based lane change behaviour is applied on motorways with more than three lanes.

As last, a recommendation concerning the use of field tests to study naturalistic driving behaviour. In this study participants had to drive in a hybrid Toyota Prius, which only a few people had driven before. In the interviews there are some indications that drivers had to get used to the car. The type

of vehicles has indeed been found in literature to influence driving behaviour. Observing participants while they drive in their own car is expected to results in a higher level of naturalistic driving behaviour in such a field study. Dash cams have been found very useful and easy to work with, since they can be easily installed in every car. A higher level of naturalistic driving behaviour also relates to the use of cruise control, since several participants of the driving experiment stated they did not use the cruise control because they did not know how to use the system.

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Part V

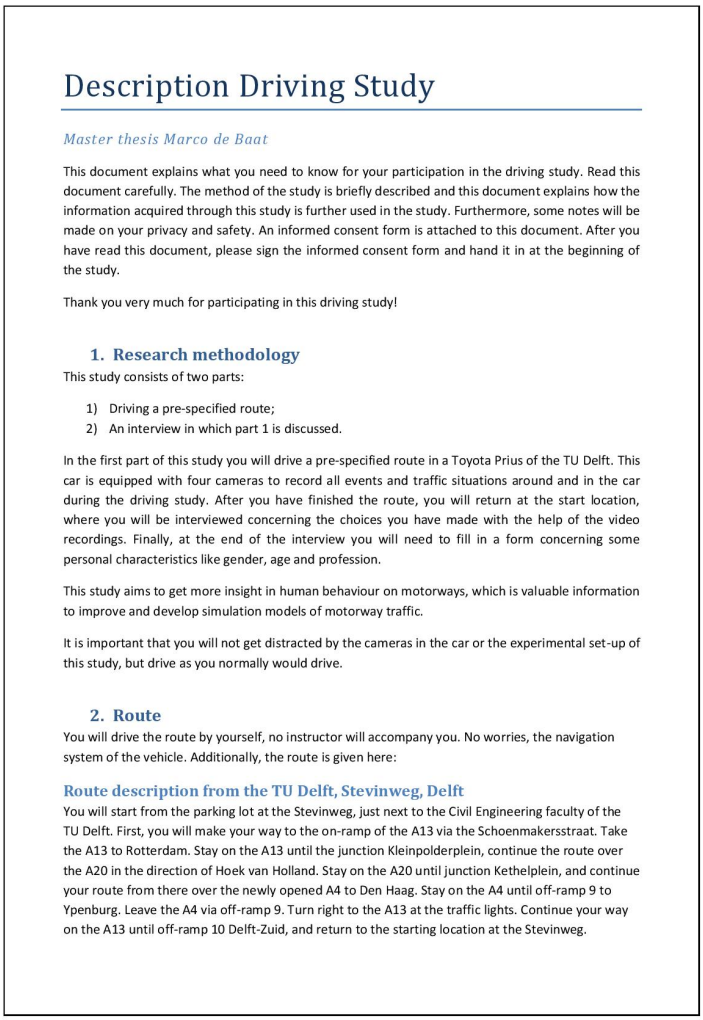
Appendices

Appendix A

Driving experiment

A.1 Informed consent form

In this section of the appendix the informed consent form is presented which the participants in the driving experiment had to read and sign before execution of the field test and interview.



Description Driving Study

Master thesis Marco de Baat

This document explains what you need to know for your participation in the driving study. Read this document carefully. The method of the study is briefly described and this document explains how the information acquired through this study is further used in the study. Furthermore, some notes will be made on your privacy and safety. An informed consent form is attached to this document. After you have read this document, please sign the informed consent form and hand it in at the beginning of the study.

Thank you very much for participating in this driving study!

1. Research methodology

This study consists of two parts:

1) Driving a pre-specified route;
2) An interview in which part 1 is discussed.

In the first part of this study you will drive a pre-specified route in a Toyota Prius of the TU Delft. This car is equipped with four cameras to record all events and traffic situations around and in the car during the driving study. After you have finished the route, you will return at the start location, where you will be interviewed concerning the choices you have made with the help of the video recordings. Finally, at the end of the interview you will need to fill in a form concerning some personal characteristics like gender, age and profession.

This study aims to get more insight in human behaviour on motorways, which is valuable information to improve and develop simulation models of motorway traffic.

It is important that you will not get distracted by the cameras in the car or the experimental set-up of this study, but drive as you normally would drive.

2. Route

You will drive the route by yourself, no instructor will accompany you. No worries, the navigation system of the vehicle. Additionally, the route is given here:

Route description from the TU Delft, Stevinweg, Delft

You will start from the parking lot at the Stevinweg, just next to the Civil Engineering faculty of the TU Delft. First, you will make your way to the on-ramp of the A13 via the Schoenmakersstraat. Take the A13 to Rotterdam. Stay on the A13 until the junction Kleinpolderplein, continue the route over the A20 in the direction of Hoek van Holland. Stay on the A20 until junction Kethelplein, and continue your route from there over the newly opened A4 to Den Haag. Stay on the A4 until off-ramp 9 to Ypenburg. Leave the A4 via off-ramp 9. Turn right to the A13 at the traffic lights. Continue your way on the A13 until off-ramp 10 Delft-Zuid, and return to the starting location at the Stevinweg.

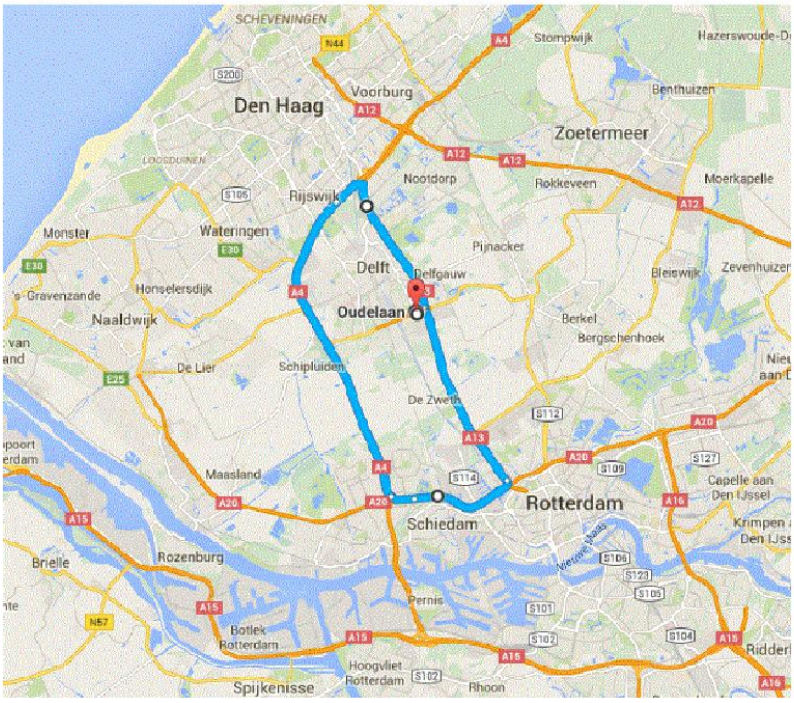


Figure 1: Route

3. Duration

Instructions before the driving experiment take approximately 10 minutes. Driving the route takes around 30 to 40 minutes. The interview is approximately 40 minutes. The total duration of this study is approximately 1:20 to 1:30 hours.

4. Privacy

Your participation in this driving experiment is anonymous. This means that all information that I gather throughout this study will be treated confidential. Privacy-sensitive information will be anonymized when results and data is published.

The information you will provide in the interview will be used to answer the research questions of this study. Video recordings will be used to construct short video clips which be used in an online questionnaire, which is also part of this graduation thesis. However, **no** video images will be used of the inside of the car on which you are recognizable. Video recordings from the inside of the car might only be used on a small scale in closed meeting presentations of my findings to my graduation committee of the TU Delft.

The video recordings from the driving study will be stored on my personal hard drive disk and will be used for this study only. Video recordings on which you are recognizable will be stored with password encryption. On request it is possible for you to see the video recordings and information

from the interview. All information and video recordings will be deleted after completion of this study.

Your participation in this study is completely voluntarily. At any time you may stop your participation without giving a reason and without any consequences.

5. Safety

You are responsible for your own safety and that of others when you drive the route. Drive as you normally would, and do not put safety at risk in need of this study. Know that violating any traffic rules and corresponding consequences are at your own risk and own responsibility. Any traffic fines are at your own cost.

If there are any problems during driving the route, always bring yourself in a safe position before you make contact with me. In case of an emergency always call the police first. In case you encounter congestion, just continue the proposed route. In case that a part of the route is closed down, get yourself in a safe location to make a phone call and contact me via +31612127372. This number is written on a paper inside the vehicle, but also store this number in your mobile phone.

In case you almost miss an off-ramp or something on your way, do not perform any dangerous action to reach a certain off-ramp. Just make a little detour by continuing on the main roadway and take the next exit for example or follow up the advice of the navigation system to finish the route.

How the car works will be explained before you will drive the route. You do not need to figure out yourself how the car works and all questions you have concerning controlling the vehicle.

6. Compensation

After the driving study you will receive a VVV gift card of 20 euro.

7. Contact

If you have any questions or comments after your participation in my study you can contact me by email.

If you have any complaints in response to this driving study, you can contact my daily supervisor from my graduation committee or the secretary of the Human Research Ethics Committee of the TU Delft.

Function:	Executive researcher	Daily supervisor	Secretary of Human Research Ethics Committee
Name:	**M.J. de Baat**	**Dr. V.L. Knoop**	**J. Groot Kormelink**
E-mailaddress:	marco_de_baat@hotmail.com	v.l.knoop@tudelft.nl	hrec@tudelft.nl
Telephone number:	0612127372	-	-

Informed Consent Form

To be filled in by participant

I declare that I am in a clear way for me informed on the nature, method, aim and risks and load of this study. I know that all information and results of this study will only be published anonymously and confidently to third parties. My questions have been answered satisfactorily.

I understand that video material or adaptations from them only will be used for analysis, scientific presentations and the online questionnaire within the framework of the graduation thesis of Marco de Baat.

I entirely agree to take part in this research voluntarily. I reserve the right to terminate my participation in this study at any time without giving a reason to terminate.

Name participant: .....

Date: ..... Signature participant: .....

To be filled in by executive researcher

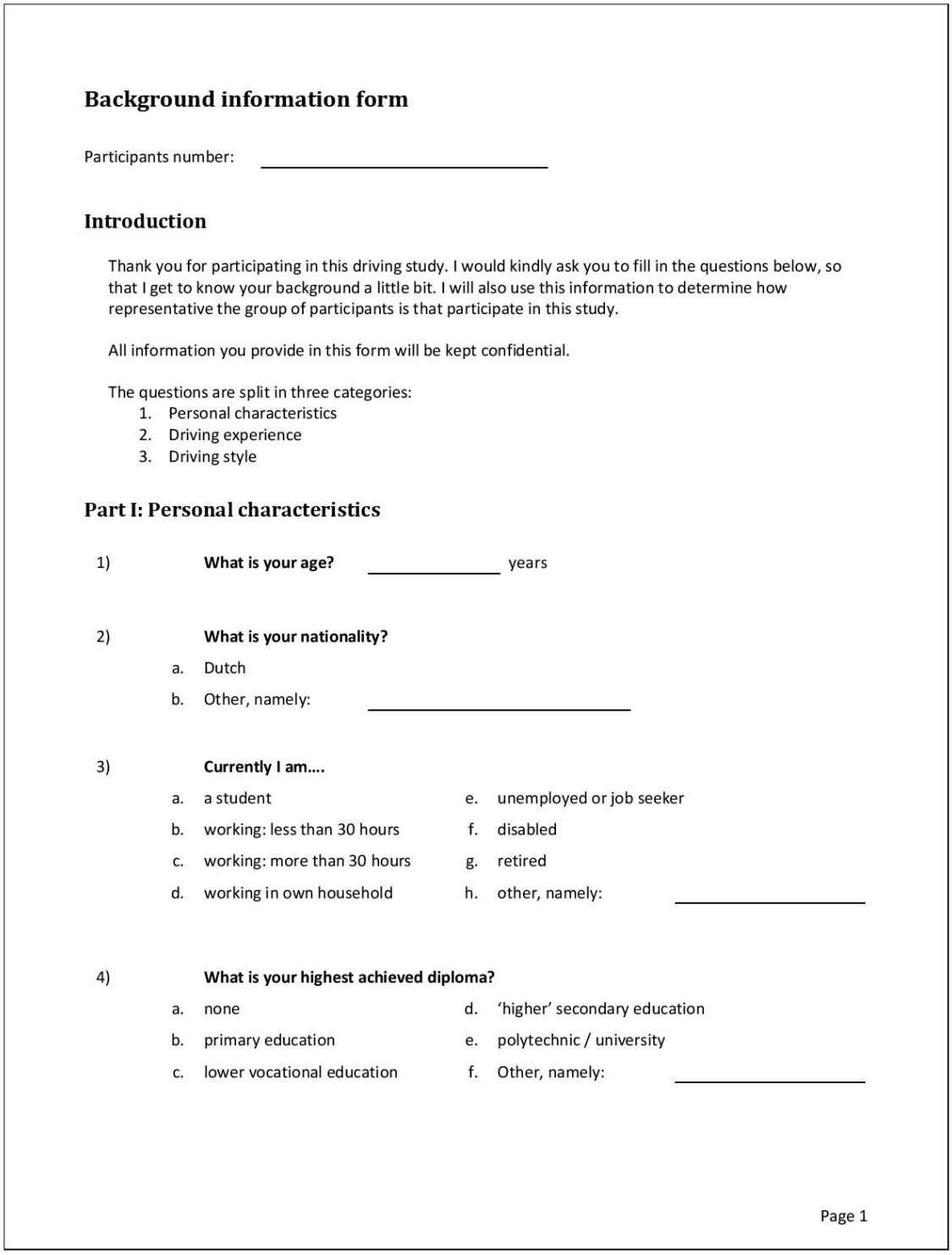
I gave an oral and written explanation of this study. I will answer remaining questions to the best of my power. The participant will not be negatively affected by a preliminary termination of his/her participation to this study.

Name researcher: .....

Date: ..... Signature researcher: .....

A.2 Background question form

This section presents the background information form that the participants of the driving experiment had to fill in after they drove the predefined route.



Background information form

Participants number: _____

Introduction

Thank you for participating in this driving study. I would kindly ask you to fill in the questions below, so that I get to know your background a little bit. I will also use this information to determine how representative the group of participants is that participate in this study.

All information you provide in this form will be kept confidential.

The questions are split in three categories:
1. Personal characteristics
2. Driving experience
3. Driving style

Part I: Personal characteristics

1) **What is your age?** _____ years

2) **What is your nationality?**
   a. Dutch
   b. Other, namely: _____

3) **Currently I am....**
   a. a student
   b. working: less than 30 hours
   c. working: more than 30 hours
   d. working in own household
   e. unemployed or job seeker
   f. disabled
   g. retired
   h. other, namely: _____

4) **What is your highest achieved diploma?**
   a. none
   b. primary education
   c. lower vocational education
   d. 'higher' secondary education
   e. polytechnic / university
   f. Other, namely: _____

Page 1

Part II: Driving experience

5) **How long do you own a driver's license?** _____ years

7) **Do you own a car? Or is there a car in general you can use?**

a. Yes, I own a car (go to question 7)
b. Yes, I have a rental car (go to question 7)
c. Yes, my husband, partner or roommate has a car which I may use (go to question 7)
d. No (go to question 8)

8) **If 'yes' to question 7. Specify the brand and type of the car.**

(If you have access to multiple cars, please name the car which you drive most frequently.)

Brand _____

Type _____

9) **When was the last time you drove a car? Driving in this study ignored.**

a. today
b. this week
c. more than a week ago
d. more than a month ago
e. more than a year ago

10) **How many hours per week do you think you drive a car?**

_____ hours per week

_____ km per week

11) **How often and in what kind of accidents have you ever been involved as a car driver?**

Explanation of terms: In a unilateral accident only one road user is involved. In a bilateral accident two or more road users are involved. Bodywork damage is damage to the car. Injury is when a human person suffered damage.

a. Unilateral accident with only bodywork damage _____ times
b. Unilateral accident with human injury _____ times
c. Bilateral accident with only bodywork damage _____ times
d. Bilateral accident with human injury _____ times

Part III: Driving style

Rate the extent to which the following statements fit your feelings, thoughts and behaviour on a five-point scale.

		Totally agree				Totally disagree
12)	**I tend to drive cautiously**	O	O	O	O	O
13)	**I use muscle relaxation techniques while driving**	O	O	O	O	O
14)	**I swear at other drivers**	O	O	O	O	O
15)	**I base my behaviour on the motto "better safe than sorry"**	O	O	O	O	O
16)	**I intend to switch on the windscreen wipers, but switch on the lights or turning indicators instead**	O	O	O	O	O
17)	**I feel nervous while driving**	O	O	O	O	O
18)	**I enjoy the excitement of dangerous driving**	O	O	O	O	O
19)	**When in a traffic jam and the lane next to me starts to move, I try to move into that lane as soon as possible**	O	O	O	O	O

20) **Do you consider yourself to drive better, worse or just as well compared to an average driver?**

a. Better

b. Just as well

c. Worse

End

A.3 Traffic conditions during driving experiment

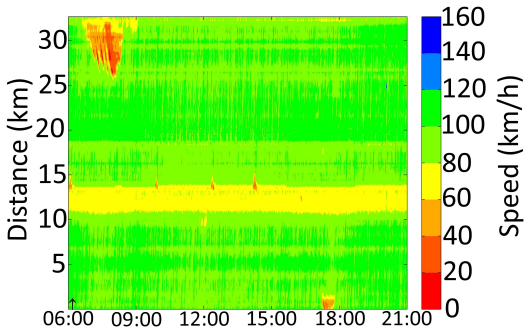


Figure A.1 – Speed contour plot of route for Monday 1 February 2016

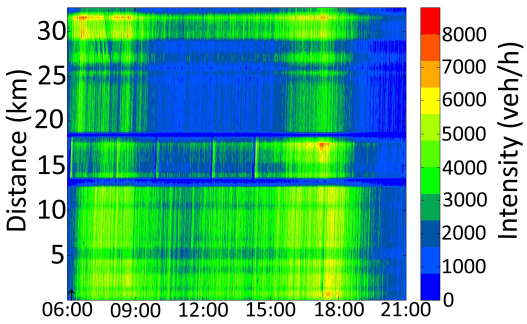


Figure A.2 – Intensity contour plot of route for Monday 1 February 2016

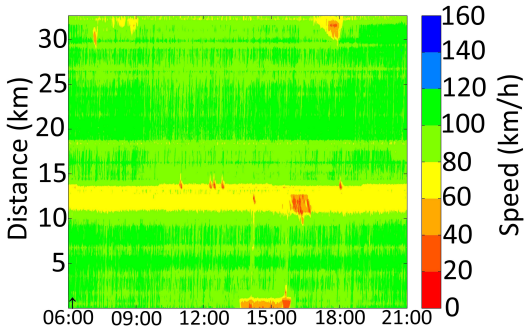


Figure A.3 – Speed contour plot of route for Friday 5 February 2016

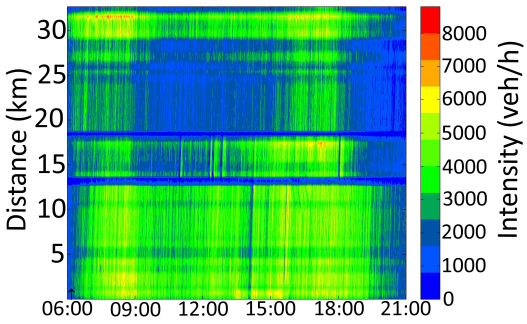


Figure A.4 – Intensity contour plot of route for Friday 5 February 2016

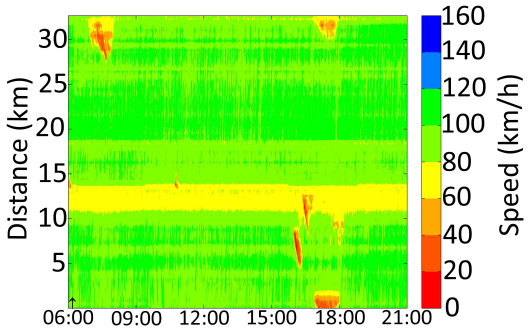


Figure A.5 – Speed contour plot of route for Monday 8 February 2016

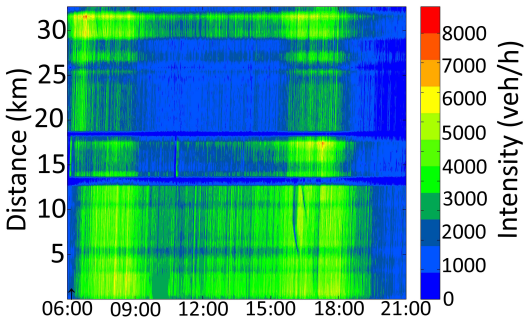


Figure A.6 – Intensity contour plot of route for Monday 8 February 2016

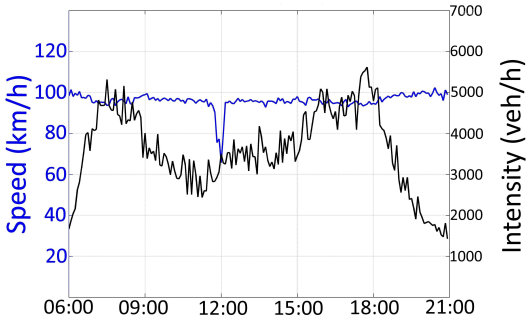


Figure A.7 – Speed and intensity over the day, 1 February 2016, A13 hmp 15.4

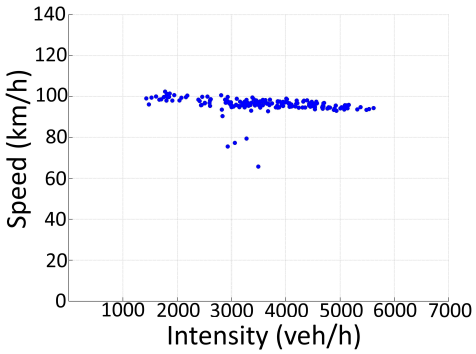


Figure A.8 – Intensity-density diagram, 1 February 2016, A13 hmp 15.4

s

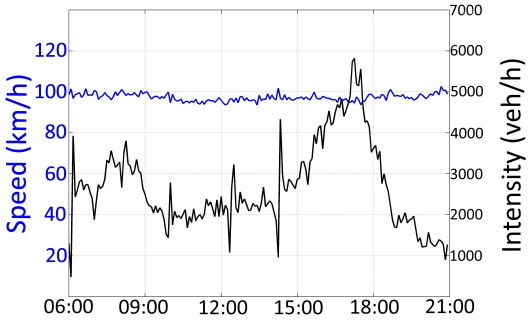


Figure A.9 – Speed and intensity over the day, 1 February 2016, A20 hmp 25.7

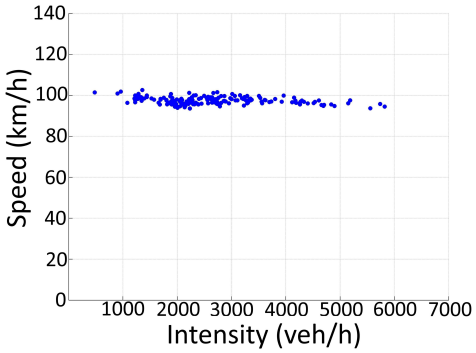


Figure A.10 – Intensity-density diagram, 1 February 2016, A20 hmp 25.7

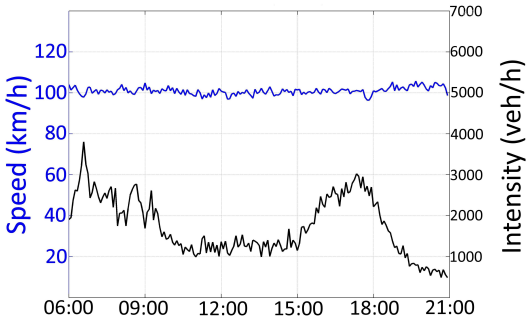


Figure A.11 – Speed and intensity over the day, 1 February 2016, A4 hmp 57.35

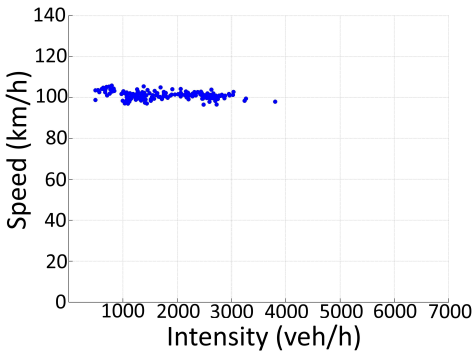


Figure A.12 – Intensity-density diagram, 1 February 2016, A4 hmp 57.35

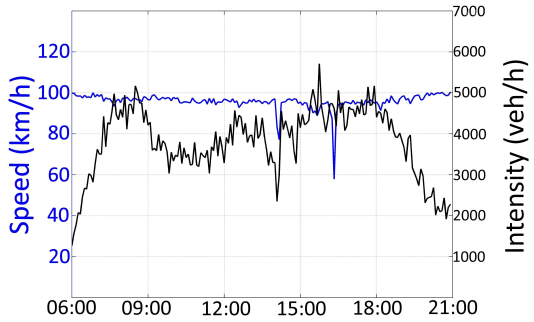


Figure A.13 – Speed and intensity over the day, 5 February 2016, A13 hmp 15.4

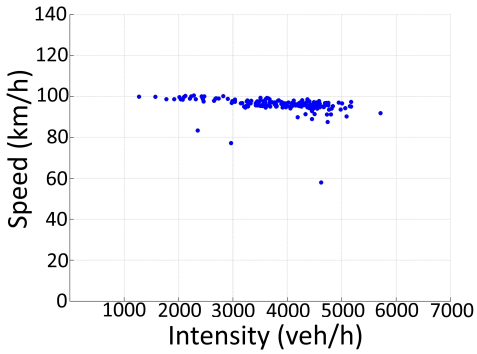


Figure A.14 – Intensity-density diagram, 5 February 2016, A13 hmp 15.4

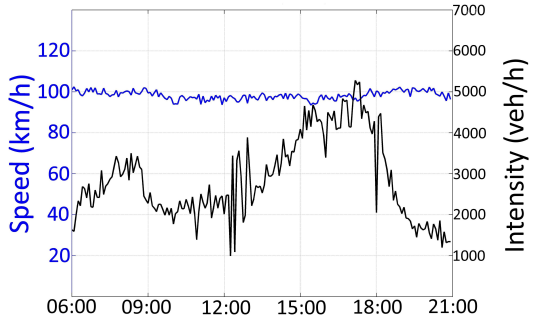


Figure A.15 – Speed and intensity over the day, 5 February 2016, A20 hmp 25.7

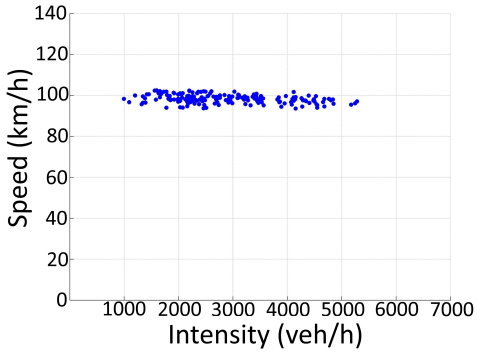


Figure A.16 – Intensity-density diagram, 5 February 2016, A20 hmp 25.7

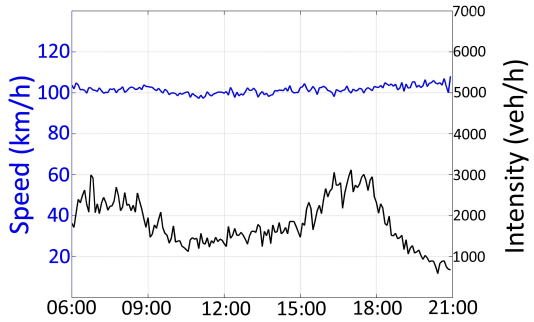


Figure A.17 – Speed and intensity over the day, 5 February 2016, A4 hmp 57.35

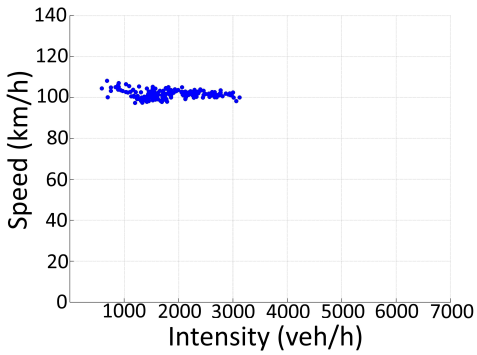


Figure A.18 – Intensity-density diagram, 5 February 2016, A4 hmp 57.35

A.4 Speed profiles of participants

The car that was used in the driving experiment was equipped with a GPS receiver that logged the speed an position of the vehicle multiple times per minute. From these logs speed profiles have been obtained, of which several are presented in this section.

Figure A.19 – Speed profile of a participant's test drive in which the 80 km zone is clearly visible

Figure A.20 – Speed profile of a participant's test drive in which the bridge opening on the A20 is clearly visible

Figure A.21 – Speed profile of a participant's test drive in which the traffic light at the connection road between the A4 and A13 is clearly visible

Figure A.22 – Speed profile of a participant's test drive in which congestion is clearly visible

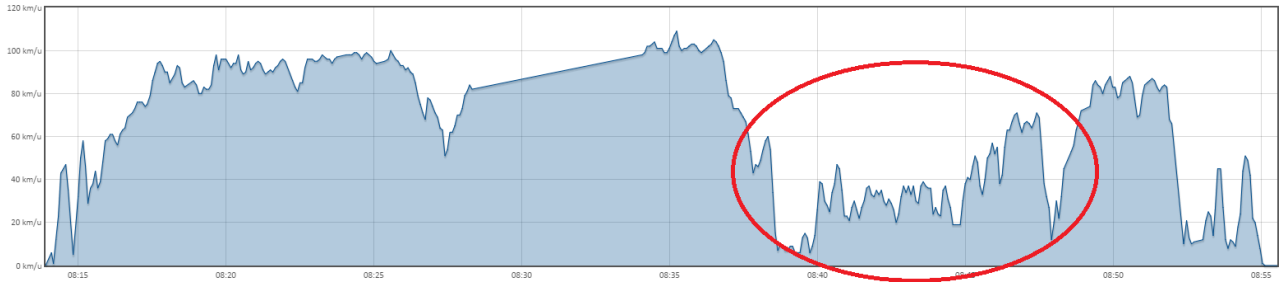


Figure A.23 – Speed profile of a participant's test drive in which congestion is also clearly visible

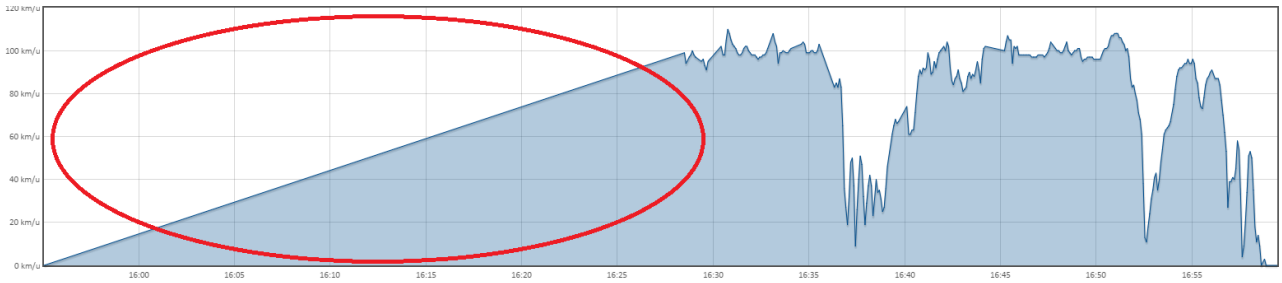


Figure A.24 – Speed profile of a participant's test drive in which a connection error of the GPS device is clearly visible

A.5 Descriptive statistics of participants driving study

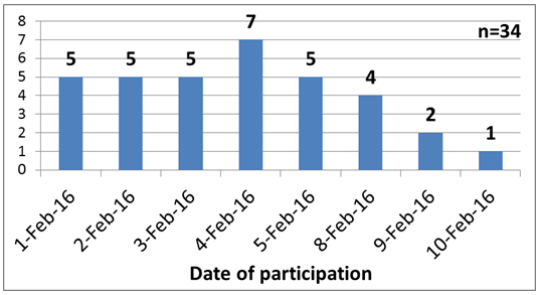


Figure A.25 – Number of participants per date

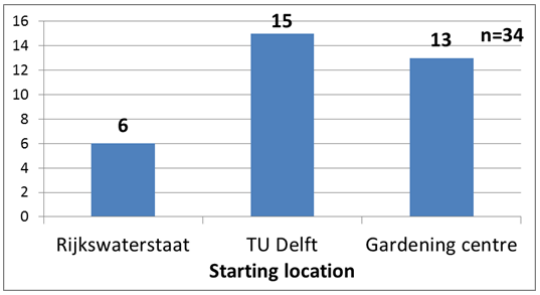


Figure A.26 – Number of participants per location

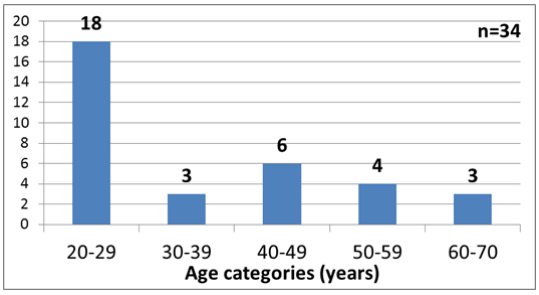


Figure A.27 – Participants per age group

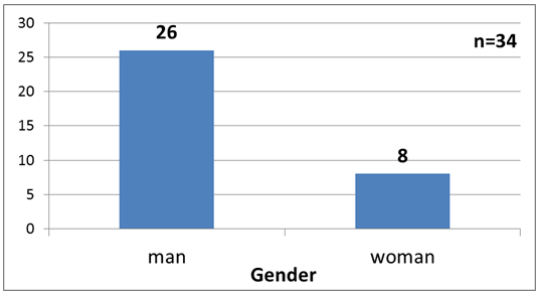


Figure A.28 – Number of participants per gender

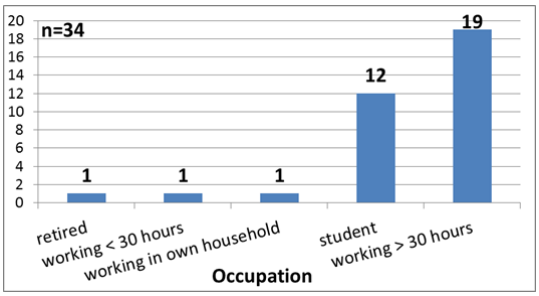


Figure A.29 – Participants per occupation

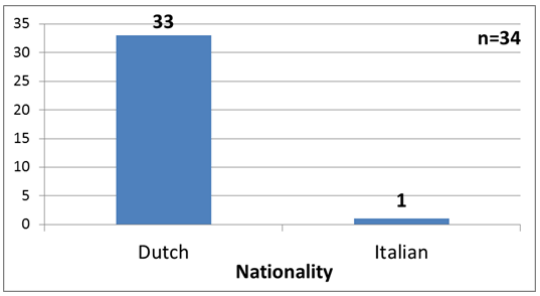


Figure A.30 – Participants per nationality

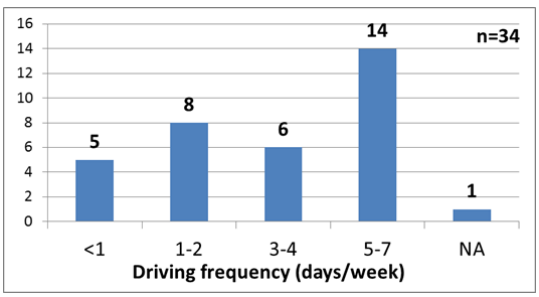


Figure A.31 – Participants per driving frequency

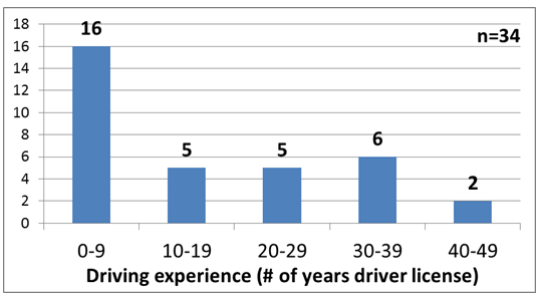


Figure A.32 – Participants per years license

A.6 Demographic characteristics of population

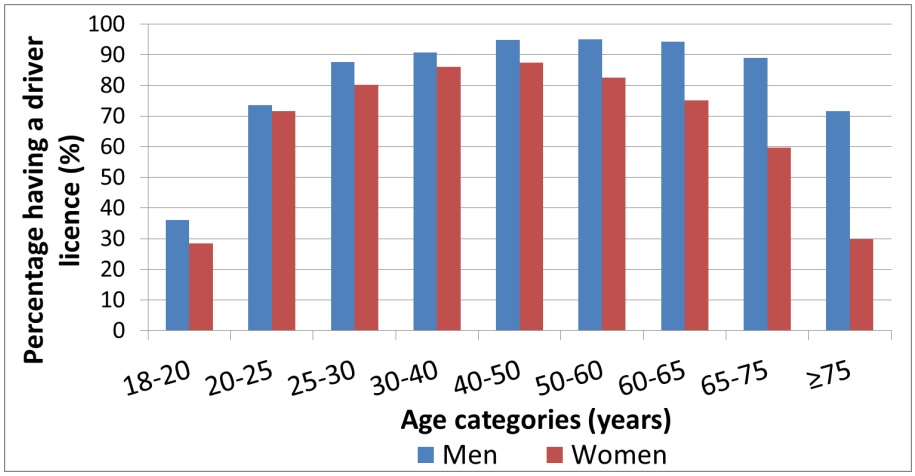


Figure A.33 – Driving license possession per age group for 2007 (CBS-Statline, 2007)

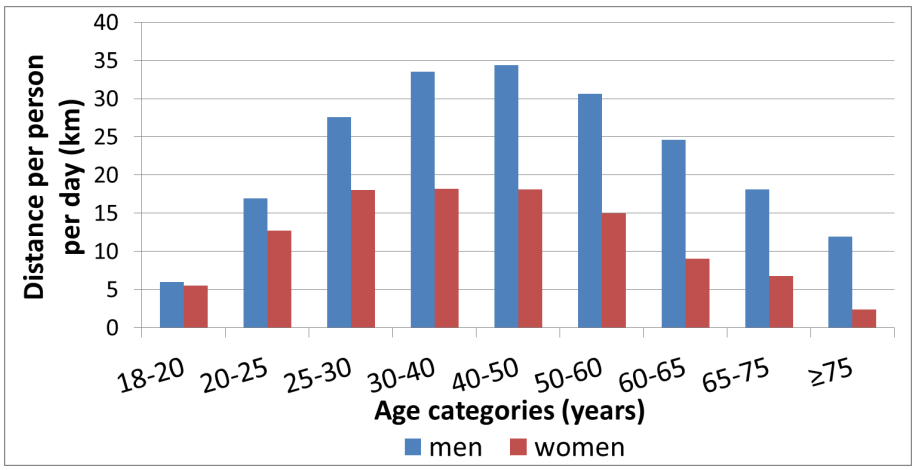


Figure A.34 – Travelled distance per day as a car driver per age group for 2007 (CBS-Statline, 2007)

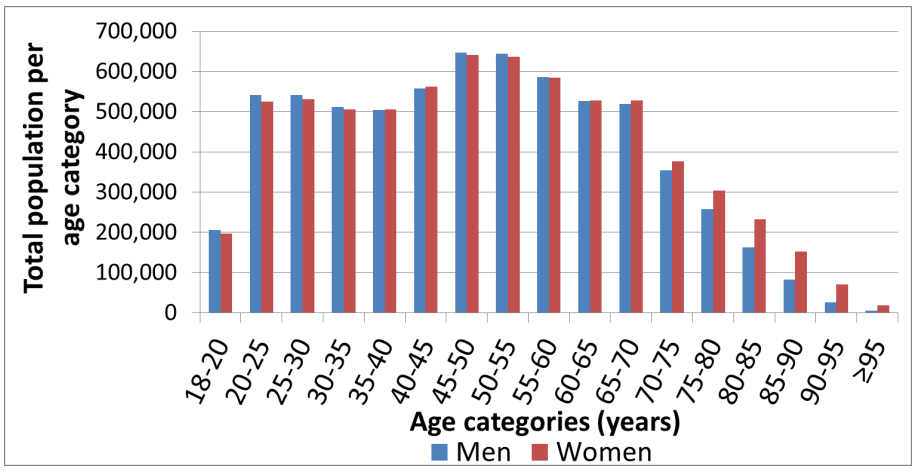


Figure A.35 – Population per age category for 2016 (CBS-Statline, 2016c)

A.7 Responses on driving style items

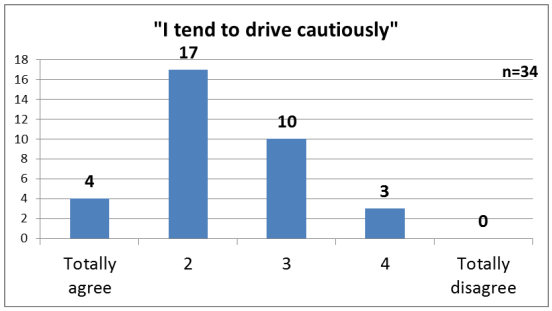


Figure A.36 – Careful driving style

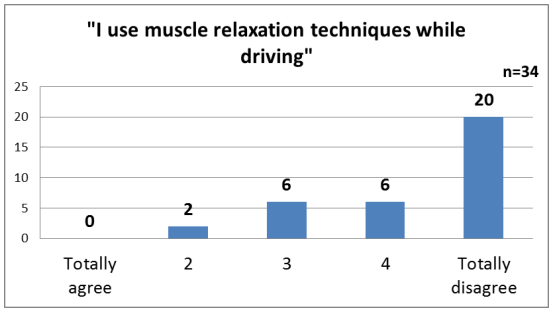


Figure A.37 – Distress-reduction driving style

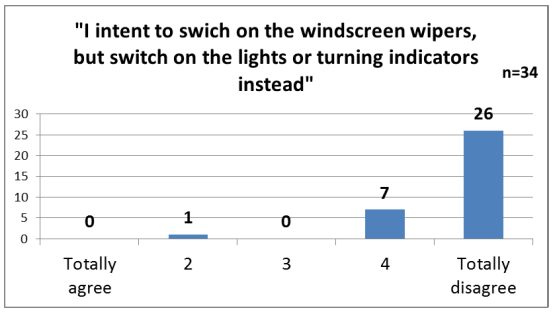


Figure A.38 – Dissociative driving style

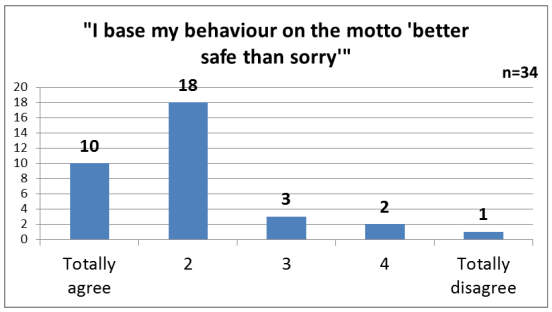


Figure A.39 – Patient driving style

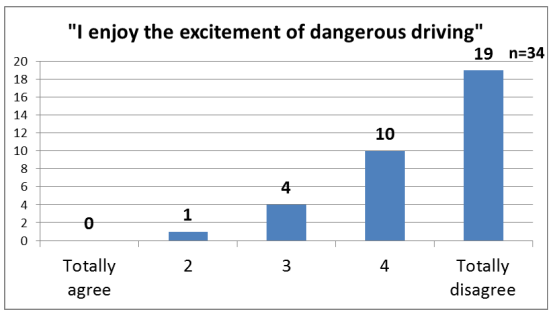


Figure A.40 – Risky driving style

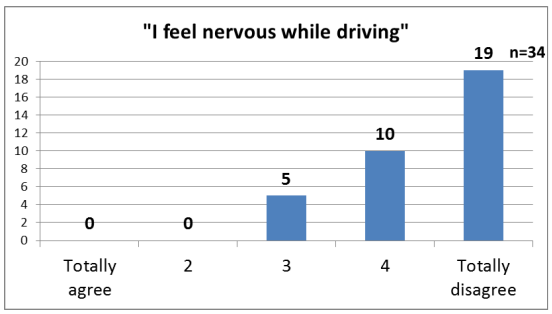


Figure A.41 – Anxious driving style

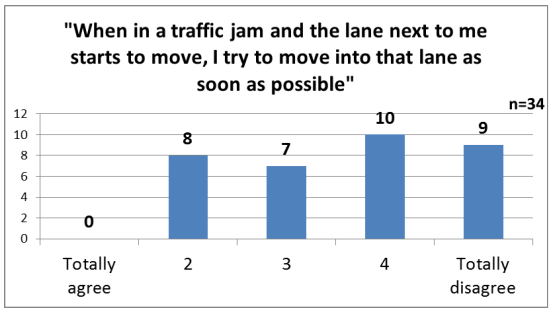


Figure A.42 – High-velocity driving style

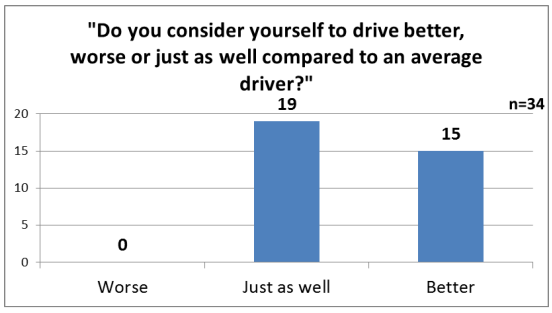


Figure A.43 – Perception of own competence

Appendix B

Online questionnaire

B.1 Flow diagram

Figure B.1 shows the various paths through the questionnaire via a flow diagram. Based on the speed choice on a three lane motorway with a speed limit of 100 km/h, each respondents is directed to one of the three branches: 'slow', 'average', 'fast'.

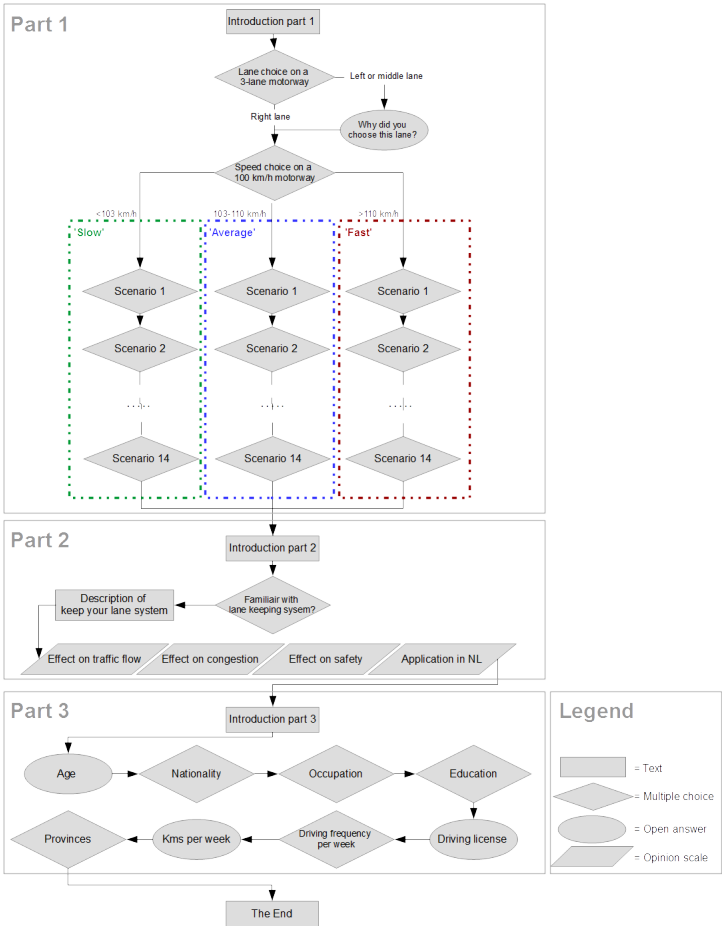


Figure B.1 – Flow diagram of online questionnaire

The 'slow' branch of the questionnaire is enlarged in figure B.2. The other two branches are similar as the 'slow' branch, except for the speeds presented in the videos and questions. Several traffic

scenarios are followed up by questions concerning a respondents motive for the shown behaviour.

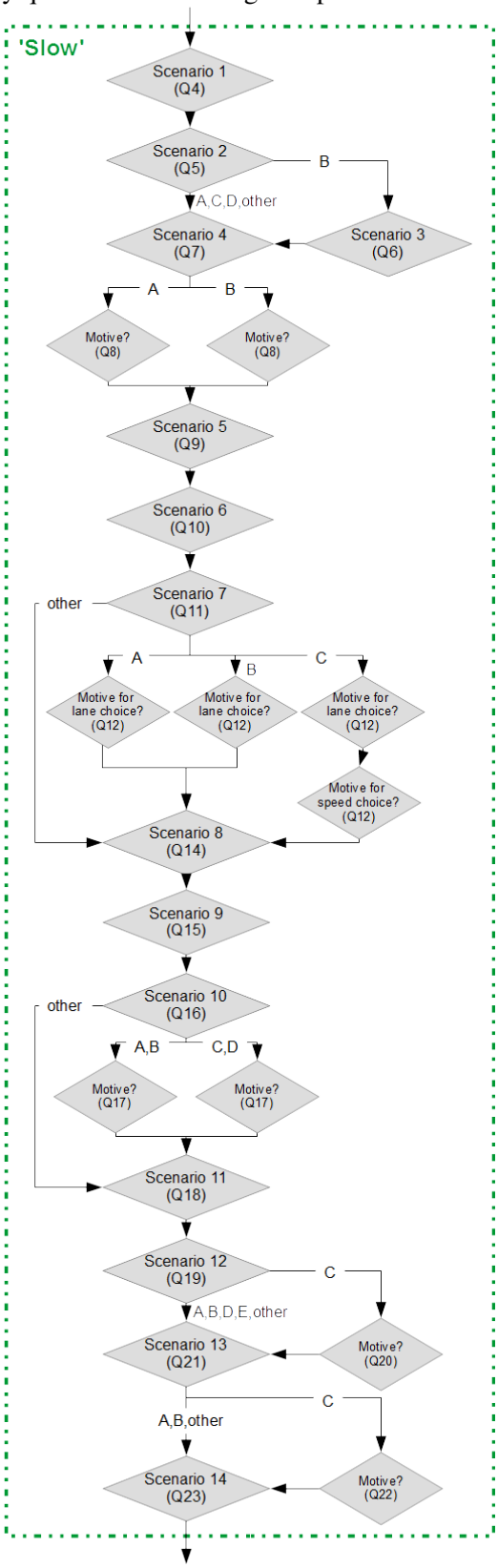


Figure B.2 – More detailed flow diagram of the 'Slow drivers' branch of the questionnaire

B.2 Set-up of scenarios

In this section all 14 scenarios that are included in the questionnaire are being discussed. A description of each video is given, the multiple choice answer for each scenario are presented and the aim of each scenarios is stated. All pictures presented throughout the section are screenshots of the last frames of each video.

Scenario 1: Overtaking via right

Description: You are driving in a tunnel on a 4 lane motorway on the third lane from the left. A truck is driving up ahead on the shoulder lane and a person car is driving in the second lane from the left while there is space for that driver to keep right on the third lane from the left. You are getting closer to the person car.

Question: What would you do in the following traffic situation?

Figure B.3 – Last frame of video describing scenario 1

Multiple choice answers:
A. I continue in this lane, I keep my current speed constant at about 100 km/h and will pass the black car via his right side
B. I continue in this lane, I adjust my speed and will stay behind the black car
C. I continue in this lane, I increase my speed well above 100 km/h and will pass the car via his right side
D. I change one lane to the left and will drive on some distance behind the black car
E. I change two lanes to the left and will pass the black car with a constant speed of about 100 km/h
F. I change two lanes to the left and will pass the black car while I will increase my speed well above 100 km/h
G. Other

Aim of this question:
This question is included to see if a driver would overtake another vehicle via its right side, which is forbidden in the Netherlands, while there is space to overtake that vehicle via its left side (overtake via right). Furthermore, when a respondent will overtake the vehicle will he increase his speed while doing so (strategy 1 vs strategy2)? Or will the respondent adjust its speed to the person car and stay behind it (strategy 3).

Scenario 2: Strategy 1,2,3

Description: You are driving on a 3 lane motorway on the shoulder lane. A slightly slower predecessor is driving in front of you, which you are approaching, while a black car just passed you with high speed.

Question: What would you do in the following traffic situation?

Figure B.4 – Last frame of video describing scenario 2

Multiple choice answers:
A. I continue driving in this lane and will adjust my speed to my predecessor
B. I change one lane to the left and keep my speed constant at about 100 km/h
C. I change one lane to the left and increase my speed well above 100 km/h
D. I change one lane to the left and will increase my speed to follow the black car that just passed me with high speed
E. Other

Aim of this question:
This question is included to check which strategy is applied by the respondent. Drivers according to strategy 1 would change one lane to the left and overtake the vehicle with a constant speed. Drivers according to strategy 2 would also change one lane to the left, but while they overtake the vehicle they increase their speed. Strategy 3 drivers would adapt their speed to the white car in front of them and stick to the current lane. Where following the much faster car that just passed is classified as strategy 4 behaviour.

Scenario 3: Strategy 1 or 2

Description: This scenario is only shown to the respondents who answered to overtake the vehicle with a constant speed. The white car you decided to overtake increases its speed a bit, which makes that you pass the white vehicle very slowly.

Question: What would you do in the following traffic situation?

Figure B.5 – Last frame of video describing scenario 3

Multiple choice answers:
A. I continue driving in this lane with my current speed
B. I continue driving in this lane and will increase my speed
C. I change on lane to the right with my current speed
D. Other

Aim of this question:
This scenario is only shown to the respondents who answered to overtake the vehicle with a constant speed. Several participants in the driving study stated they would increase their speed if the speed difference with the vehicle they try to overtake is small, while others stated they would never increase their speed while overtaking and tries to drive with a constant speed as much as possible.

Scenario 4: Strategy 1/2 or 3

Description: You are driving on a two lane motorway during congestion on the median lane. You are driving in a stop-and-go wave, while traffic on the shoulder lane drives more smooth and with a higher speed.

Question: What would you do in the following traffic situation?

Figure B.6 – Last frame of video describing scenario 4

Multiple choice answers:

A. I continue driving in this lane
B. I try to change one lane to the right

Following up question: What arguments played a role in your choice?

Multiple choice answers if answered A:
A. I don' like changing lanes when it's crowded
B. I think you do not gain much travel time from changing lanes all the time in comparison with keeping your lane during congestion
C. I do not change lanes during congestion to contribute to a smoother traffic flow
D. My current lane will probably begin driving too in a short while, so it is too much effort for me to change lanes now
E. Other

Multiple choice answers if answered B:
A. During congestion I try to get in the fastest lane as much as possible
B. Traffic on the median lane is often not driving smoothly during congestion so I prefer driving on the shoulder lane
C. Other

Aim of this question:
This scenario is included to check what drivers would do during congestion when traffic on another lane is driving with higher speeds. Several participants from the driving experiment indicated they would keep their lane during congestion, since they believe in terms of travel time there is not much difference between changing lanes all the time or keeping your lane. So would respondents keep their lane (strategy 3) or do they try to get in the fastest lane as soon as possible (strategy 1/2).

Scenario 5: Overtaking via right

Description: You just entered the motorway via on on-ramp, while on one lane to the left a black car is driving with a low speed. You need to proceed on this roadway to follow your route.

Question: What would you do in the following traffic situation?

Figure B.7 – Last frame of video describing scenario 5

Multiple choice answers:

A. I continue driving in this lane and will adapt my speed so I stay behind the black car
B. I continue driving in this lane and will increase my speed to pass the black car via his right side
C. I change one lane to the left and will drive on a good distance behind the black car
D. I change one lane to the left and will drive on a short distance behind the black car
E. Other

Aim of this question:
This scenario is included to see if a respondent would overtake another vehicle that drives relatively slow on the adjacent lane, while there is not really the possibility to overtake the black car via his left side since you need to follow this roadway.

Scenario 6: Strategy 1/2 or 3

Description: You merge onto the main roadway from an on-ramp, while you need to take the second exit from that point which is 3100 metres up ahead to continue your route.

Question: What would you do in the following traffic situation?

Figure B.8 – Last frame of video describing scenario 6

Multiple choice answers:
A. I continue in this lane and will adapt my speed to my predecessor
B. I change between this lane and one lane left of it, and will adapt my speed to my predecessor
C. I will drive in the lane in which I can drive with my desired speed
D. Other

Aim of this question:
Some participants in the driving experiment indicated they would stay in the shoulder lane when they only had to drive a relatively short distance over the motorway. Although they said to do so in congestion, the video describes a situation with rather low intensities where you are able to change lanes easily. However, there were also some other participants who indicated to minimize lane change when they were driving at this section.

Scenario 7: Strategy 3, keep right or strategy 4

Description: You are driving on a three lane motorway in the centre lane while passing a truck on the shoulder lane. There is space to change one lane to the right after you passed the truck, while a

faster driver is approaching you from behind.

Question: What would you do in the following traffic situation?

Figure B.9 – Last frame of video describing scenario 7

Multiple choice answers:
A. I continue in this lane and keep my speed constant at about 100 km/h
B. I change one lane to the right and keep my speed constant at about 100 km/h
C. I continue in this lane and will increase my speed (far) above 100 km/h
D. Other

Following up question: What arguments played a role in your choice?

Multiple choice answers if answered A or C:
A. A truck is driving on the right most lane up ahead, which I will pass soon, so it is needless to change to the shoulder lane
B. I prefer to drive in the centre lane, since from there you can change to the median and to the shoulder lane
C. The faster driver behind me can overtake me via my left side, so I do not need to make space for him
D. I prefer to drive in the same lane as much as possible
E. The shoulder lane is for trucks in my opinion, so therefore I keep driving in the centre lane
F. Other

Multiple choice answers if answered B:
A. I change one lane to the right to obey to the traffic rules
B. I change on lane to the right to make space for the faster driver behind me
C. Other

Following up question if answered C: What arguments played a role in your answer concerning your speed choice?

Multiple choice answers if answered C:
A. I increase my speed because I want to reduce the distance to my predecessors
B. I increase my speed to not delay the faster driver behind me too much
C. I increase my speed because I prefer to drive along with the 'faster' drivers on the road

D. I increase my speed because my preference speed is higher than my current speed
E. Other

Aim of this question:
This scenario is included to see if someone would change to the right, and why he would or not. Does someone always strictly keep right, or does the truck in the distance influence his lane choice? And does the vehicle from behind have any effect on your lane choice or not? In the driving experiment various responses were heard on similar situations. Some people would not keep right here because of the truck up ahead on the shoulder lane. Others would keep right to make space for the faster vehicle from behind, while on the other hand some people would stay in the centre lane since there was space for the faster driver to overtake them.

Scenario 8: Keep right

Description: You are driving on a three lane motorway in the centre lane, while passing two trucks on the shoulder lane. After you have passed the trucks there is an empty road in front of you.

Question: What would you do in the following traffic situation?

Figure B.10 – Last frame of video describing scenario 8

Multiple choice answers:
A. I continue in this lane with my current speed
B. I continue in this lane and increase my speed
C. I change one lane to the right with my current speed
D. I change one lane to the right and increase my speed
E. Other

Aim of this question:
This scenario is included to see if people would obey to the keep right rule when possible. In this case there are no other vehicles on the road, except for the truck you just passed. So not many other drivers that can influence your choice. In some cases people might just stick to the centre lane, while according to the traffic rules you need to keep right as much as possible.

Scenario 9: Strategy 1,2,3

Description: You are driving on a three lane motorway on the shoulder lane. A truck is driving in front of you on the same lane, while a faster driver is approaching you from the back on the centre

lane.

Question: What would you do in the following traffic situation?

Figure B.11 – Last frame of video describing scenario 9

Multiple choice answers:
A. I continue driving in this lane and will adjust my speed to my predecessor
B. When the car behind me passed me, I will change lanes and keep my speed constant at about 100km/h
C. When the car behind me passed me, I will change lanes and will increase my speed well above 100 km/h
D. I will change one lane to the left immediately, and keep my speed constant at about 100 km/h
E. I will change one lane to the left immediately, and will inrease my speed well above 100 km/h
F. Other

Aim of this question:
This scenario is included to see if a respondent would overtake the truck or would stay behind it (strategy 1/2 vs 3). In this case the vehicle from behind could make respondents shift from strategy 1 to strategy 2. Furthermore some multiple choice answers also imply a patient driving style.

Scenario 10: Keep right

Description: You are driving on a two lane motorway on the median lane, while you pass a truck that is driving on the shoulder lane. Up ahead another truck is driving, while a faster driver is approaching you from behind.

Question: What would you do in the following traffic situation?

Figure B.12 – Last frame of video describing scenario 10

Multiple choice answers:
A. I keep driving in this lane with my current speed
B. I keep driving in this lane and increase my speed
C. I change one lane to the right with my current speed
D. I change one lane to the right and increase my speed
E. Other

Following up question: What arguments played a role in your choice?

Multiple choice answers if answered A or B:
A. Up ahead more traffic is driving which I will pass on a short while, so it is not worth it to change one lane to the right here
B. I keep driving in this lane to prevent that I get stuck between slow traffic on the shoulder lane
C. The faster driver behind me should just be patient, in front of me drives another vehicle with a similar speed as me
D. Other

Multiple choice answers if answered C or D:
A. I change to the shoulder lane to obey to the traffic rules
B. I change to the shoulder lane to make space for the driver behind me to pass me
C. Other

Aim of this question:
Does someone always keep right? Or is this influenced by the presence of a faster vehicle while there is no space to be overtaken? Follow-up questions are included to see what factors play a role in the choice of a respondent.

Scenario 11: Strategy 4

Description: You are driving on a three lane motorway on the shoulder lane with a speed of 100 km/h. However, all other vehicles around you drive much faster and you are overtaken by them.

Question: What would you do in the following traffic situation?

Figure B.13 – Last frame of video describing scenario 11

Multiple choice answers:
A. I keep my speed constant at about 100 km/h
B. I increase my speed to synchronize it with the other drivers around me
C. Other

Aim of this question:
In strategy 4 drivers base their speed on that of others. This scenario is included to check if drivers would increase their speed to driving along with all other traffic. In the driving experiment participants frequently stated they preferred to 'go with the flow'.

Scenario 12: Courtesy lane change

Description: You are driving on a two lane motorway on the shoulder lane, while you approach a merging lane on which a vehicle is driving. However, the driver is not using its blinker.

Question: What would you do in the following traffic situation?

Figure B.14 – Last frame of video describing scenario 12

Multiple choice answers:
A. I continue driving on this lane and will adjust my speed to the car on the on-ramp, so it can merge onto the roadway in front of me
B. I continue driving on this lane and will increase my speed

C. I continue driving on this lane with my current speed
D. I change one lane to the left with my current speed
E. I change on lane to the left and will increase my speed
F. Other

Following up question if answered C: What arguments played a role in your choice?

Multiple choice answers if answered C:
A. The car on the on-ramp doesn't use it's blinker
B. The car on the on-ramp should adjust to me
C. The car could have merged much earlier onto the main roadway, so I think maybe the on-ramp merging lane continues as an off-ramp merging lane
D. The car did not indicate that it wanted to merge onto the main roadway, so I do not give him space
E. Other

Aim of this question:
In the driving experiment almost everyone indicated to make space for a vehicle on the on-ramp to merge onto the main roadway. However, one participant stated he would only make space if the merging vehicle would use its blinker. While some other participants stated they were willing to cooperate with the merging vehicle if they would not have to decrease their speed. Furthermore, how would a driver make space, will he accelerate, decelerate or change lanes in this case? Finally, if a respondent answers would continue driving in the current lane with the current speed, an additional question is presented in which the motives behind this behaviour is asked.

Scenario 13: Strategy 1,2,3

Description: You are driving on a three lane motorway in the centre lane. To follow your route you have to take the exit that starts at 600 metres from the moment the video stops. On that moment a truck is driving up ahead on the shoulder lane.

Question: What would you do in the following traffic situation?

Figure B.15 – Last frame of video describing scenario 1

Multiple choice answers:
A. I continue driving in this lane at about 100 km/h, after I pass the truck I will change one lane to the right to take the off-ramp

B. I continue driving in this lane and increase my speed (far) above 100 km/h, after I pass the truck I will change one lane to the right to take the off-ramp
C. I change one lane to the right and adjust my speed to the truck, and eventually take the off-ramp up ahead
D. Other

Following up question if answered C: If you would be familiar with the off-ramp, would you then have made the same decision?

Multiple choice answers if answered C:
A. Yes, I would have made the same choice
B. No, I would have overtaken the truck just before the off-ramp
C. Other

Aim of this question:
This scenario is included to see if respondents would overtake a truck or not just before they need to take the exit. Will they either temporarily accept a lower speed, or are they confident they can overtake the truck in time to reach the exit. Several participants from the driving experiment furthermore stated that if they would be familiar with an off-ramp they would overtake other vehicles more easily. So in case respondents answer they would not overtake the truck, they are asked if familiarity with the off-ramp would change their decision.

Scenario 14: Keep right

Description: You are driving on a three lane motorway on the third lane from the left. This road section also contains a peak hour lane on the emergency lane which is currently opened for traffic. You will pass the truck that drives on the peak hour lane.

Question: What would you do in the following traffic situation?

Figure B.16 – Picture describing scenario 14

Multiple choice answers:
A. I continue driving on this lane with my preferred speed
B. I will change one lane to the right with my preferred speed
C. I will change one lane to the left with my preferred speed
D. Other

Aim of this question:
Previous studies have shown that the peak hour lane is underutilized when opened. Some drivers are apparently not willing to strictly keep right in case of an opened peak hour. This scenario tries to find how many people would strictly keep right and how many who would not use the peak hour lane despite the available space to do so. In this scenario a picture is presented instead of a video. The peak hour lane is opened during heavy traffic, so there was no appropriate video footage available, since a situation was needed in which a driver could not be influenced by other vehicles. In this case the original picture contained several vehicles which were removed with photo editing software.

Overview of used videos

Readers of a digital version of this report can click the links in the table to go directly to the YouTube video.

Table B.1 – List of URL's to the videos that have been used per scenario

Scenario	Theme	URL to YouTube video
1	Right overtaking	https://www.youtube.com/watch?v=FJEiagCKYns
2	Strategy 1,2,3	https://www.youtube.com/watch?v=1mwKM7IVlBo
3	Strategy 1,2,3	https://www.youtube.com/watch?v=z_l9UVA6bBg
4	Strategy 1,2,3	https://www.youtube.com/watch?v=blFXCa93r1k
5	Right overtaking	https://www.youtube.com/watch?v=Un7Piyj_Spk
6	Strategy 1,2,3	https://www.youtube.com/watch?v=P5QyhELCAPk
7	Keep right	https://www.youtube.com/watch?v=kj3tLSsp5Po
8	Keep right	https://www.youtube.com/watch?v=DOdYPXHwjNA
9	Strategy 1,2,3	https://www.youtube.com/watch?v=ljBzE0jK29Y
10	Keep right	https://www.youtube.com/watch?v=7CSQ6DD-L_Y
11	Strategy 4	https://www.youtube.com/watch?v=ij4RtELjH2o
12	Courtesy lane change	https://www.youtube.com/watch?v=Q50XotNA1cM
13	Strategy 1,2,3	https://www.youtube.com/watch?v=aLBnyfIq8Bc
14	Keep right	Not applicable, since image was used.

B.3 Demographic data analysis

In this section several graphs and tables are presented of the sample of respondents that live in the Netherlands.

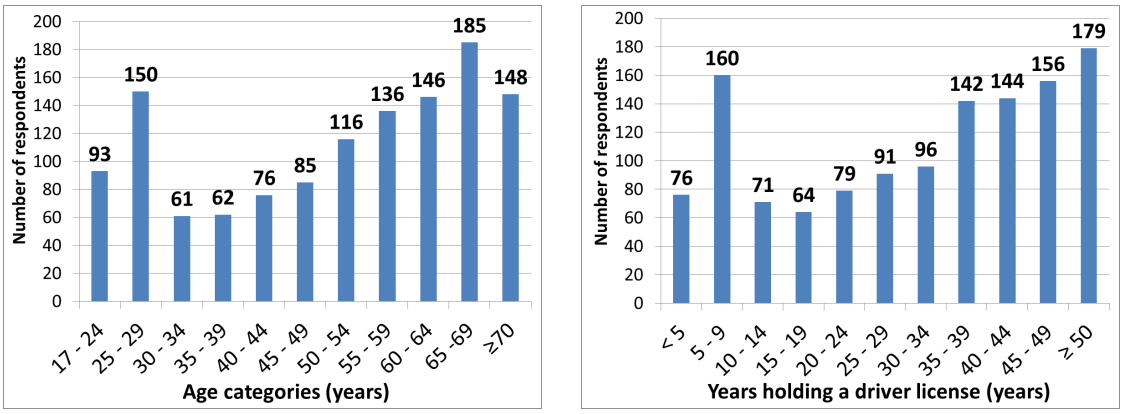


Figure B.17 – Distribution of respondents over age and years holding a driving license

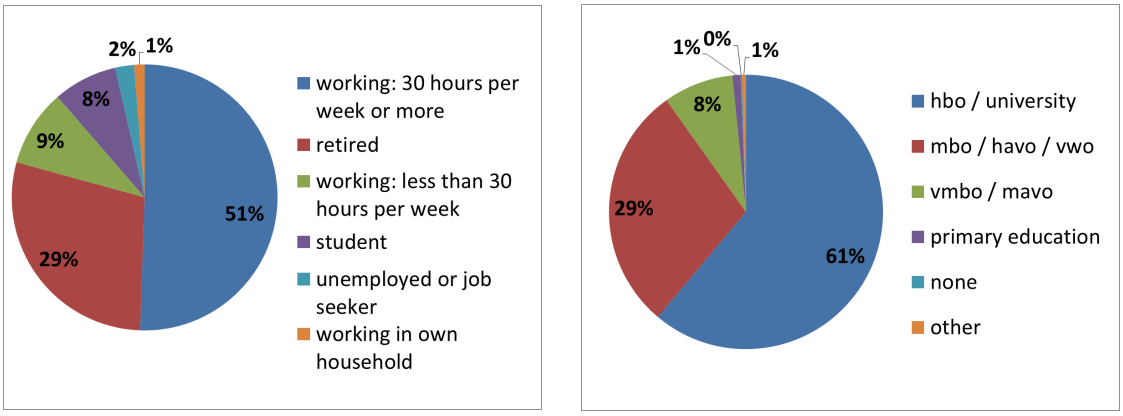


Figure B.18 – Distribution of respondents over occupation and highest completed education

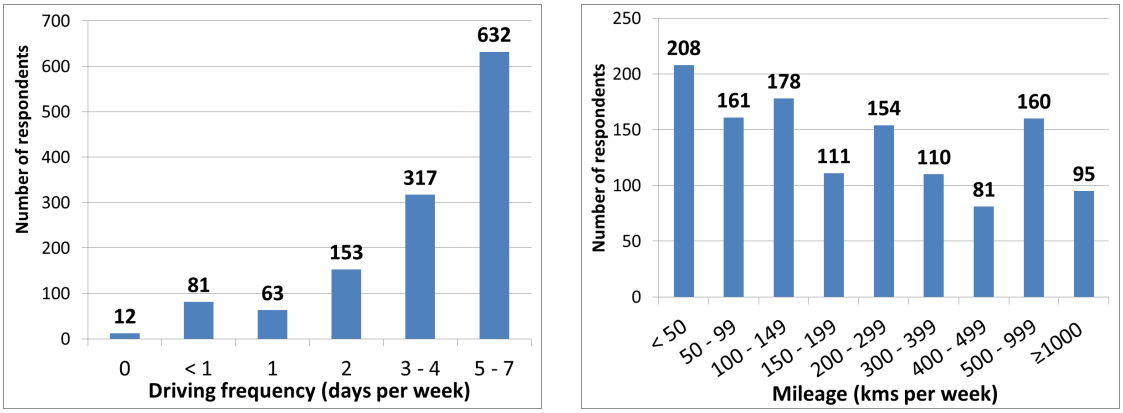


Figure B.19 – Distribution of respondents over driving frequency and average mileage per week

Nationality	Frequency	Percent
Dutch	1236	98.3%
Belgian	8	0.6%
German	6	0.5%
Greek	2	0.2%
Italian	2	0.2%
Finnish	1	0.1%
French	1	0.1%
Romanian	1	0.1%
Slovak	1	0.1%
Total	1258	100%

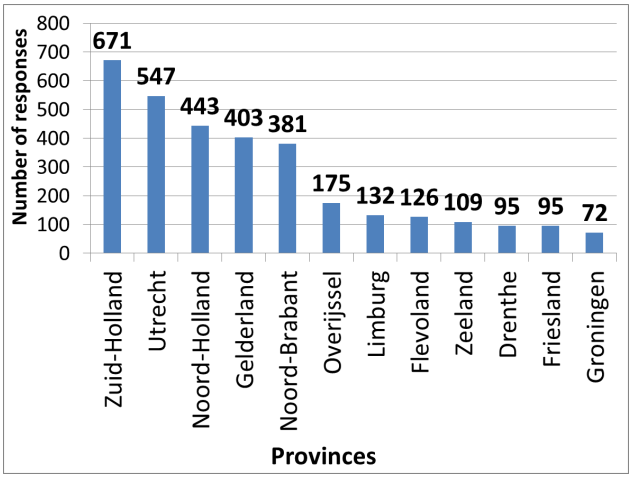
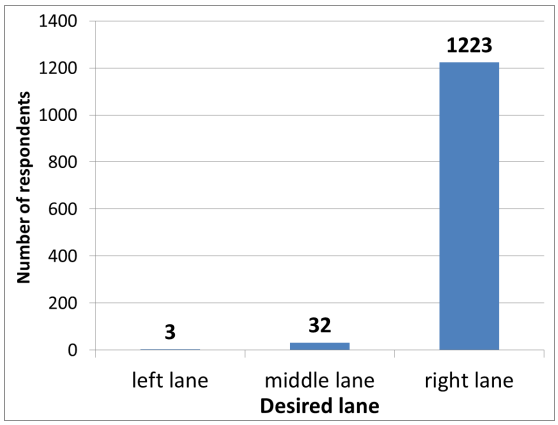


Figure B.20 – Distribution of respondents over Nationality and often visited provinces



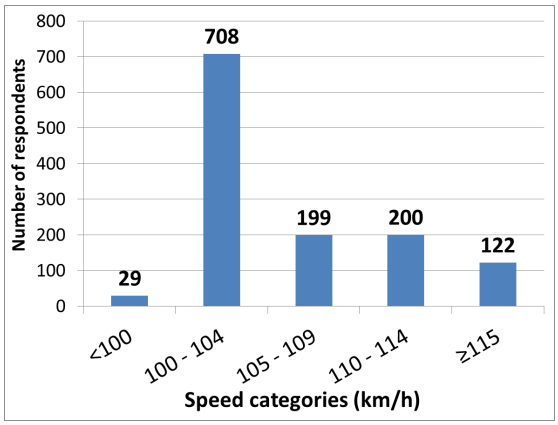


Figure B.21 – Distribution of respondents over lane and speed choice on a 3-lane motorway with a speed limit of 100 km/h

B.4 Responses per scenario

In this section of the appendix the results of each scenario are presented, which are on its turn interpreted. Furthermore, the open answers that were given are briefly discussed for each scenario.

Scenario 1 - Right overtaking

The frequency distribution over the multiple choice answers for scenario 1 are found in figure B.22. The video described a traffic situation in which a car was unnecessarily driving on the 2nd lane from the left while you were approaching that vehicle from behind. The question was whether the respondent would overtake it via its right side, its left side or stick behind it. In total 40 % of the respondents would overtake the vehicle via its left side, 20% would overtake the other vehicle via its right side (which is actually forbidden in the Netherlands), while 38% would stay behind the car an not overtake it (which can be seen as strategy 3 driving behaviour).

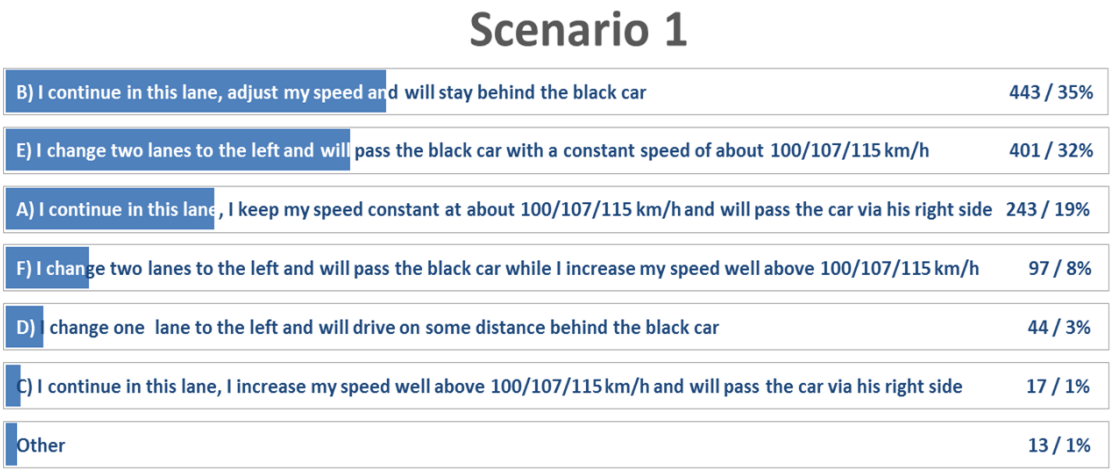


Figure B.22 – Frequency distribution of response on Scenario 1

Only 13 respondents answered differently than the pre-defined multiple choice answers. Some of these 'other' answers are quite similar as the pre-defined questions, for example: one respondent answered he would overtake the vehicle via its right side with constant speed, where after he would change two lane back to the right. This corresponds with answer E, except for the additional information on the following-up action. Four respondents answered they would change lanes to the shoulder lane.

Scenario 2 - Strategy 1,2,3

The traffic situation of scenario 2 consisted of you driving in the shoulder lane, while you were approaching a slower predecessor. The results are presented in figure B.23. About 77% of the respondents answered B, which corresponds with strategy 1 driving behaviour, in which you overtake a slower predecessor while keeping your speed constant. 12% of the respondents apply strategy 3 (lane keeping) in this situation, which means they would continue on the current lane and adapt their speed to their predecessor. About 10% of the respondents applies strategy 2 in this case (answer C). Only 11 respondents stated that they would driver along with the faster driver that just passed them, which corresponds to strategy 4 driving behaviour.

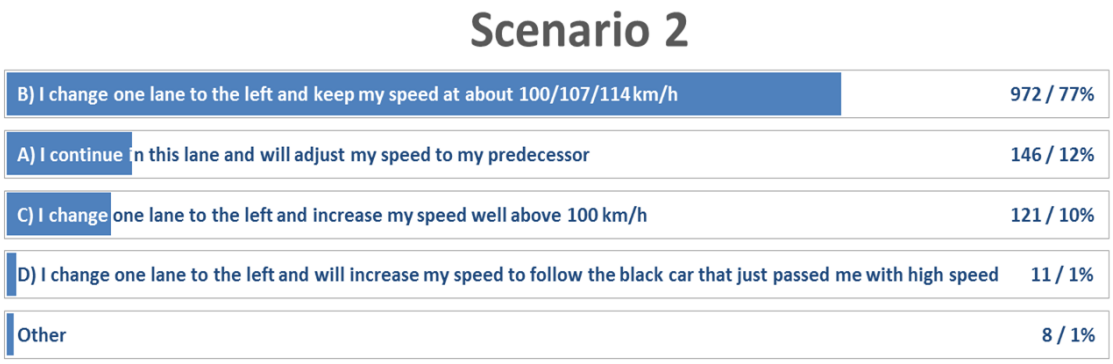


Figure B.23 – Frequency distribution response Scenario 2

Only eight respondents gave a different answer than the predefined actions. Seven of these respondents stated they would increase their speed while overtaking the vehicle, which is typically strategy 2 driving behaviour, what was tried to be captured by option C in the multiple choice answers. However it is expected that these respondents had a different opinion on the meaning of 'well above 100 km/h', and so they used the 'Other answer' option to clarify their action. Thus in fact 128 respondents would drive according to strategy 2 in this traffic situation.

Scenario 3 - Strategy 1,2,3

The third scenario was only shown to the respondent that answered B, which indicates strategy 1 driving behaviour, in the question 2. The video shows that although you change lanes to the left you are not really passing the vehicle with your current speed. The responses are shown in figure B.24. About 43% of the respondents that would initially apply strategy 1 to overtake the slower predecessor in scenario 2, would increase their speed to actually overtake another vehicle when they it seemed like their were not passing the other vehicle. On the other hand, 56% of these respondents would not increase their speed and either stay in the current lane or change back to the shoulder lane. These participants would thus not change to strategy 2 when the speed difference with the other car was very small.

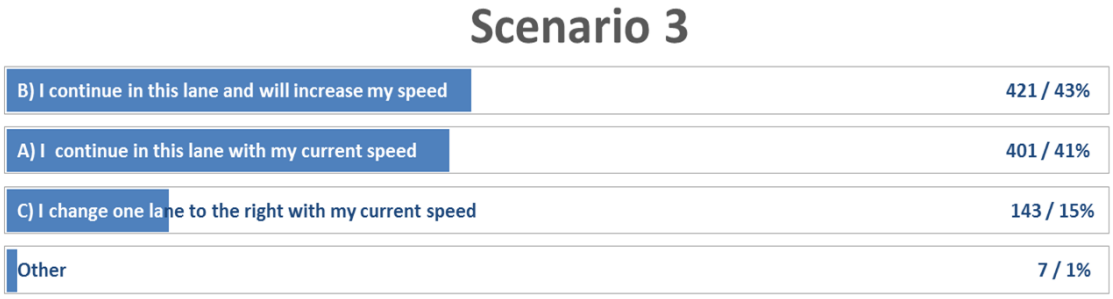


Figure B.24 – Frequency distribution response Scenario 3

Seven respondents answered via an open answer. Four of these answers correspond with strategy 2 driving behaviour, which means they would increase their speed to overtake the vehicle, while after overtaking they would return to the shoulder lane.

Scenario 4 - Strategy 1,2,3

The fourth traffic scenario described a congested situation in which you had to make to choice to stay in your lane or to try to change lane to the shoulder lane on which traffic was driving a bit faster. The results are presented in figure B.25 and show that 73% would stay in the current lane, which can be seen as strategy 3 driving behaviour. The other respondents, 27%, indicated they would try to change to the shoulder lane.

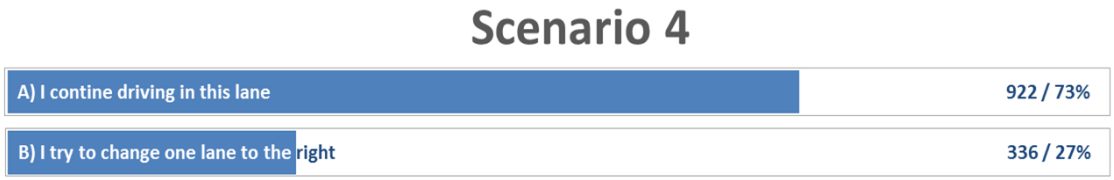


Figure B.25 – Frequency distribution response Scenario 4

To understand the driving behaviour of respondents for this scenario better, every respondent got a following-up question concerning their motivation for the chosen action. In these following-up questions respondents were allowed to select multiple answers, since various arguments can play a role in someone's decision.

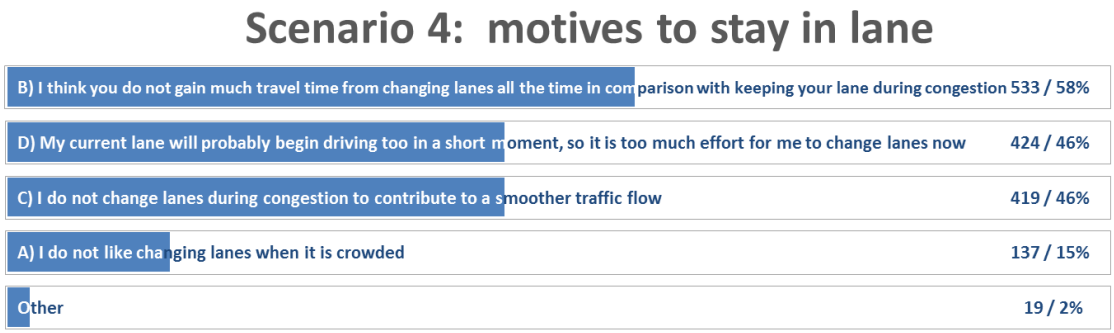


Figure B.26 – Frequency distribution of motives

The motives of respondents to stay in the lane are presented in figure B.26. Most respondents (58%) did not see benefits in changing lanes concerning their travel time, while 46% found it too much effort and/or wanted to contribute to a smoother traffic flow. About 15% stated they did not like change lanes during congestion. Some respondents apparently did not notice the functionality to select multiple answers, since in the open answer option they stated their behaviour was based on the motive of B, C and D for example. The other open answers included the unfamiliarity with this road, too small gaps on the adjacent lanes, and the fact that road safety would improve when lane changes were minimized. The frequencies of the combinations of motives are found in table B.2. Twenty unique combinations of motives have been found in the dataset. About 42% of the respondents gave a single answer as motivation to stay in their lane, which was either a, b c or d.
The motives of respondents to change lanes are presented in figure B.27. The respondents that would try to change lanes do this to improve their driving conditions, which is either driving with a higher speed or having more comfort in the form of a smoother traffic flow. Several respondents indicated via the open answer option that they tried to keep right as often as possible, and therefore they would change to the shoulder lane. One respondent stated that he wanted to drive on the shoulder lane since

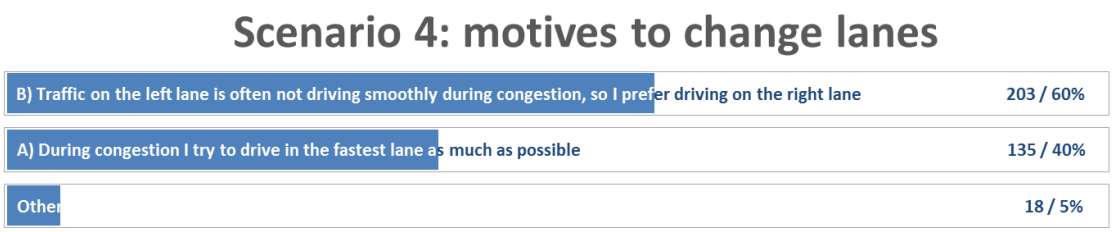


Figure B.27 – Frequency distribution of motives

there he could either go left or right in case of an emergency. Several other respondents believe that the speed on the shoulder lane is higher during congestion. Most respondents either try to change lanes to drive more smooth or to get in the fastest lane. The combination of these motives was only given 5% of the respondents that try to change lanes in congestion.

Table B.2 – Combinations of motives to stay in lane

Q4 Motives - combination of answers

Combination	Frequency	Percent
b	203	22%
c	165	18%
d	132	14%
bcd	93	10%
bd	84	9%
bc	57	6%
abcd	45	5%
cd	31	3%
a	26	3%
abd	25	3%
other	14	2%
abc	13	1%
ab	9	1%
acd	8	1%
ac	5	1%
ad	4	0%
abother	2	0%
bcother	1	0%
bdother	1	0%
cdother	1	0%
Total	919	100%

Table B.3 – Combinations of motives to change lanes

Q4 Motives - combination of answers

Combination	Frequency	Percent
b	183	54%
a	117	35%
ab	18	5%
other	16	5%
bother	2	1%
Total	336	100%

Scenario 5 - Right overtaking

This scenario relates again to the fact if a respondent would overtake another vehicle via it's right side or not, for which the results are presented in figure B.28. A car is driving on the second lane from the right and drives below 100 km/h. Most respondents, 56%, indicate they would apply strategy 3 driving behaviour and thus stay in their lane and adapt their speed. In this case 16% of the respondents indicates they will overtake the vehicle via his right side, while in scenario 1 20% would overtake the vehicle via his right side.

The open answers that were given show that the video describing scenario 5 was not totally clear for every respondents. The video namely shows an road section on the A12 near the junction Prins Clausplein. In the video you enter the highway on a parallel road section, while to reach the main roadway you need to change two lane to the left. In the survey was tried to make clear you always

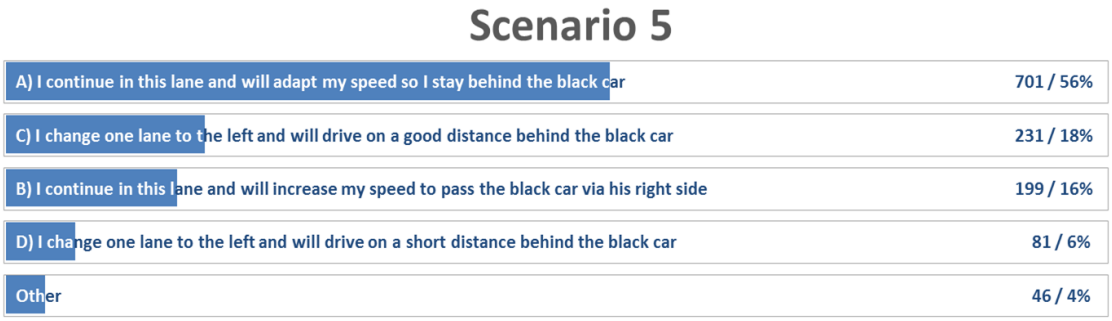


Figure B.28 – Frequency distribution response Scenario 5

had to follow the roadway you were on, unless a direction was given. In this case respondents were assumed to follow the parallel roadway, however, for many respondents this was unclear, and so it was hard to answer the question correctly.

Scenario 6 - Strategy 1,2,3

The sixth scenario describes a situation in which you enter the main roadway while you need to take the second exit from that point, which is 3100 metres up ahead, to follow your route. The results are presented in figure B.29. About 44% of the respondents indicated that would stay in the current lane and adapt their speed to the predecessor, which is clearly strategy 3 driving behaviour. Only 28 % drives in the lane in which they can drive with their desired speed, which is either strategy 1 or 2 driving behaviour. About 27% indicated they would only used the shoulder land and the centre lane, which is a combination of the speed leading strategies and the lane leading strategy, since apparently they will adapt speed when they encounter a slower predecessor when driving in the centre lane and not change to the lane in which they can drive with their desired speed. In comparison with scenario 2 many more respondents show strategy 3 driving behaviour (44% in scenario 6 versus 12% in scenario 2). The nearby exit or the short trip over the motorway thus seem to induce more people to behave according to strategy 3 or adapt a combination of the speed leading and lane leading strategies.

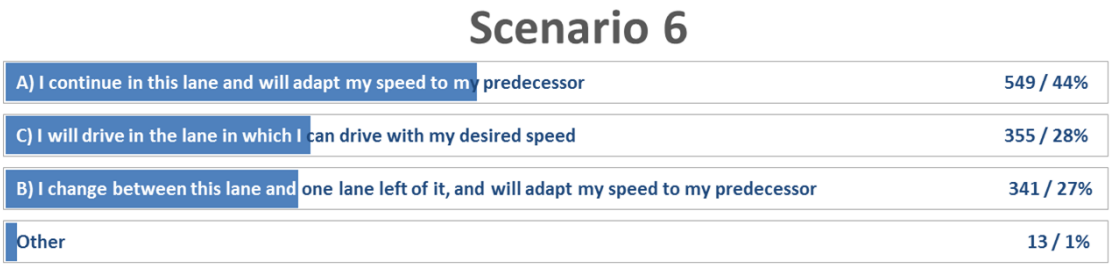


Figure B.29 – Frequency distribution response Scenario 6

Although only 13 of 1258 respondents answered via the open text box, there are some indication that the question was not completely clear. A few respondents stated that the distance to the exit was unknown, or that even the complete question was unclear. It might have happened that some respondents did not play the video, and thus that the distance to the exit was not revealed to them. Some other respondents state they would overtake slower predecessor, but would accept lower speeds when

they were approaching the exit more closely, while 3000 meters is still a far distance.

Scenario 7 - Keep right

This scenario was set-up to get insight in how strict people apply the keep right rule, which in fact is done by 57% of the respondents by indicating they would change one lane to the right as can be seen in figure B.30. About 40% of the respondents state they will continue in this lane and keep their speed constant, while only 1% would also increase their speed. To see if respondents would change one lane to the right because of the keep right rule or the faster driver that was approaching from behind following up questions were shown, of which the results are presented in figures B.31, B.32 and B.33. Again multiple factors can play a role in someone's motivation for a certain action, therefore multiple answers were allowed.

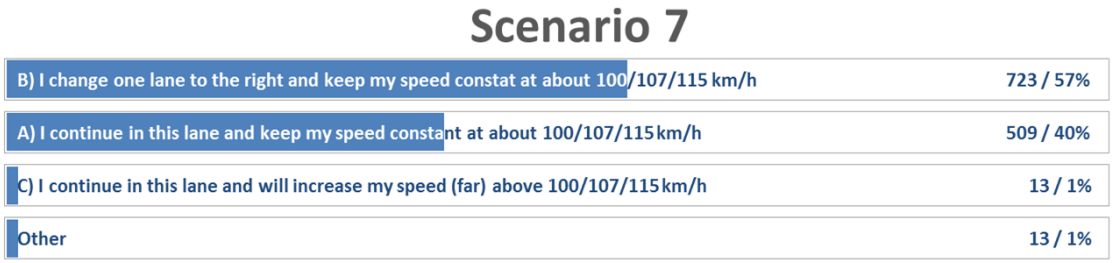


Figure B.30 – Frequency distribution response Scenario 7

The open answers of scenario 7 mostly consisted of respondents who stated that they would go right to allow the faster driver from behind to pass him, after which they would immediately go back. Which is similar with answer B, but gives some more insight in the following up action.

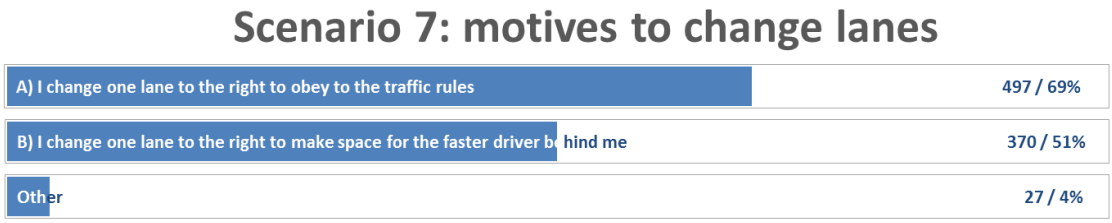


Figure B.31 – Frequency distribution of motives

In figure B.31 the motivation of changing lanes is found. Most participants, 69%, change to the shoulder lane to obey to the keep right rule, while 51% says they make space for the faster driver behind them. As can be seen in table B.4 46% is only changing to the shoulder lane because of the 'keep right' rule and is thus not affected by the other driver, 29% of the respondents changes to the right because of the faster driver and you could assume not of the keep right rule, while 21% of the drivers says to change lanes because of both the keep right rule and the faster driver in the back. If the faster driver was not there, you could then expect that 58% instead of 41% of the total of 1258 respondents would continue in the initial lane, and only 40% instead of 57% would still change to the shoulder lane. 17% of the total sample of drivers is thus influenced by the presence of a faster driver, and determines if they would keep right or not. In the open answers, several people indicated that the distance to the truck is large enough to keep right, while when this gap is smaller they would

not change lanes. One respondent indicated he did not like to be chased by another vehicle.

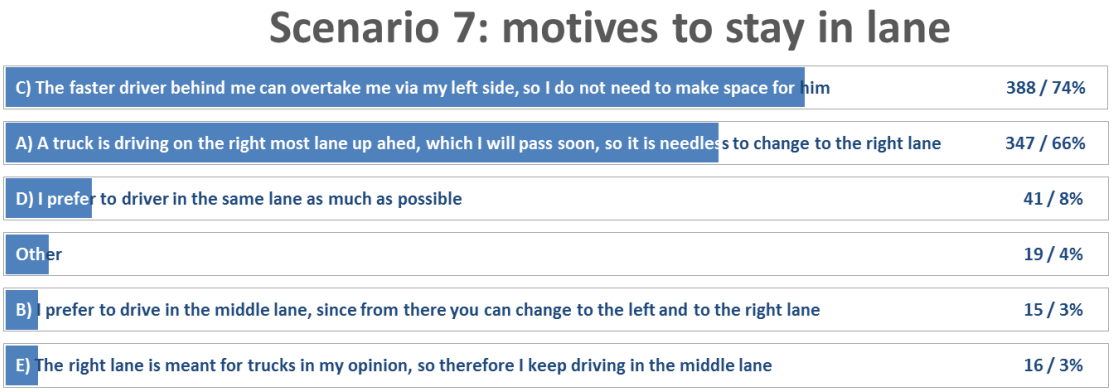


Figure B.32 – Frequency distribution of motives

The respondents that stated they would stay in the initial lane, were also asked to their motives behind their choice, of which the results are presented in figure B.32 and the frequencies of the combinations in table B.5. Most people find it unnecessary to keep right all the time when a slower vehicle drives on the shoulder lane up ahead (74%), or when other vehicles have possibilities to overtake them (66%). Only a few (8%) respondents state they prefer to drive in the same lane as much as possible. In the open answers most respondents indicated that they would not change to the shoulder lane to prevent they got stuck behind the truck. Some respondents stated that they wanted to contribute to calmer traffic by decreasing their number of lane changes.

Figure B.33 – Frequency distribution of motives

Only 15 respondents indicated that they would increase their speed in scenario 7, the motives behind this speed increase are presented in figure B.33. 11 respondents indicated they increase their speed because of other drivers, which is either the driver in the back, the presence of predecessors or the presence of faster drivers. This argumentation is in line with strategy 4 driving behaviour, in which a driver determines it's speed on that of other drivers.

Scenario 8 - Keep right

The response on scenario 8 are presented in figure B.34. This scenario describes a traffic situation in which you are driving on the centre lane while you pass a truck on the shoulder lane and the road in front of you is almost completely empty. 88% of the respondents would after passing the truck change one lane to the right, and thereby obey to the 'keep right' rule. However, about 12% of the

Table B.4 – Combinations of motives to change lanes

Q7 Motives - combination of answers

Combination	Frequency	Percent
a	332	46%
b	209	29%
ab	155	21%
other	16	2%
abother	5	1%
aother	5	1%
bother	1	0%
Total	723	100%

Table B.5 – Combinations of motives to stay in lane

Q7 Motives - combination of answers

Combination	Frequency	Percent
ac	189	36%
c	146	28%
a	107	20%
acd	20	4%
ace	12	2%
other	12	2%
abcd	5	1%
acother	5	1%
ad	5	1%
d	5	1%
b	4	1%
abc	2	0%
bcd	2	0%
cd	2	0%
cother	2	0%
abcde	1	0%
abd	1	0%
bc	1	0%
cde	1	0%
total	522	100,0

Table B.6 – Combinations of motives to increase speed

Q7 Motives - combination of answers

Combination	Frequency	Percent
b	4	31%
a	3	23%
ab	2	15%
c	2	15%
d	2	15%
total	13	100%

respondents indicate they would stay in the centre lane, which corresponds with strategy 3 driving behaviour. Only 2% of the respondents would increase their speed in this scenario. Comparing this results with scenario 7 it seems that more people tend to keep right when there are no vehicles driving on the shoulder lane up ahead.

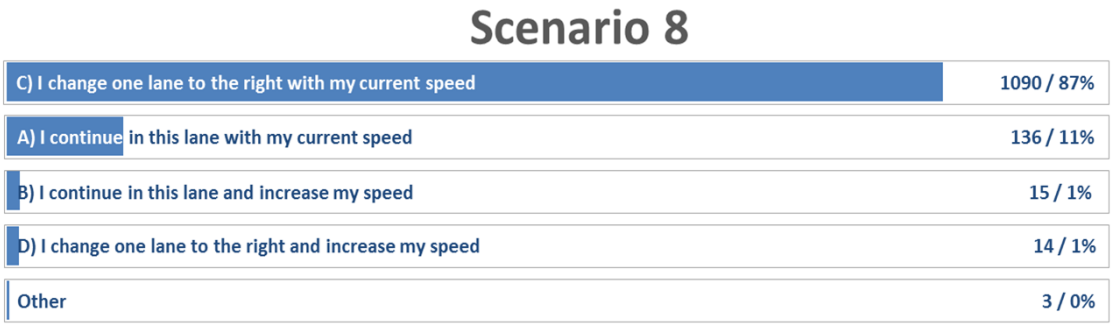


Figure B.34 – Frequency distribution response Scenario 8

Scenario 9 - Strategy 1,2,3

Scenario 9 describes a situation in which you are driving on the shoulder lane, while you are approaching a truck that drives in front of you. At the same time another car is driving behind you on the centre lane. The frequencies of the given answers are presented in figure B.35. Most people, 85%, show strategy 1 driving behaviour, which means the would change lanes to overtake the truck with a constant speed. However, most respondents (70%) indicated they would wait with changing lanes when the car behind them passed, while 15% stated they would change lanes immediately. 11% of the respondents would apply strategy 2 driving behaviour and thus increase their speed during overtaking. Only 3% would stay in the current lane and adjust their speed to the truck in front of them, which is in line with strategy 3 driving behaviour. Scenario 2 also described a situation in which you encountered a slower predecessor, in that case a car in stead of a truck. 12% of the

respondents answered in scenario 2 to drive according to strategy 3 versus 3% in scenario 9. It seems that the speed or type of predecessor has influence whether someone would apply a speed leading strategy or a lane leading strategy.

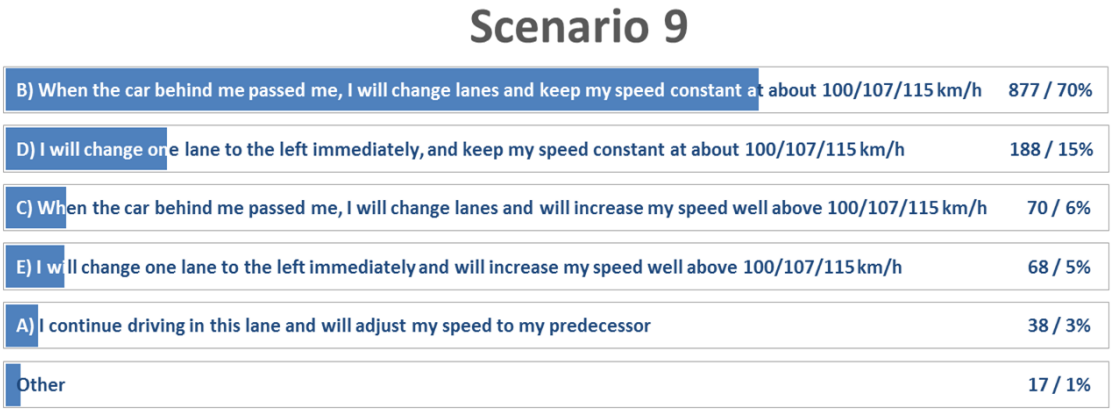


Figure B.35 – Frequency distribution response Scenario 9

Via the open answer option several respondents indicated they would have increased their speed already much earlier than the moment the video stopped. A few respondents state they would use their blinker to indicate they want to change lanes, while they would only change lanes after the driver in the back changed to the median lane.

Scenario 10 - Keep right

The video of the tenth scenario shows a two-lane roadway, on which you are driving on the median lane, while you are passing some trucks that drive on the shoulder lane. After you have passed the trucks there is some space on the right side and a faster driver is approaching you from behind. The frequencies of each answer are found in figure B.36. Most respondents (76%) tend to change one lane to the right with their current speed. About 19% of the respondents indicated they would continue on this lane, which could be seen as strategy 3 driving behaviour, since the traffic rules in the Netherlands tell someone to keep right unless overtaking. This is of course arbitrary when up ahead more vehicles are driving on the shoulder lane. To actually distinguish people that keep right and those who make space for the faster driver behind them following up questions have been set-up to ask the respondents to their motivation.
Again several respondents stated via the open answer option that they would change to the right to let the faster driver pass them and thereafter quickly change back to the median lane to prevent being stuck behind a slower vehicle. Furthermore, some respondents commented that their action in this scenario is influenced by the traffic density. When there are not many vehicles on the road, they would change to the shoulder lane, but if they notice that it is more crowded and they could get stuck on the shoulder lane they would not change lanes and stick to the current lane.
The frequencies of the motives to change lanes are found in figure B.37, while table B.7 presents the frequencies of the combinations of motives. 71% of the respondents that would change lanes in scenario 10 indicate they do that to let the driver behind them pass them. 57% of the lane changers goes to the right to obey to the traffic rules. However, table B.7 shows that 41% of the lane change only goes right to make space. If the faster driver would not be there it seems that these 41% would not change lane. Several respondents mentioned via the open answer option that they get nervous when a faster driver is tailgating them, and thus that they would make space. Some respondents also

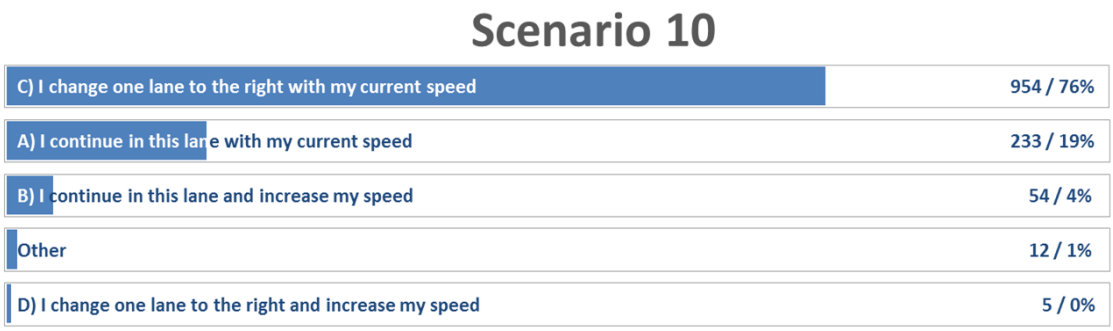


Figure B.36 – Frequency distribution response Scenario 10

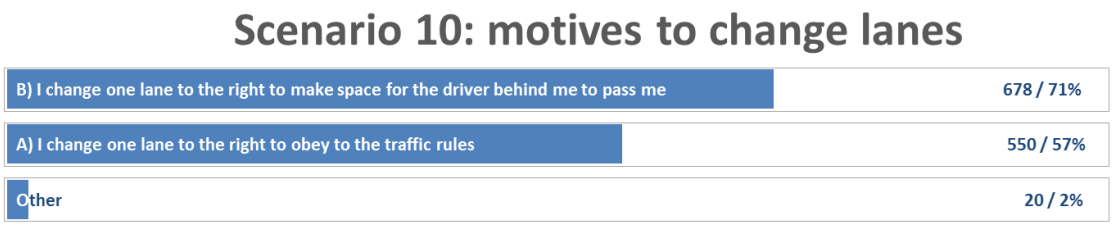


Figure B.37 – Frequency distribution of motives

state they are annoyed by drivers who unnecessary drive on the left side, and thus that they would drive on the shoulder lane as much as possible.

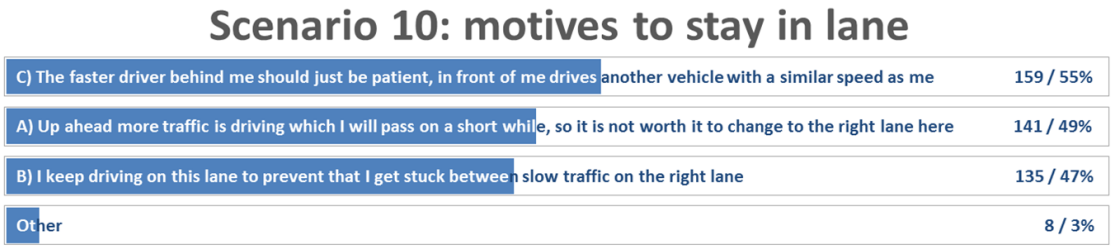


Figure B.38 – Frequency distribution of motives

In figure B.38 the frequencies of motives to stay in the lane are presented, while in table B.8 the frequencies of the combinations are presented. The three pre-defined motives have all a frequency around 50% of the respondents. There is not one motive that stands out, and also in the combinations of motives given by the respondents is quite some variance.

Scenario 11 - Strategy 4

Scenario number 11 related to strategy 4, the traffic leading strategy. The video shows a 3-lane roadway where most other drivers around you drive much fast than you, while you are driving with approximately your preferred speed as indicated in the introduction question. As can be seen in figure B.39 87% of the respondents indicates they do not let their behaviour be influenced by others,

Table B.7 – Combinations of motives to change lanes

Q10 Motives - combination of answers

Combination	Frequency	Percent
b	394	41%
ab	278	29%
a	267	28%
other	13	1%
abother	4	0%
bother	2	0%
aother	1	0%
Total	**959**	**100%**

Table B.8 – Combinations of motives to stay in lane

Q10 Motives - combination of answers

Combination	Frequency	Percent
c	61	21%
a	58	20%
b	49	17%
abc	41	14%
bc	30	10%
ac	25	9%
ab	15	5%
other	6	2%
acother	2	1%
Total	**287**	**100%**

while about 12% of the respondents say they would drive along with the other drivers, and thus drive faster than their own preferred speed which relates to strategy 4.

Figure B.39 – Frequency distribution response Scenario 11

Some respondents state via the open answer option that they partially would drive along with the other drivers, so they would increase their speed a bit, but to a certain limit. A few respondents also commented that this traffic scenario would never occur in the Netherlands. In this case the video was edited so that the displayed speed corresponded with the assumed preferred speed for each branch, so 100 for the 'slow' branch, 107 for the 'average' branch and 115 for the 'fast' branch.

Scenario 12 - Courtesy lane change

The twelfth scenario concerned the cooperation with a vehicle on the on-ramp that had to merge onto the roadway. The video showed you driving on a two-lane motorway on the shoulder lane, while a vehicle was driving on the merging lane. Just like the participants in the driving study most respondents, 72%, state that they would change one lane to the left, of which a few would also increase their speed. 10% of the respondents adjust the speed so the vehicle can merge in front of them onto the main roadway, only 1% state they would increase their speed. About 16% indicate that they would continue in the current lane with their current speed, and thereby not making space for the vehicle on the on-ramp to merge. To get more insight in the motives of someone to not make space for a merging vehicle, those respondents got a follow up question concerning their motives.

Among the open answers are some comments from respondents that they would have changed lanes earlier.

Figure B.41 presents the frequency distribution of the motives for not making space for the vehicle on the on-ramp, while table B.9 gives an overviews of the frequencies per motive combination. About 74% state that the vehicle on the on-ramp should adjust to the vehicles on the main roadway. 27% answer the car did not made clear it wanted to merge or that he did not use it's blinker. 15% of the respondents that would not make space for the vehicle on the on-ramp think that the on-ramp

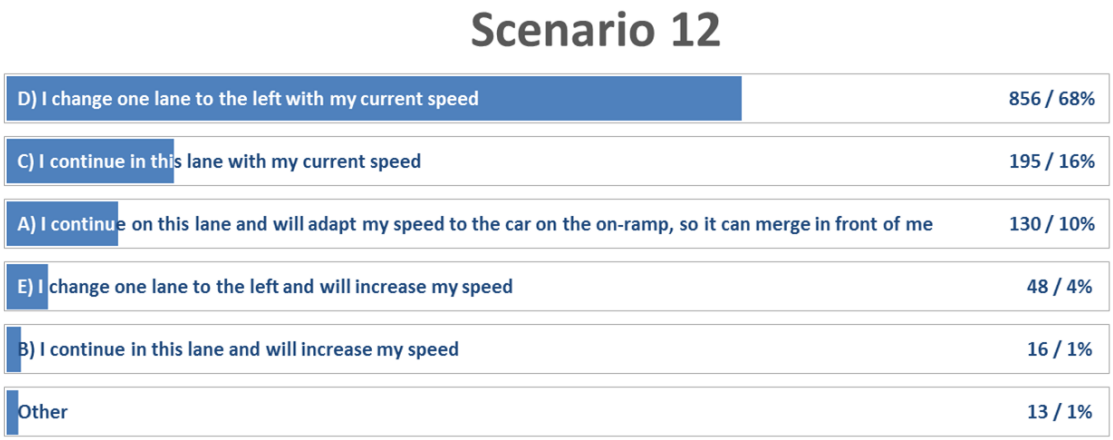


Figure B.40 – Frequency distribution response Scenario 12

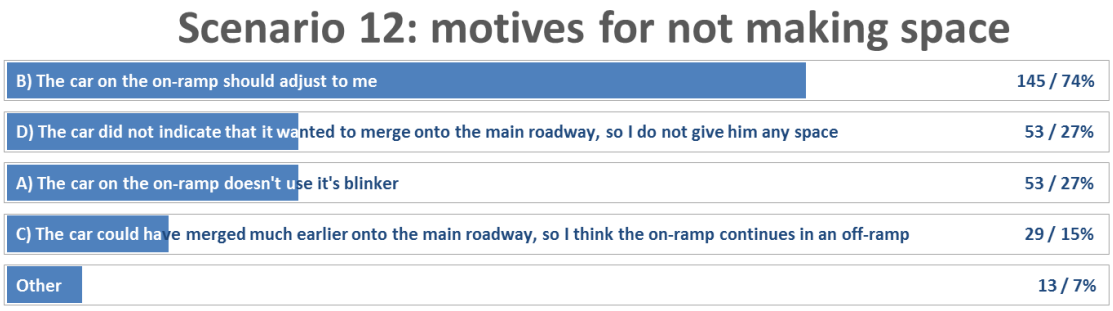


Figure B.41 – Frequency distribution of motives

might continue as an off-ramp. In reality this is not true, but thus some people stated this motive. However, some people stated via the open answer option that there was no necessity to make space for the vehicle on the on-ramp since there was sufficient space to merge. A few argued that by holding a constant speed it is easier for the merging vehicle to predict when and where he could merge onto the roadway.

Scenario 13 - Strategy 1,2,3

Scenario 13 involves the traffic situation that you are approaching an exit you need to take while you are driving on the centre lane. A truck is driving on the shoulder lane in front of you. Figure B.42 shows that 61% would not overtake the truck but will change to the shoulder lane to take the off-ramp up ahead, which corresponds with strategy 3 since they have to adapt their speed to the truck. About 20% indicate that they would overtake the truck with constant speed, which corresponds with strategy 1 driving behaviour. 19% says to overtake the truck while increasing their speed, and thus drive according to strategy 2. The respondents that stated they would change lanes and adapt their speed to the truck are given an additional question to see if familiarity with the road would change their decision.

A respondent mentioned that it was hard to asses if it was possible to overtake the truck with a constant speed in time on basis of the video. It was hard to determine distances and relative speeds

Table B.9 – Combinations of motives for not making space

Q12 Motives - combination of answers		
Combination	Frequency	Percent
b	99	51%
abd	14	7%
d	13	7%
other	11	6%
bd	9	5%
a	8	4%
ab	8	4%
abcd	8	4%
ac	7	4%
acd	3	2%
ad	3	2%
bc	3	2%
c	3	2%
bcd	2	1%
abc	1	1%
acother	1	1%
bother	1	1%
cd	1	1%
Total	195	100%

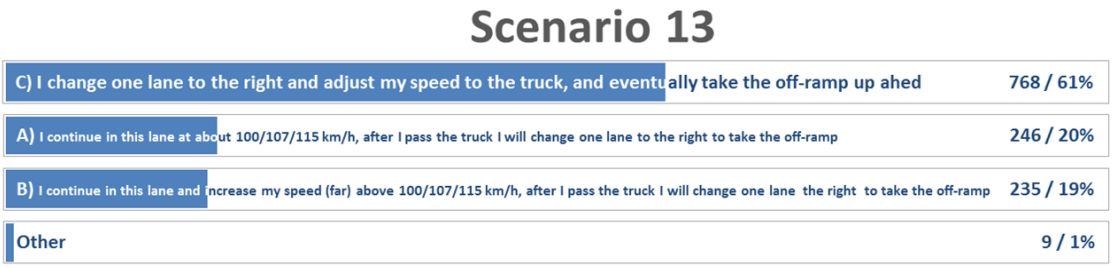


Figure B.42 – Frequency distribution response Scenario 13

from the video. One respondent indicated via the open answers that he would have changed to the shoulder lane much earlier, another respondent state that his action depends on his mood, while a third participant stated that if there was no traffic driving in front of the truck he would have overtaken it.

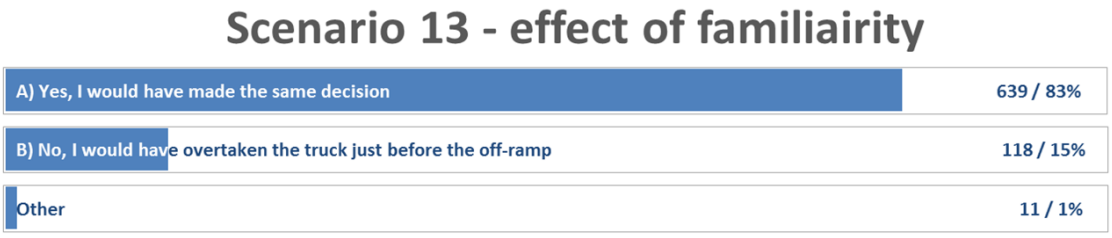


Figure B.43 – Frequency distribution of motives

Figure B.43 presents the answers of the respondents who stated they would change to the right and adapt their speed to the truck. 83% would not change their decision when they assumed to be familiar with this particular off-ramp, whereas 15% stated they would change their decision and overtake the

truck before the off-ramp. Via the open answer option several respondents state they would overtake the truck if they knew that this particular off-ramp has a long length, which is in fact the case for this off-ramp.

Scenario 14 - Keep right

The final traffic situation showed via a picture the A13 that includes a peak-hour lane. You were driving on the third lane from the left, and were passing a truck that drove on the peak-hour lane. In front of the truck was an almost completely empty road. 73% of the respondents indicate they would properly change to the shoulder lane, as the 'keep right' rule insists. On the other hand, 25% of the respondents would stay in the initial lane with their preferred speed, and thus would not keep strictly right, which can be seen as strategy 3 driving behaviour.

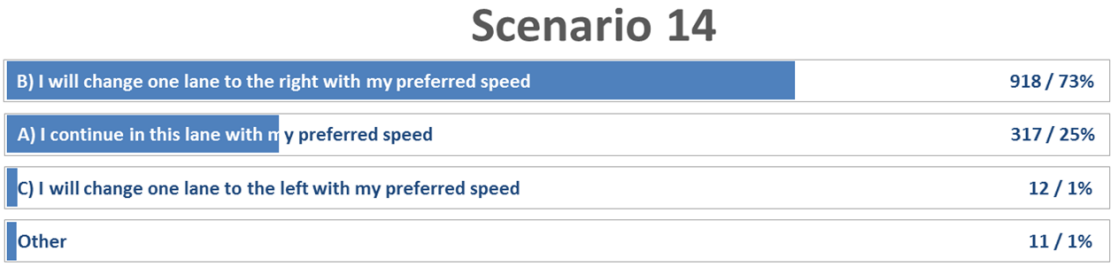


Figure B.44 – Frequency distribution response Scenario 14

B.5 Application of strategies

Table B.10 – Overview of strategy combinations found over 7 scenarios

Number of strategies	Strategies							Number per combination	Number of participants	Percentage of participants
	1	2	3	4	1/2	3/4	3*			
2	x				x			44	50	4%
		x			x			1		
			x		x			4		
			x			x		1		
3	x	x			x			75	482	38%
	x		x		x			275		
	x		x			x		54		
	x			x	x			4		
	x				x	x		26		
	x				x		x	17		
	x					x	x	9		
		x	x		x			19		
		x		x	x			1		
		x			x	x		1		
		x			x		x	1		
4	x	x	x		x			192	522	41%
	x	x	x			x		57		
	x	x		x	x			12		
	x	x			x	x		21		
	x	x			x		x	51		
	x	x				x	x	22		
	x		x	x	x			22		
	x		x	x		x		2		
	x		x		x	x		24		
	x		x		x		x	71		
	x		x			x	x	30		
	x			x	x	x		1		
	x			x	x		x	1		
	x			x		x	x	1		
		x	x	x	x			1		
		x	x	x		x		1		
		x	x		x	x		6		
		x	x			x	x	1		
		x		x	x	x		3		
		x		x		x	x	1		
			x	x		x	x	2		
5	x	x	x	x	x			27	180	14%
	x	x	x	x		x		17		
	x	x	x		x	x		19		
	x	x	x		x		x	55		
	x	x	x			x	x	18		
	x	x		x	x	x		9		
	x	x		x	x		x	19		
	x	x		x		x	x	7		
	x		x	x	x	x		1		
	x		x	x	x		x	4		
		x	x	x	x	x		1		
		x	x	x	x		x	3		
6	x	x	x	x	x	x		2	24	2%
	x	x	x	x	x		x	17		
	x	x	x	x		x	x	5		
Total	1211	665	931	11	1220	336	341	1258	1258	100%
Percentage	96%	53%	74%	13%	82%	27%	27%			

B.6 Sub-group analysis

In this section of the appendix an overview is given of the Chi-square test and Cramer's V test results for different sub-groups, as categorised via the classifications in table B.11. For each scenario these statistical tests have been done to check if there are possible differences in how subgroups responded on the questions.

Table B.11 – Categorization of personal characteristics for the sub-group analysis

Personal characteristic	Categories	Values
Age	Young Adult	17 to 29 years
	Adult	30 to 59 years
	Seniors	60 years and older
Desired speed	Slow	<103 km/h
	Average	103 to 110 km/h
	Fast	>110 km/h
Driving frequency	Infrequent	$\leq$ 2 days per week
	Frequent	$\geq$ 3 days per week
Driving experience	Novice	<10 years driving license
	Experienced	$\geq$ 10 years driving license

The Chi-square test has two conditions that needs to be met. The first condition requires that the no more than 20% of the cells have an expected counted below 5. The second states that each cell of the contingency table has a minimum expected count of at least 1. The contingency tables are not presented in the reported, only the results of the tests performed on those contingency tables. The tables below give an overview of the Chi-square and Cramer's V tests that have been done for each of these contingency tables, which consist on the one hand of one of the four personal characteristics and on the other hand of the responses from one of the 14 scenarios. The overview tables show what percentage of the cells in the contingency table have an expected count below 5, and they show the minimum expected count. Than a column shows if the conditions to apply the chi-square test are met. If the conditions are met, the Chi-square test statistic and the degrees of freedom are presented. The degrees of freedom value is used to lookup the critical value of the chi-square distribution. If the corresponding significance level is smaller than p=0.05 the difference is assumed to be significant, although the error rate is still at least 23%. However, a decreasing p value results in a decreasing error rate. A p value of for example 0.05 indicates that there is a chance of 5% that an as least as big difference can be found by coincidence.

If the Chi-square test showed a significant difference the Cramer's V test statistic is presented, which indicates the size of the difference. The Cramer's V test statistic has a different formulation of the degrees of freedom of the contingency table, so a second degrees of freedom is included in the table. The last column of each table shows the size of the difference between the responses of the several subgroups based on Cramer's V test statistic.

Table B.12 – Results of Chi-square and Cramer's V tests for different age groups

Response on each scenario per subgroup categorized in 3 age groups (without others answers)										
Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	6%	3.29	Yes	92.137	10	29.588 (p<0.001)	Significant	0.192	2	Small
2	25%	2.1	No	-	-	-	-	-	-	-
3	0%	28.16	Yes	27.164	4	18.467 (p<0.001)	Significant	0.119	2	Small
4	0%	64.9	Yes	9.89	2	9.210 (p<0.01)	Significant	0.089	1	None
5	0%	15.77	Yes	55.628	6	22.458 (p<0.001)	Significant	0.151	2	Small
6	0.00%	66.56	Yes	109.757	4	18.467 (p<0.001)	Significant	0.21	2	Medium
7	22.20%	2.51	No	-	-	-	-	-	-	-
8	16.70%	2.71	Yes	32.528	6	22.458 (p<0.001)	Significant	0.114	2	Small
9	0.00%	7.35	Yes	46.411	8	26.125 (p<0.001)	Significant	0.137	2	Small
10	25.00%	0.97	No	-	-	-	-	-	-	-
11	0.00%	30	Yes	25.498	2	13.816 (p<0.001)	Significant	0.143	1	Small
12	6.70%	3.1	Yes	70.068	8	26.125 (p<0.001)	Significant	0.168	2	Small
13	0.00%	45.16	Yes	34.893	4	18.467 (p<0.001)	Significant	0.118	2	Small
14	22.20%	2.33	No	-	-	-	-	-	-	-

Table B.13 – Results of Chi-square and Cramer's V tests for the different speed branches

Response on each scenario per subgroup categorized in 3 desired speed groups (without others answers)										
Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	11%	1.65	Yes	53.824	10	29.588 (p<0.001)	Significant	0.147	2	Small
2	17%	1.07	Yes	31.101	6	22.458 (p<0.001)	Significant	0.112	2	Small
3	0%	13.34	Yes	23.608	4	18.467 (p<0.001)	Significant	0.111	2	Small
4	0%	32.85	Yes	10.293	2	9.210 (p<0.01)	Significant	0.090	1	None
5	0%	8.09	Yes	81.260	6	22.458 (p<0.001)	Significant	0.183	2	Small
6	0%	33.42	Yes	80.394	4	18.467 (p<0.001)	Significant	0.180	2	Small
7	22%	1.25	No	-	-	-	-	-		-
8	25%	1.37	No	-	-	-	-	-		-
9	7%	3.64	Yes	79.588	8	26.125 (p<0.001)	Significant	0.179	2	Small
10	25.00%	0.49	No	-	-	-	-	-		-
11	0.00%	14.94	Yes	61.733	2	13.816 (p<0.001)	Significant	0.223	1	Small
12	13.30%	1.57	Yes	45.609	8	26.125 (p<0.001)	Significant	0.135	2	Small
13	0.00%	22.70	Yes	71.957	4	18.467 (p<0.001)	Significant	0.170	2	Small
14	22.20%	1.16	No	-	-	-	-	-		-

Table B.14 – Results of Chi-square and Cramer's V tests for frequent and infrequent drivers

Response on each scenario per subgroup categorized by driving frequency (without others answers)										
Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	8%	4.18	Yes	5.014	5	-	Not significant	-	-	-
2	13%	2.71	Yes	4.308	3	-	Not significant	-	-	-
3	0%	33.93	Yes	5.562	2	4.605 (p<0.10)	Low significant	0.076	1	None
4	0%	82.53	Yes	5.29	1	5.024 (p<0.025)	Significant	0.065	1	None
5	0%	19.78	Yes	7.763	3	6.251 (p<0.10)	Low significant	0.08	1	None
6	0.00%	83.54	Yes	1.941	2	-	Not significant	-	-	-
7	16.70%	3.18	Yes	18.911	2	13.816 (p<0.001)	Significant	0.123	1	Small
8	25.00%	3.42	No	-	-	-	-	-	-	-
9	0.00%	9.37	Yes	1.324	4	-	Not significant	-	-	-
10	25.00%	1.23	No	-	-	-	-	-	-	-
11	0.00%	38.22	Yes	0.126	1	-	Not significant	-	-	-
12	10.00%	3.95	Yes	3.247	4	-	Not significant	-	-	-
13	0.00%	58.14	Yes	1.495	2	-	Not significant	-	-	-
14	16.70%	2.94	Yes	4.01	2	-	Not significant	-	-	-

Table B.15 – Results of Chi-square and Cramer's V tests for novice and experience drivers

Response on each scenario per subgroup categorized by driving experience (without others answers)										
Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	8%	3.18	Yes	35.533	5	20.515 (p<0.001)	Significant	0.169	1	Small
2	13%	2.05	Yes	18.114	3	16.266 (p<0.001)	Significant	0.12	1	Small
3	0%	27.56	Yes	21.316	2	13.816 (p<0.001)	Significant	0.149	1	Small
4	0%	63.03	Yes	3.24	1	2.706 (p<0.10)	Low significant	0.051	1	None
5	0%	15.17	Yes	11.069	3	9.348 (p<0.025)	Significant	0.096	1	None
6	0.00%	64.09	Yes	23.535	2	13.816 (p<0.001)	Significant	0.137	1	Small
7	16.70%	2.43	Yes	16.814	2	13.816 (p<0.001)	Significant	0.116	1	Small
8	25.00%	2.63	No	-	-	-	-	-	-	-
9	0.00%	7.13	Yes	18.164	4	13.277 (p<0.01)	Significant	0.121	1	Small
10	25.00%	0.94	No	-	-	-	-	-	-	-
11	0.00%	29.01	Yes	15.681	1	10.828 (p<0.001)	Significant	0.112	1	Small
12	10.00%	2.99	Yes	23.833	4	18.467 (p<0.001)	Significant	0.138	1	Small
13	0.00%	44.22	Yes	14.346	2	13.816 (p<0.001)	Significant	0.107	1	Small
14	16.70%	2.24	Yes	5.687	2	4.605 (p<0.10)	Low significant	0.068	1	None

B.7 International comparison

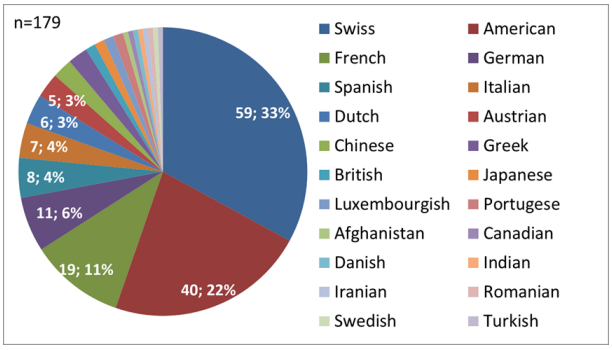


Figure B.45 – Nationality of respondents from international survey

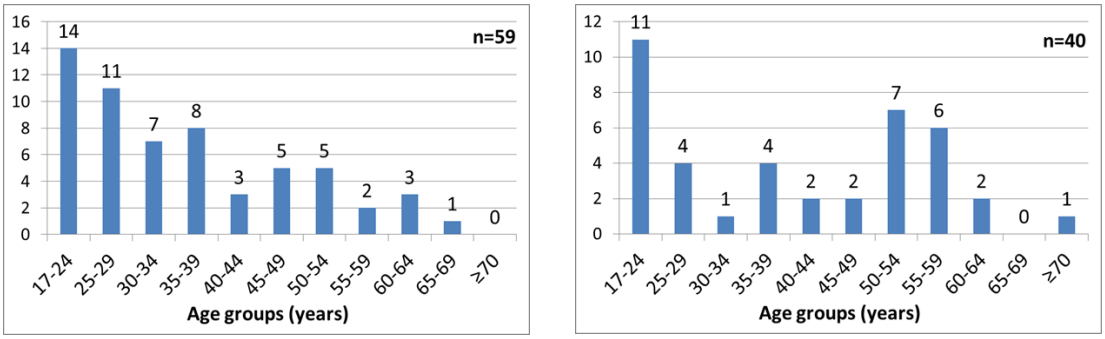


Figure B.46 – Age of Swiss (left) and American (right) respondents

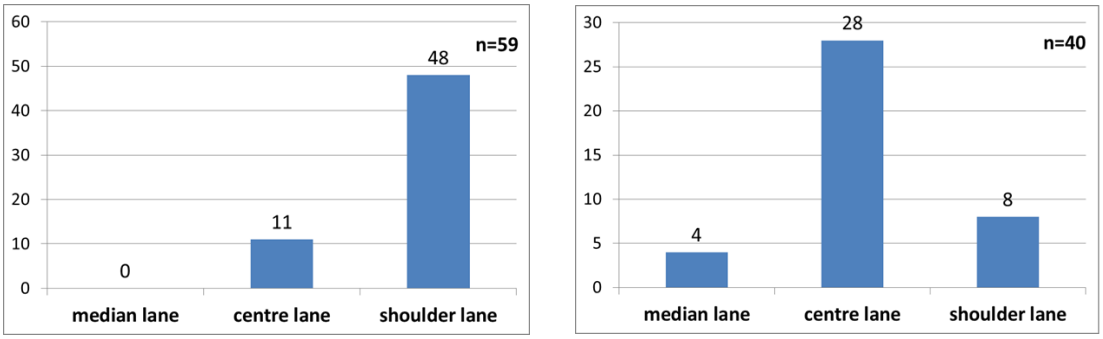


Figure B.47 – Lane choice of Swiss (left) and American (right) respondents

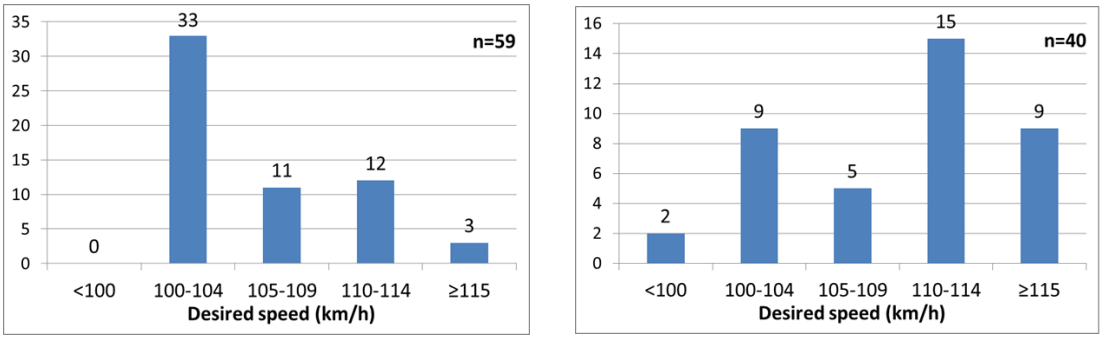


Figure B.48 – Speed choice of Swiss (left) and American (right) respondents

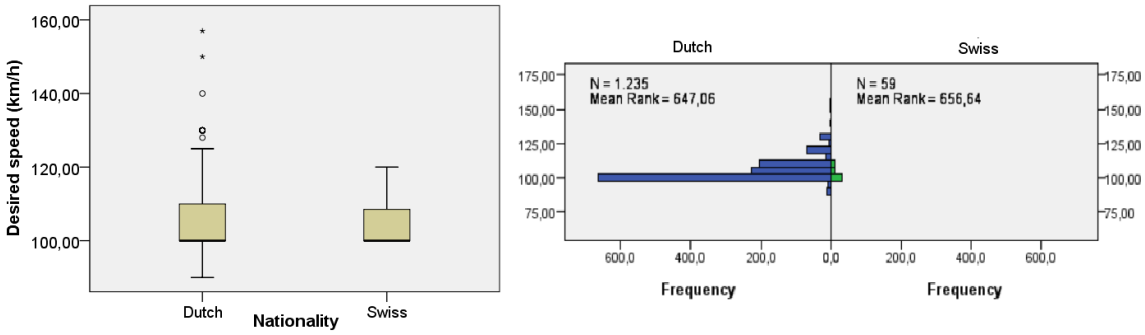


Figure B.49 – Graphs to compare the desired speed distributions of Dutch and Swiss respondents

Table B.16 – Chi-square test results of comparison of responses by Dutch and Swiss

Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	25%	0.73	No	-	-	-	-	-	-	-
2	13%	0.5	No	-	-	-	-	-	-	-
3	0%	6.45	Yes	10.591	2	9.210 (p<0.01)	Significant	0.103	1	Small
4	0%	15.38	Yes	8.106	1	6.635 (p<0.01)	Significant	0.079	1	Negligible
5	13%	3.75	Yes	13.343	3	11.345 (p<0.01)	Significant	0.103	1	Small
6	0.00%	16.09	Yes	1.45	2	-	Not significant	-	-	-
7	16.70%	0.59	No	-	-	-	-	-	-	-
8	25.00%	0.67	No	-	-	-	-	-	-	-
9	30.00%	1.85	No	-	-	-	-	-	-	-
10	37.50%	0.22	No	-	-	-	-	-	-	-
11	0.00%	7.01	Yes	0	0	-	Not significant	-	-	-
12	20.00%	0.76	No	-	-	-	-	-	-	-
13	0.00%	10.8	Yes	14.516	2	13.816 (p<0.001)	Significant	0.106	1	Small
14	16.70%	0.73	No	-	-	-	-	-	-	-

Table B.17 – Chi-square test results of comparison of aggregated responses by Dutch and Swiss

Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	0%	11.75	Yes	9.625	2	9.210 (p<0.01)	Significant	0.086	1	Negligible
2	-	-	-	-	-	-	-	-	-	-
3	0%	18.91	Yes	4.630	1	3.841 (p<0.05)	Significant	0.068	1	Negligible
4	-	-	-	-	-	-	-	-	-	-
5	0%	8.93	Yes	11.252	2	9.210 (p<0.01)	Significant	0.095	1	Negligible
6	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-
8	25%	0.67	No							
9	17%	1.85	Yes	5.971	2	4.605 (p<0.10)	Low significant	0.068	1	Negligible
10	0.00%	13.84	Yes	12.383	1	10.828 (p<0.001)	Significant	0.098	1	Negligible
11	-	-	-	-	-	-	-	-	-	-
12	0.00%	8.72	Yes	4.627	1	3.841 (p<0.05)	Significant	0.06	1	Negligible
13	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-

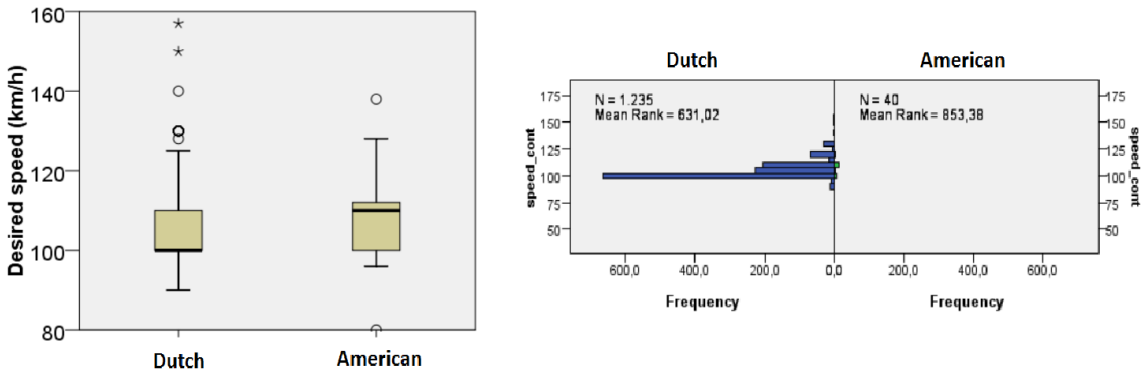


Figure B.50 – Graphs to compare the desired speed distributions of American and Dutch respondents

Table B.18 – Chi-square test results of comparison of responses by Dutch and American

Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	25%	0.61	No	-	-	-	-	-	-	-
2	38%	1.37	No	-	-	-	-	-	-	-
3	17%	4.65	Yes	9.787	2	9.210 (p<0.01)	Significant	0.1	1	Small
4	0%	11	Yes	0.000	1	-	Not significant	-	-	-
5	13%	2.58	Yes	41.605	3	16.266 (p<0.001)	Significant	0.184	1	Small
6	0%	10.75	Yes	6.155	2	5.991 (p<0.05)	Significant	0.07	1	Negligible
7	17%	0.4	No	-	-	-	-	-	-	-
8	25%	0.45	No	-	-	-	-	-	-	-
9	30%	1.29	No	-	-	-	-	-	-	-
10	25%	0.23	No	-	-	-	-	-	-	-
11	0%	5.19	Yes	50.357	1	10.828 (p<0.001)	Significant	0.199	1	Small
12	30%	0.58	No	-	-	-	-	-	-	-
13	0%	7.74	Yes	5.529	2	4.605 (p<0.10)	Low significant	0.066	1	Negligible
14	17%	0.57	No	-	-	-	-	-	-	-

Table B.19 – Chi-square test results of comparison of aggregated responses by Dutch and American

Sc.	Conditions Chi-Square			Chi-Square				Cramer's V		
	Exp. counts <5	Min. exp. count	Cond. met?	χ^2	df	Critical value (significance level)	Association	Test statistic	df*	Association
1	0%	9.11	Yes	70.327	2	13.816 (p<0.001)	Significant	0.235	1	Moderate
2	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-
5	0%	5.85	Yes	3.664	1	2.706 (p<0.10)	Low significant	0.054	1	Negligible
6	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-
8	0%	5.72	Yes	113.740	1	10.828 (p<0.001)	Significant	0.298	1	Moderate
9	33%	1.29	No	-	-	-	-	-	-	-
10	0%	9.72	Yes	12.003	1	10.828 (p<0.001)	Significant	0.097	1	Negligible
11	-	-	-	-	-	-	-	-	-	-
12	0%	6.31	Yes	0.333	1	-	Not significant	-	-	-
13	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-

B.8 Lane keeping system

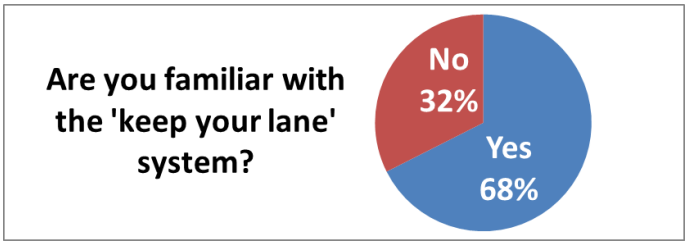


Figure B.51 – Familiarity of respondents with the 'Keep your lane' question

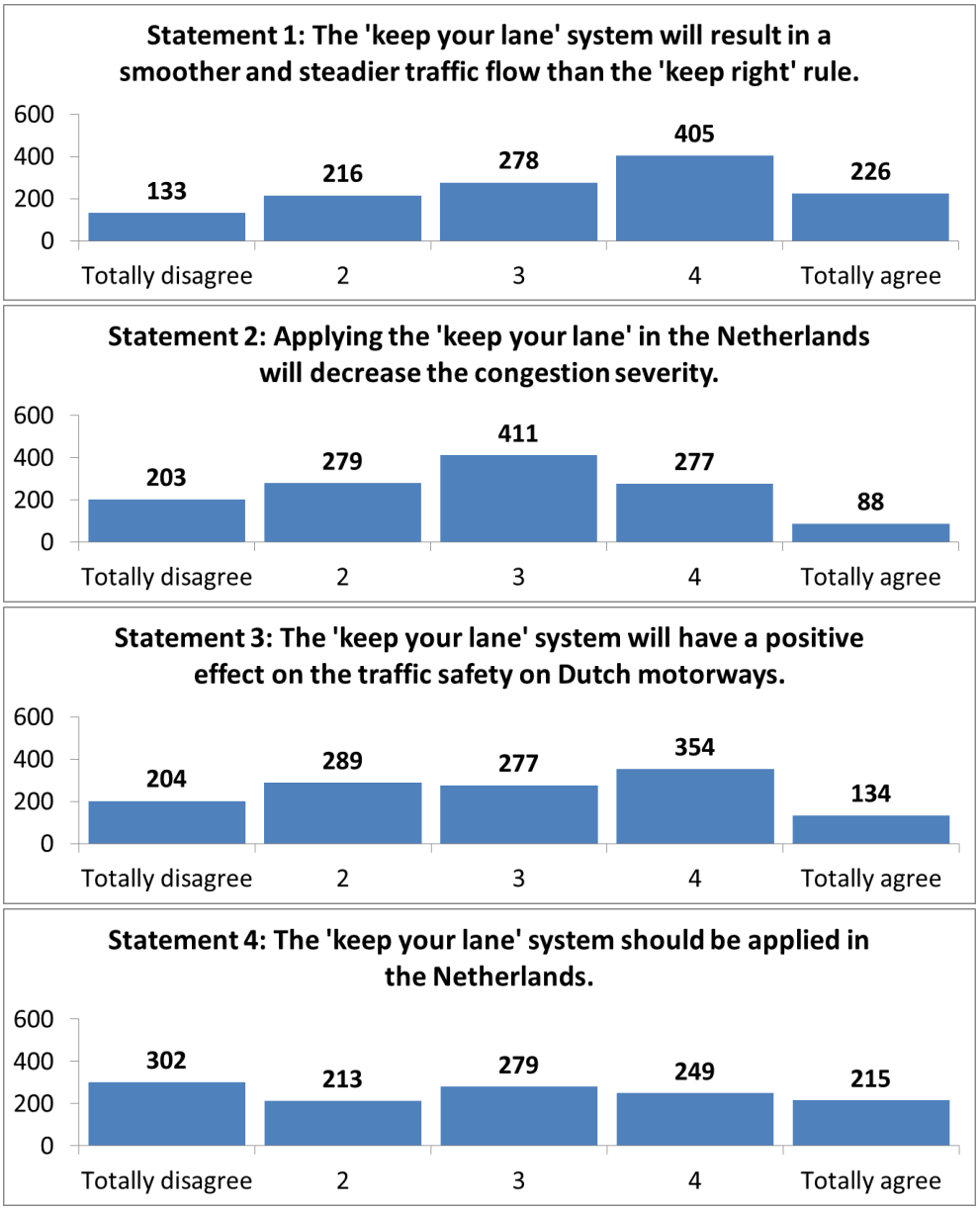


Figure B.52 – Responses on statements concerning the 'Keep your lane' system

B.9 Scenario overview

Sc.	Theme	Description	Last frame of video
1	Right overtaking	You are driving in a tunnel on a 4 lane motorway on the third lane from the left. A truck is driving up ahead on the shoulder lane and a person car is driving in the second lane from the left while there is space for that driver to keep right on the third lane from the left. You are getting closer to the person car.	
2	Strategy 1,2,3	You are driving on a 3 lane motorway on the shoulder lane. A slightly slower predecessor is driving in front of you, which you are approaching, while a black car just passed you with high speed.	
3	Strategy 1,2,3	This scenario is only shown to the respondents who answered to overtake the vehicle with a constant speed. The white car you decided to overtake increases its speed a bit, which makes that you pass the white vehicle very slowly.	
4	Strategy 1,2,3	You are driving on a two lane motorway during congestion on the median lane. You are driving in a stop-and-go wave, while traffic on the shoulder lane drives smoother and with a higher speed.	
5	Right overtaking	You just entered the motorway via an on-ramp, while on one lane to the left a black car is driving with a low speed. You need to proceed on this roadway to follow your route.	
6	Strategy 1,2,3	You merge onto the main roadway from an on-ramp, while you need to take the second exit from that point which is 3100 metres up ahead to continue your route.	
7	Keep right/Strategy 4	You are driving on a three lane motorway in the centre lane while passing a truck on the shoulder lane. There is space to change one lane to the right after you passed the truck, while a faster driver is approaching you from behind.	

Sc.	Theme	Description	Last frame of video
8	Keep right	You are driving on a three lane motorway in the centre lane, while passing two trucks on the shoulder lane. After you have passed the trucks there is an empty road in front of you.	
9	Strategy 1,2,3	You are driving on a three lane motorway on the shoulder lane. A truck is driving in front of you on the same lane, while a faster driver is approaching you from the back on the centre lane.	
10	Keep right	You are driving on a two lane motorway on the median lane, while you pass a truck that is driving on the shoulder lane. Up ahead another truck is driving, while a faster driver is approaching you from behind.	
11	Strategy 4	You are driving on a three lane motorway on the shoulder lane with a speed of 100 km/h. However, all other vehicles around you drive much faster and you are overtaken by them.	
12	Courtesy lane change	You are driving on a two lane motorway on the shoulder lane, while you approach a merging lane on which a vehicle is driving. However, the driver is not using its blinker.	
13	Strategy 1,2,3	You are driving on a three lane motorway in the centre lane. To follow your route you have to take the exit that starts at 600 metres from the moment the video stops. On that moment a truck is driving up ahead on the shoulder lane.	
14	Keep right	You are driving on a three lane motorway on the shoulder lane. This road section contains a peak hour lane which is currently opened for traffic. You will pass the truck that drives on the peak hour lane.