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Maura Houtenbos **Expecting the unexpected**

TRAIL

thesis series

Maura Houtenbos

Expecting the unexpected

A study of interactive driving behaviour at intersections

Stellingen behorende bij het proefschrift

"Expecting the unexpected:
a study of interactive driving behaviour at intersections"

Maura Houtenbos, 8 januari 2008

I. De beschikbare tijdruimte voor het afwikkelen van een interactiesituatie bepaalt voor een groot deel of men in staat is adequaat te reageren op een onverwachte gebeurtenis.

II. Door het koppelen van rijsimulatoren wordt een nieuw onderzoeksveld geopend dat ons in staat stelt de nuances van interactiegedrag beter te begrijpen.

III. Gezien het hoge aantal ontmoetingen in het verkeer en het lage aantal ongevallen waarin deze resulteert kan geconcludeerd worden dat de mens goed is in het veilig interacteren.

IV. De sleutel tot een succesvol ondersteunend systeem voor bestuurders van een voertuig is het bepalen in welke situaties ondersteuning daadwerkelijk nodig is en wanneer bestuurders het prima alleen afkunnen.

V. Men heeft vaak een onverwachte gebeurtenis nodig om zich bewust te worden van de oorspronkelijke verwachting.

VI. Het blootstellen van proefpersonen aan een ervaring waarvan men weet dat de proefpersonen er onwel van kunnen worden neigt naar het onethische.

VII. De sleutel tot controle is het vermogen belangrijke aspecten van de omgeving te kunnen volgen of er zelfs op te kunnen anticiperen. Daarom is elk brein, in essentie, een anticipatiemachine (Dennet, 1991).

VIII. Gebrek aan ervaring met de verschillen in optrekeigenschappen van een diesel- en een benzineauto kan resulteren in onveilige situaties, met name op kruispunten.

IX. Bill Gates is verantwoordelijk voor meer vertraging bij de afronding van het proefschrift dan het ontcijferen en verwerken van de commentaren van de promotor.

X. Tijdens literatuuronderzoek zal menig promovendus kenmerken van Roodkapje vertonen. Huppelend van het ene artikel naar het andere artikel, merken promovendi zich opeens diep in het bos van literatuur te bevinden en komen vervolgens later aan bij Oma dan gepland.

Deze stellingen worden opponeerbaar en verdedigbaar geacht en zijn als zodanig goedgekeurd door de promotoren prof.dr. A.R. Hale en prof.dr.ir. P.A. Wieringa.

Propositions pertaining to the dissertation

"Expecting the unexpected:
a study of interactive driving behaviour at intersections"

Maura Houtenbos, January 8, 2008

I. The available space-time to negotiate an interaction situation largely determines whether one will be able to react adequately to an unexpected event.

II. Using linked driving simulators opens up a whole new research field allowing us to better understand the nuances of interaction behaviour.

III. Given the high number of encounters in traffic and the low number of accidents in which these result, we can conclude that people are good at interacting safely.

IV. The key to a successful advanced driver assistance system is determining in which situations drivers actually need assistance and in which drivers are fine on their own.

V. It often needs an unexpected event to make one aware of one's initial expectation.

VI. Knowingly exposing participants to an experience that could cause them to feel sick is on the verge of the unethical.

VII. The key to control is the ability to track or even anticipate the important features of the environment, so all brains are, in essence, anticipation machines (Dennet, 1991).

VIII. Lack of experience with the difference in acceleration qualities between diesel- and petrol-driven cars can result in unsafe situations, particularly at intersections.

IX. Bill Gates is responsible for more delay in finalising the PhD thesis than figuring out and processing the supervisor's comments.

X. During literature research, many a PhD student will resemble Little Red Riding Hood. Hopping from one article to the next, PhD students will suddenly discover that they are deep in the forest of literature, and therefore arrive at Grandma's house later than planned.

These propositions are considered to be opposable and defendable and as such have been approved by the supervisors prof.dr. A.R. Hale en prof.dr.ir. P.A. Wieringa.

Expecting the unexpected

A study of interactive driving behaviour at intersections

Maura Houtenbos

Expecting the unexpected

A study of interactive driving behaviour at intersections

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.dr.ir. J.T. Fokkema
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op dinsdag 8 januari 2008 om 12:30 uur

door

Maura HOUTENBOS

doctorandus in de psychologie
geboren te Seria, Brunei

Dit proefschrift is goedgekeurd door de promotoren:
Prof. dr. A.R. Hale
Prof. dr. ir. P.A. Wieringa

Samenstelling Promotiecommissie:

Rector Magnificus	Voorzitter
Prof. dr. A.R. Hale	Technische Universiteit Delft, promotor
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Prof. dr. K.A. Brookhuis	Technische Universiteit Delft
Dr. M.P. Hagenzieker	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam

Dr. M.P. Hagenzieker heeft als begeleider in belangrijke mate aan de totstandkoming van het proefschrift bijgedragen.

Dit proefschrift is het resultaat van onderzoek tussen 2002 en 2007 uitgevoerd bij Technische Universiteit Delft, Faculteit Techniek Bestuur en Management, Veiligheidskunde en bij Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV. Het onderzoek maakte deel uit van het BAMADAS (Behavioural Analysis and Modelling for the Design and Implementation of Advanced Driver Assistance Systems) onderzoeksprogramma gefinancierd door NWO en Connekt. Dit proefschrift is mede tot stand gekomen met steun van Sectie Veiligheidskunde, TBM.

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Preface

Both Delft University of Technology (Faculties Technology, Policy and Management & Mechanical, Maritime and Materials Engineering) and SWOV Institute for Road Safety Research provided me with a pleasant and rich environment in which the research presented in this thesis could be conducted, for which I am quite grateful. The staff at both institutes proved to be indispensable, particularly in preparing the online studies. The people at Green Dino Virtual Realities I would like to thank for providing me with the opportunity to experiment with two linked driving simulators, which has been a quite a unique experience.

Having affiliations with different faculties as well as with a research institute definitely proved to be advantageous during the analysis of the results. I would like to thank Saskia, Jacques, Jolieke and Frank for their expert advice concerning statistical matters. You have been my guru's! Joost de Winter deserves to be mentioned separately, as I really wouldn't have known where to start without his enormous amount of help ploughing through the initial mount of data. Thanks a million!

Furthermore, I would like to thank everyone who participated in the studies and experiments which provided me with the interesting data this thesis is based on. Without these participants, this thesis would not exist! I would also like to thank the interns who have helped me during the different studies and experiments, particularly Bart Schulte and Riny van Melzen.

I would also like to mention the people at TNO Human Factors, department of Skilled Behaviour, who provided me with a warm welcome into the world of applied traffic psychology during the final phase of my psychology studies. Rino, Marika and others: thanks for a great internship and putting me on the path to PhD research.

My fellow PhD-students within BAMADAS and AIDA I would like to thank for the wonderful discussions, constructive feedback, pep talks and their lovely company at conferences. Geertje, Nina and Cornelie, it has been great experiencing the PhD adventure with you! My ex-colleagues at the Safety Science section I would also like to thank for the many discussions, and of course for the fun and games after work. My colleagues (and ex-colleagues) at SWOV are thanked for continually showing their interest in my research or simply in me and for the hallway and lunchtime discussions with often dubious subjects. Jolieke, Saskia, Sjoerd, Ragnhild, Nicole, Peter, Martijn and everyone I forgot, thanks! Jolieke, Saskia and Sjoerd, I look forward to continuing our fun traditions we have developed over the years!

Jolieke Mesken and Geertje Hegeman have been my sparring partners at SWOV and Delft during my life as a PhD student and I am happy that you have agreed to stand by me in the final hours!

I am also in debt to the four people who have supervised the development of this thesis. Tom Heijer, thank you for your enthusiasm and your positive, “can do” mentality. Marjan Hagenzieker, thank you so much for your constructive feedback and clever suggestions, which never failed to rekindle my motivation. Particularly when the going got rough you were able to reassure me which definitely helped me get to the finish line. Peter Wieringa, I would particularly like to thank you for bringing me in contact with so many people who have helped this research, even across the Dutch borders! And Andrew Hale, thank you for the way you committed yourself to supervising this thesis, always being available for questions or concrete advice and being able to identify the obstacles that needed to be tackled before completing the thesis with such apparent ease. I realise I have been quite lucky to have you as my promotor!

Not as involved with respect to the content of this thesis, but more so with respect to the consequences it has had for my social life, I would like to thank my friends and family, including my (unofficial) in-laws, for showing their interest but also for having been so supportive (and quite patient), especially throughout the final year. To all the friends I have accumulated over the years at the Santhorst, Rijnlands, Vrije Hogeschool, Vrije Universiteit and Partitus: thank you for your friendship! Fanja ⊘, I have especially loved being friends with you since we were just giggling girls… let’s continue until we’re giggling grannies! Bram, although you’ve grown taller than me, you’ll always be my little brother. Good luck with your Masters in Bath! Dear mom and dad (I’ll keep it decent), thanks for your support and advice, not only concerning my thesis but especially concerning all the big and little things in life. I hope I made you proud.. you deserve to be! Finally, the sentences I know many people enjoy reading in other people’s theses (at least I do!). Dear Caspar, thank you for being you, being there (even though you left me for Japan, you B. 😉), being patient, being able to calm me, reassure me, help me, laugh with me (and at me). I’m grateful to have you in my life! You definitely deserve a HPK!

Table of Contents

1. Introduction

1.1. Background

During the last century traffic has increased dramatically. Following this increase, problems involved with traffic have changed accordingly. For example, as driving speeds increased, consequences of traffic accidents became more severe. Traffic safety has become an important and socially relevant topic, especially as the amount of road users is still increasing.

However, it is remarkable that, with so many interactions in traffic, so few accidents actually occur, considering the limited communication possibilities between road users, particularly when they are in a car. Besides these communication limitations, other aspects contribute to the complexity of interactions in traffic. As Chauvin and Saad (2000) point out, the amount of experience of road users may differ, as may their goals, knowledge and strategies. They mention a number of measures in driving situations that support and organise interactions. First of all, the infrastructure and formal rules play an important role in organising the way in which interactions will develop. Also, means of communication such as the use of indicator, headlights and horn are mentioned by Chauvin and Saad. We could also add changes in approach-speed, gestures and eye contact to the list of means of communication.

Accidents are frequently attributed to behaviour of the road users involved, which is often seen as deviating from some normative behaviour (Brookhuis, de Waard, & Janssen, 2001). From this point of view, it is often assumed that the accident could only have been prevented by this same road user not exhibiting this behaviour. An aspect which is often neglected is that the accident could also have been prevented by the other road users involved performing some kind of behaviour which compensates for the behaviour of the first road user. As 'deviating behaviour' occurs much more frequently than accidents, it could imply that this compensation mechanism must be quite robust. One should ask oneself when a particular action should actually be considered a 'deviating behaviour', as these are often compensated for so smoothly that they are hard to recognise as deviating. Also, there is no easily definable boundary of 'normal' or 'correct' behaviour, especially if we take into account that normative traffic rules are often open to interpretation and even require interpretation in order to make them applicable to the diversity of situations met in practice. So far, a detailed understanding of this compensatory mechanism has not yet been achieved.

Most of the research on traffic behaviour has focused on the individual road user, despite the fact that road users rarely encounter traffic situations in which they are not confronted with other road users. Most models of the driving task represent the driving task from the perspective of one individual road user. For example, the models Michon (1985) discusses in an overview article on driver behaviour models primarily take only one active road user into account. Up until now, models of driving behaviour which focus on the interaction between road users and their impact on each other are still not found.

Take, for example, an intersection with two road users approaching each other from different directions. In this case, direct verbal communication with each other is not possible. Despite this, situations like these rarely develop into an accident. Michon (1985) points out that the interactions between road users are mediated by distinctive and frequently subtle cues. In the past, attempts to describe the relations between such cues and the road user's behaviour have been made, which have often taken the form of ethological models (Bliersbach & Dellen, 1980; Shor, 1964; van der Molen, 1983). In these models an attempt is made to determine specific behaviour, which elicits stimulus configurations. Unfortunately, as the focus is on the observable interaction situation, these models have not been able to describe the information processing of road users in interaction situations, which can be considered to drive the overt behaviour (e.g., paying attention to stimuli, interpreting them and deciding how to respond).

In interactions with other car drivers at an intersection, time is usually limited. Therefore, car drivers need to anticipate the upcoming interaction situation by developing adequate ideas about what is about to happen in the near future to be able to cross the intersection in the most safe and efficient manner. The main assumption on which this thesis research was based, states that these ideas, which are essentially expectancies, play an important role in interaction situations in traffic. Therefore, the concept of expectancy takes a central role in this thesis.

1.2. Significance for Advanced Driver Assistance Systems (ADAS)

Development of ADA Systems has increased in recent years. Harbluk, Noy, and Matthews (1999) mention three factors that have contributed to the increase in on-board ADAS. First of all, technological advances have enabled the integration of information and communication systems within cars. Second, the rapid increase in traffic intensity has made the driving environment more demanding. Thirdly, they mention the increased demand of traffic participants to maximise driving efficiency and productivity of driving time through the use of in-vehicle technology.

Specific knowledge about the effects of these technological advances on driving behaviour is still lacking. However, this knowledge is essential to address the safety aspect of the new driving task (due to ADAS), which is often neglected. The HASTE project, which focused on In Vehicle Information Systems, noticed that methodologies to assess safety implications of these systems are still lacking (Carsten & Brookhuis, 2005). Harbluk et al. (1999) remark that ADAS could result in fundamental changes in the nature of driving with possible adverse effects. The technology driven engineering approach (often employed in the development of ADAS) can take the human out of the loop (Wieringa & Stassen, 1999), changing the nature of the driving task towards a more supervisory level of control. Noy (1999) also stresses the need to evaluate the impact of new technologies on transportation safety prior to their implementation or commercialisation. According to Noy, an important risk of ADAS is behavioural adaptation, which is defined as a change in behaviour that occurs in response to a change in technology, but which was not intended by the designer (OECD Scientific Expert Group, 1990).

Current ADAS concepts have mostly neglected the interaction aspect of the driving task, which may lead to unexpected driver behaviour and to unforeseen and dangerous responses by surrounding road users. Chauvin and Saad (2000) also stress the importance of investigating the potential impact of new support systems being developed in car driving. As these systems are expected to have a special impact on driver behaviour in terms of for example, the speed driven and/or the safety margins adopted in car-following situations, they will change drivers' behaviour and may thus alter the way they usually interact with other road users. To be able to make any predictions about the impact of ADAS on driving behaviour at intersections, a deeper insight into interaction behaviour in traffic is needed to provide more extensive and safer design and use criteria.

1.3. Research questions

The main objective of this thesis is to achieve an understanding of the interaction process between road users. Expectancy seems to be a key concept in understanding interaction behaviour and has therefore been the focus of the research carried out for this thesis.

To accomplish this objective, the following research questions will be studied throughout this thesis:

- What is the role of expectancy in interaction behaviour at intersections?
- What is the influence of expectancy on traffic safety at intersections?
- What are the implications of human interaction behaviour for ADAS?

1.4. Restrictions

As the main objective of this thesis concerns a rather broad field of research, a number of restrictions were applied. The research discussed in this thesis has been limited to interactions between car drivers at urban intersections, due to practical considerations. The focus has been on urban intersections as the amount of encounters at urban intersections is assumed to be higher than at intersections in rural areas. Also, the great variety of road users (e.g. pedestrians, cyclists, car drivers) has been restricted to a subset of this large group, namely car drivers. This choice was made with driving simulator experiments in mind. Behaviour of other road users (e.g. pedestrians and cyclists) is not yet very well represented in these simulators. This thesis will also discuss the potential impact of ADAS on the interaction process. As ADAS will mostly affect the behaviour of this particular subset of road users, this also justifies the restriction to car drivers.

1.5. Outline of the thesis

The general outline of this thesis is schematically represented in Figure 1.1. The first part of the thesis, consisting of Chapters 1, 2 and 3 provides an introduction to the rest of the thesis. In Chapter 2 a theoretical framework will be presented. The key concept of this thesis, "expectancy", will be introduced and research relevant to this concept is discussed. Also, several categories of driving behaviour models found in literature will be discussed in the context of interaction behaviour. In Chapter 3, the various methods applied in this thesis research, ranging from an explorative to an experimental approach, will be discussed in greater detail.

In the second part of the thesis, consisting of Chapters 4, 5 and 6, the research carried out during this PhD project is presented and discussed. In Chapter 4 the research conducted in the explorative phase is presented, whilst in Chapter 5 and 6 the research conducted in the subsequent experimental phase using two linked driving-simulators is discussed.

In the final part and chapter of this thesis the results will be discussed in line with the abovementioned research questions. Chapter 7 provides an overview of the key findings and discusses them within the theoretical framework presented in Chapter 2. Implications of the results will also be discussed.

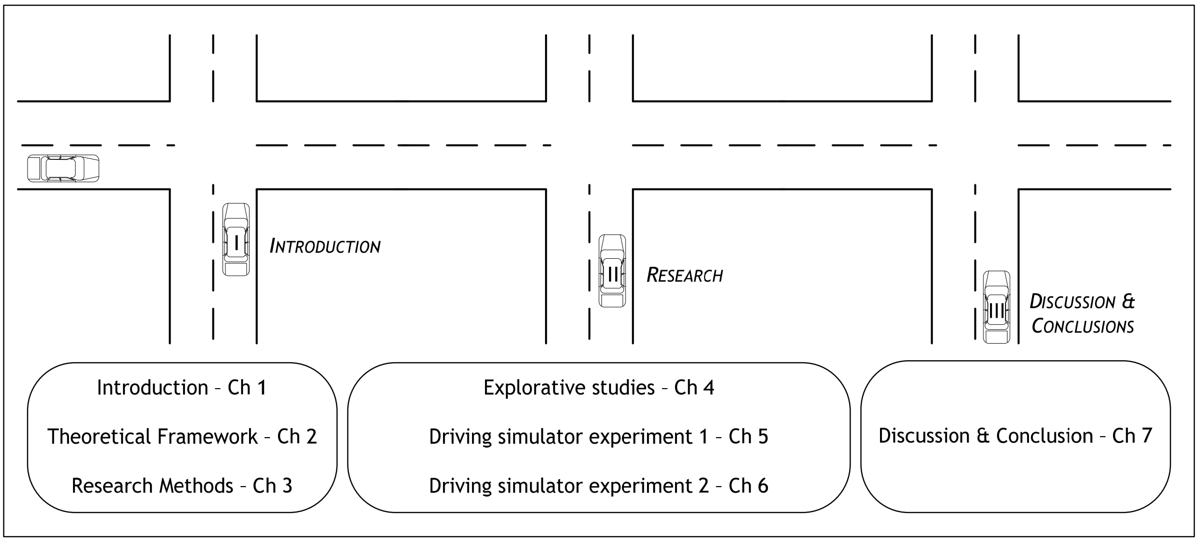


Figure 1.1: Schematic representation of thesis outline

2. Theoretical Framework[1]

2.1. Introduction

Many aspects of driving behaviour have been thoroughly researched and consequently many researchers have created models that attempt to describe driving behaviour. All these models vary in their applicability to specific situations and aspects of the driving task. Also, they vary in their focus and intended use. As introduced in the previous chapter, the main focus of the research in this thesis is on the interaction aspect of the driving task. Therefore, this chapter will focus on finding or developing a model that is applicable to interaction behaviour in driving.

Many researchers have agreed that there are two main goals that road users have while participating in traffic (e.g., Cnossen, Meijman, & Rothengatter, 2004; Fuller, 1984; Hale, Stoop, & Hommels, 1990; Hoedemaeker, 1999; Hollnagel, Nåbo, & Lau, 2003); first of all, getting from A to B in the least amount of time (i.e. efficiency) and second, doing so in a safe manner (i.e. safety). Obviously, drivers might have other goals as well (e.g., comfort, interest in the scenery along the way), but these are considered less relevant than the two main goals agreed upon by the abovementioned researchers. In order to interact with other road users in a safe but also efficient manner, drivers will need to anticipate future events. A model that can help to explain interaction behaviour in driving will thus need to incorporate the process of anticipation.

Concerning the safety-goal in traffic, accidents are often attributed to deviating behaviour of road users (Brookhuis, de Waard, & Janssen, 2001). In Chapter 1 it was

[1] This chapter is based on the literature research conducted for several conference proceedings and a journal article (Houtenbos, 2004, 2005; Houtenbos, Hagenzieker, Wieringa, & Hale, 2004; Houtenbos, Jagtman, Hagenzieker, Wieringa, & Hale, 2005).

pointed out that the compensatory mechanism that allows road users to compensate for each others' deviating behaviour is not yet fully understood.

Furthermore, in interaction with other road users there is a need to negotiate with them regarding the use of the available space. Traffic rules exist to facilitate these negotiations. In the Netherlands, for example, the right hand right of way rule applies to interaction situations at intersections with no designated priority. When road users' paths will cross at the intersection, the rule dictates that the road user approaching the intersection from the right has priority over the road user approaching the intersection from the left. However, it is not always apparent if this rule should be applied. For example, when one road user perceives another road user approaching the intersection from the right, it often depends on the latter's distance to the intersection and their speed whether the first road user should wait and give way. It is also sometimes unclear whether an intersection has any designated priority or not. Thus, drivers coming from the left could think themselves (wrongfully) on a protected priority road. Both formal and informal (e.g., that incorporate the distance and speed) rules in traffic are assumed to affect the negotiation process in interaction with other road users by influencing the expectancy of the situation.

Taking this into account, a model of interaction behaviour in traffic should:

- ❖ indicate how and when expectancy is important in the interaction process and incorporate anticipation behaviour of road users
- ❖ incorporate the effect of one road user's behaviour on the others' (i.e., incorporate the compensatory mechanism)
- ❖ indicate how expectancy can be influenced (e.g., by formal and informal traffic rules or the availability of information) and thus influence the interaction/negotiation process

Such a model will allow us to understand the interaction process better and help to pinpoint aspects of the interaction task that could benefit from Advanced Driver Assistance Systems (ADAS), which could eventually lead to increased traffic safety.

In this chapter, the concept of expectancy will be elaborated on and, subsequently, several existing models of driving behaviour will be discussed. The focus will be on the way expectancy is incorporated in these models and the extent to which these models are applicable to the interaction process in driving. Finally, a concept model of the interaction process is postulated, to which we will hark back in the final chapter of this thesis.

2.2. Expectancy: a key concept in interaction behaviour

A main assumption that underlies this thesis is the central role of expectancy in interaction behaviour in driving. Practically everyone can think of an instance where something almost went wrong in a traffic situation that involved interaction with other road users. The odds are that one or more aspects of this situation seemed to be unexpected. In normal situations where everything goes the way it should, things usually happen the way we expect them to happen. However, what is still unclear, is how exactly these expectations influence our behaviour or even how they are formed.

In traffic, expectations of the outside world are especially important due to the time constraints in such situations. In order to react adequately and fast enough to the demands of many traffic situations so that traffic flow is not hindered, anticipation of what is about to happen is required. To achieve a certain level of anticipation, adequate expectations are essential. When we know what to expect, we know what to anticipate and therefore what to prepare for.

The concept of expectancy has often been used in previous traffic research. Lunenfeld & Alexander (1984), for example, believe that the information drivers gather from the environment is compared to information which they have in storage (similar to the use of mental models, which are discussed in Section 2.2.2). The information in storage is somehow mediated by habit and expectancy. Their studies focused on the concept of positive guidance which aims to facilitate the driving task by arranging the road environment in such a way that it corresponds to road users' expectations.

Like Lunenfeld and Alexander, many researchers have focused their expectancy studies on the relation with the road environment rather than on the relation with the behaviour of other road users. For example, in a discussion on expectancy and positive guidance, Russel (1998) only mentions characteristics of the roadway environment as influencing road users' expectations. De Waard, Steyvers and Brookhuis (2004) studied the effect of a visually ambiguous road configuration on driving behaviour and found that unexpected road configurations confused drivers, especially as age increased. In a study on fixation times Martens and Fox (2007) concluded that fixation times for traffic signs and road markings decreased when subjects expected them to be there.

Although the abovementioned research has focused mainly on a road user interacting with the road environment (like most research concerning driver expectancy), it is likely that the same mechanism applies to road users interacting with other road users.

2.2.1. What happens when expectancies are not justified?

There are some studies that have focused on expectancy concerning the behaviour of other road users, which have mainly dealt with situations in which the expectancies did not turn out to be justified. Expectancies are considered to be "not justified" when the expectancy eventually does not match the actual outcome of a certain situation. Thus, the label "unjustified" can only be linked to a certain expectancy after the situation that was included in the expectancy has ended.

It has been proposed that images are formed in anticipation of perceiving objects and events (Neisser, 1976, 1978). Whenever imagined and observed objects are similar, object perception will be facilitated, whereas if the imagined and observed objects differ, they will produce interference. In laboratory studies on the probability of a stimulus appearing, subjects took longer to respond to a stimulus when the probability of it appearing was lower (Näätänen & Summala, 1976). In a reaction time study using stimuli that varied in expectancy, reaction times increased when subjects were not previously warned about a stimulus appearing (Olson & Sivak, 1986). The hypothesis that expectations must play a role in driving behaviour is supported by Russell (1998), who mentions that when a driver's expectancy is incorrect (i.e. unjustified), either the driver takes longer to respond properly or he/she may respond poorly or wrongly. In accordance, Martens (2004) found that information that did not correspond to one's expectancies was either missed or responded to slower as compared to the situations in which the information did correspond to expectancies. These findings imply that when a driver encounters an unexpected situation, this increases the time needed to respond and consequently, accidents are more likely to occur.

In Finland, Räsänen and Summala (1998) conducted a variant on a black spot analysis on a specific type of accident, namely bicycle-car accidents. They identified two common mechanisms underlying the accidents. The first one concerned the allocation of attention such that others were not detected and the second one concerned unjustified expectations about the behaviour of others. Especially drivers turning right hit cyclists because they looked left for cars during the critical phase. A possible conclusion could be that the drivers did not look right, because they did not 'expect' a cyclist to appear from a direction inconsistent with normal car traffic flow. Räsänen and Summala (1998) also bring up that drivers' learned routines may fail to take account of a cyclist properly and cyclists' expectations may fail if they interpret driver behaviour wrongly. For example a driver slowing down while approaching an intersection could be interpreted by a cyclist as an indication of a turn that will be made, but could also be interpreted as an indication to the cyclist that the driver has noticed the cyclist, and intends to yield.

Summala, Pasanen, Räsänen and Sievänen (1996) provide an explanation for car-bicycle-collisions in line with this 'unjustified expectations'-mechanism: drivers develop a visual scanning behaviour, which favours detecting motor vehicles, but ignores cyclists. This seems to suggest that the drivers, whose routines fail to take cyclists into account in time, are more focused on other drivers than on cyclists or even pedestrians and are thus more likely to expect drivers and not to expect cyclists.

Similarly, in a laboratory study on the detection of (headlights of) motorcycles, subjects appeared to develop a perceptual set for responding on the basis of headlights rather than on the presence of a motorcyclist (Hole & Tyrrell, 1995). Thus, when no headlights were detected, subjects tended not to expect motorcyclists. In their study focusing on so-called "looked-but-failed-to-see" errors in traffic, Herslund and Jørgensen (2003) suggest that road users who are expected to be present, but not actually there, can cause road users who are actually in the field of vision, but not expected, to be overlooked. As expectancy is developed through experience with similar situations, it appears that experienced road users are more likely to miss road users due to unjustified expectations (Herslund & Jørgensen, 2003).

The abovementioned studies show that unjustified expectancies can lead to road users not being perceived, which has obvious implications for traffic safety. In the research on expectancy in traffic situations, the focus has been on situations in which expectancies were not justified by the actual outcome (when accidents have occurred), instead of how expectancies are used in successful situations. Success can be the result of a justified expectancy, but also the result of an unjustified expectancy if there still was enough time to correct it. Perhaps this is because trying to describe the way expectancies work in successful situations is easier after describing the way they seem to fail when things go wrong. Thus, a challenge lies in determining the role of expectancies in successful traffic behaviour.

2.2.2. Mental models, schemata and scripts

Expectancy as a concept is related to the concepts of schemata, scripts and mental models (Abelson, 1981). Carroll en Olson (1987) define a mental model (of a certain system) as a rich and elaborate structure, reflecting the user's understanding of what the system contains, how it works and why it works that way. It can be conceived of as knowledge about the system that is sufficient to permit the user to mentally try out actions before choosing one to execute. Assuming road users use mental models while participating in traffic, these models will (among other aspects) need to include the formal and informal traffic rules that apply in a particular situation.

Similar to mental models, schemata are general cognitive structures that allow us to organise perceptual information (e.g., see Martens, 2000; Schank & Abelson, 1977). They are built up as experience is gained with situations that are similar in some way and help to interpret information when another similar, but new, situation is encountered. Scripts are essentially schemata that are focused on a particular event and help us to determine what behaviour is appropriate in a certain kind of situation. For example, a road user will have a schema for driving on a motorway and the matching script will indicate the appropriate behaviour while driving on the motorway.

Mental models and schemata help road users to cope with the complex traffic environment and help to focus on the elements that are relevant to the road user's goals; safety and efficiency. Van Elslande & Fauncher-Alberton (1996) mention studies which state that time constraints imposed on the cognitive processes implemented when driving require the acquisition of structured knowledge on which to base the expectancies specific to each journey (Alexander & Lunenfeld, 1986; Saad, Delhomme, & van Elslande, 1990; Theeuwes, 1996; Theeuwes & Hagenzieker, 1993). This seems very relevant for interactions in traffic, as time constraints are definitely involved here. We could consider the structured knowledge mentioned above to correspond to mental models. Several researchers have indicated that road users use schemata to extract expectations about how the traffic situation will develop (e.g., Martens, 2000; Theeuwes & Godthelp, 1995). In turn, expectations determine which schema is activated and information is interpreted in the context of that schema. Information that does not fit in the schema might not be perceived or might activate a different schema. However, activating a new schema takes time and might explain why response times increase when an unexpected event is encountered. In conclusion, a concept like mental models or schemata seems relevant to include in a model on interaction behaviour in traffic.

2.2.3. Expectancy and situation awareness

Situation awareness (SA), as originally proposed by Endsley (1995), was defined as perceiving the elements of the current situation (SA level 1), comprehension of the current situation (SA level 2) and finally, projection of the future actions of the elements in the current situation (SA level 3). Endsley's model also includes preconceptions and expectations, which are assumed to influence both situation awareness and the decisions to be made. As van der Hulst (1999) points out, situation awareness in driving involves the continuous updating of knowledge about the position and behaviour of other road users and confidence in the correctness and actuality of this knowledge. Acquiring and maintaining situation awareness is particularly relevant as the complexity of the task increases (Endsley, 1995). Thus, especially when studying a complex driving skill such as interacting in traffic, situation awareness seems a relevant concept to include in a model of information processing in interaction processes.

Situation awareness is defined as a state of knowledge that can be achieved through situation assessment (Endsley, 1995). Situation assessment consists of several processes that aim to achieve, acquire or maintain that state of knowledge. Although situation awareness is defined as a state of knowledge, it does not include all of the knowledge of an individual. The knowledge referred to by situation awareness only pertains to the current state of a particular dynamic situation. Thus, information in long term memory, such as mental models, influences situation awareness through directing comprehension, projection and expectations but is not explicitly included in the definition of situation awareness.

Chauvin & Saad (2000) have linked the concept of expectancy with Endsley's (1995) concept of situation awareness. According to them, managing interactions with road users calls for a driver to understand their current behaviour and anticipate their intentions, which corresponds to the second and third level of situation awareness. Being able to do so depends on the information other road users communicate explicitly, through the use of formal signs, or implicitly, through their behaviour. It also depends on the recipients' body of knowledge, which structures expectations and enables them to formulate hypotheses about adjustments that other users may force them to make in their driving (Saad, Mundutéguy, & Darses, 1999). This body of knowledge not only contains formal rules, but also informal rules, which can sometimes be free interpretations of formal rules. Informal rules are acquired through practice and experience with similar situations.

The model of situation awareness was intended for use in the generation of design implications for enhancing operator situation awareness. As this thesis also aims to indicate design implications for Advanced Driver Assistance Systems (ADAS) that support drivers in interaction, this also justifies the role of situation awareness in a model of interaction behaviour.

2.3. Models of driving behaviour

Numerous models of driving behaviour have been discussed in overview articles and textbooks (e.g., Fuller, 2005; Hoedemaeker, 1999; Huguenin, 1988; Michon, 1985; Ranney, 1994; Rothengatter, 1997; Wickens, 1992). In the following section, a number of these models will be discussed following Ranney's (1994) distinction between motivational models and information processing models. The focus of this section will be on the way expectancy has been incorporated in existing models of driving behaviour and on the extent to which existing models are applicable to interaction behaviour in driving. Also, models will be discussed that specifically take the effect of ADAS into account.

2.3.1. Motivational models

Ranney (1994) mentions several main assumptions that motivational models have in common. Firstly, motivational models assume that the driving-task is self-paced. In motivational models, risk is often seen as a key concept in influencing driving behaviour. All drivers decide on the level of risk they are willing to tolerate. A distinction is often made between the objective risk and subjective risk. The objective risk can be defined as the physical safety conditions, whereas the subjective risk is the experienced safety or "safety feeling" (OECD Scientific Expert Group, 1990). Three influential motivational models are Wilde's risk compensation model (1982), the risk threshold model or zero-risk model (Näätänen & Summala, 1976) and Fuller's risk-avoidance model (Fuller, 1984).

The model proposed by Wilde in 1982, supposes that a driver takes three aspects into account in order to anticipate what is likely to happen in the near future. The first aspect is the driver’s own vehicle path (i.e., speed and direction). Second are the infrastructural elements and third are the pathways of other road users. By taking the pathways of other road users into account, the model seems applicable to interaction behaviour.

The model of Näätänen and Summala (1976) includes the road user subjectively evaluating the probability of a hazardous event and the model explicitly includes the concept of expectancy. Their model supposes that drivers generally do not experience feelings of risk until a certain threshold is reached. Thus, drivers will adopt safety margins that incorporate the amount of time or space available between the driver and a perceived hazard. A hazard is any object, condition or situation that tends to produce an accident when drivers fail to respond successfully (Dewar, Olson, & Alexander, 2002). The moment the risk threshold is reached, depends on the probability of a hazardous event occurring, the remaining amount of time or space and the subjective evaluation of the consequences of the hazardous event.

Furthermore, Näätänen and Summala have elaborated on the concept of expectancy and made a distinction between different types of expectancy. First of all, they mention “continuation” expectancy where one will assume perceived events or states of affairs to continue in the immediate future. A second type of expectancy is called “event” expectancy, where one will assume that an event that hardly ever occurs, cannot and thus, will not occur in the (immediate) future. And finally they distinguish “temporal” expectancy where one will assume a certain event to occur (or not to occur) at a certain moment in time. Although other road users are not mentioned explicitly in the model, the concept of expectancy allows the model to be applied to behaviour of a road user in interaction.

Fuller’s (1984) risk-avoidance model takes both safety and efficiency into account. According to Fuller, attaining a desired travel objective (i.e., efficiency) as well as avoiding aversive stimuli (i.e., safety) is a predominant driver motivation. His model is based on the conflict between these two motivations. Fuller’s model incorporates the aspect of anticipation as well. Drivers can make an anticipatory avoidance response, before being certain if this was actually required for the sake of safety. A driver can also decide not to make an anticipatory response and eventually decide that some kind of response is still needed. In that case, a delayed avoidance response can be made, which, however, does leave less time to make an adequate avoidance response than if the driver were to have made an anticipatory response. The fact that Fuller’s model incorporates both safety and efficiency and explicitly deals with anticipation, makes the model applicable to the interaction situation.

2.3.2. Models of cognition

Other attempts to model human behaviour (in driving) involve models of cognition, such as information processing models and hierarchical frameworks of (driving) tasks.

According to Ranney (1994), information processing models are often represented as a sequence of stages, such as perception, decision making, response selection and response execution. Wickens' (1992) model of human information processing is a composite of other models and indeed includes the abovementioned stages. The model assumes that through all of the stages the data is transformed, which requires a certain amount of time. Endsley's model of situation awareness (1995) is similar as it also includes stages where the information is perceived, a decision is made and responses are executed. Endsley's model, however, positions "situation awareness" as a stage before the one where the decision is made. Situation awareness (SA) consists of three chronologically ordered levels, as explained in Section 2.2.3.

Another type of model has focused on human errors and can be used to pinpoint aspects in the design of a certain product or system that tend to provoke human errors, which can consequently be modified (Hale, Stoop, & Hommels, 1990). A first step towards a cognitive model of human performance is a task analysis. Human performance models within the driving context have often focused on modelling a subtask (e.g., steering or lane keeping), rather than attempting to analyse the complete (and complex) driving task. However, hierarchical structuring of the different subtasks has attempted to facilitate this. Michon (1985) introduced three levels of skills and control: the strategical level (planning), the tactical level (manoeuvring) and the operational level (control). Rasmussen (1983) made a similar threefold distinction between levels of control of task performance. Each level indicates how much attention is needed to perform a certain task. The knowledge based level requires the most attention, followed by the rule based level and finally, at the skill based level, the least attention is required to perform a task. Hale, Stoop and Hommels (1990) proposed to arrange both threefold distinctions in a matrix, thus creating nine cells (Table 2.1). Experienced drivers are assumed to perform tasks mainly below the diagonal from the top left to the bottom right, whereas novice drivers are assumed to mainly perform tasks above that diagonal. They hypothesized that drivers operating at rule- or skill-based level will act more homogenously and predictably than drivers operating at a knowledge-based level.

Table 2.1: Relation between levels of task classification (columns) and levels of behaviour (rows) (Adapted from Hale, Stoop, & Hommels, 1990; Hoedemaeker, 1999).

	Strategical tasks	Tactical tasks	Operational tasks
Knowledge based	Navigating in a strange town	Controlling a skidding vehicle	Novice driver on first lesson
Rule based	Choice between familiar routes	Passing other vehicles	Driving an unfamiliar vehicle
Skill based	Home/work travel	Negotiating familiar junctions	Vehicle handling in curves

An alternative approach to modelling cognition is put forward by Hollnagel (1993), who suggests focusing on performance rather on the details of human information processing. The Contextual Control Model (COCOM) consists of a cyclical model that is based on the perceptual cycle of Neisser (1976), but extended beyond the perception process to include a description of action and control. The cyclical model includes three key concepts (Hollnagel & Woods, 2005). First of all, the "construct", which refers to one's knowledge and assumptions concerning the situation. Based on this construct, information is interpreted and actions are selected. Subsequently, the action (the second concept) affects the process to be controlled, which, in turn, elicits an event and feedback on the action (the third concept). Both the events and feedback, together with disturbances from the environment, have an effect on the construct, by which the cyclical structure is completed.

Hollnagel's COCOM distinguishes between four control modes which represent a continuum of control, ranging from hardly any control (scrambled control) to total control (strategic control)(1998). Normal human performance is typically a mixture of the intermediate control modes: opportunistic (mainly feedback control) and tactical (mainly feedforward control). This allows the human to perform both reactively as well as proactively (Hollnagel & Woods, 2005).

Particularly the representation of information processing in stages in combination with the concept of situation awareness (which is also described in stages) seems useful in a model describing interactive behaviour in driving as the situation awareness theory incorporates the need to anticipate.

2.3.3. The role of ADAS in models on driving behaviour

No models of general driving behaviour were found that explicitly reserve a role for the effect of advanced driver assistance systems (ADAS). This is corroborated by Engström and Hollnagel (2005) who state that models specifically aimed at the interaction with in-vehicle functions are considerably less common than the substantial number of more generic driver behaviour models. They argue that particularly a generic model of drivers' interactions with in-vehicle systems is still lacking. Also, they express their concern about both the technological and methodological developments in the area of in-vehicle systems being generally performed without reference to a common framework.

Hollnagel, Nåbo and Lau (2003) argue that a practical model of driving must allow several goals to be pursued at the same time (i.e. control can exist on several levels simultaneously) and that the driver and the car should be described as a joint system, especially now that more and more advanced driver assistance systems (ADAS) are being applied in today's cars. They introduced the Driver in Control (DiC) model which includes a "Joint Driver Vehicle System" (JDVS). When the JDVS is in control, unexpected conditions can be prevented, but also if an unexpected condition is encountered, it is possible to effectively recover from it. Thus, similar to Fuller's risk-avoidance model (1984), expectancy is related to a certain amount of time available to prevent or recover from an unexpected (and unwanted) event. The DiC model distinguishes between 4 hierarchically organised levels of control in driving (i.e., from the bottom-up: tracking, regulating, monitoring and targeting). Two types of control are distinguished as well. Anticipatory control is related to three levels (regulating, monitoring and targeting) and compensatory control is related to two levels (tracking and regulating). The abovementioned levels of control have also been described in the context of an extended control model (ECOM), which is similar to the COCOM model (discussed in the previous subsection), but allows for more actions to take place at the same time corresponding to goals at different levels (Hollnagel & Woods, 2005).

2.3.4. Evaluation

This brief overview of models of human behaviour demonstrates that although concepts relating to expectancy and anticipation have been incorporated in models of driving behaviour, the impact of one road user's behaviour on that of another is an aspect of interaction behaviour that has not found its way into driver behaviour modelling yet. The aim of this thesis research is to gain more understanding of this interaction process in driving. An interaction process implies the involvement of more than one road user, but most models of driving behaviour have been developed taking the perspective of only one individual road user.

Technology allows more and more opportunities to provide road users with all sorts of information or even actively support aspects of the driving task. However, hardly any models of driving behaviour were found that explicitly incorporate the role of ADAS, which indicates another gap in the field of driver behaviour modelling.

2.4. Modelling interaction in driving behaviour

2.4.1. A concept model of interaction behaviour in driving

Based on the models discussed in Section 2.3, it can be concluded that a model that explicitly incorporates the impact of the behaviour of one road user on that of another is still lacking. A model that describes the interaction process between drivers should reserve a central role for the concept of expectancy, which allows drivers to interact safely and efficiently. This thesis attempts to formulate a model that can be used to describe the interaction process on a cognitive level. The model (Figure 2.1 & Figure 2.2) is based on models of information processing (Endsley, 1995; Wickens & Hollands, 2000) to which the concept of expectancy has been added.

This model consists of two interdependent models, which initially served to aid hypothesis development. The first model (Figure 2.1) aims to describe the entire interaction situation, thus including at least two road users. The second model (Figure 2.2) is a more detailed model of the information processing that occurs in each of the road users as presented in the first model. The second model served mainly to generate ideas about the role of expectancy and it will be adapted according to the results of the studies performed throughout this thesis' research. In Chapter 7, the adapted models will be presented and discussed again in the light of the results of the research performed.

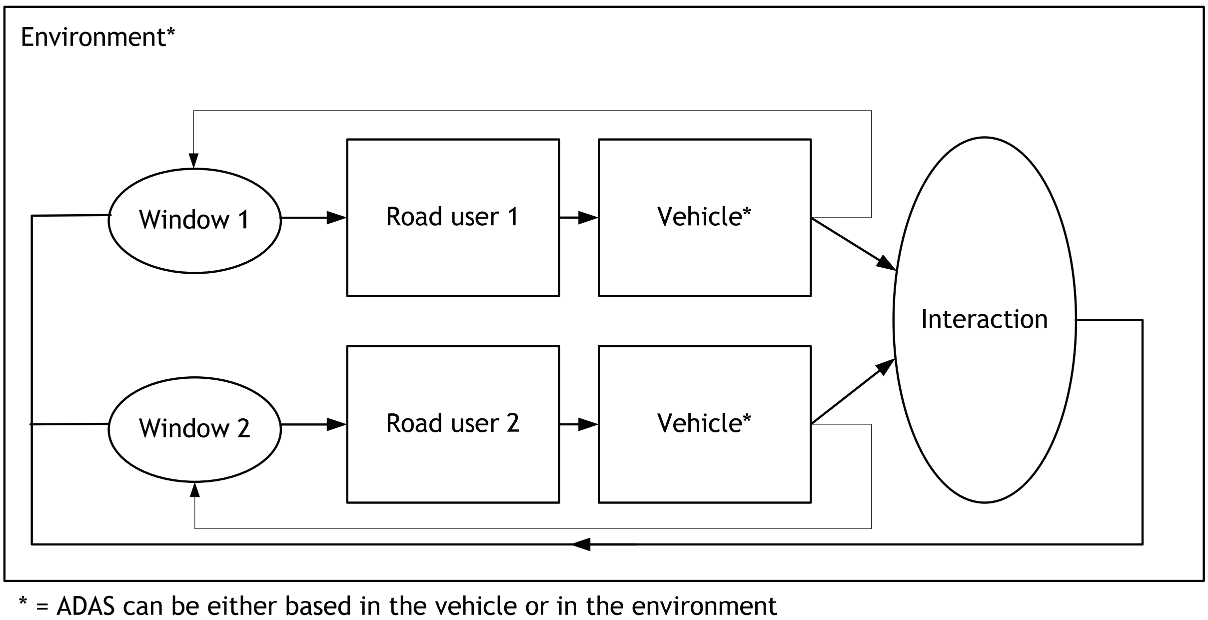


Figure 2.1:Interaction in driving

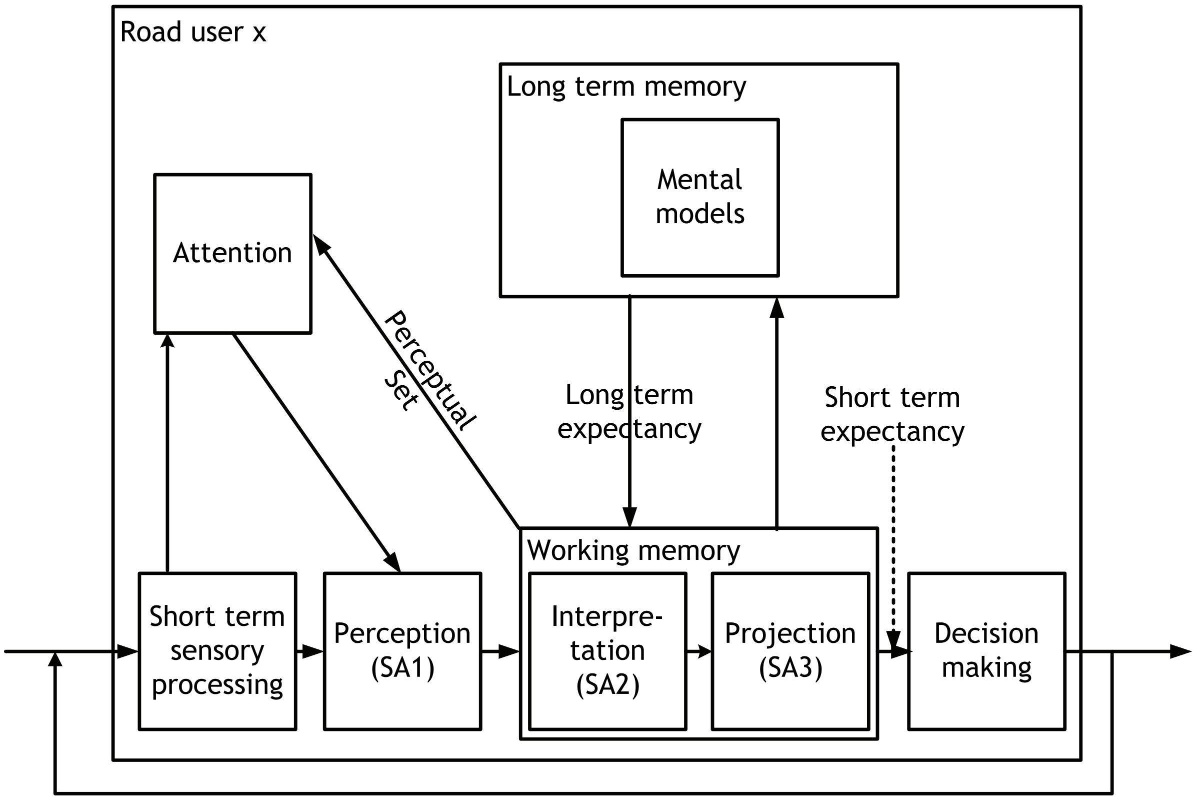


Figure 2.2: Information processing in driving

The main idea of the first model is that all road users involved in the interaction perceive the environment through a 'window' which produces a physically filtered perception of the environment. Due to these windows, both road users will receive different information from the environment as they both are at different positions in the situation. Thus, the window in this model is a filtering process that takes place outside the road user, physically selecting what information from the environment can be further processed by the road user (illustrated in Figure 2.2). Further internal selection processes influenced by attention (among other aspects) determine what is eventually perceived and are shown in the second model. Subsequently, the road users react through their vehicle to the situation they have perceived. Actions of all road users come together to create the interaction, which can in turn be perceived by all involved road users again through their personal window. For reasons of clarity only two road users are presented here, but it is possible to add more road users. In this model ADAS is represented by an asterisk in the vehicle and environment boxes as ADAS may or may not be present in either of the road users' vehicles or the environment.

The second model (Figure 2.2) looks more closely at the road user in the first model. It aims to describe the information processing of the road users involved in the interaction and includes aspects which are presumed to play an important role in interactions (e.g. expectancy). The information from the outside world, which was filtered by the window in the first model, enters the road user's short term sensory processing. What is subsequently perceived is –at least in part – determined by the focus of attention. In turn, the focus of attention on particular aspects of the situation is determined by what is included in working memory at a certain moment in time. The perception stage in this model corresponds to the first level of situation awareness (SA). This is where the role of expectancy comes in. Based on the mental models of certain situations in traffic that a road user keeps in his long term memory and the situational aspects that are perceived, a long term expectancy is elicited. Subsequently, the perceived aspects of the situation are interpreted in the framework of this long term expectancy. This stage corresponds to the second level of SA. When the situation has been interpreted, the road user can make a projection of the state of the situation in the future (level 3 of SA) which will result in a short term expectancy. Short term expectancies are thus based on a long term expectancy but include specific aspects of the current situation, whereas long term expectancies are only general ideas about what to expect in similar situations. Based on this short term expectancy, a decision is made about which action is appropriate in the situation at hand. The action is made through the road user's vehicle, which brings us back to the first model.

The distinction made in the second model between 'long term' and 'short term' expectancies is based on the distinction made by Knapp (1998/1999). He states that drivers bring two types of expectancy to their driving experience. Long term (or a priori) expectancy is based on past experience, upbringing, culture and education. Short-term (or ad hoc) driver expectancy is based on local practices or situations encountered on a particular roadway during a particular trip. In the second model long term expectancies are considered to be similar to 'empty' scripts or schemata driven by information contained in mental models. For instance, anyone would know roughly what driving behaviour to expect when thinking of driving on a motorway. These expectations are referred to as long-term expectancies. Subsequently, short-term expectancies are considered to be the same scripts and schemata, but fed with information gathered through perception of the environment at a particular moment in time. For example, these would incorporate the specific characteristics and behaviour of a given vehicle on the motorway giving rise to expectations about behaviour such as close following or attempts to pass on the inside.

2.4.2. Application of the interaction model

As stated in the introduction to this chapter, a model of interaction behaviour should satisfy the following criteria:

- indicate how and when expectancy is important in the interaction process and incorporate anticipation behaviour of road users
- incorporate the effect of one road user's behaviour on the others' (i.e., incorporate the compensatory mechanism)

- ❖ indicate how expectancy can be influenced by formal and informal traffic rules and thus influence the interaction/negotiation process

The proposed model reserves an explicit role for expectancy in the information processing of road users in the process of interaction, in which general, long term expectancies develop into short term expectancies as the information from the environment is interpreted. Short term expectancies are based on the projection of the current situation into the future and thus allow road users to anticipate and (start to) react to what they expect to happen. Furthermore, the model allows for the interaction of road users by including all interaction partners in one model (Figure 2.1). Their individual behaviours act upon each other and become available in the environment, which can subsequently be perceived and incorporated in road users' expectancies and ultimately in their behaviour. Finally, formal and informal rules are situated in the road users' long term memory and in particular in mental models of typical traffic situations. Long term expectancies and thus also short term expectancies are based on these mental models.

In Chapter 4, an explorative study is reported that was aimed at studying (long and short term) expectancies that occur in interaction situations at intersections. Chapter 5 and Chapter 6 deal with the effect of one road user's behaviour on the other by discussing two driving simulator experiments that included interaction situations between two car drivers. In these experiments long and short term expectancies were manipulated by use of formal and informal traffic rules to determine the effect on behaviour. In Chapter 7, the results of the studies and experiments are discussed and several adaptations to the proposed model are made.

3. Research Methods

3.1. Introduction

As the previous two chapters have pointed out, the focus of this thesis is on interaction behaviour at intersections. As expectancy is assumed to be a key concept in the interaction process (illustrated in Chapter 2), this thesis research has focused mainly on that particular concept. The research performed for this thesis was broken down into two phases. The first phase was of a more explorative nature, in which particularly the concept of expectancy was explored. This explorative phase was followed by an experimental phase in which the effect of expectancy on interaction behaviour was manipulated and studied. In this chapter, the instruments and techniques applied in this thesis research will be discussed. A detailed account of the design and results of the studies and experiments conducted can be found in Chapter 4 through 6.

3.2. Research methods in the explorative phase

The first research question asks what the role of expectancy in interaction behaviour at intersections might be. It should be noted that at this phase in the research, the focus was on *exploration* of the concept of expectancy rather than on hypothesis *testing*. This was explored by focusing on which aspects people mention in their expectancies of interaction situations (Chapter 4). When research is focused on the exploration of constructs, qualitative research methods are often applied (Miles & Huberman, 1994). The field of qualitative research is characterised by a wide variety of research methods, which differ in the extent to which they are laborious to apply, in the extent the researcher already needs to have a theory concerning the object of research and the type of results they yield.

To prevent the results taking a too limited view of particular aspects of the concept of expectancy, the study performed in the explorative phase of this research involved concept mapping, the results of which were analysed using Homogeneity analysis by means of alternating the least squares (HOMALS) and qualitative data analysis. The combination of the concept mapping technique and HOMALS allows for a greater level of involvement and interpretation of both respondents and researchers than the qualitative data analysis was able to do. However, the qualitative data analysis allows for a more detailed exploration of the expectancies provided by the respondents. The two chosen methods therefore complement each other. In the following section, the abovementioned techniques will be discussed in greater detail.

3.2.1. Concept mapping

The approach used in the explorative study (reported in Chapter 4) was based on a method advocated by Jackson and Trochim (2002), who argue this approach to be valuable to analyse open-ended survey responses. Although they used the approach of concept mapping in an organisational research background, it seemed useful to apply this approach to explore the concept of expectancy in interaction situations at urban intersections.

Concept mapping, as discussed by Jackson and Trochim, consists of several phases. The first phase involves a survey in which participant's responses triggered by a relevant situation or stimulus are captured in a so-called "free list in context". Jackson and Trochim describe responses in this format as responses that typically vary from a few phrases to a couple of paragraphs and represent a wide variety of concepts with varying frequency. After the respondents have provided their "free lists in context", the next phase can commence: creating units of analysis. The authors describe a unit of analysis as consisting of a sentence or phrase containing only one concept. Unitising responses is done by breaking sentences into single concept phrases. This is preferably done by trained researchers to ensure that unitising is done consistently. All statements are then printed on cards, together with a random number to ensure that each statement is considered independently of other statements. The following phase consists of sorting the statements. This should be done by a group of at least 10 respondents, who sort the statements into piles of similar statements. The respondents are allowed to make as many piles as they like. However, they are not allowed to make a pile with remaining cards that they feel are not similar to any of the other piles. Instead they should make a new pile for each "odd" statement. After sorting all statements, they are asked to give each pile a name that adequately reflects the similarity between the statements in the pile.

The sorting results of each respondent are subsequently transferred into a data matrix and analysed. Such an analysis produces a plot which visually illustrates similarities between statements. The particular method chosen to analyse the data of the concept mapping study in this thesis (HOMALS) is similar to the method applied by Jackson and Trochim (both are multidimensional scaling techniques). Due to reasons of software availability and prior experience with the technique, HOMALS (which is discussed in the next section) was used to analyse the concept mapping data. For more information on the exact method applied by Jackson and Trochim, please refer to their article on the concept mapping technique (Jackson & Trochim, 2002).

In conclusion, the concept mapping technique was thought to be a promising approach to generate and cluster aspects that play a role in expectancies of interactions between car drivers at urban intersections. The concept mapping technique has been somewhat adapted and subsequently used in the study reported in Chapter 4.

3.2.2. HOMALS

To create a visual indication of statements (which are based on the elicited expectancies in the concept generation phase, Section 3.2.1) that are considered similar by respondents, a multiple correspondence analysis called "HOMALS" was applied (see e.g., Tenenhaus & Young, 1985; van der Kloot, 1997). HOMALS stands for "Homogeneity analysis by means of alternating the least squares". HOMALS is similar to a principal components analysis, but can be used with nominal data. HOMALS is also similar to correspondence analysis, but allows for more than two variables to be analysed. The method is particularly useful for explorative research, as it gives good insight into the data, which can subsequently lead to generation of hypotheses.

As the word "homogeneity" suggests, HOMALS aims to indicate clusters of objects that have shown homogenous response patterns. The result of a HOMALS analysis is a plot which displays similar objects close together and less similar objects further apart. To apply this method to the data of the concept mapping study, the piles of similar statements made by the respondents were entered into a data matrix (in SPSS). The rows in the matrix represent the statements (i.e. objects) which were sorted by the respondents. Each column in the matrix contains the sorting data of one respondent. The cells contain integers which indicate the pile number a particular statement was sorted in. For example, if Respondent X made 4 piles, the column for that respondent would contain integers from 1 to 4 indicating in which pile each particular statement was sorted. The HOMALS analysis visually describes the relationships between the objects (in this case the statements) in a space of two or more dimensions. HOMALS allows the researcher to specify the number of dimensions of the solution, although the default value is "2". This has the advantage of producing a two-dimensional plot that is usually easier to interpret than solutions using more than two dimensions. The maximum fit for a solution with two dimensions is 2.00. However, the interpretability of the solution is commonly seen as more relevant than goodness of fit. The plot of the solution allows the researcher to gain insight into the relationships between statements and to identify clusters of statements that are similar in some respect for many respondents. As a detailed discussion of the alternating least squares algorithm used in HOMALS lies beyond the scope of this thesis, the reader is referred to more specialised literature (e.g., Tenenhaus & Young, 1985; van der Kloot, 1997).

3.2.3. Qualitative data analysis

The expectancies were also qualitatively analysed to gain more insight into the expectancies and also determine clusters of aspects. As Miles and Huberman (1994) remark, qualitative data analysis often involves assembling and subclustering of words. These words can be organised in a way that allows the researcher to contrast, compare, analyse and detect patterns in them. Thus, qualitative data analysis allows the expectancies to be studied in greater detail than the combination of concept mapping and the HOMALS approach allowed.

To qualitatively analyse the expectancies, a coding scheme was developed in an iterative process as recommended by Miles and Huberman (1994). The iterative process involves "check-coding" which allows the initial codes to be further developed while a subset of responses is coded and includes rephrasing the definitions of codes. Clear operational definitions are indispensable when either working with a single researcher over time (consistent application of codes) or working with multiple researchers to assure that they think about the same phenomena as they code, because the codes will drive the retrieval and organisation of data for analysis (Miles & Huberman, 1994).

The final coding scheme allowed phrases within the expectancy to be associated with more than one code (i.e., multiple coding). For example, "at the priority intersection" would be associated with a code indicating a reference to location and a code indicating a reference to right of way. Miles and Huberman (1994) remark that multiple coding is particularly useful in exploratory studies.

Furthermore, Miles and Huberman (1994) distinguish between first-level coding and pattern coding. First-level coding consists of summarising segments of data, which was done in this study using the coding scheme. A subsequent level of analysis includes pattern coding, which is a way of grouping those summaries into a smaller number of sets, themes or constructs. Pattern coding has several important functions. First of all, it reduces large amounts of data into a smaller amount of analytic units. Also, it helps the researcher to elaborate a cognitive map and allows common themes to surface. In this study, pattern coding was performed by visually exploring the results for each type of code that was applied using the coding scheme and looking for common aspects or subclusters within each code. It should be noted that it is not necessary to apply a pattern code to every bit of data that already has a first-level code if this is not considered meaningful or helpful (Miles & Huberman, 1994).

3.3. Research methods in the experimental phase

Using the results obtained from the explorative phase in this thesis' research (Section 3.2), two experiments were designed to answer the other two research questions:

- What is the influence of expectancy on traffic safety at intersections?
- What are the implications of human interaction behaviour for ADAS?

The main objective of these experiments was to determine the effect of expectancy on driver behaviour in interaction situations at intersections. As the use of driving simulators would allow expectancies to be more easily experimentally manipulated (as opposed to, for example, using an instrumented vehicle in real traffic), the experiments were conducted in two linked driving simulators. Another advantage of using driving simulators is that it allows an interaction situation to be created within a controlled environment. The exact design and the results of these experiments are presented in Chapters 5 and 6.

3.3.1. Driving Simulators

The following section considers the use of driving simulators in research on driving behaviour in general and in the experiments conducted for this thesis.

Considerations

Researchers with questions concerning driving behaviour have often used a driving simulator as an instrument in their studies (*Simulators and Traffic Psychology*, 1996). As Nilsson points out, an important advantage of simulators over field studies is that they allow driving conditions and environmental conditions to be kept constant (1993). However, she also points out some limitations which are primarily caused by physical aspects and can affect the validity of the research. Drivers in a simulator can experience unfamiliar combinations of visual and motion cues, which can lead to behaviour they would not normally display in real traffic situations. This mismatch between the vestibular cues and visual cues is described by Wertheim (1996) and often referred to as the intersensory mismatch (Reason & Brand, 1975). This mismatch can cause simulator sickness, especially in fixed base simulators (Wertheim, 1998). However, use of simulators with a moving base does not seem to entirely prevent simulator sickness from occurring. Simulator sickness is known to occur in particular when participants are required to negotiate many sharp curves during the experiment.

Furthermore, in an article on driving simulator validity, Kaptein, Theeuwes and van der Horst (1996) conclude that the validity of a fixed base driving simulator is limited. Researchers should realise that although the results will generally have relative validity, they will rarely have absolute validity. Thus, the direction of the effects found will be similar to the effects found in reality but the size of the effect will not necessarily be similar to the size of effect found in reality. Researchers should take the abovementioned consideration into account when interpreting data obtained using a (fixed base) driving simulator.

In conclusion, despite the increased tendency towards simulator sickness in fixed base simulators and the limited validity of the results, other considerations related to, for example, cost, availability and the opportunity to link two driving simulators, led to the decision to use fixed base simulators for the experiments discussed in this thesis.

Specifics

The experiments were conducted in two linked Green Dino fixed-base simulators at Delft University of Technology (Figure 3.1). These simulators were connected in a way that allowed the drivers of both simulators to encounter each other in the same virtual world. Participants were seated in a booth which represented the front seat of a car. The simulator is provided with all normal controls (steering wheel, accelerator, brake). The simulator was used in an automatic gear shift mode so that participants did not need to shift gear during the driving session. Force feedback was provided on the steering wheel according to the self-aligning torque of the front wheels. Motion cueing was provided through vibration elements in the steering wheel and the driver's seat. As the simulator booth does not contain windows, the view through the front and side windows was projected (180 degrees) on the (tilted) walls of the booth, by three projectors. The front view projection has a resolution of 1024x786 pixels; the side-views feature resolutions of 800x600 pixels. The dashboard, the vehicle interior and mirrors are integrated in the projected image. Auditory information is provided through headphones (e.g., engine and environmental sounds as well as route instructions). For more information about these simulators, please contact www.greendino.nl.

3.3.2. Behavioural indicators/measures

The driving simulator experiments in this thesis focused on the effects of expectancy manipulations on the behaviour of road users in interaction situations. The first experiment, which had a more explorative nature, focused mainly on yielding behaviour, but also included some measures of safety. To elaborate more on the safety effects, the follow-up experiment included a wider variety of behavioural indicators of safety effects. As the results indicated effects on interaction efficiency as well, some behavioural indicators related to efficiency effects were also included. The following section will discuss the variety of measures used to indicate general effects found in road users' behaviour.

Figure 3.1: Green Dino linked driving simulators

Safety indicators

Jagtman (2004) makes a distinction between direct and indirect criteria for assessing traffic safety. Direct criteria involve analyses of accidents (e.g., in-depth analyses, analysis of accident patterns). As she points out, using accidents to assess safety can often be problematic. For example, even when conducting simulator studies, the frequency of crashes will often be too low to allow for any conclusions to be drawn. Also, when assessing the safety at a particular site, the use of accidents as a safety indicator can be biased, due to accidents not being reported (Chin & Quek, 1997). An alternative approach has been suggested (e.g.,Hydén, 1987; Perkins & Harris, 1967), that argues that near-accidents and conflicts can be used as an indirect indicator of traffic safety, when accident frequency is too low to draw sound conclusions. This type of approach is disputed by Williams (1981), stating that the many studies devoted to the evaluation of the traffic conflicts technique have failed to establish that conflicts are directly related to road accidents. The fact that the definition and operationalisation of accidents as well as conflicts has differed throughout the many studies using the conflict technique, is considered part of the problem. Despite the seemingly unclear relationship between traffic safety and traffic conflicts, researchers are still convinced that using these conflicts is a useful alternative (e.g., Svensson & Hydén, 2006). They argue that a more comprehensive understanding of the connection between behaviour and safety can be achieved by considering both unsuccessful and successful interactive situations.

Chin and Quek (1997) point out that, besides studies using subjective observations of conflicts, some studies have tried a more quantitative approach using the concepts of time and space between vehicles. For example, time to collision at the onset of braking, the minimum time to collision in an interaction situation (van der Horst, 1990a) and post-encroachment time (i.e. the time difference between one vehicle leaving the intersection crossing point and the other arriving) have been frequently used (Allen, Shin, & Cooper, 1977). In order to calculate time to collision (TTC), the presence of a so-called collision course is necessary. A collision course is present when one of the interaction partners, if he/she follows the current trajectory, will enter the intersecting area before the other has left. Thus, when even the smallest time gap exists between departure of the first party from the intersecting area and arrival of the second party, time to collision will be infinite. In such a case, post encroachment time (PET) seems to be a more appropriate measure (van der Horst, 1990b). PET, unfortunately, does not incorporate the speed of the interaction partners, but is based only on the time between two interaction partners reaching and leaving the point where their paths intersected. Quantitative measures involving time and space available between two interaction partners such as the measures mentioned above were also included in the experiments reported in Chapter 5 and Chapter 6.

As the scientific world does not seem to have agreed upon one specific measure to assess safety of traffic situations, several of the most commonly used measures were applied in the experiments (i.e., near misses, collisions, TTC_{min}[2]) to provide us with an indication of safety. Also, a new Safety indicator was included, which is essentially a combination of TTC_{min} and PET, to overcome the abovementioned drawbacks of both measures. This Safety indicator reflects the difference between both road users' time to an estimated collision point when the participant is at a certain distance from the intersection. Please refer to de Winter et al. for more information on the Safety indicator (2006).

Efficiency indicators

Many studies have attempted to quantify the relationship between safety (often defined as "risk of a crash") and individual driving speed (Aarts & van Schagen, 2006). Efficiency and speed are alike in that both concepts require the dimension of time and distance travelled. It seems plausible that a similar trade-off relationship that exists between safety and driving speed should exist between safety and efficiency.

Efficiency is often discussed on a rather general level, taking the whole traffic system into account rather than considering the efficiency of individual interactions. Studies

[2] TTC_{min} was included only in Chapter 6, as this experiment concentrated more on the effects on interaction safety.

focusing on the optimisation of traffic flow often take the average speeds of all vehicles on a certain road section into account. When looking for an indicator of efficiency on the level of individual interactions it is necessary to look at the behaviour of the individuals involved. As the focus of the experiments was mainly on the interaction process, driving speeds of both drivers involved in the interaction were combined to assess the efficiency of the interaction.

In an experiment focused on interaction behaviour in critical situations Hancock and de Ridder (2003) found that drivers tend to try to solve (critical) interaction situations by only releasing the accelerator. Only if that is not sufficient, would they apply the brakes. This result supports the idea of a trade-off relationship between safety and efficiency. By only releasing the accelerator, drivers might hope to slow down enough for the interaction to develop safely without losing too much speed. Thus, driving behaviour involving the accelerator and the brakes might also provide us with information concerning the efficiency of the interaction.

3.3.3. Subjective measures

To help interpret the behavioural data derived from the experiment reported in Chapter 6, this experiment included the use of some subjective measures. Subjective measures, which are often rating scales, can be used to assess a participant's personal experiences, which cannot be assessed directly or objectively. A great advantage of using rating scales is that it can provide a researcher with quantitative judgements of qualitative aspects, which are less laborious to analyse. Usually, a rating scale takes the form of a dimension along which a respondent is asked to indicate how they rate a particular aspect. Oborne distinguishes two types of rating scales (1976). Analogue rating scales generally consist of a straight line of fixed length, with defining phrases placed at each end of the line. The other type, category rating scales, generally consist of a series of ordinally positioned adjectives. Both types of rating scales have their drawbacks. Analogue scales cannot be used as an actual scale without further evidence. The researcher can only safely draw conclusions if respondents choose the scale extremes. Responses anywhere else on the scale are difficult to interpret. Category rating scales are ordinal, but not necessarily on an interval scale, which again, complicates the interpretation process. However, rating scales of both types or a combination of types have been constructed and validated and are being used extensively in psychological research domains. In fact, the advantages of rating scales seem to outweigh the drawbacks. Several rating scales that have been previously used by a range of other researchers and proved to be useful, were applied in the driving simulator experiments and will be discussed below.

Yielding Behaviour Questionnaire

To link the observed yielding behaviour at the intersections with subjective estimates of yielding behaviour a questionnaire was used. The Yielding Behaviour Questionnaire (YBQ) used in this research was taken from a study which focused on driving behaviour at intersections (Björklund & Åberg, 2005). This study included a series of schematically presented intersections, with another road user approaching the intersection from different directions, either maintaining speed or slowing down. Participants were asked to indicate how often they would take right of way in the presented situation, on a 5-point scale ranging from "never" to "always". The situations were reconstructed based on the description provided by Björklund & Åberg and the response scale was translated into Dutch. The results of this questionnaire were used to determine the relationship between reported yielding behaviour and yielding behaviour as observed in the driving simulator.

Acceptance scale

When a new car feature is the focus of driving behaviour research, the acceptance of that feature by the driver is often assessed using a rating scale. The Acceptance scale introduced by van der Laan, Heino and de Waard (1997) has been successfully used in several previous driving simulator studies and consists of two subscales referring to the experienced usefulness and pleasantness of the new feature (de Waard, van der Hulst, & Brookhuis, 1999; Hoedemaeker, 1999; Jamson, 2006; Rothengatter, 1997). De Waard et al., for example, provided young and elderly drivers with visual and auditive feedback when their behaviour deviated from legally accepted behaviour. Participants were asked to indicate their acceptance of the feedback feature using the Acceptance scale. De Waard et al. (1999) found effects of exposure (i.e. participants changing their opinion after having experience with the system) as well as effects of group (i.e. elderly drivers generally having a more positive opinion about the system). In another simulator study, Jamson (2006) did not use the two subscales, but instead combined all items to create an overall score of acceptability of Intelligent Speed Adaptation (ISA). She subsequently used this score to correlate it with reported and observed tendencies to speed and the proportion of time participant chose to use the ISA system. The results showed that participants who tended to speed also tended to rate acceptability of a voluntary ISA system as low.

In the second driving simulator experiment (Chapter 6), participants were provided with extra information about other approaching road users. To determine participants' acceptance of this new feature in the car, they filled out the abovementioned Acceptance scale (van der Laan, Heino, & De Waard, 1997). This tool to determine driver acceptance of new technology has the advantage of being simple to use. The scale consists of nine 5-point rating-scale items, which load on two scales (see 6). Each of the nine items consists of a 5 point scale with two opposite adjectives at either end of the scale. Participants were presented with the following statement: "I experienced the extra information as… (adjective)" Subsequently, participants were required to indicate on the 5 point scale to what extent either adjective was applicable.

To analyse the results of the scale the responses generally need to be coded from -2 to +2 from left to right, except for items 3, 6 and 8 that should be coded from +2 to -2. Van Der Laan et al. have labelled the two scales as "usefulness"(item 1, 3, 5, 7 and 9) and "satisfying" (item 2, 4, 6 and 8). The items are combined to form the two scales. The scale label '"satisfying" for the second scale, does not, however, seem to cover the overtones of the scale. The scale includes adjectives such as "pleasant", "nice", "likeable" and "desirable", which are all adjectives describing the overall pleasantness of the technology to be assessed. As "useful" is an item belonging to the "usefulness" scale (together with "good", "effective", "assisting" and "raising alertness"), it seems that using "pleasantness" as a label for the second scale (which includes "pleasant") would cover the essence of the scale to a greater extent. Therefore, in this thesis, the second scale will be referred to as the "pleasantness" scale, rather than the "satisfying" scale. After coding the responses, reliability analyses can be performed on items of both scales. According to Van Der Laan et al., Cronbach's α for this scale should be at least 0.65 [3]. If so, an average score for both scales per participant can be computed and used in further analyses to determine how "useful" and "pleasant" participants considered the extra information to be.

Rating Scale Mental Effort

In driving behaviour research, many studies have taken (subjective) workload into account, in particular when parts of the driving task are automated. For example, an increase in subjective workload can lead to compensatory actions concerning speed and headway (Fuller, 2005). However, when the situation does not allow for such compensatory actions, this will have a negative effect on performance. Stanton and Young (2002) mention several studies relating workload to concepts such as stress, feedback and situation awareness. They conclude that high workload has been shown to have a negative effect on situation awareness. However, the effects of stress and feedback on mental workload are not as straightforward. It seems plausible that measures indicating the level of (subjective) workload are related to both safety and efficiency and can help to gain insight into the trade-off between the two concepts. Hence, a suitable measuring instrument was sought for this research.

Measuring subjective mental workload is often conducted using a rating scale. For example, the National Aeronautics and Space Administration Task Load Index (NASA-TLX) is a multidimensional rating scale measuring six (subjective) factors of workload (Hart & Staveland, 1988), whereas the Rating Scale Mental Effort (RSME) is a unidimensional rating scale (Zijlstra & Van Doorn, 1985). Zijlstra has demonstrated that the RSME is a reliable and valid tool, able to provide an indication of the amount of mental effort experienced by participants (Zijlstra, 1993). The RSME has been

[3] A common rule of thumb concerning the interpretation of Cronbach's α implies that above .8, Cronbach's α is considered "good" and between .6 and .8 Cronbach's α is considered "moderate". However, a small number of items on a scale, as well as measuring psychological constructs can lead to a lower value for Cronbach's α, while the scale might still be reliable (Field, 2005).

successfully applied in a considerable number of (Dutch) studies on driving behaviour. For example, in a driving simulator experiment in which participants could be auditorily and visually informed when their behaviour deviated from legally acceptable behaviour, the results showed that self-reported effort (using the RSME) slightly increased when they received feedback versus when they did not (de Waard, van der Hulst, & Brookhuis, 1999). In another driving simulator study that included a new feature in the car, participants were required to drive with and without Adaptive Cruise Control (ACC) and rate their subjective mental effort accordingly (Hoedemaeker, 1999). Results showed that when driving with ACC, participants experienced less mental effort than when driving without. Based on these studies, it seems that new features in the car can indeed have an impact on subjectively experienced mental effort, be it an increase (e.g., de Waard, van der Hulst, & Brookhuis, 1999) or a decrease (e.g., Hoedemaeker, 1999). As the effects of these new features on subjective mental workload seem to depend on the specific feature, it is hard to predict the effect of providing extra information on participants' subjective mental workload.

To determine if the level of subjectively experienced mental effort is affected by the new feature in the car, the Rating Scale Mental Effort (RSME) was used in the second driving simulator experiment (Zijlstra & Van Doorn, 1985). The RSME was chosen over the NASA-TLX as the unidimensional rating scale is more easily administered and has been extensively applied using Dutch respondents. The verbally labelled rating scale consists of a 15cm long line where the labels are placed at varying intervals along the line, based on the psychophysical scaling method employed by Zijlstra and Van Doorn (1985). Participants were asked to indicate the level of subjectively experienced mental effort by placing an "X" anywhere along the scale (not necessarily next to a label).

Driver Behaviour Questionnaire

The Driver Behaviour Questionnaire (DBQ) is a questionnaire consisting of different types of risky behaviour in traffic. The questionnaire is based on the theory put forward by Reason et al. concerning errors and violations in driving (Reason, Manstead, Stradling, Baxter, & Campbell, 1990). It includes violations, rule-based mistakes, knowledge-based mistakes, but also slips and lapses.

Many studies have used the DBQ and many different versions exist. The version used in the research for this thesis was a Dutch version which has been previously used in a large cross-cultural study (Lajunen, Parker, & Summala, 2004; Ozkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006). The questionnaire consists of 28 items, which can be answered using a 6-point scale ranging from "0" (never) to "5" (nearly all the time) indicating how often a participant commits the mentioned behaviours when driving. The results of the DBQ can be used to categorise participants as, for example, “violators” or “erroneous drivers” and link this with behaviour observed in the driving simulator.

3.4. Conclusion

Sections 3.2 and 3.3 have discussed a wide range of research methods varying from the more qualitative end of the spectrum to the more quantitative end, corresponding to the extent to which the research was explorative. A selection of the discussed methods and measures was included in the research conducted for this thesis. The specific use of all of these research methods & measuring instruments will be described in Chapters 4 to 6.

4. Expectancy at intersections: explorative studies[4]

4.1. Introduction

In Chapter 2, the importance of expectancy as a concept when studying interaction behaviour in driving was emphasized. In the model of interaction behaviour presented in that chapter, a distinction was made between short and long term expectancies. Long term expectancies correspond to a general idea of what will happen in a certain type of situation. Subsequently, information from the situation at hand is used to adapt this general idea into a more specific short term expectancy concerning the developing situation. To further explore the concept of expectancies in the interaction process, the research discussed in this chapter used two different qualitative techniques, which were discussed in the previous chapter. Based on the results of the explorative research discussed in this chapter driving simulator studies were designed and conducted (Chapters 5 and 6). The use of the two different qualitative techniques in this chapter was founded on the notion that if the results of both techniques are in agreement with each other, this would provide a more solid base for the design of the simulator studies. Thus, the explorative research in this chapter was aimed at providing focus for the driving simulator studies.

First of all, the concept mapping technique was applied using two groups of respondents, resulting in two conceptual maps of the respondents' expectancies. Concept mapping starts with a concept generation phase in which responses are

[4] This chapter is based on several conference proceedings and a journal article discussing the concept mapping study (Houtenbos, 2004, 2005; Houtenbos, Hagenzieker, Wieringa, & Hale, 2005a, 2005b, 2005c; Houtenbos, Jagtman, Hagenzieker, Wieringa, & Hale, 2005).

generated by respondents who are triggered by relevant situations or stimuli (Jackson & Trochim, 2002, discussed in the previous chapter). In this case, the object of a relevant situation or stimulus would be an interaction situation at an urban intersection. However, the best method to present the stimulus in such a way that it would elicit a broad range of aspects that can be relevant in expectancies in interaction is not that straightforward. For example, the respondent could be presented with a verbal description, a photograph or video images of an interaction situation or the respondent could even be asked to drive through several intersections (virtually or in real life).

In traffic research, both still pictures and video fragments have been used (e.g., Finn & Bragg, 1986; Renge, 2000; Vogel, Kircher, Alm, & Nilsson, 2003). The choice for either method seems to depend largely on the objective of the study. For example, in a study that aimed to determine the effect of driving experience on understanding other road users' formal and informal signals, Renge (2000) used still pictures of traffic scenes. He points out that a field experiment would not allow for the same level of control over situation-specific elements as the use of either video fragments or still pictures. Also, he argues that video fragments (that include vehicle movements and other situational changes) could distract the respondent who should be focusing on the signals conveyed in the presented situation. In contrast to the method chosen by Renge (2000), Vogel, Kircher, Alm and Nilsson (2003) used video fragments of traffic scenes in an experiment to determine factors that influence the skill to predict the development of a traffic situation. As information concerning speed and the development of the situation over time was deemed necessary to predict the future development of the situation, Vogel et al. decided on using video fragments. Also, Vogel et al. (2003) state that moving scenes instead of still pictures were used to allow the respondents to become more immersed in the situation.

The study reported in this chapter is not as focused on a specific aspect of the driving task as in the studies of Renge and Vogel et al, but has a more explorative nature. Thus, it was eventually decided to use both stimulus types (i.e., still pictures as well as video fragments). The concept generation phase involved presenting respondents with stimuli on an internetsite. Presenting still pictures online was considerably less complicated than presenting video fragments online without noticeable hesitations, which is why the first study included only still pictures as stimuli. After having gained experience with online presentation of stimuli, it was decided to repeat the concept generation phase using (very short) video fragments to see if more or different aspects would be generated.

The aim of the explorative research was to explore the concept of expectancy in general (within the urban intersection situation), rather than focus on a specifically configured interaction situation. Thus, to prevent the results taking a too limited view of the concept of expectancy, the stimuli used in this research were intended to show sufficient variation. It is plausible that variation in stimuli will induce different types of expectancies. Varying the complexity of the stimulus-situation allows for variation while staying within the fixed boundaries of the specific interaction situation.

In several other studies, the complexity of the traffic scene was varied (e.g., Nunes & Recarte, 2005; Vogel, Kircher, Alm, & Nilsson, 2003; Ward, Parkes, & Crone, 1995). For example, Ward et al. (1995) defined complexity as "a greater variation in size, colour, contour and number of elements". Based on this definition, traffic scenes to be included in the experiment were rated on their level of complexity (i.e. low, moderate or high) as was the case in the study by Vogel et al. (2003). However, Vogel et al. (2003) did not indicate how complexity was rated, but only mentioned it was rated by "two independent observers". Nunes and Recarte (2005) state that anticipating trajectories and actions of other road users increases complexity. This implies that an interaction situation which involves more interaction partners or an intersection which has more branches would also increase complexity, as more trajectories and actions should be anticipated. Also, increased complexity is mentioned in a similar context as increased processing demands (Nunes & Recarte, 2005), implying that aspects which can be assumed to increase processing demands might also imply a more complex situation. Jahn, Oehme, Krems and Gelau (2005) also place complexity in the same context; as the extent to which a situation in traffic is demanding. In their experiment, they classified traffic situations based on the demands they placed upon the driver in terms of information processing and vehicle handling, resulting in "high demand" and "low demand" situations. A complex intersection is mentioned as an example of a high demand situation, whereas a situation that allows free driving (i.e. without interactions with other road users) is mentioned as an example of a low demand situation. Similarly, complexity has been defined as the amount of information which should be taken into account simultaneously (Twisk & Hagenzieker, 1993). Based on that definition, a T-junction is assumed to be less complex than a four-way intersection. These ideas were incorporated into the coding of complexity used in this study, as described in Section 4.2.3 below.

In summary, the main objectives of the explorative study discussed in this chapter were to investigate which aspects are mentioned in expectancies of interaction situations (at urban intersections) and to learn more about the effect of using either still pictures or video fragments on the expectancies that are reported. It should be noted that the concept of complexity was used to select a varying range of stimuli to be included in this research. The effects of complexity on the content of expectancies were not so much of interest.

4.2. Method

4.2.1. Design

This study consisted of two stages. In the first stage, respondents were presented with still pictures and in the second stage with video fragments. In both stages, expectancies were elicited using the abovementioned stimulus types (i.e. concept generating). The Still picture stage also included respondents sorting the expectancies (i.e. concept sorting), which the Video fragment stage did not. After the Video fragment stage, expectancies generated in both stages were qualitatively analysed to investigate the expectancies in greater detail and to determine the effect of the type of stimulus used.

4.2.2. Respondents

Respondents for this study were approached by placing an advertisement in local newspapers. In this ad, an internet address was provided where respondents could find information and also start with the study immediately.

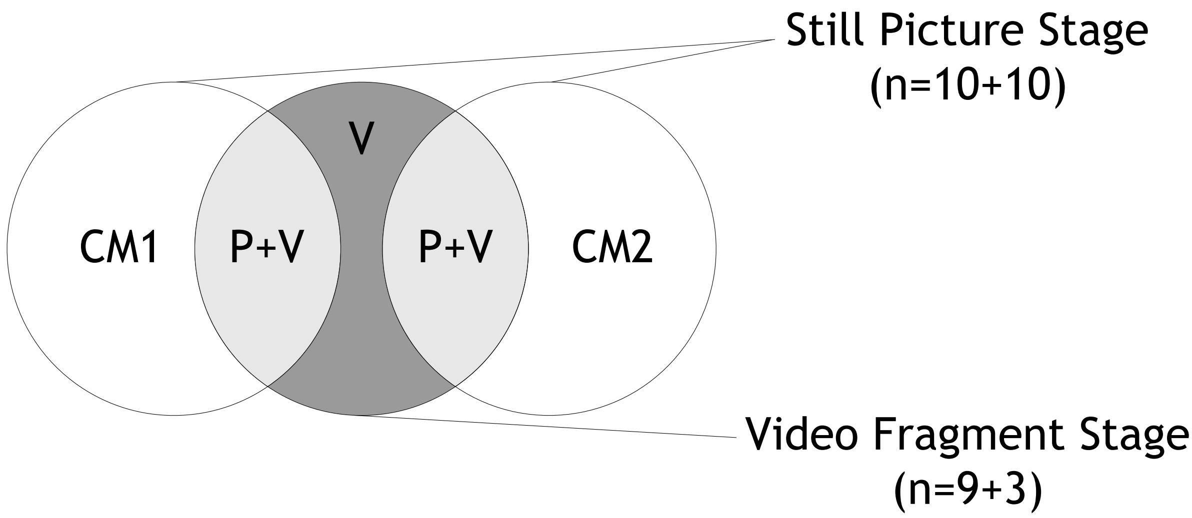


Figure 4.1: Respondents per stage

As indicated in Figure 4.1, the Still picture stage used two groups of ten respondents who completed the two phases of the concept mapping approach (CM1 & CM2). Respondents who completed the concept sorting phase in the Still pictures stage were paid € 15. After a few months, all respondents who had participated in the Still picture stage were invited to take part in the Video fragment stage. Nine respondents accepted the invitation and were thus also presented with video fragments (V) after having been presented with the still pictures (P) during the prior stage (Figure 4.1). As this P+V group was smaller than expected, an advertisement was placed in the university paper to recruit some extra respondents resulting in an additional 3 respondents taking part in the Video fragment stage (i.e., V group).

Although it was not an objective of the study to ensure that the sample should be a random cross-section of all drivers, creating two similar respondent groups was considered important. When using two groups that are similar with respect to the variation in age and driving experience, differences between the results are less likely to be caused by differences between the two respondent groups, and can thus be attributed to differences between the presented interaction situations. To create the respondent groups, respondents were asked to indicate their mileage by selecting one out of the following five categories: 1 (0 – 5000 km/yr), 2 (5000 – 10000 km/yr), 3 (10000 – 15000 km/yr), 4 (15000 – 20000 km/yr) and 5 (20000 km/yr or more). For selection purposes, the number of years since receiving their driver's license was recoded: 1 (0-15 yrs), 2 (15-30 yrs) and 3 (30 yrs or more). Table 4.1 shows that the two Concept Mapping (CM) groups had a similar distribution of age, mileage and the number of years since receiving a driver's license. In both CM groups, sex was evenly distributed (50 % of the respondents were male).

Table 4.1: Descriptive statistics for respondents in the Still picture stage

	CM 1 Group (n=10)			CM 2 Group (n=10)		
	Age (yrs)	Mileage category	Driver's License category	Age (yrs)	Mileage category	Driver's License category
Mean	45.40	3.50	2.10	46.40	3.40	2.00
Std. Deviation	13.75	1.58	0.88	15.12	1.43	0.82

Table 4.2: Descriptive statistics for respondents in the Video fragment stage

	P+V Group and V Group together (n = 9 + 3 = 12)		
	Age (yrs)	Mileage category	Driver's License category
Mean	41.00	3.75	1.92
Std. Deviation	14.16	1.48	0.90

The Video fragment stage included 9 respondents from the Still picture stage and 3 relatively young respondents, who were additionally recruited. The resulting respondent group ([P+V] + V) was, however, still quite similar to the CM group (Table 4.2) although the gender distribution was not equal. The P+V group included five female respondents, and the V group included one.

4.2.3. Stimuli

The stimuli for the concept generation part of this study were developed by recording video images of the approach to a number of (urban) intersections from within a moving car. These recordings were then extracted and searched for interaction situations. Interaction situations were defined as situations in which some kind of decision regarding the course of the situation needed to be made by one or more of the road users involved in the situation. Eventually, 17 interaction situations were selected and still pictures were extracted from the video recordings for use in the Still picture stage of the study.

As indicated in Section 4.1, varying the complexity of the situations is assumed to increase the types of aspects mentioned in the expectancies. Similar to the way in which complexity scores were assigned to intersections by Twisk and Hagenzieker (1993), the still pictures for the first stage of this study were rated on 6 aspects in order to assess the variation in complexity of the situation.

1. Number of interaction partners.
   - ❖ Rated "one" or "more" corresponding to a "less" or "more" complex situation
2. Number of different types of interaction partners
   - ❖ Rated "one" or "more" corresponding to a "less" or "more" complex situation
   - ❖ The types or interaction partners were cyclists, pedestrians or car drivers. Each situation involves at least one car driver as an interaction partner.
3. Number of branches of the intersection that interaction partners could possibly come from
   - ❖ Rated "few" or "many" corresponding to a "less" or "more" complex situation
   - ❖ A T-junction is an example of "few", whereas a 4-way intersection would be rated as "many".
4. Is it an intersection without any designated priority?
   - ❖ A priority intersection or an intersection with traffic lights corresponds to a less complex situation, whereas an intersection without any designated priority is considered a more complex situation.
5. How many pieces of static information regarding right of way can be found in the still picture?
   - ❖ Zebras, triangular markings and traffic signs would each be rated as one piece of static information regarding right of way.

- ❖ No inferences are made about the effect of the amount of static information on complexity. However, this rating aspect was included to select situations that included both relatively little static information and situations that included relatively many pieces of static information.

6. Should the 'respondent's car' give right of way according to traffic rules?
   - ❖ This aspect was also included to select situations with maximum variation.

Finally, in order to achieve a set of stimuli which showed a considerable degree of variation (mainly in complexity), ten still pictures were selected based on the abovementioned aspects (Appendix E). Pictures of situations where a roundabout was involved were excluded. This exclusion resulted from the fact that the still picture made on a roundabout did not display the roundabout features clearly enough. Consequently, respondents would not be able to tell that the picture was made on a roundabout and would not be able to judge the situation in the correct context.

Appendix F shows the still pictures selected. The video fragments used in the second stage of this study were quite short clips (10s) ending with the corresponding still picture used in first stage. This picture remained on screen as the respondents typed in their expectancy. The still pictures and video fragments were presented on the respondents' own computer screen, as this study was conducted online.

4.2.4. Procedure

The Still picture stage of this study followed the concept mapping approach which consists of two phases. During the first phase, concepts (in this case, expectancies) were generated, which were subsequently sorted in the concept sorting phase. For more details on this technique, please refer to Chapter 3. The Video fragment stage only used the first phase; that of concept generation, the results of which were only qualitatively analysed to see if more or different aspects would be generated using dynamic stimuli rather than static stimuli.

In both the Still picture and the Video fragment stage, respondents could start with the study immediately upon arrival on the website. First, respondents were asked to fill out a form with personal information (name, address, age, sex and information concerning their driving experience). After completing the form, the concept generation phase of the study commenced. Respondents were presented with the 10 still pictures or video fragments in random order and were asked to answer the following two questions for each situation (in Dutch):

- ❖ What do you expect will happen here?
- ❖ Why do you expect that?

Respondents typed their free text answers into a space below the stimulus which allowed for an unlimited amount of words.

Depending on the stage of the study, concept generation was either the only task for the respondents (i.e. in the Video fragment stage) or the respondents were additionally invited to take part in the concept sorting phase of the study (i.e. in the Still picture stage of the study).

Before the concept sorting could commence, the free text answers provided during the concept generation phase of the Still picture stage of the study needed to be transformed by the researcher into uniform units of analysis. In this study the chosen format for the units of analysis was an 'if…, then…' statement. The if-then statements fit the two questions the respondents answered (mentioned above). The 'why'-question corresponds to the 'if'-part of the statement, whilst the 'what'-question corresponds to the 'then'-part of the statement. Also, the if-then statements correspond to driving behaviour modelling using "production-rules" (Michon, 1989). See Table 4.3 for an example (derived from the pilot study).

Table 4.3: Example of creating a unit of analysis

Original response	'If…, then…' statement
Decrease speed or even stop before the VW Golf crosses the road.	If a car is starting to cross the road, then I will decrease speed or even stop.

A pilot study preceding the actual study showed that 8 pictures brought up about 25 statements per person. It would not be feasible to expect the respondents in the second phase of the study to sort several hundred statements. For each respondent, ten if-then statements were therefore selected (one statement per situation was randomly selected), resulting in a total of 100 statements per concept mapping group (10 respondents and 10 situations).

These respondents completed the concept sorting phase at either SWOV Institute for Road Safety Research or Delft University of Technology (whichever was more convenient for the respondent). Respondents were presented with all statements printed on cards (100) as well as all pictures (10) presented in the concept generation phase. The cards showed one statement each and were printed on the same colour paper as the corresponding picture (from which they had been generated). The pictures were provided in order to help the respondents understand the situation described in the statement. Take for example the following statement (derived from the pilot study): 'If I see this type of car, then I'm usually more careful when approaching the intersection'. Without the picture the respondent would not be able to know what exactly is meant by this statement. Respondents were subsequently asked to sort the cards according to their own judgment considering their similarities. They were also required to label each category of statements to reflect the contents of the sorted piles.

4.2.5. Qualitative data analysis

All responses provided by the P+V group and the V group were analysed using a coding scheme that contained a large collection of variables. Developing the coding scheme was an iterative process which involved coding subsets of responses and adjusting both the coding scheme and variable definitions. The first version of the coding scheme was based on the concept mapping results, including variables corresponding to clusters found in the HOMALS solutions. The final version of the coding scheme consisted of several sections (Appendix G). The first section identified the response in terms of the corresponding respondent, situation and stimulus type. The second section included items that related to the road users involved in the expectancy. The third section focused on the actions referred to in the expectancy from the own or from other road users' point of view. The content of these phrases proved difficult to code reliably (see the section below on reliability issues and was also largely covered by other variables in the coding scheme (such as the variables in the fourth section). Therefore, it was decided to leave the section containing "actions" out of the further analysis of the (coded) expectancies and out of the appendix. The fourth section coded descriptions of different types of aspects that were mentioned in the expectancy. Aspects included the position and movements of road users, characteristics of the infrastructure and the rules applying. The fifth section focused on yielding behaviour described in the expectancy, whilst the final section focused on expectancies that indicated uncertainty or mentioned a certain level of vigilance.

Reliability Issues

The degree of interrater reliability has important implications for the validity of the results of the study (Stemler, 2004). If two raters could not reliably code the responses, any subsequent analyses would yield meaningless results. To assess the reliability of the coding scheme, a second rater coded a random subset of seven expectancies generated by the P+V group or V group. Items that required a phrase as entry rather than a numerical value, were recoded, to facilitate overall comparison of both raters' entries. For example, the items in Section 4 (Appendix G) were coded "0" when the field was left blank and "1" when an entry was made. Items that only required the rater to copy the entry from the sheet of responses (i.e. Section 1: Situation & RandomCode) were left out of the comparison to prevent overestimation of reliability. The datafile consisted of the raters as columns (i.e. 2 columns) and the items of all seven coding schemes as rows (i.e., 56 items * 7 coding schemes = 392 rows).

Pearsons correlation indicated that the raters coded the responses consistently ($r=.901$, $N=392$, $p< .001$). As a correlation does not indicate the consensus between two raters, the percent of agreement was also determined. Taking all entries for the seven coding schemes together (i.e. 392), only 35 instances of disagreement were found, resulting in 91% agreement. Of these disagreements, 10 were accounted for by variables in the "action" section of the coding scheme, which were not included in further analysis. The other instances of disagreement seemed rather random.

As many items of the coding scheme had binary codes (0/1), this could have caused overestimation of reliability. An alternative measure for consensus is Cohen's kappa, which is based on the percent agreement measure, but corrected for the amount of agreement expected by chance alone (Stemler, 2004). Cohen's kappa also indicated considerable agreement (Cohen's kappa=.803, p<.001). In conclusion, both the measure of consistency as the measures of consensus indicated that the coding scheme can be considered a reliable instrument.

4.3. Results

The following section will first discuss the concept mapping results. After that, the results of the qualitative analysis of the expectancies of the P+V group and V group will be discussed.

4.3.1. Concept mapping

For each concept mapping group, all respondents (n=10) sorted all statements (100 per group), of which ten statements were based on their own expectancies generated in the concept generation phase. This was done to control for the amount of interpretation needed to sort statements based on expectancies of other respondents. Combining all respondents into one concept mapping group (n=20) would either entail that they would have to sort 200 statements (i.e. 2 x 100 statements) or that a smaller proportion of the statements to be sorted would be based on their own expectancies. Neither option is desirable. The first option would involve a sorting task that is much too cumbersome for the respondents. The second option would involve an uneven distribution of situations within the statements based on respondents' own expectancies. In the chosen procedure using two concept mapping groups, each respondent sorts one statement per situation (i.e. still picture) that is based on their own response.

Per concept mapping group, the results for each respondent were entered into an SPSS data table. A HOMALS Analysis (Homogeneity analysis by means of alternating the least squares) was performed to identify clusters of expectations and discover patterns in the way they were categorised by the respondents. It should be stressed that this approach is mainly explorative. Thus, no hypotheses were tested here. A more detailed account of the HOMALS data analysis technique can be found in Chapter 3.

CM 1 Group

The results of the HOMALS analysis using the data for all the statements of the first CM group, showed two outliers, both of which involved ‘speed bumps’ (statement nr. 17 and 54). The fact that these statements were displayed as outliers in the original solution is probably caused by the focus of these statements. Speed bumps are not particularly relevant to interaction situations in general, but were mentioned in several statements because some of the photographed situations included speed bumps. Due to the specific character of speed bumps the statements including speed bumps were probably difficult to put together with other statements and were thus placed in separate piles. These statements were therefore left out of the final HOMALS solution as they complicated the interpretation of the results. The HOMALS solution without statement nr. 17 and 54 can be found in Figure 4.2 and had a moderate fit (0.48 + 0.40= 0.88). As mentioned in Chapter 3, the maximum fit for a solution with two dimensions is 2.00. However, the interpretability of the solution is commonly seen as more relevant than goodness of fit. For a (random) selection of translated statements, see Appendix H (the original statements were in Dutch). Visual inspection of the solution and all statements involved allowed the researcher to discern four clusters (Figure 4.2). For the reader's convenience, the boundaries of each cluster as well as their labels, were manually added to the solution provided by SPSS.

In the rather large cluster of statements that included ‘right of way’, a distinction can be made between statements that address ‘giving right of way actively’ (which are found more to the right of the graph) and statements that address ‘someone else taking right of way’ (which are found mainly to the left of the previously mentioned statements). This distinction implies that the first dimension of this HOMALS solution could be interpreted as a varying point of view (from ‘other’ to ‘self’). The cluster labelled ‘indication of direction of travel’ mainly includes references to behaviour of other road users which supports the suggested interpretation of the first dimension.

The distinct cluster at the top of Figure 4.2 contains statements that address uncertainty about the (safe) development of the situation. They include waiting to see how things will develop, watching out and anticipating problems concerning the safe development of the situation. The statements on the other end of the second dimension (in the cluster labelled 'indication of direction of travel') are often just observations that do not indicate uncertainty. The second dimension could therefore be interpreted the level of uncertainty about the (safe) development of the situation.

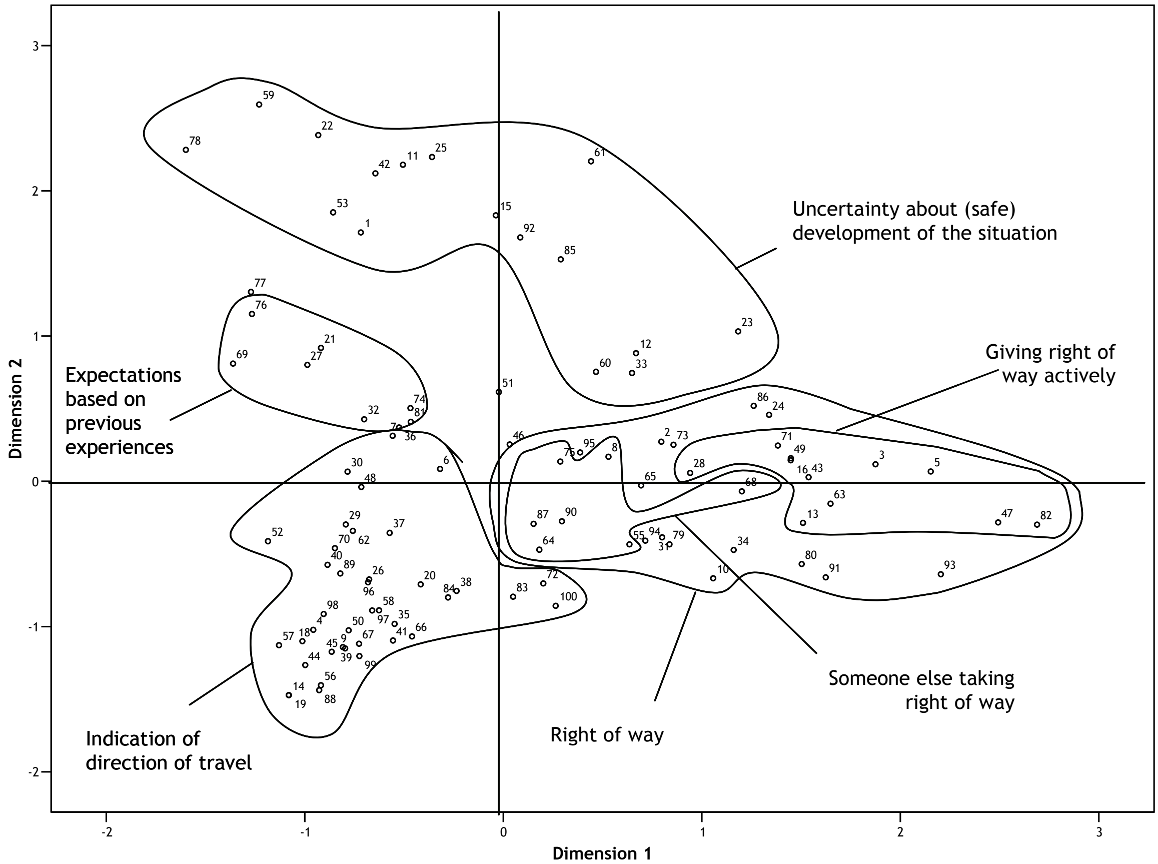


Figure 4.2: Concept map for CM 1 Group

Another large cluster includes statements addressing the direction in which road users are travelling. Again, several subclusters can be distinguished, like the cluster of statements that address 'continuing to drive in the present direction'. Also, statements addressing different ways of indicating the direction of travel are placed in close proximity to each other. These indicators include: the exact position of the vehicle on the road, the gaze direction of cyclists, driving speed and the way the previous distance has been covered. The statements in this cluster provide important information about what clues road users use to infer where other road users will be in the near future.

The (small) cluster in the top left quadrant of Figure 4.2 contains statements that address expectations that are clearly based on previous experiences (e.g. prototypical behaviour of certain types of road users or in particular situations) corresponding to the definition used in Chapter 2 for long term expectancies. All four clusters are identified in Figure 4.2.

CM 2 Group

The results of the HOMALS analysis for the second concept mapping group (CM 2 Group) were also searched for outliers. Two statements were left out of the final solution, which shows five clusters (Figure 4.3). These two statements (from the same respondent) included references to other traffic approaching with higher speed. For some reason, it seems that these statements were not interpreted unambiguously by the group of respondents and so were not consistently clustered. The final solution had a moderate fit (0.55 + 0.37= 0.92).

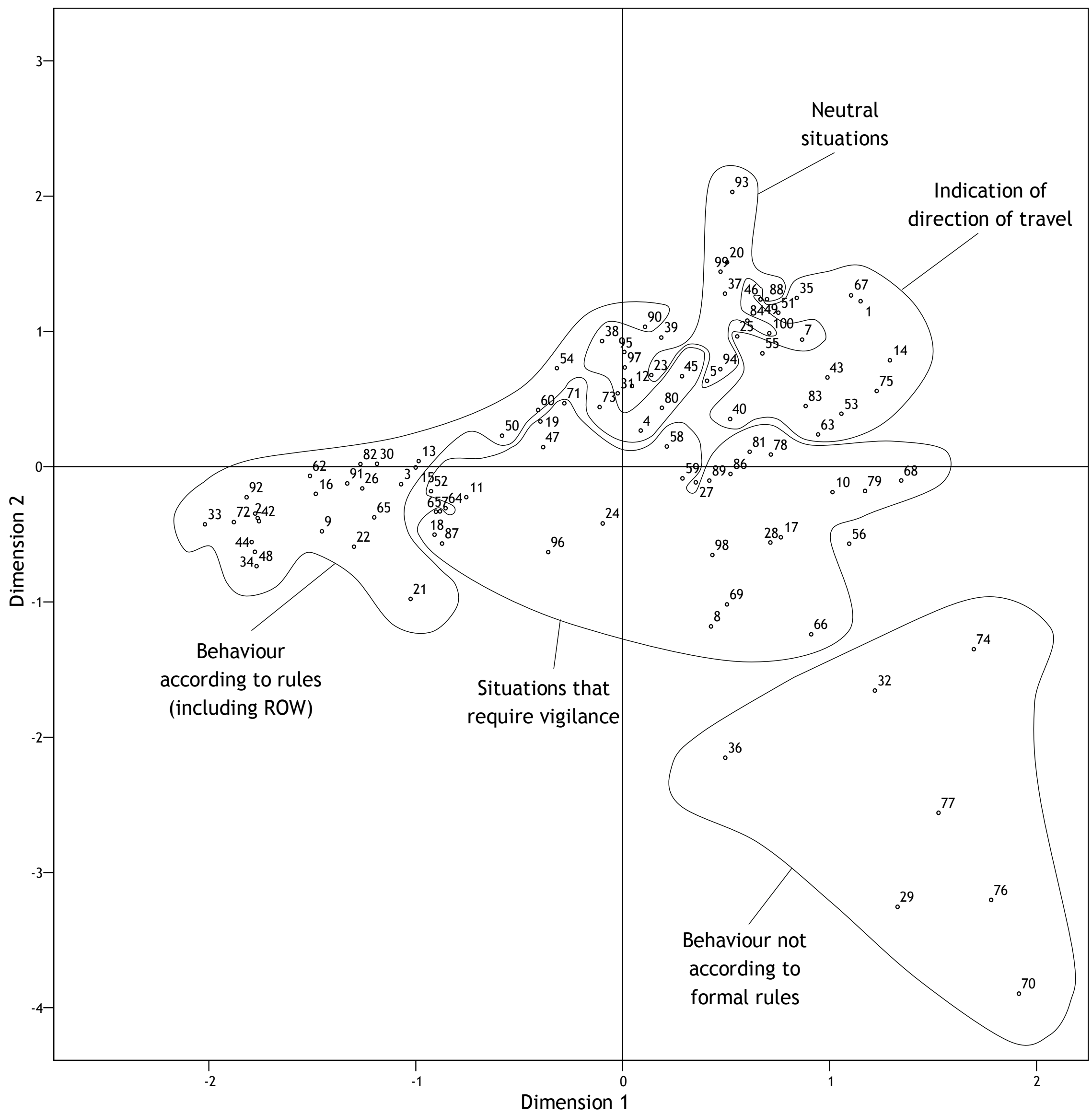


Figure 4.3: Concept map for CM 2 Group

Starting at the left of Figure 4.3, the first cluster includes statements that refer to behaviour according to rules that apply in the presented situation, and thus including many statements that explicitly refer to right of way. For example "If I approach an intersection without any designated priority, then traffic from the left will have to give me priority".

A second cluster contains statements that refer to situations that require vigilance. Phrases such as “unclear”, “uncertain” and “watching out” are mentioned. An example: "If the white car continues on his way, he will have to watch out for crossing pedestrians".

The cluster at the bottom right of Figure 4.3 includes statements that refer to behaviour that is not according to the formal rules that apply in a certain situation. This can vary from behaviour that is interpreted as wrong or antisocial, to references to behaviour according to informal rules.

The three abovementioned clusters cover the range of the first dimension, which might be interpreted as a varying application of the rules to the situation. On the negative end of the first dimension, statements are found which refer to behaviour according to the rules, whereas the statements in the last mentioned cluster refer to behaviour which is *not* according to the rules.

Another cluster in the top right quadrant contains statements that explicitly refer to direction of travel with phrases such as “turning left/right”, “continuing on one’s way” and “making a U-turn”. The cluster at the top of Figure 4.3 includes statements that refer to neutral situations, in which “nothing” is expected to happen. Statements include phrases such as “nothing will happen”, “I don’t expect any problems” and “nothing special will happen”. These two clusters both refer to relatively neutral situations in which nothing unexpected happens and can be found on the positive end of the second dimension. This could imply that the second dimension reflects a certain degree of uncertainty concerning the way the situation will develop. On the negative end of the second dimension are statements that refer to situations that require vigilance and more extremely, statements that refer to behaviour which is not according to the rules. These could be interpreted as being less certain than the situations referred to in the top half of the figure.

Comparing the two concept maps

The HOMALS solutions or "concept maps" generated using the sorting data of the two concept mapping groups show both differences and similarities. The HOMALS solutions are the result of an iterative optimization processthat aims to depict similar statements (i.e. often sorted in the same pile) close together and different statements (i.e. not often sorted in the same pile) far apart. The physical position on the top, bottom, left or right of the figure is arbitrary; the figure could just as well have been mirrored. Interpretation of the solution should focus on the relative positions of statements, rather than on their absolute positions. It should be noted that the two solutions do not relate to the same 100 statements, as the respondents only sorted statements based on the expectancies by members of their own concept mapping group. Thus, differences between the two solutions can be caused by differences in the two sets of statements to be sorted. Similarities found between the solutions can be interpreted to mean that the aspects mentioned there are generally relevant in expectancies of interaction situations at urban intersections.

In both solutions a cluster was found that included references to right of way. The clusters did, however, show some differences. In the first solution, the references to right of way could be further classified according to the perspective taken in that particular statement ('other' vs. 'self'). In the second solution, the cluster focused mainly on behaviour in traffic according to rules that are applicable in that situation and obviously, the right of way rule was mentioned quite often.

Another set of clusters that show similarities are the clusters labelled "uncertainty about (safe) development of the situation" (in the 1st solution) and "situations that require vigilance" (in the 2nd solution). In both clusters statements can be found that include phrases such as "unclear" and "wait and see". The cluster in the first solution includes more statements that focus on uncertainty regarding the way the situation will develop, whereas the cluster in the second solution includes more statements that focus on the need to watch out in that particular situation.

Both solutions included a cluster labelled "indication of direction of travel", although the cluster in the first solution is much larger than in the second. This could be caused by the different set of statements sorted by each group.

In conclusion, it seems the two concept maps of expectancies in interaction situations at urban intersections show distinct similarities, relating to priority, rules and uncertainty and direction of travel. These similarities will be used in the qualitative analysis of the expectancies discussed in the following section.

4.3.2. Qualitative analysis

After the Video fragment stage, the expectancies generated by the P+V group when presented with still pictures and video fragments as well as the expectancies generated by the V group when presented with video fragments were qualitatively analysed. Thus, a total of 210 (180+30) expectancies were analysed. The HOMALS results were used to guide the qualitative analysis by including items corresponding to the similar clusters in both concept maps (described in the previous section) in the coding scheme. The qualitative analysis is expected to provide more insight into the expectancies by focusing on the role of the aspects mentioned in similar clusters found in the HOMALS solutions. Using the coding scheme, it was possible to indicate how often certain aspects were mentioned and if that aspect was mentioned more often in response to a particular situation or in a response to a particular stimulus type (still picture or video fragment). For example, we can test if phrases indicating uncertainty are found less in expectancies generated by video fragments, which could be explained by the extra ten seconds of information that could potentially reduce uncertainty.

In Chapter 2 a concept model of driving behaviour in interaction was introduced. In this model, two types of expectancies are distinguished: short term expectancies and long term expectancies. The qualitative analysis will furthermore try to determine whether this distinction expresses itself in the short and long term expectancies of the respondents..

Although complexity was not entered into this study as an independent variable, the results will be explored to reveal any indications of an effect of complexity. Comparing situations which were assumed to be more complex with situations that were assumed to be less complex, might provide indications of an effect of complexity.

Due to the rather detailed coding scheme, counts per variable were often too low for meaningful statistical testing. Thus, for different sections of the coding scheme (Appendix G) variables were counted and visually explored. Some responses were too short (e.g., "No idea") or just left empty by the respondents and were consequently excluded from counting and visual exploration (n=6). An overview of relatively high or low counts for coding scheme variables per situation can be found in Appendix I.

Items indicating aspects mentioned in the expectancy

Figure 4.4 provides an indication of the frequency with which coded aspects in Section 4 of the coding scheme were mentioned in expectancies and shows only aspects that were found in at least 25% of the expectancies. These aspects will be discussed in more detail in the following section. The aspects which were found in less than 25% of the expectancies can be found in Table 4.4. The fact that these aspects were mentioned less often than the other aspects can be partly explained by the fact that at least some of them are rather specific (e.g., "traffic lights" or "position of the wheels"), whereas the aspects in Figure 4.4 focus on a more general level (e.g., "infrastructure" or "position"). Furthermore, phrases such as "triangular road markings" were coded for the aspect "Right of way" but also for the aspect "Road markings" and thus included in Figure 4.4. As the aspects in Table 4.4 were not mentioned that often, it was decided to focus on the set of eight aspects that were mentioned in at least one out of four expectancies.

Within each of these aspects, the data was visually explored for subclusters, using the pattern coding technique described in Chapter 3. Not all instances of a certain aspect could be assigned to a subcluster, and some instances were assigned to more than one subcluster. In the discussion on the different subclusters, references are made to particular situations, of which the pictures can be found in Appendix F.

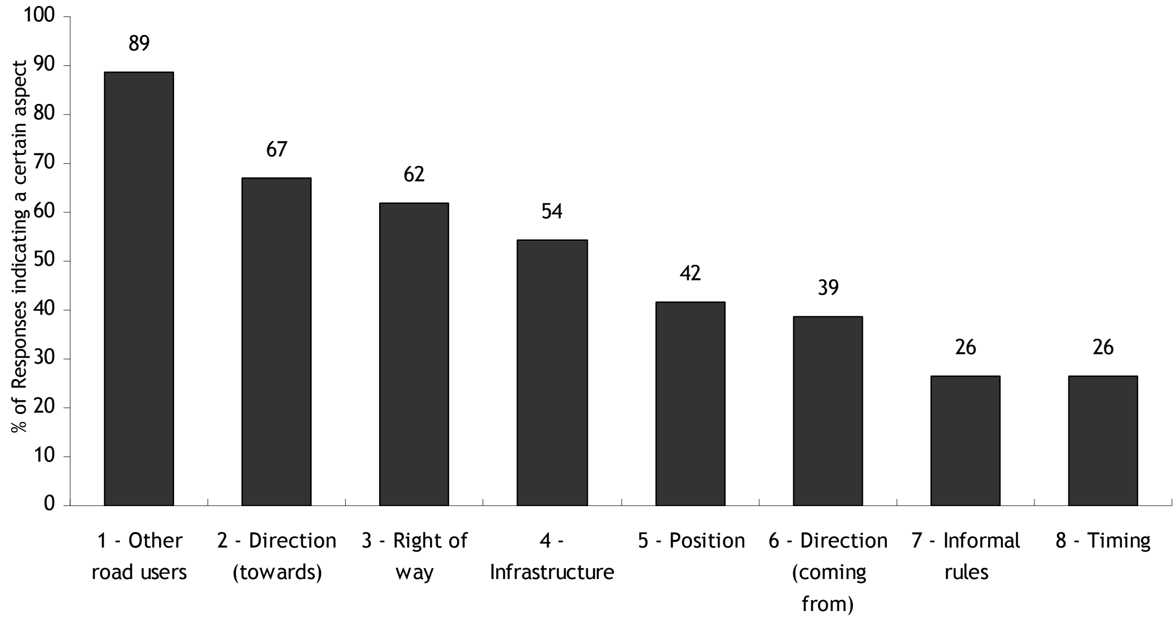


Figure 4.4: Aspects mentioned in at least 25% of the expectancies (N=204)

Table 4.4: Aspects mentioned in less than 25% of the expectancies (N=204)

Aspect	Number of times mentioned (%)
9 - Occupation of the road (busyness)	23 (12%)
10 - Formal rules (except for right of way)	19 (10%)
11 – Traffic signs	17 (9%)
12 - Hindering/Obstructing	17 (9%)
13 – Other aspects (Residual category)	16 (8%)
14 - Speed	15 (8%)
15 - Road markings	14 (7%)
16 - Being visible to others	10 (5%)
17 - Traffic lights	7 (4%)
18 - Not indicating direction	7 (4%)
19 - Position of the wheels	4 (2%)

1 - Other road users

References made to other road users were made in the majority of expectancies (181 out of 204) and could roughly be grouped into two clusters which relate to the distinction made in Section 2 of the coding scheme. This distinction focused on road users being mentioned either specifically or in general. When respondents refer to traffic in general in their expectancy (e.g., "traffic approaching from the left"), this could be interpreted as a reference to a long term expectancy. Similarly, when referring to road users in a more specific way (e.g., “the yellow car”), this could be interpreted as an element of a short term expectancy, which incorporates specific elements of the situation at hand. This distinction in the respondents’ verbalisations of their expectancies in interaction situations supports the idea of the distinction made between long and short term expectancies in the model proposed in Chapter 2.

To determine which situational elements have an effect on whether a respondent mentions specific road users or rather road users in general, a cross tabulation was made of expectancies per situation that included 'only specific road users', 'only road users in general', an even count or expectancies in which no other road users were mentioned at all. Situations 2 and 3 show a similar pattern: relatively high counts for 'only specific road users' (14 and 16 counts respectively) and relatively low counts for the other categories. Situations 1 and 4 also showed patterns similar to each other: relatively high counts for 'only road users in general' (10 and 11 counts respectively) and lower counts for 'only specific road users'. Perhaps the fact that specific road users are mentioned more often in Situations 2 and 3 can be explained by the relevance of these road users (from the respondent’s point of view). In Situations 2 and 3 the probability of a conflict with specific road users (taking proximity in time and space into account), seems higher than in Situations 1 and 4. In Situations 1 and 4 it is more likely that the specific road users will have passed the intersection by the time the respondent will reach the intersection, making these specific road users less relevant.

Another two situations that seem to be similar to each other are Situations 7 and 8, which show equal counts for 'specific road users' and 'road users in general' (9-9 counts and 7-7 counts respectively). An explanation could be that mentioning specific road users rather than road users in general is a personal tendency. However, a cross tabulation did not indicate such a relationship. Perhaps respondents randomly chose to articulate their expectancies in Situations 7 and 8, focusing either on specific road users or on road users in general.

2 - Direction (towards)

To further specify the aspects referring to direction of travel (a cluster found in both HOMALS solutions), three corresponding aspects were coded in the expectancies. The first one, 'direction towards', is discussed here. In 137 (out of 204) expectancies, aspects indicating a direction a road user is moving towards were mentioned. They could be grouped into three clusters. One cluster contains phrases which refer to the approach to elements of the infrastructure (e.g., “approaching an intersection” or “approaching a busy road” (45 counts)). Another cluster could be made containing phrases which refer to someone continuing on his/her way (55 counts). Examples include “just carrying on”, “continuing on my way” and “straight on”. A third cluster contains phrases referring to a particular manoeuvre, such as “turning right”, “turning left” and “crossing” (62 counts).

In a cross tabulation with Situation, Situation 2 stands out. Relatively high counts were found for both references to continuation of someone's way (16 counts) and for specific manoeuvres (21). Perhaps this can be explained by the fact that Situation 2 includes a relatively high amount of different road users travelling on different components of the infrastructure (e.g., the curb, a cycle-path, the road).

3 - Right of way (ROW)

In both HOMALS solutions a cluster was found containing references to right of way. Phrases recorded under "ROW" using the coding scheme could be grouped into three clusters. One cluster contains phrases indicating elements of the infrastructure that relate to right of way (33 counts). For example, "a priority intersection", "a zebra crossing" and "give-way road-markings". Furthermore, a cluster was identified that contains references to the right of way rule in a particular situation (70 counts). For example, "I will have to yield", "the cyclist has right of way". This cluster focuses more on the theoretical right of way rather than on what will actually happen. The latter is the focus of a third cluster, containing references to right of way regarding the actions that are expected. Examples include: "take right of way without hesitating" and "brake to let the other car precede".

Situation 2 shows a relatively high count for 'Action' together with a relatively low count for 'Rule' (12 and 2 counts respectively). Situation 2 includes many different types of (oncoming) road users. This could explain the relatively high count for phrases referring to which actions will be taken in this situation. The low count for 'Rule' might be explained by the fact that because of the oncoming road users, the most familiar right of way rule (priority to the right) does not apply in this situation. In contrast, Situation 0 shows a relatively high count for 'Rule' but also a quite high count for 'Action' (13 and 9 respectively). This situation shows a car, which is relatively near, approaching the intersection from the right. The car approaching from the right might have triggered the relatively high count of references to the way the situation should develop (according to the rules) as this is the prototypical situation in which to apply the priority to the right rule.

4 - Infrastructure

Out of 204 expectancies, 111 expectancies included a reference to an aspect of the infrastructure. To cluster the elements of the infrastructure mentioned, the context seems quite important. Based on the context in which the phrase was mentioned (i.e. the expectancy), references to infrastructural elements could roughly be clustered in two groups. The first cluster contains references to location, like, for example, "I have to turn right into the <u>side street</u>" or "Cars on <u>the road</u>…". These references to location could also be grouped into three subclusters, corresponding to past, present and future locations and thus also coded under "Direction (coming from)", "Position" and "Direction (towards)" respectively. The second cluster of infrastructural elements contains references to right of way such as: “priority intersection” or “an intersection with equivalent roads” and are consequently also coded under “ROW”. Thus, it seems that the majority of infrastructural elements are mentioned in the context of either location or right of way.

Infrastructural elements were also coded under “Number of static elements”. A distinction was made between explicitly mentioning the presence of static elements and explicitly mentioning the absence of a particular static element. An example of the latter would be: "I don't see any triangular markings so I assume it’s a junction without any designated priority". Although the static elements (presence and absence) were not mentioned all that often (32 and 10 counts respectively), Situations 1 and 4 show relatively high counts of static elements mentioned as being present (6 and 7 counts respectively), which might be explained by the fact that both Situations 1 and 4 indicate the approach to a speed bump. Situation 5 also includes a speed bump, but perhaps in a less conspicuous way. Speed bumps were mentioned to indicate location (“I’m approaching a speed bump”) as well as to indicate aspects relevant to the right of way situation (“I see a speed bump, which prevents that other road users will have to yield to me”).

5 - Position

Most references to position seem to include an element of the infrastructure (65 counts). For example, “on the main road” and “at the intersection”. Situations 6 and 8 showed relatively high counts for references to position including an element of the infrastructure (11 and 14 counts respectively). These included phrases such as "at the intersection" and "on the street" and do not, by themselves, convey very much information. A smaller cluster could also be distinguished that includes references to other road users (10 counts). For example, “to my right” and “behind the vehicle from the left” are indications of someone’s position relative to another road user’s position.

6 - Direction (coming from)

In 85 expectancies, a reference was made to the direction a road user is coming from. These expectancies could be categorized into 4 clusters of which 1 cluster contains references to the infrastructure (16 counts). The other clusters contain phrases that focus on “from the left” (24 counts), “from the right” (43 counts) and “from both/all sides” (16 counts). Situation 0 and 1 show relatively high counts for references to road users coming from the right. Both of these show another driver approaching the intersection from the right. In the Netherlands, a driver is required to yield to road users approaching an intersection from the right, making a road user from the right relevant in one’s expectancy of the situation as one is responsible for yielding to that driver. Situations 2 and 7 show relatively low counts for phrases relating to the direction a road user is coming from. This might also be explained by relevance. In these situations, the origin of the road users has less direct implications for the respondent's own actions than, for example, the direction towards which road users are travelling. The direction towards which they are expected to travel could be considered more relevant as this determines the likelihood of a conflict with these road users. Indeed, the highest counts for direction towards are found for Situations 2, 3 and 7.

7 - Informal rules

In total, 54 expectancies included a reference to an informal rule. The word “rule” implies that the described behaviour not only applies to the situation presented but to situations that are similar as well. Furthermore, “informal” implies that the described behaviour is not embedded in formal rules. That can occur if behaviour is against the rules but also when no formal rules are applicable to the situation. The majority of informal rules applied to the right of way (ROW) regulation (21 + 7 counts) and focused mainly on situations in which a road user takes into account that another road user may not behave according to the formal ROW regulations (21 counts). For example: “Car’s might not yield to me, as they are on a more important street, while I’m coming from a vague little street”. Other informal rules that included ROW focused on the expectation of road users to keep to the ROW regulations (7 counts). For example: “I assume that the car from the right will routinely take priority without hesitating”.

Other phrases indicating an informal rule focused on the continuation of behaviour (6 counts, e.g.: “the car from the left will proceed, because he is already on the intersection”) and the approach of other road users (9 counts, e.g.: “driving in a 30 km/h zone […] thus expecting traffic from all directions and children playing on the street”). Situation 7 showed the highest count for informal rules that take into account that another road user might not behave according to the ROW regulations. This situation shows a cyclist on a priority road and a car from an intersecting road approaching to enter the priority road. The relatively high count could be explained by the ambiguity of the situation: it is not clear if the car has enough time and space to enter the priority road without obstructing the cyclist. As it might not be clear if the formal ROW rule applies in this situation, this might induce informal rules.

8 - Timing

In 54 expectancies, aspects relating to timing within the interaction process were identified. Within these aspects, two clusters were distinguished, which seem to indicate two types of interaction situations. The first cluster includes references to situations where at least one interaction partner is required to take action, for example by waiting, braking or stopping (37 counts). In contrast, the second cluster includes explicit references to situations which do not require any of the interaction partners to do anything, because their relative positions and speeds will not pose a threat towards safe development of the interaction situation (12 counts).

This distinction implies that the decision to brake, wait or stop is relevant in road users' expectancies in this type of interaction situations. Striking is the fact that the actions referred to in these expectancies mostly relate to slowing down and thus to yielding. References to the opposite behaviour such as, for example, accelerating instead of braking are mentioned considerably less often. Thirty-seven instances of some form of yielding behaviour were counted versus five instances of taking priority, perhaps indicating the salience of the need to yield in unexpected situations.

Situation 0 showed a relatively high count for a road user needing to wait compared with the other situations. This could be explained by the fact that this situation shows a car approaching an intersection, which is rather close by, from the right, which calls for the respondent to yield. Other situations that include another driver approaching the intersection from the right were taken further away from the intersection, which leaves the respondent with more options concerning the way the situation is expected to develop.

Although the subcluster that included phrases indicating that nothing would happen was rather small (12 counts), Situations 5 and 8 show relatively high counts (4 counts). These situations are similar in that they both involve another road user approaching the intersection from the left. Their distance to the intersection was such that it is indeed plausible that they would have cleared the intersection by the time the respondent's car would arrive.

Items focusing on uncertainty and vigilance

In 63 expectancies, phrases referring to uncertainty were identified. In the situations as presented to the respondents in this study, it turned out that uncertainty was more often triggered by other road users (34 +16 counts) than by unclear aspects of the situation (13 counts: e.g. "I don't see a priority sign, so I will probably have to yield to traffic from the right"). Uncertainty concerning other road users focused mainly on the behaviour of specific road users (34 counts : e.g. "I'm not sure if he will turn right or left") but also on taking the approach of road users in general into account (16 counts: e.g. "…possibly traffic from the right"). Respondents also indicated uncertainty concerning their own behaviour (12 counts: e.g. "I might turn left or I might turn right"), which might have been inherent to the study. Respondents did not know where "their" car would go and sometimes reported a dependency on their own direction in their expectancies. The relatively high count in Situation 2 for uncertainty concerning actions of other road users (9 counts) can be explained by the larger number of different types of road users involved. Examples of phrases included in this category support that explanation: "the *pedestrian* could perhaps hesitate and…", "where the *cyclist* is going is unclear (let's wait and see)" and "…the red *bus* could turn left".

Phrases indicating increased vigilance were also coded (e.g., "so I will have to watch out"). To determine if such phrases were mentioned more often in situations which showed high counts for Uncertainty a cross tabulation was made. However, the situations which showed high counts for Uncertainty did not show a different pattern for Vigilance than situations that showed relatively low counts for Uncertainty. Thus, the results did not seem to indicate that situations that elicited relatively high counts for Uncertainty also elicited relatively high counts for Vigilance. Furthermore, a cross tabulation was made to determine if Uncertainty is associated with situations in which the respondent did not indicate who would yield. The results indicated that situations showing relatively high counts for Uncertainty (Situations 0, 1, 2 and 9 showing 9, 10, 11 and 9 counts respectively) corresponded to relatively high counts for not indicating who will yield, with the exception of Situation 0 (5 counts). Situations 1, 2 and 9 showed 8, 12 and 11 counts respectively, whereas situations showing relatively low counts for Uncertainty (Situation 4 and 7: 4 and 5 counts respectively) were associated with relatively low counts for the respondent not indicating who will yield (6 and 4 counts respectively). Although these results are certainly not conclusive they do suggest that uncertainty in an interaction situation might be associated with feeling uncertain about who will yield, which seems to be a plausible idea. However, it should be kept in mind that respondents were not explicitly asked to report who they expected to yield. Thus, respondents might actually have had an idea concerning who would yield, but for some reason decided not to include that in their expectancy.

The effect of stimulus type on the expectancies

As mentioned in the introduction, both still pictures and video fragments were used to determine if more or different aspects would be generated by different stimulus types. Figure 4.5 seems to indicate that an effect may be present for a number of aspects, namely right of way, infrastructure, position, the direction road users are coming from and perhaps also for informal rules. All of the abovementioned aspects were mentioned in a higher percentage of the expectancies generated by video fragments as compared to expectancies generated by still pictures. A higher percentage of expectancies generated by video fragments is also associated with references to uncertainty (resp. 29% vs. 25%) and increased vigilance (resp. 34% vs. 13%). To determine the significance of this effect of stimulus type, the mean number of times a particular aspect was mentioned by a respondent per stimulus type was compared in a paired samples t-test, which compares the responses of the same respondent to the still pictures and the video fragments. Thus, these analyses only included the responses provided by the P+V group (n=9). Possibly due to the small number of respondents, none of the abovementioned effects proved to be significant in a paired samples t-test. The (non significant) effect for all the abovementioned variables was, however, found in the same direction (i.e. they were mentioned more often in expectancies generated by video fragments). To determine the significance of this overall effect, two new variables were computed, reflecting the mean amount of counts per stimulus type of the abovementioned variables taken together. A paired samples t-test using these two variables did indeed indicate that taking the abovementioned aspects together, they were mentioned significantly more often in expectancies generated by video fragments (t_8=-2.806; p < .05).

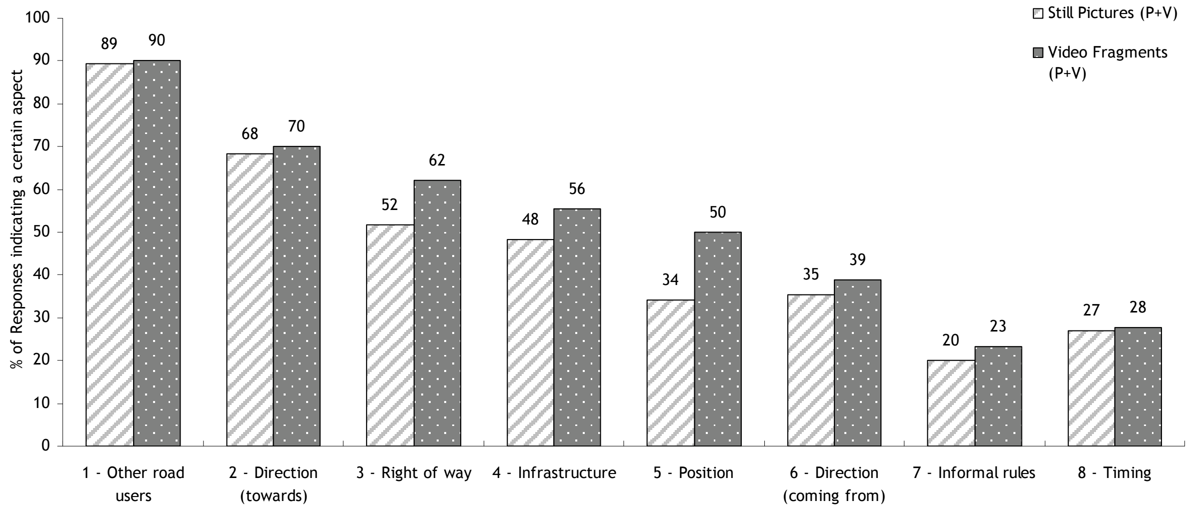


Figure 4.5: Aspects mentioned per stimulus type (only by the P+V group)

Respondents indicated who they expected to yield in 56% of all expectancies (115 counts). In 82 out of these 115 counts, the respondent indicated that “self” would yield versus that “other” (28 counts) or “both” (5 counts) would yield. Taking only the expectancies provided by the P+V group, 28% of the expectancies reported after seeing a still picture indicated that “self” would yield, versus 47% of the expectancies reported after seeing a video fragment. A paired samples t-test showed that when reacting to a video fragment, respondents indicated that “self” would yield significantly more often than when reacting to a still picture (t_8= -2.858; p< .05). It would be interesting to determine if the inclusion of the dynamic led to more yielding in situations from either the left or the right or even if yielding decisions depended on different estimates of approach speed. However, the limited amount of data does not allow for such detailed analysis.

The effect of complexity

As put forward in the introduction, complexity was not entered into this study because of an interest in its direct effect on expectancies, but to generate a more varied set of expectancies. However, to determine if uncertainty and increased vigilance are associated with interaction situations that are assumed to be more complex, a complexity score was computed for each situation. This complexity score was put together by allocating one point for each of the four aspects (Appendix E) that are assumed to increase complexity. The maximum complexity score (CS=4) was found for Situation 2, which also showed the highest count for references to uncertainty. Appendix I provides an overview of the qualitative data analysis results per situation and also includes the complexity scores (CS). The highest complexity score was not only associated with relatively high counts for uncertainty, respondents also referred relatively often to specific road users (as opposed to road users in general), to the direction in which road users are moving (continuing on one's way or specific manoeuvres) and to the right of way in that particular situation (distinguishing between what should happen and what will happen). The second highest complexity score (CS=3) was associated with Situation 0 and also showed relatively high counts for references to the right of way in that situation (both to what should happen and to what will happen).

Situations which showed relatively low counts for references to uncertainty received a complexity score of 1 or 2 (Situation 4 and Situation 7). Situations that showed relatively high counts for references to timing indicating that nothing will happen also corresponded to complexity scores of 1 or 2 (Situation 8 and Situation 5).

4.4. Discussion

4.4.1. Overview of the results

The main objective of the explorative studies presented in this chapter was to investigate which kinds of aspects are mentioned in expectancies of interaction situations at intersections. Both the concept mapping studies and the qualitative data analysis of the expectancies revealed a great variety of aspects which could be grouped into meaningful clusters of aspects. Some aspects surfaced in both concept maps: right of way (ROW), uncertainty and indication of direction of travel. In line with this finding, the qualitative data analysis indicated that most aspects mentioned in the expectancies seemed to fall into one of the following three categories:

- ❖ References to right of way
- ❖ References to other road users
- ❖ References to the location of other road users
  - ♦ Past location: the direction road users are coming from
  - ♦ Present location: the present position road users are at
  - ♦ Future location: the direction towards which road users are moving

In summary, references to right of way were found both in the concept maps as well as in the qualitative data analysis as were references to the location of other road users. References to other road users were not explicitly found as a separate cluster in the concept maps but implied by the clusters focusing on behaviour of other road users (e.g., road users yielding or moving in a certain direction). Expressed uncertainty can be related to all three of the abovementioned categories. A respondent might have been uncertain concerning who would yield (i.e., 1. ROW), or concerning what another road user would be about to do (i.e., 2. Other road users) or perhaps concerning where another road user might be headed (i.e., 3. Location of other road users).

Not surprisingly, ROW surfaced as an important aspect of expectations of interactions, as right of way is very relevant to interaction situations at intersections. Perhaps even less surprising is the category relating to references to other road users. The respondents were shown images of interaction situations, which, per definition, always included at least one other road user. When expressing their expectancies, it is highly likely that other road users feature in their answers. Also not so surprising are the clusters containing statements indicating in what direction road users are going. The (future) whereabouts of other road users involved are likely to be included in expectancies of interaction situations.

4.4.2. Short and long term expectancies

Visual exploration of the references to right of way coded in the qualitative data analysis revealed two clusters. The clusters 'Rule' and 'Action' could be interpreted to correspond to two steps in the interaction process. The first step is to determine what is appropriate behaviour in a particular situation (what *should* happen). The following step is to determine what is likely to happen in a particular situation (what *will* happen). The first step might draw more heavily upon the long term expectancy which is subsequently transformed into a more specific short term expectancy by the second step.

An indication of the distinction between long and short term expectancies was also found for the references to other road users. References to road users in general seem to correspond to long term expectancies, relating to general ideas about what could happen in similar situations. Expectancies incorporating references to specific road users seem to correspond to short term expectancies, relating to an expectancy that fits that specific situation.

In conclusion, the abovementioned results seem to support the distinction made in the model proposed in Chapter 2 between long and short term expectancies.

4.4.3. Still pictures and video fragments

As indicated in the introduction, traffic research has made use of both still pictures and video fragments. Both types of stimuli were included in the qualitative data analysis of the present study. To determine the effect of stimulus type, the data were visually explored and if that seemed to indicate an effect, the data were statistically tested (providing the counts were sufficient). Overall, the counts for the responses to still pictures and video fragments did not differ that often. The results only indicated that video fragments seem to elicit relatively higher counts for references to right of way, relatively higher counts for references to increased vigilance and relatively higher counts of "self" being the party to yield. Perhaps the video fragments allowed the respondent to become more personally involved in the situation, inducing the higher counts for increased vigilance and "self" as the party to yield, also increasing the relevance of aspects relating to right of way. This conclusion is in line with the argument put forward by Vogel et al. (2003). They propose that moving scenes allow respondents to become more immersed in the situation.

Furthermore, as the video fragments provided the respondents with more information than the corresponding still pictures, this should be able to reduce their uncertainty. The results however did not provide evidence to support this. To determine how the extra information provided by the dynamic stimuli is really related to a driver's uncertainty, more research will need to be conducted.

4.4.4. Complexity

The results of the qualitative data analysis seemed to indicate a positive relationship between complexity and uncertainty. However, it should be noted that the way of creating a complexity score which was used assumes that each aspect has an equally large effect on the complexity of the situation and is thus not very refined. Also, complexity was not entered into this study as an independent variable and the effects could therefore not be systematically analysed. These results can however be used to give direction to further research.

4.4.5. From explorative to experimental research

It seemed that both concept maps included a dimension which could be interpreted as a varying degree of uncertainty. Based on this finding, a tentative conclusion could be that uncertainty fulfils an important role in interaction situations. According to the model mentioned in Chapter 2, it seems plausible that situations in which a driver is uncertain are more likely to lead to dangerous situations. Before a hypothesis that includes this concept can be tested, the concept of uncertainty will need to be focused on a particular aspect of the driving task in interaction. Focusing uncertainty on the aspects found through the qualitative data analysis (right of way, other road users and their location) leads to a testable and meaningful hypothesis: "uncertainty concerning right of way and the location (past, present and future) of a road user is more likely to lead to dangerous situations". In the simulator studies discussed in the following two chapters the driving simulator scenarios incorporate uncertainty and focus it on both right of way and other road users' locations. Thus, the participants were confronted with situations in which it was uncertain where the road user was coming from (left or right) and where the other road user would be in the immediate futre (i.e., would the road user stop at the intersection or proceed to cross the intersection) and, consequently, it was uncertain whether the participant would need to yield or not to avoid a collision. The results will be analysed to determine the effect of this particular operationalisation of uncertainty on the safety of the interaction situation.

5. Using linked simulators to determine the effect of expectancy[5]

5.1. Introduction

The research discussed in the previous chapter indicated that uncertainty appears to be an important aspect for road users dealing with interaction situations. In the two driving simulator studies that will be discussed in this and the following chapter, the aspect of uncertainty has been incorporated. This was operationalised in both the right of way and the location of other road users, which were two other aspects that surfaced in the qualitative research discussed in the previous chapter.

The model postulated in Chapter 2 reserved a central role for the concept of expectancy and assumed a distinction between long term and short term expectancies. To recapitulate, long term expectancies correspond to a general idea concerning what will happen in a particular situation and can be based on, for example, rules or previous experiences. Short term expectancies are based on long term expectancies but fed with information from the currently perceived traffic situation. The results of the qualitative research in the previous chapter seemed to support this distinction and it was decided that expectancy should be central to the experimental research for this thesis.

In the questionnaire study conducted by Björklund and Åberg (2005) both long and short term expectancies were implicitly incorporated. This questionnaire included schematical drawings of intersection situations that varied in infrastructural design,

[5] This chapter is based on two similar papers discussing preliminary results of this experiment (Houtenbos, de Winter, Hagenzieker, Wieringa, & Hale, 2006a, 2006b).

the direction the "other" driver was coming from and if the other driver maintained speed or slowed down while approaching the intersection. Respondents were asked to indicate on a 5-point scale (ranging from never to always) how often they would yield in the situation presented. The direction the "other" driver was coming from is likely to have elicited a short term expectancy concerning who would yield based on a long term expectancy regarding the right hand priority rule. Subsequently, the speed behaviour of the other road user (i.e. maintain speed or slow down) is likely to have further specified (or contradicted) the long term expectancy into a short term expectancy. The design of stimuli for the questionnaire can therefore be interpreted as having incorporated both long and short term expectancies.

One could say that any expectancy a road user has is associated with a degree of experienced uncertainty, which can be defined and experienced in advance of the actual outcome of the situation as well as during the time the situation is being experienced. Uncertainty also seems to have a long and a short term component. Long term uncertainty relates to variation experienced in previous encounters and short term uncertainty can be elicited where the current situation seems to contradict the rules or previous experiences, reflected in the long term expectancy. For example, when a road user perceives another road user coming from the left this could elicit the short term expectancy that that other road user will yield. The road user holding that expectancy can be more (or less) sure that that expectancy will be justified as the situation develops. A situation that did not develop according to a more general (i.e. long term) expectancy can be labelled (after the fact) as an unexpected situation. The model posed in Chapter 2 suggests that, while the situation is still developing, short term expectancies will be elicited based on the activated long term expectancy and what is perceived in the current situation. If the perceived aspects of the situation seem to conflict with the long term expectancy, the resulting short term expectancy is likely to be associated with a higher level of uncertainty (Figure 5.1). For example, when a road users perceives another road user coming from the left, but subsequently perceives this road user maintaining speed, this is likely to elicit a more uncertain short term expectancy concerning this road user’s yielding behaviour than if the road user had been perceived slowing down. This example shows how expectancy and uncertainty may be linked.

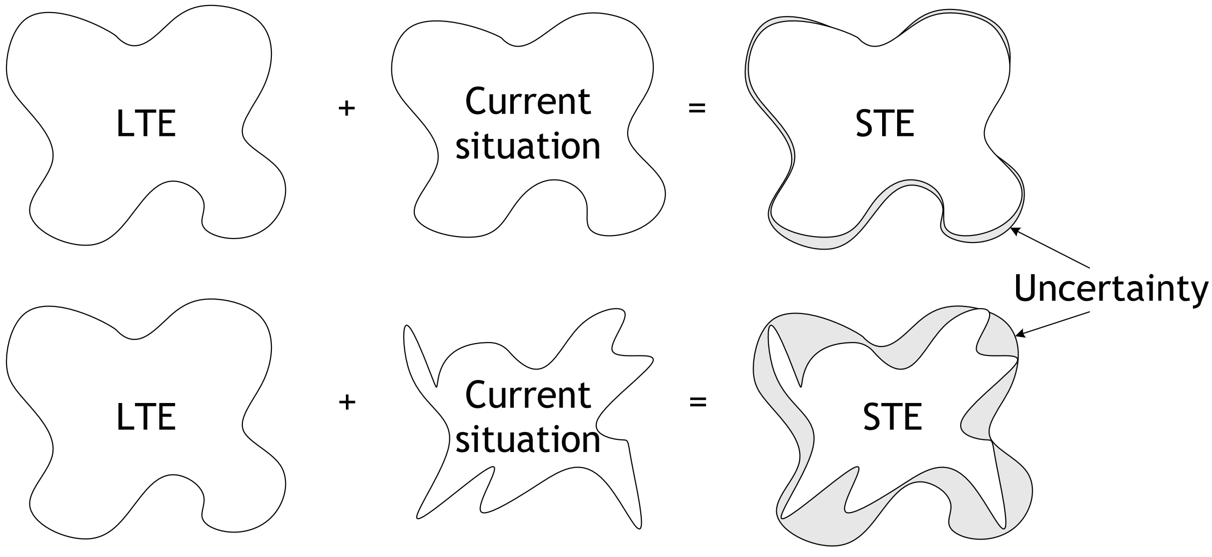


Figure 5.1: Schematic representation of the process of short term expectancy elicitation incorporating the concept of uncertainty.

The Björklund and Åberg study not only incorporated expectancies, but also attempted to vary the extent to which uncertainty (associated with these expectancies) is experienced by the respondents, although Björklund and Åberg (2005) referred to it as “ambiguity”. Uncertainty concerning who will yield is expected to increase particularly when the approach strategy of the other road user (i.e. maintain speed or slow down) conflicts with the long term expectancy based on the priority rule. For example, when the other driver approaches the intersection from the right (thus having right of way) while slowing down, this is in conflict with the likely long term expectancy concerning the behaviour of a road user who has right of way (i.e. maintain speed) eliciting uncertainty concerning the short term expectancy or, to speak with Björklund and Åberg’s term, creating an ambiguous situation. Similarly, uncertainty is likely to be elicited when another driver approaches the intersection from the left while maintaining speed.

The results of the Björklund and Åberg questionnaire showed that the right-hand priority rule is an important determinant for driver's reported yielding behaviour. Furthermore, relative road width as well as the approach strategy of the other driver influenced respondents' reported yielding behaviour. The results indicated that the other driver’s approach strategy (i.e. maintain speed or slow down) was more important when the other driver was coming from the left than when coming from the right.

The results of the qualitative research discussed in the previous chapter and the Björklund and Åberg study (2005) suggested an effect of uncertainty on interaction behaviour at intersections. To determine that effect empirically, an attempt was made to manipulate the expectancies and the level of uncertainty associated with those expectancies. Situations similar to the situations in the Björklund and Åberg questionnaire (i.e. different combinations of the other road user's approach strategy and the direction the other road user comes from) were implemented in a driving simulator experiment. As Björklund and Åberg pointed out themselves, their data resulted from self-reports, which could be biased by socially desirable responding or distortion of memories. This also serves as a justification for a simulator study that is based on the situations used in the Björklund and Åberg questionnaire.

Furthermore, the research discussed in Section 2.2.1 of Chapter 2 suggests that accidents are more likely to occur when a driver encounters an unexpected situation, as this increases the time needed to respond. As the Björklund and Åberg study did not discuss the manipulated effects in the context of interaction safety, the present study will also examine the effects of expectancy and uncertainty on the level of safety of the interaction situations.

5.1.1. Research questions and hypotheses

This experiment aims to answer the following two questions:

- ❖ How does uncertainty affect interaction behaviour (yielding in particular)?
- ❖ How does uncertainty affect the safety of the interaction?

Varying which road user has right of way (according to the right-hand right of way rule) as well as varying the other road user's approach strategy, is assumed to elicit certain or uncertain short term expectancies. We expect to find similar effects for each aspect on observed yielding behaviour as found in the Björklund and Åberg study (2005) for reported yielding behaviour.

Furthermore, this experiment was intended to gain more insight into interaction behaviour at intersections beyond the abovementioned focus on yielding behaviour. Concerning interaction safety, we expect to find less safe interactions as a result of increased uncertainty.

5.2. Method

5.2.1. Participants

Twenty-seven Dutch participants were obtained from the SWOV participants database. Participants had all obtained their driving licence at least 5 years before taking part in the experiment and had driven at least 5000 km in the previous year (14 ◎, 13 ◎). They were aged between 25 and 73 (mean age 49). All participants were paid € 20. Nineteen participants completed the entire experiment (9 ◎, 10 ◎). Unfortunately, due to the pre-programmed maximum duration of a driving session (which apparently was too short in some cases), some participants could not complete all situations before the driving session was stopped. Also, due to a technical failure, some participants experienced collisions with road users who suddenly appeared from behind. These situations were deleted from the data file.

Due to simulator sickness, 5 participants completed only some of the situations of their first driving session and 3 participants could not even start with the driving sessions after the practice trial. This left complete data for 19 participants and partial data for 5 participants.

5.2.2. Apparatus

As the focus in this study is on interaction behaviour, two driving simulators were linked to enable two drivers to encounter each other in the same virtual world. As this was a quite innovative approach, the linked simulators were used only in one half of the experiment whilst the other half was conducted in the traditional way (preprogramming the other driver's behaviour in the participants' simulator). It was assumed that linking two simulators and allowing two real drivers to interact with each other would provide us with different, and at least in theory more relevant information concerning the interaction process than a traditional driving simulator could. In a traditional setting, the participant can only react to the other road user, whereas in this linked setting, the participant can actually interact with the other road user.

The two linked simulators used were Green Dino fixed-base simulators at Delft University of Technology. Participants were seated in a booth which represented the front seat of a car. The simulator was used in an automatic gear shift mode. Auditory information was provided through headphones (e.g., engine and environmental sounds as well as route instructions). For more detailed information on the driving simulators, please refer to Chapter 3.

5.2.3. Stimuli

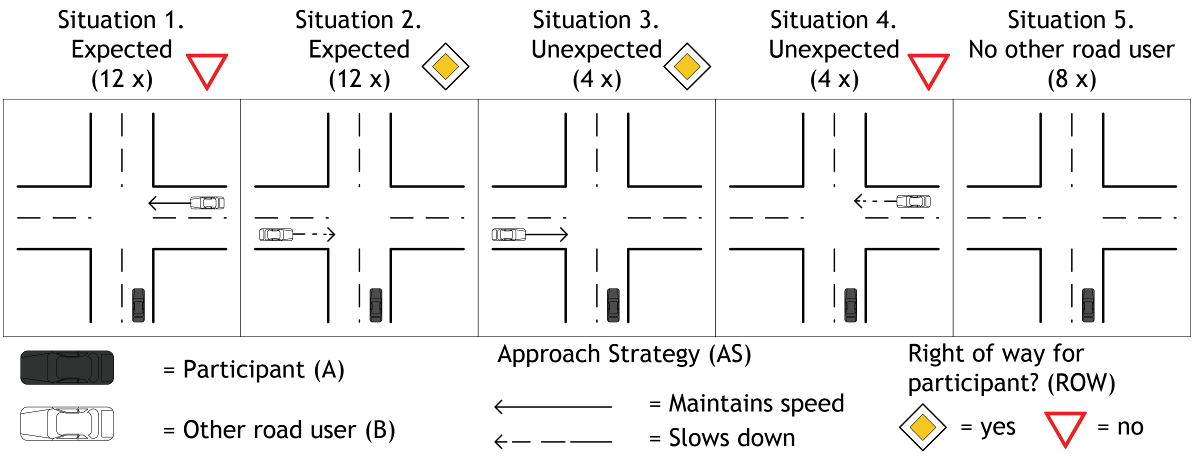


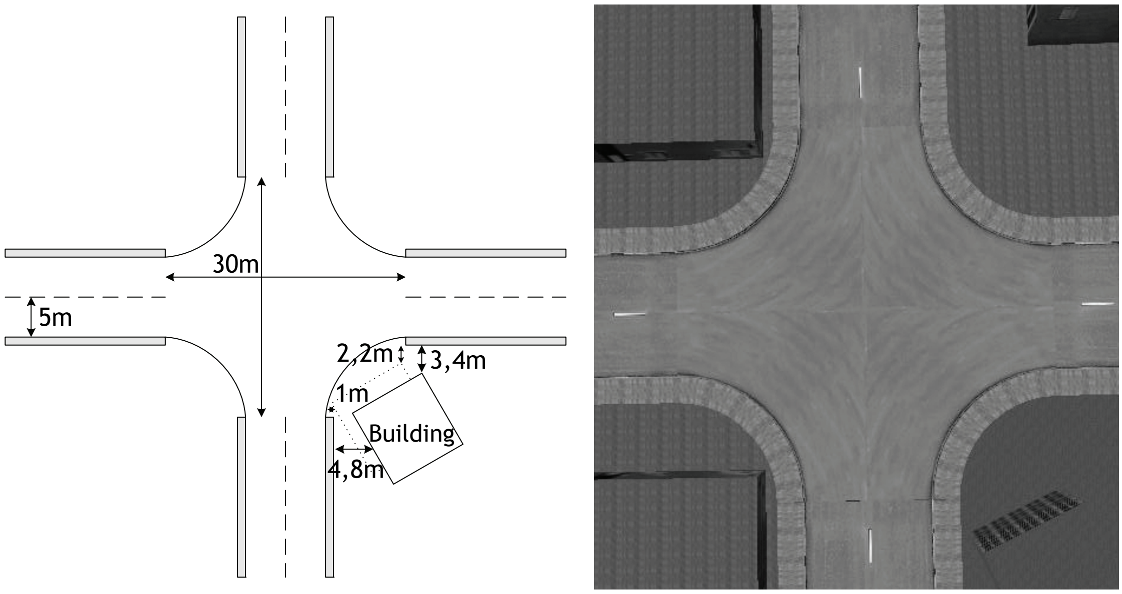
Figure 5.2: Schematic representation of the situations encountered in the driving session

The experiment contained 5 different situations that varied in the amount of uncertainty they were intended to elicit concerning the short term expectancy (Figure 5.2). In Situation 1 (⬅), participants encountered a driver from the right at an intersection without any designated priority. In the Netherlands, at these intersections a driver approaching from the right has right of way and the participant should yield. As the other driver maintained speed, this is assumed to portray an intention of taking right of way and is thus expected behaviour. In Situation 2 (⇢), participants encountered a driver approaching the intersection from the left, who was slowing down. This is assumed to portray an intention to yield and is also expected behaviour. In Situation 1 (⬅) and 2 (⇢) the situation develops in accordance with the long term expectancy based on the right hand right of way rule and consequently are not expected to elicit high levels of uncertainty. In Situation 3 (➡), participants encountered a road user approaching from the left. However, this time, the other driver did not slow down, but maintained speed. As the participant should actually receive right of way in a situation like this, the behaviour of the other road user is regarded as unexpected. In Situation 4 (⇠), participants encountered a driver approaching the intersection from the right and slowing down. As the participant is supposed to be the one to yield in this kind of situation, the behaviour of the other road user is again regarded as unexpected. In Situation 3 (➡) and 4 (⇠) the situation does not develop in accordance with the long term expectancy based on the right hand right of way rule and consequently are expected to elicit high levels of uncertainty.

The intersecting driver had an initial speed of 50 km/h at about 150m before the intersection at the time that the participant was also 150m before the intersection. Situation 5 is added to determine what the participant's behaviour is when encountering no other road users.

In addition to the road users needed to create the experimental situations, participants could also encounter oncoming road users on the road stretches between intersections to make the driving task more realistic. Although participants still experienced the environment as rather sober, this was the only way to ensure that other (non-experimental) road users would not influence intersection behaviour without having to add extra intersections and thus making a driving session even longer. The expected situations (Situation 1, ⬅ & 2, ⇢) were encountered three times more often (twelve times each) than the unexpected situations (Situation 3, ➡ & 4, ⇠) to prevent the unexpected situations becoming as expected as Situation 1 (⬅)& 2 (⇢). Situation 5 was encountered eight times.

Intersections were 30m by 30m wide and lane width was 5m (Figure 5.3). Situations also varied in the visibility of the intersecting road. In half the situations buildings were placed closer to the sidewalk than in the other half. However, it should be noted that overall, buildings were placed so close to the pavement that road users on the intersecting road could only be perceived relatively late. In this experiment, variations in visibility were only made to create a more dynamic environment for participants and not to purposely elicit certain effects. Intersections were connected by straight road stretches of 600m. Also, 9 curves were included in the route to prevent participants only having to drive straight on (Figure 5.4). Figure 5.4 provides a schematical illustration of the route driven by the participants. An arrow indicates that at that intersection, another driver approached from the direction indicated by the arrow. The absence of an arrow at an intersection indicates that participants would not encounter another road user at that intersection (Situation 5). The numbers placed at each intersection refer to the situations introduced in Figure 5.2. Driving behaviour at connecting road stretches and curves were not included in the data analysis.



(a) (b)

Figure 5.3: Schematic representation (a) and screenshot (b) (birds-eye view) of a stimulus intersection

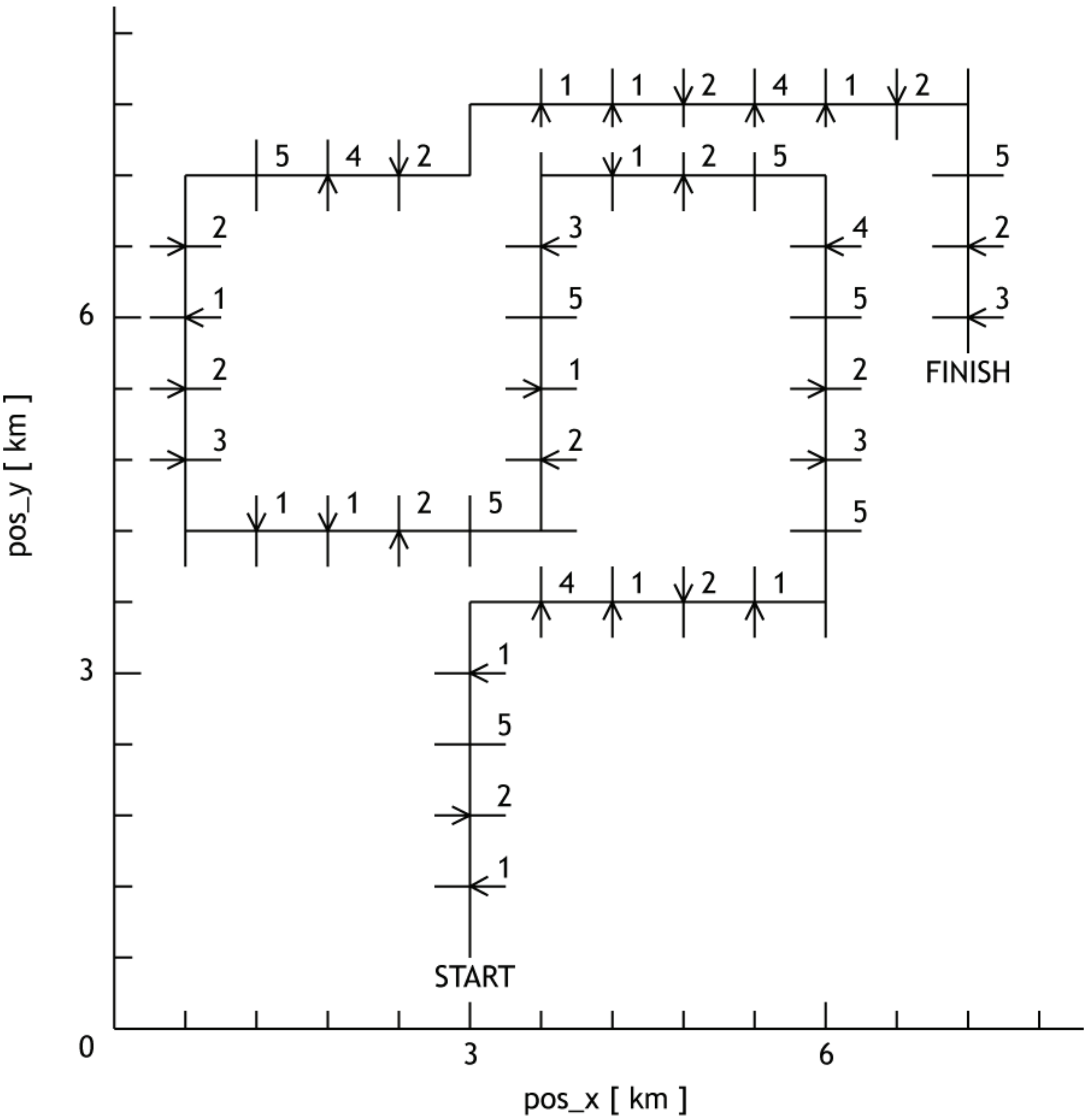


Figure 5.4: Route

5.2.4. Experimental design

Each participant completed two driving sessions (i.e. Session P and Session E). During Session P, participants only encountered road users who were pre-programmed to behave in a certain way as they approached the intersection (i.e. maintain speed or slow down), corresponding to the way driving simulator experiments are conducted traditionally. During Session E, participants encountered other road users who were controlled by the experimenter in the other simulator. Although the experimenter was also instructed to behave in a certain way (i.e. maintain speed or slow down), the behaviour at a detailed level in the two sessions was different. In Session P, the programmed road user's speed was adjusted online to the speed of the participant to increase the probability of an interaction situation between the participant and the other road user. In Session E, the experimenter was launched with an initial speed at a fixed distance to the intersection and was subsequently required to approach the intersection by operating the simulator's accelerator and brake pedals. The behaviour of the other road users (B) in Session P was rather rigid, in that when maintaining speed, they would carry on without taking the behaviour of the participant into account. Also, when decreasing speed, they would eventually come to a standstill at the intersection and wait indefinitely (and thus, force the participant to take right of way). During Session E, the experimenter controlling the other road user (B) did take the behaviour of the participant into account. When instructed to maintain speed, the experimenter did, however, release the throttle when approaching the intersection to be able to brake in time, if it appeared to her that she would not receive right of way (contrary to the programmed road user). As soon as the experimenter could assume that the participant would yield, she would accelerate again. When adopting the "slow down" strategy, the experimenter would approach the intersection much more cautiously, first releasing the throttle and subsequently applying the brakes to come to a standstill at the intersection. The experimenter waited to see if the participant would stop and yield before crossing the intersection.

The order in which Sessions P and E were completed was balanced over the participants. The order in which the situations were presented was randomly chosen, but was identical for all participants in all sessions. During the experiment participants were not made aware that in one of the sessions the other road user was being controlled by a "real" driver. In Section 5.3 discussing the results, the success of this "deception" is reported.

5.2.5. Procedure

Participants were presented with an instruction leaflet in which they were informed about the task and the possibility of simulator sickness occurring. They were instructed to drive as they would normally drive in a similar (real-life) situation. However, participants were explicitly asked to keep to the speed limit of 50 km/h. When the participants had finished reading the instruction leaflet, they were asked to take their place in the simulator. Subsequently, the experimenter provided a verbal instruction. The way to operate an automatic gear was explained and the importance of keeping to the speed limit of 50 km/h was stressed. No information is available concerning participants' prior experiences with automatic gear shift mode, but a practice trial allowed participants to get used to this mode of operation. Also, participants were told that they could experience symptoms of simulator sickness such as nausea and/or dizziness, particularly when turning a corner. They were advised to indicate if they experienced such symptoms and not to continue driving. Participants were told that the route to be followed would be communicated to them through headphones. Participants were instructed to drive straight on unless told otherwise. Instructions to take a turn were first given about 300m before the intersection and repeated 75m before the intersection. Sounds corresponding to the car and the environment could also be heard through the headphones. Participants were told that in case of a collision they would be told and placed a while back along the route. In such instances, they should turn the ignition key and continue their session. As soon as the experimenter noticed that participants were occasionally being hit by road users suddenly appearing from behind (due to a programming fault), subsequent participants were informed that this could happen and assured that it was not intended. The data for these occurrences were eliminated from the data set.

Participants started with a 6 minute practice trial, which took place in the same virtual environment as the actual experiment, but in reversed direction (from FINISH towards START in Figure 5.4.) Subsequently, participants commenced with the first session (P or E) which took about 45 minutes. After a short break, participants continued with the second session (resp. E or P), which also took about 45 minutes. After the final session, participants were asked to answer two questions concerning their driving behaviour (was it representative of their normal driving?) and the distinction between the first and the second session (did they notice anything different?).

5.2.6. Data collection and analyses

The main independent and dependent variables that were included in the analyses of the results (Section 5.3.2 and 5.3.3) are introduced in Table 5.1 and Table 5.2 respectively. Data concerning speed, throttle, brake and position were sampled with 4 Hz.

As participants encountered all situations more than once, the initial data-file consisted of one line per situation encounter which included the mean score per participant in that particular situation for many variables. For each separate analysis an aggregate file was created that included the mean score for a particular dependent variable in different combinations of independent variables. For example, to determine the effect of situation on yielding behaviour, an aggregated file was created with four scores for Mean Yield per participant (i.e. Mean Yield when Situation=1, Situation=2, Situation=3, Situation=4) , making it possible to conduct an ANOVA with binary variables.

Table 5.1: Main independent variables

Variable	Explanation	Range
Situation	As described in Figure 5.2	1-5
ROW	Indicates if the participant had right of way (ROW)	no/ yes
AS	Indicates the approach strategy (AS) of the other road user	slow down/ maintain speed
Uncertainty	Indicates if the situation was designed to elicit uncertainty	no/ yes
Encounter	Indicates how often the participant had encountered that particular situation	1-12
Number	Indicates how many situations the participant encountered in total during the session	1-40
Session	Indicates if the other road user was programmed (P) or controlled by the experimenter (E)	P/ E
Order	Indicates in which order the participant completed the sessions	P-E/ E-P
Visibility[1]	Due to placement of the buildings visibility was either "low" or "high"	low/high

[1]*Visibility was not intentionally entered as an independent variable into the experiment, but merely varied to create a more realistic environment for the participant. As Visibility did seem to have an effect it has been added to this table.*

Table 5.2: Main dependent variables (calculated for each encounter)

Variable	Explanation	Range
DTI_Throttle	The participant's distance to the intersection (DTI) in meters when the throttle is first released.	0-150
DTI_Brake	The participant's distance to the intersection (DTI) in meters when the brake is first pressed.	0-150
DTI_BVisible	The participant's distance to the intersection when the other road user (B) could be perceived.	0-150
Mean Yield	Indicates how often a participant yielded	0 (never) - 1 (always)
Safety index[1]	The natural log of the difference between the time in seconds to the estimated collision point of the participant and the other road user, when the participant is 15m from the centre of the intersection. The smaller the Safety index score, the more dangerous the interaction would be, but values >3 indicate that one of the interaction partners stood still, and the index cannot really discriminate anymore.	≥ 0
Near miss	Indicates how often the difference in time to the estimated collision point of the participant and the other road user was less than 1.5 seconds	0 (never) - 1 (always)
Collision	Indicates if a collision occurred	0 (no) / 1 (yes)

[1] *The Safety index is essentially a combination of both TTC_{min} and PET, to overcome the drawbacks of both measures as discussed in Chapter 3. Please refer to de Winter et al. for more information on the Safety indicator (2006).*

The experiment had a within-subjects design (4 situations, 2 sessions, 2 ROW, AS and expectancy conditions), so the effects of these within-subject factors were analysed using the GLM ANOVA for repeated measures. An ANOVA for repeated measures assumes sphericity (i.e., equal variances of the differences between levels of the repeated measures factor). To test if the sphericity assumption was violated, Mauchly's test was conducted. The Greenhouse-Geisser is a commonly used correction for violations of the sphericity assumption. By adjusting the degrees of freedom using the Greenhouse-Geisser correction the repeated measures ANOVA becomes more conservative (Field, 2005). Due to the application of the Greenhouse-Geisser correction, degrees of freedom for similar analyses can vary. The effects of the between-subject factors were also analysed using a repeated measures ANOVA. An alpha of .05 was used to determine the significance of effects.

Post hoc analyses for the within-subjects factor 'Situation' were performed using t-tests and the Bonferroni adjustment for multiple comparisons. This adjustment divides alpha by the number of comparisons made (in consideration of chance capitalisation). For example, an analysis that includes Situation with four levels, six comparisons need to be made to determine which Situation means differ. In this case, application of the Bonferroni adjustment results in an alpha level of .008 (α=.05/6) (for more information on the statistical techniques applied please refer to: Field, 2005).

To check if participants who could not complete the experiment due to simulator sickness behaved different from the participants who were able complete the experiment an independent samples T-test was performed for all main independent variables (except Collision) using Simulator Sickness as grouping variable. As no significant effects were found, data for situations completed by participants who had to withdraw were included in further analyses. Also, no effect was found of collisions on subsequent yielding behaviour, so encounters which were preceded by a collision were also included in further analyses.

5.3. Results

The results will be reported in three interrelated parts. The first part provides an explorative and descriptive overview of the findings in this experiment to determine which statistical analyses would be most relevant. These analyses are subsequently presented in the second and third part of the results respectively. The second part focuses on the results that relate to the main research questions posed in Section 5.1.1. The third part covers findings that were not directly related to the main research questions, but were none the less considered interesting or important.

5.3.1. Exploring the data

The continuous recording of participants' behavioural data allows for more detailed differentiation between phases that generally occurred during the interaction process (in this experiment):

- The participant releases the throttle in anticipation of the intersection
- The participant brakes, also in anticipation of the intersection
- The other road user comes into view
- One of the two road users yields
- The participant presses the throttle again

When asked about their driving behaviour in the simulator compared to their normal driving, the majority of subjects indicated that their behaviour was (quite) representative of their "normal" driving with one exception in relation to the phase listed above of the participant pressing the brake (before the other road user comes into view). During the practice trials, many participants indicated that releasing the throttle had a lesser decreasing effect on their driving speed than they expected and that they consequently had to apply the brakes more often than they would during normal driving. The majority of subjects also indicated that they either did not notice any differences between the two sessions or that the only difference they had noticed was that in one session the other road user would sometimes wait indefinitely at the intersection. During the experiment, none of the participants had been aware that one session involved the experimenter driving in the other simulator.

Figure 5.6 through Figure 5.9 show plots where the distance to the intersection (DTI) for both interaction partners is displayed per Situation (1-4), Session (P/E) and Order (P-E/ E-P). On the horizontal axis, the participants' (A) longitudinal distance to the intersection is displayed, while on the vertical axis the other road user's (B) longitudinal distance to the intersection is displayed. The plots indicate the relative intersection approach of both drivers and the final yielding result. A diagonal line from the bottom left corner straight to the upper right corner (or parallel) is found when both road users approach the intersection at the same speed. In the right upper corner of each graph, the octagon represents the intersection (Figure 5.5). When the line passes the octagon on the left, this indicates that the participant (A) yielded, whereas when the line passes the octagon on the right, this indicates that the other road user (B) yielded.

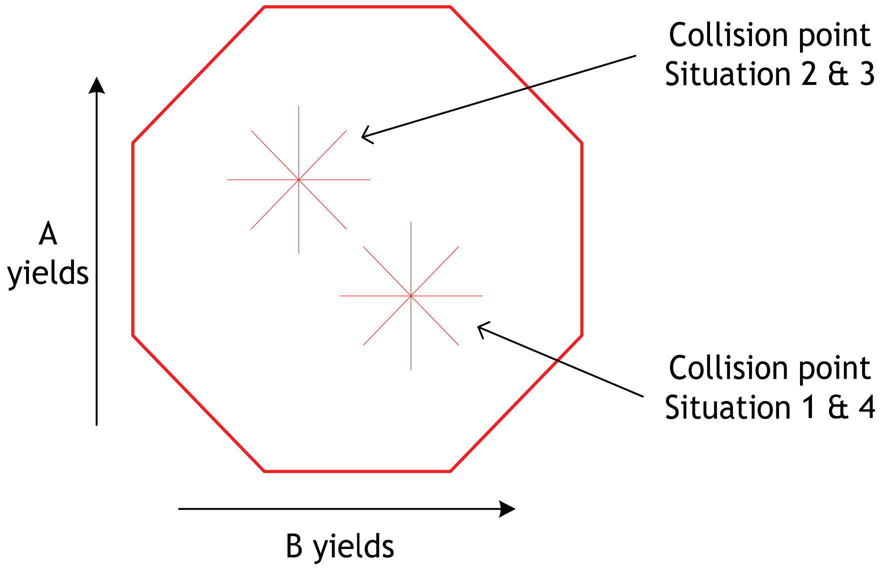
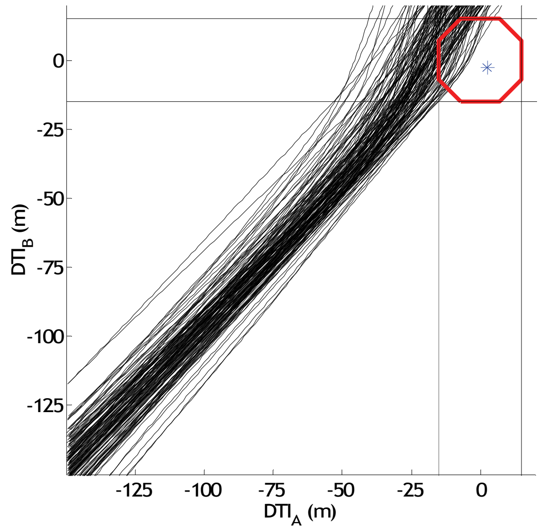
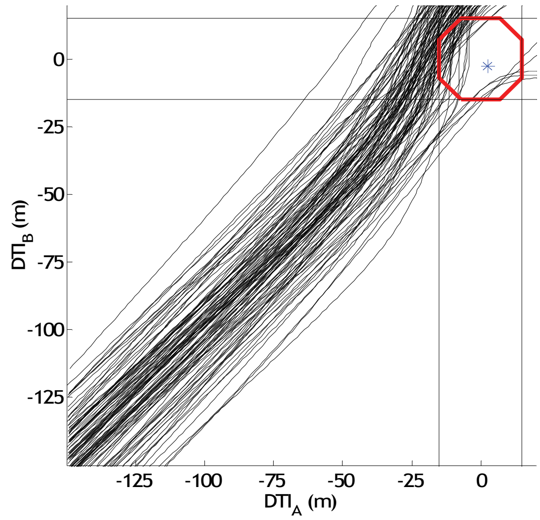


Figure 5.5: Explanation of interaction plots.

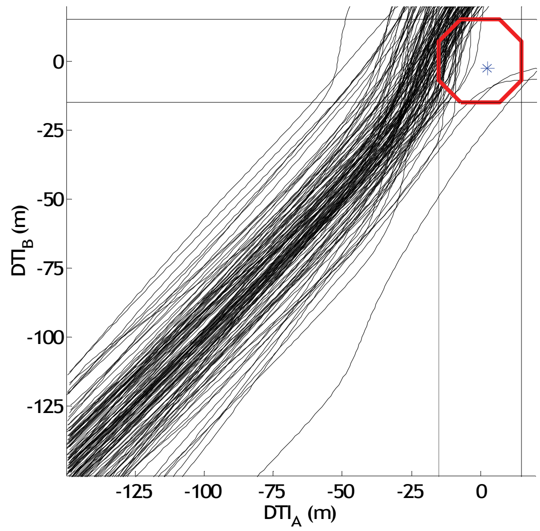
In Situations 1 (⬅) and 4 (⬅┅) the other road user approached the intersection from the right. Thus, trajectories of both interaction partners would intersect when the participant had already passed the centre of the intersection and the other road user was still heading towards the centre of the intersection. In these situations, the resulting estimated collision point, represented by an asterisk, is found in the lower right corner of the octagon. The opposite is found for Situations 2 (┅➡) and 3 (➡), where the other road user approaches the intersection from the left and the estimated collision point is found in the upper left corner of the octagon. Please note that interactions that resulted in collisions were not included in the interaction plots due to differences in the way the data for these collisions were logged (Figure 5.6 through Figure 5.9). Lines that closely pass the collision point (the asterisk) can be considered less safe.



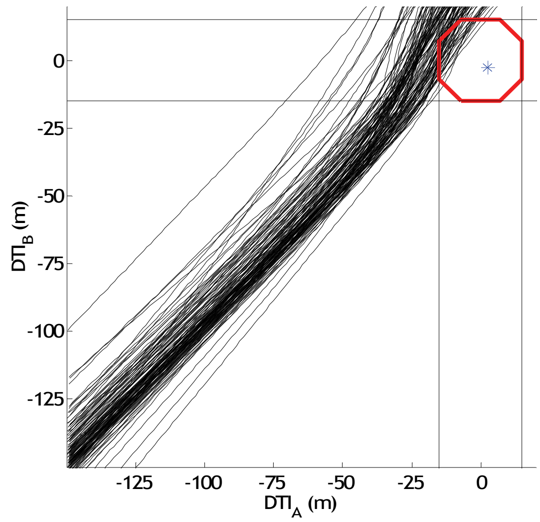
Situation 1 (1st Session P)



Situation 1 (2nd Session E)

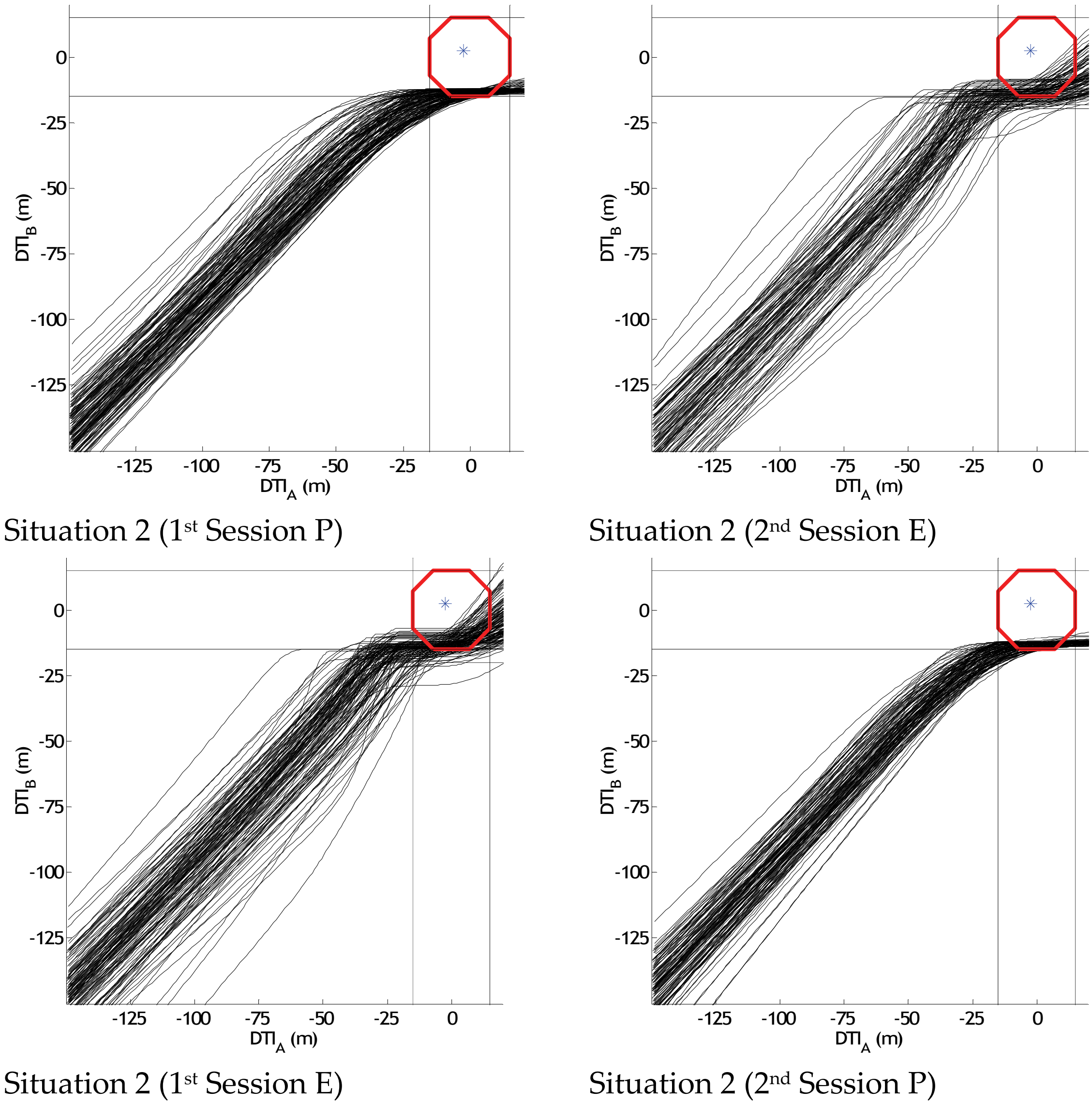


Situation 1 (1st Session E)



Situation 1 (2nd Session P)

Figure 5.6: Interaction plots for Situation 1 (⬅)



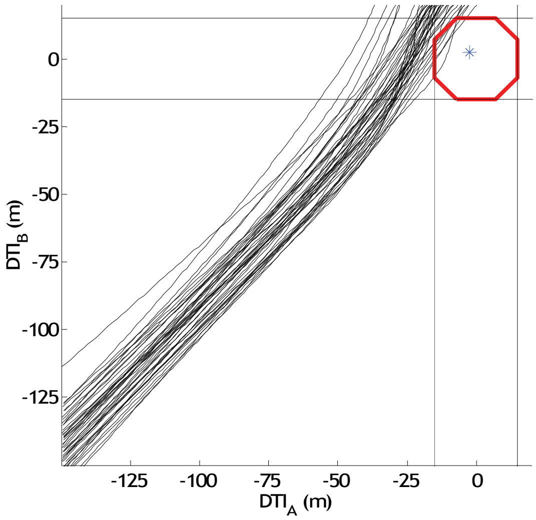
Situation 2 (1st Session P)

Situation 2 (2nd Session E)

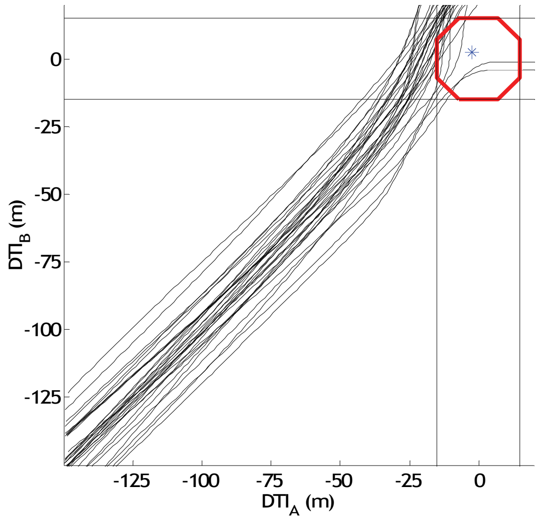
Situation 2 (1st Session E)

Situation 2 (2nd Session P)

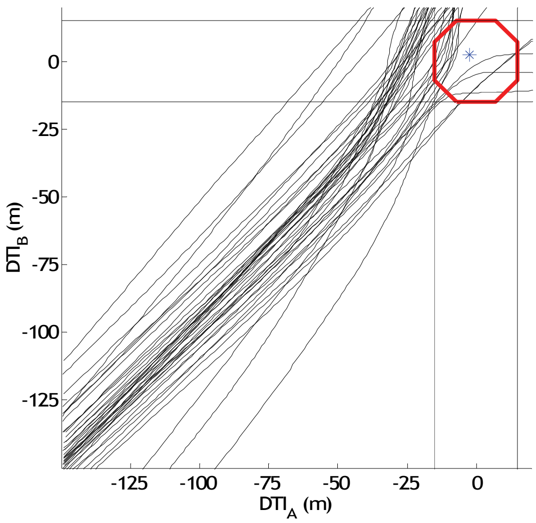
Figure 5.7: Interaction plots for Situation 2 (⠒➔)



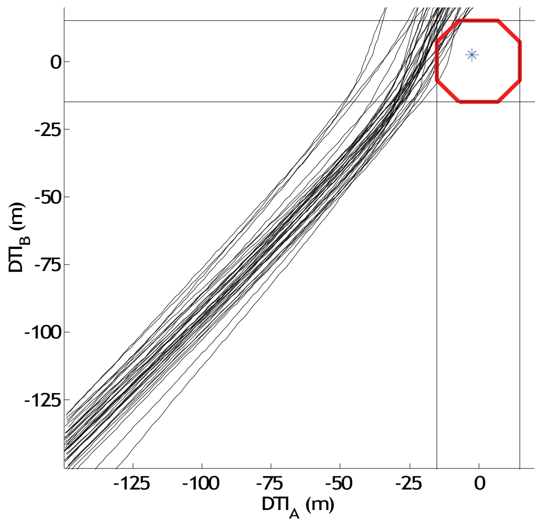
Situation 3 (1st Session P)



Situation 3 (2nd Session E)

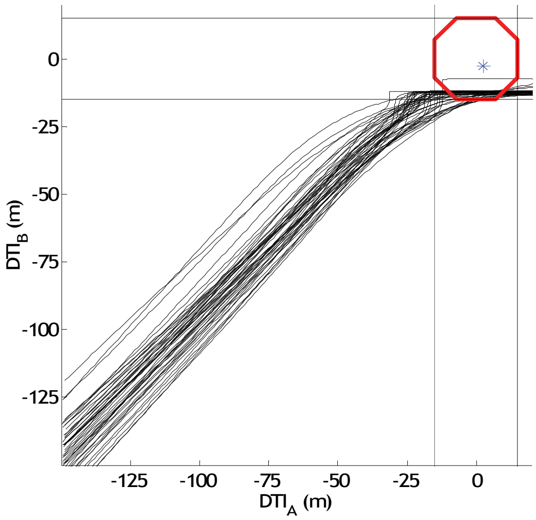


Situation 3 (1st Session E)

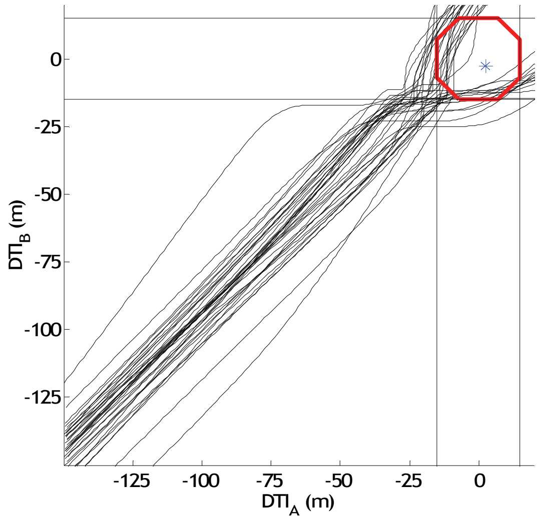


Situation 3 (2nd Session P)

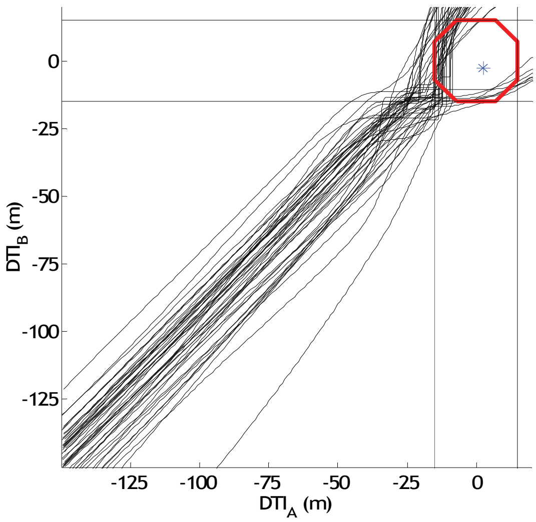
Figure 5.8: Interaction plots for Situation 3 (➡)



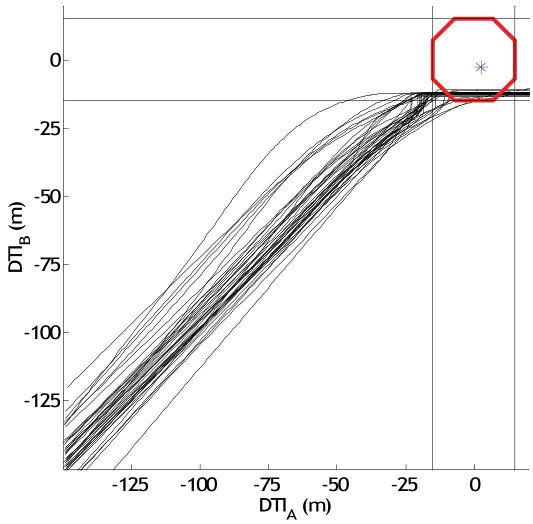
Situation 4 (1st Session P)



Situation 4 (2nd Session E)



Situation 4 (1st Session E)

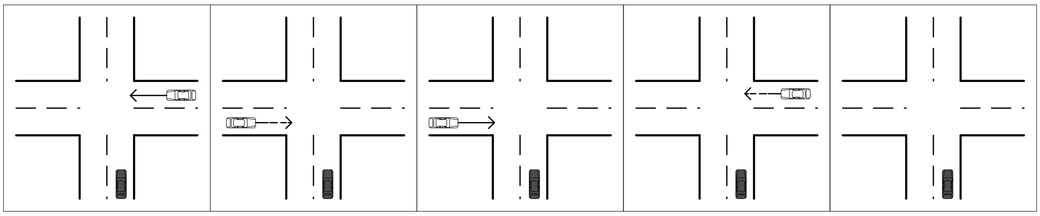


Situation 4 (2nd Session P)

Figure 5.9: Interaction plots for Situation 4 (⬅··)

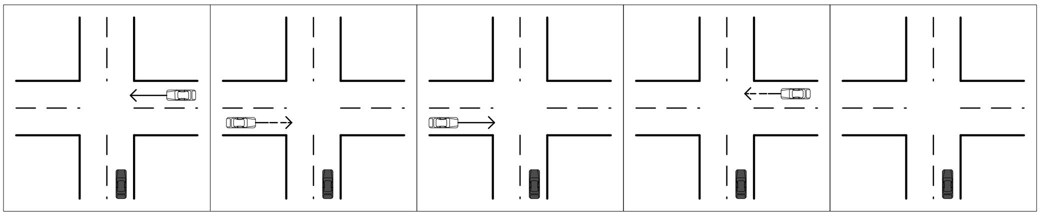
The abovementioned interaction plots provide information about the interaction process, namely the relative approach to the intersection of both interaction partners and the result of the interaction process (i.e. which interaction partner yielded). Information about the different phases occurring throughout the interaction process, mentioned at the start of this subsection, can be found in Table 5.3 & Table 5.4 for Session P and Session E respectively. In addition, the mean safety score, and the proportion and number of near misses and collisions per situation are presented in these tables.

Table 5.3: Mean of main dependent variables per situation (only for Session P)



Situation	1 (Exp)	2 (Exp)	3 (Unexp)	4 (Unexp)	5
DTI_Throttle	89.56	93.41	90.35	92.47	92.12
DTI_Brake	44.46	49.37	46.44	47.04	49.04
DTI_BVisible	30.62	30.08	28.74	29.44	-
Mean Yield	1.00	.00	1.00	.00	-
Safety index	1.19	1.76	.96	5.90	-
Near Miss	.05 (n=13)	.00 (n=0)	.17 (n=14)	.06 (n=5)	-
Collisions	-	-	n=1	-	-

Table 5.4: Mean of main dependent variables per situation (only for Session E)



Situation	1 (Exp)	2 (Exp)	3 (Unexp)	4 (Unexp)	5
DTI_Throttle	88.34	88.94	92.50	90.54	91.75
DTI_Brake	45.23	49.63	46.59	45.65	48.84
DTI_BVisible	30.07	30.95	27.75	31.35	-
Yield	.97	.00	.90	.75	-
Safety index	1.68	6.13	.83	2.76	-
Near Miss	.09 (n=22)	.14 (n=33)	.26 (n=20)	.05 (n=4)	-
Collisions	n=2	-	n=2	-	-

Discussion of the explored data

The first research question relates to the effect of uncertainty on interaction behaviour and yielding in particular. The interaction plots for Situations 1 (⬅), 3 (➡) and 4 (⇠) in Session P clearly showed less variation in yielding behaviour than the plots for these situations in Session E. This effect can also be found in the results for Mean Yield indicated in Table 5.3 and Table 5.4. This might be at least partly explained by some artefacts in the experiment. As mentioned in Section 5.2.4, the programmed road user's speed was adjusted online to increase the probability of both road users arriving at the intersection simultaneously, which was not the case when the experimenter controlled the other road user in Session E. The decision to yield is more likely to vary when the participant is presented with another road user at different distances to the intersection (DTI) than when the other road user's DTI is very alike. For Situation 4 (⇠), another artefact may have also played a role: the way the Approach Strategy of the other road user was programmed. In the case of the "slowing down" approach, the other road user in Session P would slow down and subsequently wait indefinitely for the participant to cross the intersection, thus forcing the participant to take right of way. All in all, it seems, in Session P, that the Approach Strategy of the programmed road user fully determined the yielding behaviour of the participant in all Situations, (Table 5.3). This can be interpreted as showing that there was no uncertainty or need for the participant to greatly adapt the long term expectancy into a very different short term expectancy.

Not only did yielding behaviour vary more in Session E, so did the relative approach of both road users, indicated by the tighter bundles of lines for the plots for Session P compared to the more loosely arranged lines in the plots for Session E. This can be largely explained by the extent to which the behaviour of the other road user varied. In both sessions, the other road user was launched with an initial speed of 50 km/h and subsequent behaviour depended on the assigned Approach Strategy. In Session P, the behaviour of the programmed road user depended solely on the Approach Strategy as the programmed road user was not "aware" of the behaviour of the participant. Although the Approach Strategy largely determined the behaviour of the experimenter in Session E as well, she did take the behaviour of the participant somewhat into account to try and avoid a collision while trying to keep to the assigned Approach Strategy (as opposed to the programmed road user), resulting inherently in increased variation in her approach behaviour. Moreover, the fact that this road user was controlled by the experimenter resulted in more variation in approach behaviour (e.g., speed) compared with the programmed road user as well. The relative effect of the Approach Strategy and Right of Way on the participants' yielding behaviour will be statistically tested in the second part of the results section.

The second research question focuses on the effect of uncertainty on the safety of the interaction. Table 5.3 and Table 5.4 include data for the dependent variables related to interaction safety. In Session E, the values for the Safety index seem generally to be higher for the situations which are not assumed to elicit uncertainty (i.e., Situations 1 (⬅) and 2 (⇢)) and lower for situations that are assumed to elicit it (i.e., Situations 3 (➡) and 4 (⇠)) compared to the Safety index values in Session P. The results for both sessions indicate a higher mean Safety index, but also a higher proportion of Near Misses for Situation 4 (⇠) than for Situation 3 (➡) which suggests that the effect of uncertainty on interaction safety is not as straightforward as we hypothesized in Section 5.1.1. The analyses in the following sections will determine which situations were significantly less safe and attempt to determine the aspects that contributed to the decreased safety.

5.3.2. Main research questions

In this part the main questions that were posed when designing this experiment will be answered.

- ❖ How does uncertainty affect interaction behaviour (yielding in particular)?
- ❖ How is the safety of the interaction influenced by uncertainty?

How does uncertainty affect interaction behaviour (yielding in particular)?

The manipulation of Uncertainty was done by combining two factors: the Approach Strategy of the other road user (AS) and the participant's right of way (ROW). Although we would have liked to determine the effect of uncertainty on several phases that occur throughout the interaction process, such as the moment participants decide to release the throttle or press the brake as well as yielding behaviour, this was not possible. As Table 5.3 and Table 5.4 show, the participants' average distance to the intersection when they could first perceive the other road user was less than the average distance to the intersection when the participant first released the throttle or applied the brakes. Thus, any effects found for the participant's distance to the intersection when releasing the throttle or pressing the brakes cannot be attributed to the applied uncertainty manipulations (i.e. the different combinations of the other road user's approach strategy, AS, and right of way, ROW). Although the effect of the uncertainty manipulations can only be determined for yielding behaviour, an effect of uncertainty might still be present in the participant's braking and throttle behaviour. However, this is likely to be a more general long term uncertainty caused by the approach to an intersection with rather poor visibility of the intersecting roads and should not be different for each of the five situations. This shortcoming in the experimental design was repaired in the follow-up experiment reported in Chapter 6.

Analyses of yielding behaviour only included the situations encountered in Session E, as in Session P yielding behaviour was in practice imposed upon participants by the way the other road user was programmed (Table 5.3).

To determine the effect of uncertainty on the participant's yielding behaviour, we analysed the effect of both uncertainty factors (AS & ROW) on the mean score for Yield. A GLM ANOVA for repeated measures was performed using the Mean Yield scores for Situation 3 (➡) & 1 (⬅) and 2 (⇢) & 4 (⇠) respectively. The results showed a significant main effect of AS ($F_{1,20}$=165.49; p< .001); participants tended to yield more often when the other road user approached the intersection while maintaining speed than when slowing down. Also, a significant main effect of ROW was found ($F_{1,20}$=91.16; p< .001); participants tended to yield more often when they did not have right of way. The interaction between AS and ROW was found to be significant ($F_{1,20}$=63.47; p< .001) and is illustrated in Figure 5.10. The plot shows that when participants had right of way, they did not always take it. When the other driver appeared to maintain speed, participants tended to yield very often instead of take right of way (i.e. Situation 3, ➡).

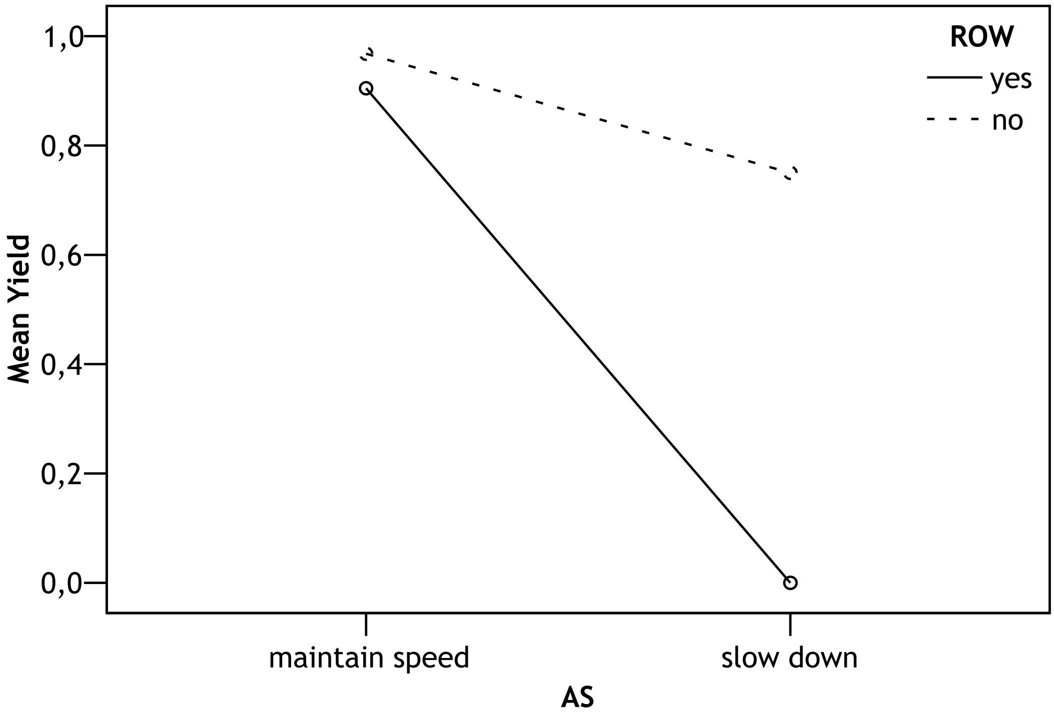


Figure 5.10: Interaction between AS and ROW

Having previously encountered a particular situation might have had an effect on the participants' expectancies and thus on the extent of elicited uncertainty, when confronted with a similar situation again. Based on altered expectancies, participants might adjust their yielding behaviour. To determine if such an effect was present, Mean Yield scores were compared for all the encounters with a particular situation. Only encounters within the same visibility condition were compared to ensure that effects found could only be attributed to the number of completed encounters. However, no (significant) effects were found.

The results found are similar to the results found by Björklund and Åberg in their questionnaire study mentioned earlier. Figure 5.11 shows the mean observed yielding found in the present study as well as mean reported yielding found by Björklund and Åberg. Participants tended to yield more often in situations where the other road user maintained speed (Situation 1, ⬅ & 3, ➡), than when the other road user slowed down (Situation 2, ⇢ & 4, ⇠), which was also indicated by the questionnaire respondents. When the other driver did not have right of way but approached the intersection while maintaining speed (Situation 3, ➡), both studies found that the approach strategy of the other drivers seemed to persuade the participant to yield instead of take right of way. When participants did not have right of way, they generally tended to yield (Situation 1, ⬅ & 4, ⬅┅), especially when the other driver maintained speed (Situation 1, ⬅), which was also indicated by the respondents to the questionnaire. In situations where the participant did have right of way (Situation 2, ┅➡ & 3, ➡), the results found in the experiment are a bit more extreme than those indicated by the questionnaire study. It should be kept in mind that the respondents in the questionnaire study and the participants in the simulator experiment were not the same. Thus, factors such as national driving culture, experience and age could have had an effect on the results. To be able to determine the relationship between reported and observed behaviour, participants in the follow-up experiment were asked to report their behaviour in a shortened version of the Björklund and Åberg questionnaire and also display their behaviour in a similar driving simulator experiment. These results will be presented in Chapter 6.

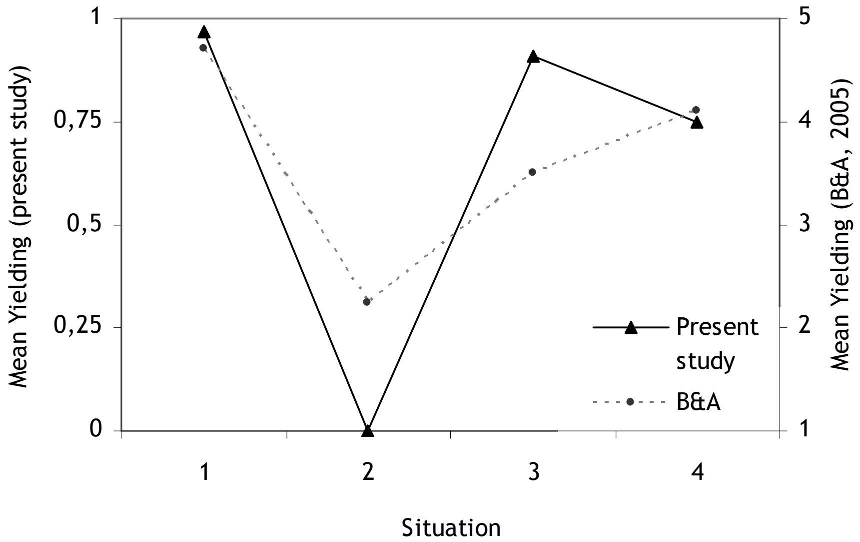


Figure 5.11: Mean Yielding per Situation
(B&Å results adapted from Björklund & Åberg, 2005)

How is the safety of the interaction influenced by uncertainty?
To determine how safety differs over the interaction situations, we started by inspecting the collisions that occurred between the participant and the other road user. As there were only five such instances they were visually inspected for common factors (Table 5.5).

All collisions occurred in the low visibility condition. Furthermore, no collisions occurred in Situation 2 (┅➡) and 4 (⬅┅). Four out of five collisions occurred with the experimenter as opposed to one collision with the pre-programmed road user. That collision occurred with a participant who also had a collision in Session E.

Table 5.5: Visual inspection of collisions

	Participant	Visibility	Situation	Encounter	Session	Order
Collision 1	19	Low	1	1	E	E-P
Collision 2	36	Low	1	9	E	P-E
Collision 3	36	Low	3	1	P	P-E
Collision 4	1	Low	3	3	E	E-P
Collision 5	10	Low	3	3	E	E-P

Subsequently, analyses were performed including near misses and the scores for the Safety index to see if these show a similar relationship with the different situations as the collisions. If so, this would allow us to learn more about the dangerous situations, as the greater number of near misses as well as the Safety index allow for a more detailed analysis than the small number of collisions. Encounters that resulted in a collision were excluded from these analyses. The total number of near misses amounted to 111 (vs. 1224 non-near misses).

To determine if near misses also occurred mostly in the low visibility condition, a GLM ANOVA for repeated measures was performed using the proportion of Near Misses in the Low versus the High Visibility condition. The results show that participants tended to experience more near misses in the low visibility condition (Mean $NearMiss_{low}$=0.10 vs. Mean $NearMiss_{high}$= 0.07; $F_{1,23}$= 4.948; p< .05). The same analysis was conducted using the Safety index as the dependent variable, but no significant effects were found.

To determine if the proportion of Near Misses was influenced by uncertainty, a GLM ANOVA for repeated measures was performed using the proportion of Near Misses for each combination of AS and ROW. Session was also included as a factor. The results showed a main effect for all three factors. Significantly more near misses occurred in the session with the experimenter as the interaction partner ($F_{1,18}$= 14.01; p< .01). As with the collisions, more near misses occurred when the other road user approached the intersection while maintaining speed ($F_{1,18}$= 8.47; p< .01). Also, the main effect found for ROW indicated that more near misses occurred when the participant had right of way independent of the other road user's Approach Strategy, thus when the other road user approached the intersection from the left ($F_{1,18}$= 7.24; p< .05). No significant interaction effects were found, although the combined effects of Session and ROW did indicate a trend ($F_{1,18}$= 4.03; p< .10) which suggests that an increase in near misses in Session E is found particularly when the participant had right of way. The interaction between AS and ROW also indicated a trend ($F_{1,18}$= 4.34; p< .10), which suggests that a higher proportion of near misses is most likely to be found in the particular combination of AS and ROW that created Situation 3 (➡). The same analysis was conducted using the Safety index and indicated main effects for

AS ($F_{1,18}$= 287.91; $p< .001$) and ROW ($F_{1,18}$= 8.68; $p< .01$). Situations where the other road user slowed down produced significantly higher scores for the Safety index than when the other road user maintained speed (4.253 vs. 1.189). As mentioned in Section 5.2.6, Safety index scores above about 3 indicate that one of the interaction partners came to a standstill somewhere in the interaction process. Particularly in Session P, when the other road user was assigned to slow down, the car would eventually come to a standstill and wait indefinitely when the intersection had been reached. Situations where participants did not have right of way yielded higher scores for the Safety index than when the participant did have right of way (3.037 vs. 2.406). The results also indicated an interaction effect between ROW and Session ($F_{1,18}$= 30.69; $p< .001$). In Session P, the participant not having right of way yielded higher safety scores than when the participant did have right of way. The effect of ROW is reversed in Session E, which shows higher scores for the Safety index in situations where the participant did have right of way.

To determine if near misses occur more often during earlier encounters with a particular situation a GLM ANOVA for repeated measures was carried out. A similar analysis was done using the Safety index. As some situations (i.e. Situation 3, ➡ and 4, ⬅··) included only four encounters, only the proportion of near misses for the first four encounters per situation were used to control for the amount of experience participants' would have gained with the particular situations. No effect was found of the number of encounters experienced on the proportion of near misses or on the Safety index. However, the results showed a main effect of situation ($F_{2.227,40.078}$= 6.33; $p< .01$) on Near Miss. Post hoc tests indicated that the proportion of near misses in Situation 3 (➡) was significantly higher than in Situation 2 (··➡) and 4 (⬅··) in the first four encounters. The post hoc tests for the analysis using the Safety index showed a similar pattern. The lowest Safety index scores were found for Situation 3 (➡), followed by Situation 1(⬅). Situation 2 (··➡) and 4 (⬅··) showed the highest Safety index scores ($F_{2.125,38.253}$= 4.34; $p< .10$).

Table 5.6 provides an overview of the results found for the Safety index, the Near misses and the Collisions. These different safety indicators used seem to be in accordance with each other regarding the conditions that seem to elicit decreased safety.

Table 5.6: Overview of results for different safety measures

		Safety Index	Near Miss	Collision
Visibility	low	more		5
	high	less		none
AS	slow down	less	higher	none
	maintain speed	more	lower	5
ROW	no	less	higher	2
	yes	more	lower	3
Session	E	more	higher when ROW=yes	4
	P	less	higher when ROW=no	1
Situation	1		low	2
	2	less	highest	None
	3	more	lowest	3
	4	less	highest	None

*Note: Cells that are **bold and underlined** indicate decreased safety*

5.3.3. Additional analyses

In the following part, some extra questions are answered that were not the initial focus of this experiment, but which arose out of observations or analyses made during it. These questions are included here, for their potential to give direction to the follow-up experiment or further research:

- What are the characteristics of participants who performed less safely?
- Are there effects of variables that were initially not intended to elicit an effect?

What are the characteristics of participants who performed less safely?

If we can identify some common characteristics of participants who experienced less safe interactions, this might be useful to determine categories of participants who could use extra support.

To identify the participants who were involved in collisions, the data (n=4) were visually inspected (Table 5.7), as were the data for participants who experienced a near miss in at least 10% of their encounters with another road user (n=7, Table 5.8).

Table 5.7: Personal characteristics of participants involved in collisions

	Sex	Age (yrs)	License (yrs)	Mileage(km/yr)
Pp 01	Female	54	36	10000 – 15000
Pp 10	Male	42	24	20000 +
Pp 19	Female	62	41	5000 - 10000
Pp 36[1]	Male	25	6	15000 – 20000

[1]This participant was involved in two collisions

Table 5.8: Personal characteristics of participants who experienced a near miss in at least 10% of their encounters with the other road user

	Sex	Age (yrs)	License (yrs)	Mileage(km/yr)
Pp 5	Female	42	23	10000 – 15000
Pp 13	Male	54	34	5000 - 10000
Pp 16	Male	61	38	15000 – 20000
Pp 17	Female	59	18	10000 – 15000
Pp 27	Female	37	18	10000 – 15000
Pp 36	Male	25	6	15000 – 20000
Pp 37	Female	41	19	5000 - 10000

Comparing the two tables shows that only one participant (Pp 36) appears in both tables, suggesting that people who experience a relatively high proportion of near misses might generally be different people than those who experience a collision, although Table 5.6 does seem to indicate consistent results for near misses and collisions. Obviously, such a statement needs to be substantiated by evidence which these present data cannot provide. Overall, the characteristics presented in Table 5.7 and Table 5.8 do not seem to provide a clear profile of a driver involved in less safe interactions. Thus, an attempt was made to identify these drivers based on their behaviour throughout the interaction process, such as throttle and braking behaviour.

To determine if participants who experienced less safe interactions can be distinguished by their 'throttle behaviour' during an intersection approach, two GLM ANOVA's for repeated measures were conducted. The first analysis included "Collision involvement" as a grouping variable to split the participants into two groups based on whether they had been involved in a collision. Encounters that developed into a collision were not included in the analysis to see if differences can be found in behaviours that did not lead to a collision. The second analysis split up the participants based on their experience of a near miss in at least 10 % of their encounters with the other road user. The participant's distance to the intersection when the throttle was first released (for each of the five situations) was used as the dependent variable. For this analysis, encounters that resulted in a collision or a near miss were not included to see if differences can be found in behaviours that did not lead to a collision or a near miss.

When analysing all encounters, the results did not show an effect for Collision involvement. As most collisions occurred during Session E and in the low visibility condition the analysis was repeated using only these encounters (i.e., Visibility low, other road user controlled by the experimenter and not resulting in a collision). These results showed that participants who were involved in collisions tended to first release the throttle when they were closer to the intersection than participants who did not experience a collision ($F_{1,19}$= 5.66; p< .05). The difference between the two groups' mean distance to the intersection when first releasing the throttle ranged between 8 and 24 meters (17m on average), depending on the situation (1 to 5).

The second repeated measures analysis also used two groups of participants (based on whether or not they had experienced a near miss in at least 10 % of their encounters) and included all encounters, both from Sessions E and P, for Situation 1 to 5, except the ones that resulted in a collision or a near miss. The results showed that these participants too released the throttle when they were (on average 11m) closer to the intersection ($F_{1,22}$= 5.04; p< .05). The differences between the two groups ranged from 5 to 14 meters (depending on the situation).

Similarly, to determine if participants involved in less safe interactions could be distinguished by their 'braking behaviour' during an intersection approach the same repeated measures analyses were performed. No significant effects were found for Collision involvement, even when the analysis was limited to Session E, but having experienced a relatively high proportion of near miss did show a main effect. Similar to the effect on throttle behaviour, participants who had experienced a near miss in at least 10% of their encounters tended to release the brakes when they were (11m on average) closer to the intersection than participants who experienced fewer near misses ($F_{1,20}$= 8.99; p< .01).

The mean distances to the intersection when releasing the throttle or braking for each group can be found in Figure 5.12. None of the analyses indicated a main effect for Situation. Note that the participants' distance to the intersection (DTI) when the other road user became visible (ranging from 28 to 31 meters, Table 5.3 and Table 5.4) is overall much less than the DTI's relating to throttle and braking behaviour, suggesting that the differences between the different groups of participants were found primarily in anticipatory or proactive behaviour rather than in reactive behaviour.

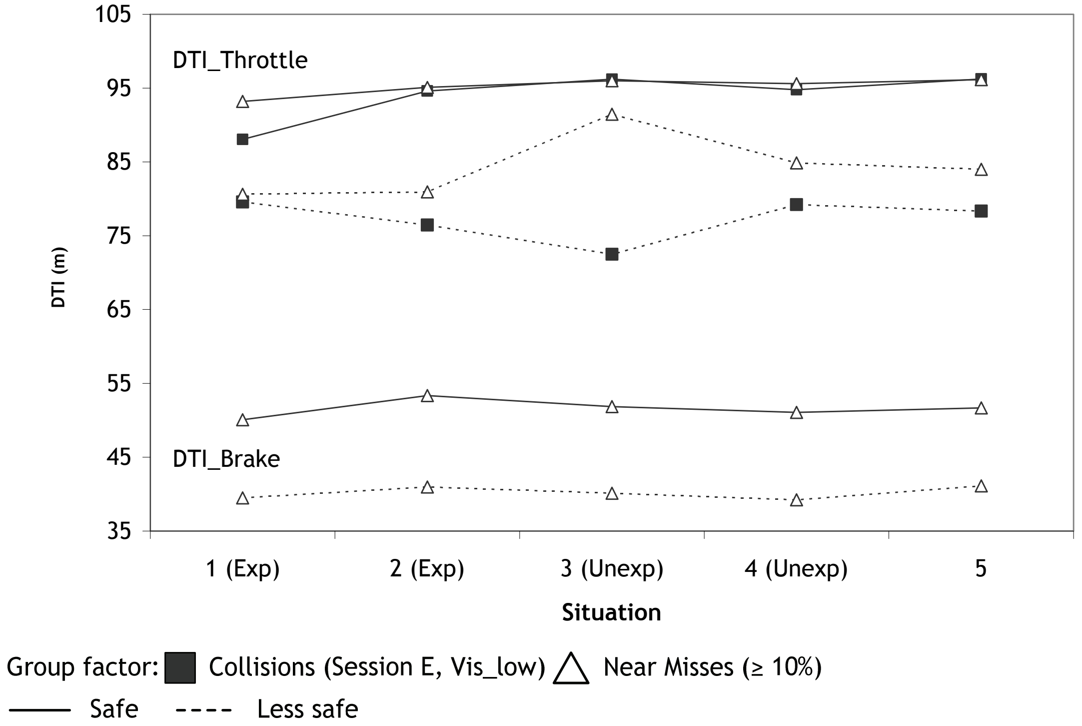


Figure 5.12: DTI for throttle and brake application for safe and less safe participants (based on their involvement in collisions and near misses).

Are there effects of variables that were initially not intended to elicit an effect?
As the interaction plots in part 1 of this results section indicated (particularly in Situation 4, ⬅▪▪) that Order influenced intersection behaviour, this is analysed here. To determine if the Order in which participants completed the two sessions had an effect on Mean Yield a repeated measures ANOVA was performed with Order as between-subjects factor. Although participants tended to yield more often when Session E was completed first in Situation 4, the results of the analysis did not indicate a significant effect.

A repeated measures ANOVA was conducted to determine if the Order in which participants completed the two sessions had an effect on the proportion of Near Misses. No significant differences were found for the different order conditions.

As the inspection of collisions showed that all collisions occurred in the Low Visibility condition, a GLM ANOVA repeated measures was performed for the Mean Yield scores in both visibility conditions, to determine if visibility of the intersecting road also had an effect on which road user will yield. Neither a main effect of Visibility nor an interaction effect between Visibility and Situation were found to be significant.

To determine if there was an effect of gender on yielding behaviour an ANOVA for repeated measures was performed using sex as between-subjects factor. The results indicated that males, contrary to expectation based on the idea that males drive more aggressively, tended to yield more often than females ($F_{1,19}$= 5.97; p< .05), particularly in Situation 4, (⬅▪▪).

5.4. Discussion & Conclusions

5.4.1. Approach Strategy and Right of Way

A key finding in this experiment is the fact that the effect of the other road user's Approach Strategy is able to overrule the effect of the right-hand rule with respect to yielding behaviour. This occurs when the other road user approaches the intersection from the left while maintaining speed (Situation 3, ➡), a combination which was assumed to elicit uncertain short term expectancies. The results also indicated that participants generally show yielding behaviour that is in accordance with the right-hand rule and that they generally tend to yield when confronted with a crossing road user maintaining speed. These effects were also found for reported yielding behaviour in the questionnaire study by Björklund and Åberg (2005). Based on these results it can be concluded that the right-hand rule is an important determining factor for yielding behaviour, which can be overruled by behaviour of other road users, which makes behaviour more cautious than if the rules were adhered to blindly.

The effects of uncertainty due to the manipulations of approach strategy and right of way will be discussed in the context of interaction safety in the next section.

5.4.2. Interaction safety

A notable finding relating to interaction safety is that situations which are designed to elicit uncertain short term expectancies (Situation 3 ,➡ and 4, ⬅▪▪) do not necessarily develop into unsafe interaction situations. Situation 3 (➡) did indeed lead to an increase in unsafe interactions, but Situation 4 (⬅▪▪) seems to have led to the opposite. Despite the increase in unsafe interactions in Situation 3 (➡), these were far less common than if the participants had stuck to their right of way, indicating that there was a very great degree of compensation by the participants for the "unsafe" behaviour of the other road user. Overall, the relationship between interaction safety and uncertainty of expectancies does not appear to be as straightforward as we suggested at the start of this chapter. The interaction space between both road users may be offer an explanation. A road user maintaining speed leaves less time for both road users to negotiate crossing the intersection (i.e. less interaction space) compared to a road user slowing down. As Näätänen and Summala (1976) pointed out, the amount of time or space available can indeed affect the probability of a hazardous event occurring. The interaction space explanation can also account for the finding that all collisions took place in the low Visibility condition. Low visibility of the intersecting road leaves less time for both road users to adapt expectancies to the behaviour of the interaction partner (i.e. decreased interaction space). The concept of interaction space was included in the follow-up experiment to explore the merits of this explanation.

Furthermore, the results suggest that the increased safety found in Situation 4 (⬅▪▪) may have come at the cost of efficiency, as participants tended to show yielding behaviour when confronted with this situation. When both interaction partners slowly approach the intersection, this tends to lead to a safer interaction situation but also to a less efficient interaction situation as it will take both road users more time to cross the intersection. The follow-up experiment discussed in the next chapter will further explore the relationship between safety and efficiency.

Another remarkable finding relating to interaction safety is that participants who were involved in less safe interactions, showed different proactive interaction behaviour in normal interaction situations compared to participants who were not involved in (as many) less safe interactions. Before the other road user was even visible to the participants, the less safe group tended to release the throttle at a point closer to the intersection than their safer counterparts. They tended to apply the brakes when they had approached the intersection more closely as well. To determine if this is a consistent finding, the analyses using groups of participants based on their involvement in less safe interaction situations will be repeated in the next chapter, which discusses the follow-up experiment.

5.4.3. Linked simulators

Although it was not the main focus of this experiment to evaluate the use of linked simulators, the innovative aspect of this approach does call for such a discussion. The results for this experiment showed more variation in yielding behaviour when using the linked simulators to introduce true interaction behaviour. The effect of relative positions of both interaction partners' vehicles could be responsible for some of the variation found in yielding behaviour. The experimenter was most likely not able to maintain speed as strictly as the programmed road user or slow down with the same deceleration rate on each encounter. This is likely to have had an effect on the variation in relative positions of both road users' vehicles.

Although the experimenter's behaviour could be considered "semi-programmed", as she behaved according to a preset protocol dictating when to maintain speed or slow down, it is still a step closer to natural interaction behaviour found in daily traffic. To allow for even more natural interaction behaviour, the follow-up experiment, discussed in the next chapter, included some situations in which the experimenter in the linked simulator did not have to follow a preset protocol. However, this experimental set-up does have its drawbacks. By letting both interaction partners behave freely, it will be difficult to attribute the findings to specific aspects of the situation.

The results also indicated more safety critical situations in the session with the experimenter compared to the session with the programmed road user, which might also partly be due to the increased variation in behaviours of the other road user in Session E. Increased variability may have introduced more uncertainty, leading to decreased safety. These results, however, also suggest that a study of the safety effects in interaction situations would be more fruitful when using two linked simulators. All in all, it seems that – in this experiment – the use of just a single driving simulator (Session P) elicited more artificial interaction behaviour than the use of the linked simulators did. Therefore, it was decided to use only linked simulators for the follow-up experiment.

5.4.4. Limitations

A limitation of the present experimental set-up is that in all situations involving another road user, participants would only encounter a single other road user at each intersection. It is likely that, eventually, participants learned that after dealing with that road user, the intersection would be clear and no further anticipatory actions were required, whereas, in real life, a driver can never be sure that no other drivers will be encountered and will behave accordingly.

Another factor that could have influenced behaviour of participants as they approached the intersection was the fact that there were no road users following the participant. This could have affected the moment the participants chose to first release the throttle as they approached the intersection, which was generally rather far from the intersection. If the participant would have seen a road user directly behind him or her, this could have persuaded the participant to delay releasing the throttle so as not to hinder that road user.

Obviously, the situation becomes more complex as more road users are involved in the interaction situation and more intentions need to be inferred. To be able to determine an effect of uncertainty of expectancies it was necessary to keep the experimental situations clear and simple and focus on a selection of the large number of variations possible in real life interactions.

Another limitation has already been mentioned throughout this chapter. The results have indicated that visibility of the intersecting road was such that participants tended to release the throttle and apply the brakes some time before they could have perceived the other road user. Consequently, effects of the uncertainty manipulations on these behaviours could not be determined. The follow-up experiment discussed in the next chapter will therefore also include intersections with improved visibility to be able to assess those effects.

6. Providing extra information at intersections: effect on expectancy[6]

6.1. Introduction

6.1.1. Expectancy and interaction space

The previous experiment attempted to affect participants' expectancies by manipulating both the other road user's approach strategy as well as by manipulating which road user had right of way. The results showed that both manipulations had a significant effect on the participants' yielding behaviour, presumably due to (uncertainty of) the expectancies, leading to the selection of different actions (to yield or not to yield). When the approach strategy did not correspond to the right of way situation (presumably eliciting uncertainty) this did not necessarily lead to less safe situations. Of the two situations intended to elicit uncertainty, only the combination of the other road user maintaining speed and the participant having right of way led to a decrease in safety. The difference between these two situations lies in the amount of time and space available to both road users to adapt to the unexpected situation: the so-called "interaction space".

According to the model postulated in Chapter 2, adapting to an unexpected situation requires adaptation of the active expectancy using perceived aspects of the situation. Based on the previous experiment it seems that certain characteristics of the interaction situation will allow for a varying amount of short term adaptation of the active expectancies (as the situation develops). For example, when both road users approach the intersection at relatively higher speeds, less time will be available for both road users to adapt their expectancies before their paths will intersect than

[6] An abridged version of this chapter will be submitted to a peer reviewed journal.

when both road users approach the intersection while slowing down. The latter approach is likely to increase interaction space and with that the time available for short term adaptation of expectancies. When road users perceive the developing situation as corresponding to their active expectancy (eliciting relatively little uncertainty), it is likely that little time is needed to adapt the expectancy. However, when the developing situation seems to conflict with their active expectancy (eliciting higher levels of uncertainty), presumably more time is needed to adequately adapt the expectancy which will enable the road user to select a more appropriate action if necessary.

In addition to manipulating aspects which are assumed to affect (uncertainty of) expectancies (i.e. approach strategy and having right of way), the experiment discussed in this chapter includes an attempt to manipulate the resulting interaction space as well, to further explore the role of interaction space in the interaction process.

6.1.2. Manipulating interaction space

Visibility

Studies focussing on intersection safety have often taken "intersection sight distance" into account (e.g., Dewar, 2002). That is, an intersection should allow all approaching drivers an unobstructed view of a minimum recommended length of roadway of the intersecting roads. This unobstructed view allows road users to anticipate the development of the interaction process at the upcoming intersection. Intersection sight distance can be affected by, for example, buildings, fences and traffic control devices. A related concept is "stopping sight distance" which is the total distance needed to perceive an event and come to a standstill (Layton, 2004). The abovementioned distances depend on the “design speed” of the road; a higher design speed increases the required intersection sight distance.

As the previous experiment (Chapter 5) demonstrated, visibility of the intersecting roads can affect driving behaviour at intersections. When visibility of the intersecting road is decreased (e.g., due to buildings blocking the view), interaction partners are not able to perceive each other until they are relatively close to the intersection. When the interaction partners have a clear view of the intersection, perception of each other can occur at a much earlier moment. The first experiment (unintentionally) included two visibility conditions. The results of that experiment suggested that visibility of the intersecting road is a way to manipulate the interaction space. Thus, in the experiment discussed here, visibility was purposely manipulated.

Extra information

In a user needs survey related to ADAS (n=1049) 82% of the respondents indicated a (great) need for a blind spot warning at unsignalised intersections in an urban environment (van Driel & van Arem, 2005). A need for other types of blind spot warnings was indicated as well. Apparently, a majority of respondents would like to be informed about activities at a moment in time when they cannot perceive them directly. Translating this idea to the intersection situations in the experiment reported in the previous chapter, it seems that an insufficient intersection sight distance can create such a "blind spot". At intersections, the view of other road users approaching is often obstructed by buildings for a certain period of time. Thus, drivers might also appreciate information about what is happening in that particular "blind spot".

The results of the experiment reported in the previous chapter indicated that situations in which the participant encountered a road user approaching the intersection who maintained speed could be considered the least safe. We consequently considered specifically informing participants in the follow-up experiment about road users approaching the intersection from both directions while maintaining speed or perhaps even only about road users maintaining speed approaching the intersection from the left (i.e. an unexpected situation). Informing a driver about road users maintaining speed might lead to (earlier) braking and yielding. This, by itself, is not such a problem. However, in situations where the other road user does not display any intent of yielding (i.e. maintaining speed) but should do so according to the priority regulation at the intersection, braking could be construed as "rewarding" that road user for behaviour that is essentially undesirable. Also, only informing a driver about a selection of approaching road users might cause some other road users to go unnoticed, which might in turn produce undesirable situations. Therefore we eventually decided on informing participants about all approaching road users instead.

Advanced Driver Assistance Systems (ADAS) are systems that partly support or take over the driver's tasks. Naniopoulos (2000) typifies ADAS as systems that support the modification of the driving task by providing information, advice and assistance, influencing the behaviour of users of equipped and non-equipped vehicles both directly and indirectly. An objective of this thesis research is to identify aspects of the interaction process that could be aided by ADAS. In the experiment reported here, it was decided to focus on the "providing information aspect" of ADAS. Providing road users with information concerning the behaviour of other road users is assumed to have a similar (positive) effect on the available interaction space as increasing visibility of the intersection road.

An alternative to informing the driver would be to use vehicle-to-vehicle communication and inform the vehicle (or the ADA system in the vehicle) about other vehicles in the vicinity, similar to the cooperative system discussed by van Arem, van Driel and Visser (2006). However, as this thesis is mainly focused on understanding the behavioural aspects of an interaction situation, it was decided to study the effects of providing information to the driver rather than to a system.

In summary, the attempt to manipulate interaction space in the present experiment involved varying visibility of the intersecting road and providing participants with information concerning the approach of the road user on the intersecting road.

6.1.3. Measures of driving behaviour

Safety

The previous experiment studied the effects of the manipulations of expectancy on the safety of the interaction using the Safety index and the number of near misses and collisions. To study the effect on safety in greater detail the present experiment included a wider variety of measures that could provide information concerning the safety of the interaction (Table 6.4). A detailed discussion of these measures and their use in prior studies can be found in Chapter 3 (Section 3.3.2).

Efficiency

The results of the previous experiment suggested that safety might come at the cost of efficiency. For example, in the previous experiment, when confronted with another road user slowing down who has right of way (i.e. an unexpected situation), many participants came to a complete standstill, thus increasing the amount of time needed for both road users to cross the intersection. On the other hand, interactions in this particular situation seemed to be rather safe as well. The abovementioned behaviour of the participant could be identified as a "stop and wait" strategy as opposed to a "flying" strategy, where either one or both road users adapt to the other's behaviour so they can both cross the intersection without anyone having to come to a standstill. Perhaps when the available interaction space is sufficient to ensure a safe interaction, the road user might choose to decrease the interaction space by increasing speed, thus creating a trade-off between "excess" safety and efficiency of the interaction.

Literature discussing a trade-off between safety and efficiency has focused mainly on the engineering aspects of the situation rather than on the behavioural aspects (e.g., Zhang & Prevedouros, 2003). To investigate the presumed trade-off relationship between safety and efficiency, the present experiment included several behavioural indicators of the efficiency of the interaction (Table 6.4). As the focus of this experiment was mainly on the interaction process, one of the behavioural indicators involved combining the driving speeds of both drivers to assess the efficiency of the interaction.

Yielding
The concept mapping study discussed in Chapter 4 indicated that aspects concerning right of way play an important role in driver's expectations concerning interaction situations. Both the results of Björklund and Åberg (2005) and the results discussed in Chapter 5 have shown that the right of way regulation and the approach strategy of the other road user influence yielding behaviour. Combining these two aspects creates situations that differ in the amount of uncertainty they elicit and can either be considered expected or unexpected. When the approach strategy corresponds to the right of way regulation, the resulting situation could be considered 'expected', whereas an approach strategy that is in conflict with the right of way regulation could result in a situation that could be considered 'unexpected'. Combining different approach strategies of the other road user and the road user having right of way was an attempt to manipulate the participant's expectancies and corresponding levels of uncertainty. We expect to find similar effects of these particular manipulations on yielding behaviour as we found in the previous experiment.

Subjective measures
To help interpret the behavioural data derived in this experiment, some additional subjective measures where included: a measure indicating mental workload (Rating Scale Mental Effort), a measure indicating participants' estimation of their yielding behaviour (Yielding Behaviour Questionnaire), a measure of participants' risky behaviour in traffic (Driver Behaviour Questionnaire) and a measure to assess the acceptance of new car features (Acceptance scale). These measures as well as their use in prior studies are discussed in detail in Chapter 3 (Section 3.3.3).

6.1.4. Research questions

Main research questions
As mentioned above, both providing extra information and increasing visibility of the intersecting roads are assumed to increase the available interaction space. The effect of both aspects on different indicators of driving behaviour will be assessed in this chapter. The main research question for this experiment is:

- ❖ How do the different manipulations of interaction space affect driving behaviour at intersections?

The effect on driving behaviour will be assessed by investigating several types of behavioural indicators relating to the safety and efficiency (and their trade-off) of the interaction as well as yielding behaviour. A more specific research question addresses both aspects that are assumed to increase interaction space as well as the behavioural indicators:

- ❖ How do extra information and/or increased visibility affect the behavioural indicators of:
  - ♦ safety
  - ♦ efficiency
  - ♦ yielding behaviour
  - ♦ subjective mental effort (n.a. for visibility)
  - ♦ subjective acceptance (n.a. for visibility)

The effects found for the subjective measures concerning acceptance and mental effort can only be attributed to an effect of extra information. In the case of acceptance this is obvious; acceptance of the extra information is assessed after the sessions where the driver was provided with extra information. As mental effort is measured using a rating scale to be completed after a session, effects can only be attributed to extra information and not to visibility. Visibility was varied within experimental sessions whereas providing extra information was varied between experimental sessions.

Participants in the previous experiment always encountered a road user with a predetermined (i.e. Fixed) approach strategy (i.e. the other road user was instructed or programmed to either maintain speed or slow down according to a pre-determined plan). It is likely that this would have an effect on the way the interaction develops. To determine the effect of the approach strategy being fixed, the present experiment included three different Approach Conditions. The first two Approach Conditions correspond to the combinations of Approach Strategy and Right of Way in the previous experiment. The first Approach Condition is defined as Fixed_expected, where the predetermined Approach Strategy is in accordance with Right of Way and thus expected. The second Approach Condition is defined as Fixed_unexpected, where the predetermined Approach Strategy conflicts with Right of Way and is thus unexpected. The final, added Approach Condition is defined as Free and includes situations with the experimenter approaching the intersection without a predetermined Approach Strategy. In these situations the experimenter approached the intersection from a random direction (left or right) which in itself determines the right of way situation (i.e. a "free" approach). The experimenter did not receive instructions concerning the Approach Strategy to be followed and approached the intersection as she would in an interaction situation in real life, letting the relative positions and speeds of both road users determine if she should yield or if she could cross the intersection. Thus, another research question deals with the effect of the different Approach Conditions:

- ❖ What is the effect of the Approach Conditions Fixed_expected, Fixed_unexpected and Free on driving behaviour at intersections?

Additional analyses
Additional analyses were conducted to answer questions prompted by other results found either in the previous or present experiment. The first additional analysis was aimed at checking the repeatability of the results of the experiment discussed in the previous chapter concerning the effects of Approach Strategy and Right of Way on yielding behaviour.

Furthermore, participants were asked to assess their yielding behaviour for a number of schematically represented situations, including the situations that were part of the experiment. Their self-reported yielding behaviour will be compared with observed yielding behaviour as they displayed it in the experiment. This second additional analysis might provide more insight into the role of their expectancies concerning the presented situations and what their behaviour is when actually confronted with these situations. Of particular interest is the comparison between self-reported and observed yielding behaviour in the unexpected situations. Are people able to correctly predict what they do in such situations?

Furthermore, additional analyses will focus on the results of the customised questionnaire to learn more about participants' experiences throughout the experiment, particularly concerning experiences with the extra information provided.

As the results of the previous experiment suggested that participants involved in collisions released the throttle later than participants who were not involved in collisions, the results for the present experiment will be analysed for similar effects. And, to determine if "less safe" drivers in this experiment could be identified by their reported violating behaviour, the Driver Behaviour Questionnaire was included in this experiment.

6.1.5. Hypotheses

Based on the model postulated in Chapter 2 and the results of the first experiment, we expect to find that situations where the approach strategy of the other road user is to maintain speed, will be indicated as less safe, especially when the approach strategy can be interpreted as unexpected due to the right of way regulation. These situations are assumed to need extra interaction space and thus allow less time to adjust expectancies and select an appropriate course of action. Following the same line of reasoning, when an attempt is made to increase interaction space, either by increasing visibility or providing extra information concerning the approach of other road users, we expect to find a positive effect on safety, particularly in those unexpected situations. It may be that combining increased visibility with providing extra information will not increase safety any further, as the separate influences may already have made their maximum impact on safety.

As the previous experiment already seemed to indicate a trade-off relationship between safety and efficiency, we expect to find evidence for such a relationship in the present experiment. Thus, although situations where the approach strategy of the other road user is to maintain speed are expected to be less safe, we also expect the interaction to be more efficient. Limited interaction space might force road users to select a certain course of action within a smaller amount of time, resulting in a more efficient interaction. On the other hand, increasing interaction space by improving visibility might also have a positive effect on efficiency. Road users will be able to adjust their expectations about the other parties' behaviour during a longer period when they are able to perceive the other road user at a greater distance from the intersection. Similarly, increasing interaction space by providing the participant with extra information concerning the behaviour of another road user approaching the intersection could also enhance interaction efficiency. The effect of providing information is expected to be largest when visibility is low. When both visibility is high and information is provided, this will probably provide the driver with redundant information. Thus, the added value of each attempt to increase interaction space is predicted to become less when both are applied.

Concerning the effect of the three different approach conditions on driving behaviour at intersections, we might expect the largest differences between the condition where the approach strategy of the other road user was fixed, but unexpected and the other two conditions, in which the approach strategies are assumed to be considerably less unexpected. In the Free condition, the experimenter was instructed to negotiate the intersection as she normally would do, without being informed about the direction the participant would approach from. Assuming the experimenter will comply with the right of way rules (based on the main effect of the Right of Way regulation found in the previous experiment), the effect of the Free Approach Condition on the participants' behaviour should be similar to the effect of the Fixed_expected Approach Condition and thus, both should be safer than the Fixed_unexpected Approach Condition. However, we might also expect differences between the Fixed_expected and Free Approach Condition due to an effect of predetermination of the Approach Strategy. As the Free condition will allow the experimenter to fully adapt her behaviour to the behaviour of the participant instead of having to follow a predetermined Approach Strategy, we might expect increased safety and perhaps also efficiency in the Free Approach Condition as compared to the Fixed_unexpected condition.

6.2. Method

6.2.1. Participants

Thirty-three Dutch participants were obtained from the SWOV participants-database or recruited by placing an advertisement in a local newspaper. They were advised not to take part if they tended to get car sick as simulator sickness seems to occur more often with people that have that tendency (Hoffman, Molino, & Vaughan, 2003). Participants had all obtained their driving licence at least 5 years before taking part in the experiment and had driven at least 5000 km in the previous year. Seven participants dropped out due to simulator sickness. Thus, twenty-six participants completed the experiment (8 ꩜, 18 ꩜). They were aged between 25 and 70 (mean age: 53 ± 12 yrs). All participants were paid € 20.

6.2.2. Apparatus

The exact same simulators were used as in the driving simulator experiment discussed in the previous chapter. Please refer to Chapter 3 for more details on the simulators.

6.2.3. Stimuli

This experiment consisted of 4 driving sessions which will be discussed in more detail in the design and procedure section. Each session contained the same 5 situations that varied in expectancy as in the experiment discussed in the previous chapter. In Situation 5 the participant did not encounter another road user at the intersection. Additionally, per session, 2 intersections (Situation 6 & 7) were added where the experimenter approached the intersection from either the left or right (randomly assigned) without displaying any predetermined behaviour (i.e. maintaining speed or slowing down). This allowed us to gain some insight into the natural interaction process. Table 6.1 provides an overview of the situations included in this experiment.

Participants drove through a simulated environment which is similar to the environment in the first experiment. However, as visibility proved to play a role in the previous experiment it was purposely entered as an independent variable in this experiment. Visibility had three levels. The first level (i.e. Visibility Low) is similar to the actual visibility levels in the previous experiment (where the other road user would generally become visible between 25 and 35m to the intersection). In the present experiment, “Low” was designed so that the participant could perceive the other road user at about 30m to the intersection. To create more interaction space, the buildings in the other two Visibility levels (i.e. “Medium” and “High”) were further away from the intersection. Participants were supposed to be able to see the other road user at 50 and 80m to the intersection, respectively. The required stopping sight distance for a road with a design speed of 50 km/h in the Netherlands is set at 50 meters (CROW, 2002). The actual mean visibility distances can be found in Table 6.2. Although Visibility turned out to be better than initially intended (due to the approach speeds of both road users), the most important manipulation turned out to be successful; all visibility conditions produced (significantly) different Visibility results ($F_{2,50}$= 3535.46; p< .001).

Table 6.1: Description of situations per session

Situation	1	2	3	4	5	6/7
	◄——	- - - -►	——►	◄- - - -		► / ◄
Approach Strategy (AS) other road user[1]	M	S	M	S	-	-
Approach Direction (AD) other road user[2]	R	L	L	R	-	L/R
Approach Condition (AC) other road user[3]	F_E	F_E	F_U	F_U		Free
Right of Way (ROW) for the participant?	No	Yes	Yes	No	-	Yes/No
Visibility Low	2x	2x	-	-	-	-
Visibility Medium	2x	2x	1x	1x	2x	-
Visibility High	2x	2x	1x	1x	2x	2x
Total encounters per session	6x	6x	2x	2x	4x	2x

[1]M: Maintain speed; S: Slow down

[2]R: Right; L: Left

[3]F_E: Fixed_expected; F_U: Fixed_unexpected

Table 6.2: Distance to intersection when the participant could first perceive the other road user

	Design Distance	Mean	SD
Visibility Low	30m	40.58m	3.29m
Visibility Medium	50m	60.01m	2.64m
Visibility High	80m	85.30m	3.09m

As in the first experiment, cars were the only type of other road users. The previous experiment included both oncoming cars as well as cars coming from the intersection road. The oncoming cars were added to enhance the reality of the driving task, but, due to technical difficulties, turned out to display unexpected behaviour resulting in the extra cars suddenly appearing somewhere and colliding with unsuspecting participants. Thus, it was decided that the only other road users encountered in the present experiment would be controlled by the experimenter, and no extra traffic was to be generated. Furthermore, in two out of four sessions, participants were provided with extra information concerning the behaviour of all other road users approaching the intersection. The extra information was presented through headphones (auditory information) as well as on the dashboard (visual information). Through the headphones, participants were alerted by a series of beeps, presented to the ear which corresponded to the direction from which the other driver was approaching. The length and pitch of the beeps corresponded to the approach speed of the other road user. That is, long and low pitched beeps indicated a slowly approaching road user, whereas short high pitched beeps indicated a rapidly approaching road user. A red flashing light to the left or right of the centre of the speedometer indicated road users approaching from either the left or the right. The rate of flashing of the light corresponded to speed of the other road user as well.

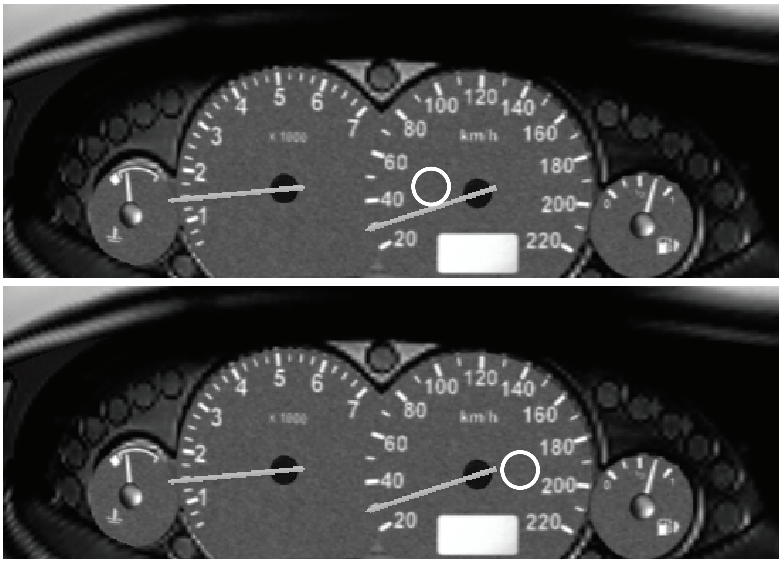


Figure 6.1: Location of flashing lights on speedometer

6.2.4. Subjective measures

To determine the relationship between reported and displayed behaviour, participants received several rating scales and questionnaires preceding and during the experiment. In total, six different types of subjective measures were administered. These measures will only be briefly described in this chapter. For a more extensive review of these rating scales and questionnaires and their use in previous research, please refer to Chapter 3 which deals with the research methods employed in this thesis research. A copy of the standardised questionnaires can be found in Appendix A through Appendix D.

Rating Scale Mental Effort

The Rating Scale Mental Effort (RSME) is a subjective scale used to determine participants' perceived mental effort (Zijlstra & Van Doorn, 1985). This scale was added to determine the effect of extra information on mental effort and completed after each session.

Acceptance Scale

After all sessions with extra information, participants filled out an acceptance scale for the beeps and lights separately (van der Laan, Heino, & De Waard, 1997). This scale was used to determine participants' acceptance of the way extra information was provided in this experiment.

Yielding behaviour questionnaire
The interaction situations used in the questionnaire by Björklund and Åberg (2005) on which both driving simulator studies in this thesis were based were presented to the participants of this second experiment after they completed all four driving sessions. This enables a direct comparison between self-reported and observed yielding behaviour.

Customised questionnaire
An extra questionnaire was prepared with specific questions concerning the participants' experiences throughout the experiment.

Driver Behaviour Questionnaire
The Dutch translation of the Driver Behaviour Questionnaire (DBQ) as used in Lajunen, Parker and Summala (2004) was used to see if less safe drivers in the experiment could be identified based on the DBQ scales (i.e. violations, errors and lapses). The questionnaire was completed before the participants started with the experimental sessions.

6.2.5. Design
Many participants in Experiment 1 indicated that the sessions were rather long, which is likely to have contributed to the sizeable proportion of participants dropping out with simulator sickness. To prevent such a large proportion of participants dropping out again, it was decided to have shorter driving sessions and consequently more (short) breaks. In total, there were 4 driving sessions; 2 with and 2 without extra information. Each session could be completed in about 15 minutes, as we also decreased the length of the road stretches between the intersections (by 250m resulting in 350m instead of 600m between intersections).

Four order conditions were defined. All groups started with two practice sessions and continued with a session without extra information, followed by two sessions with extra information and completed the experiment with a session without extra information. The order of situations per session type was randomised resulting in two different "routes". All participants encountered each route twice (once without and once with extra information).

6.2.6. Procedure
All participants completed the DBQ questionnaire on the internet prior to their participation in the experiment. Participants arrived at the laboratory and were presented with an instruction leaflet explaining what the experiment entailed. The leaflet discussed the way the extra information would be provided and stressed that participants were to try and keep to the speed limit of 50 km/h. Subsequently, participants took their place in the simulator where the experimenter explained the way to operate the simulator and informed them again that symptoms of simulator sickness might occur. Figure 6.2 indicates the order in which the sessions were

completed by the participants. Each participant started with a 4 minute practice session (without extra information; PS(-)) in which they would only encounter a pre-programmed road user, allowing the experimenter to stay with the participant and answer any questions the participant might have. Following the first practice session, they completed an RSME and continued with the second (four minute) practice session in which extra information was provided (PS(+)). RSME's were to be completed after each session. In between sessions, participants were allowed to take a break (as long as they felt necessary; B1-3) before continuing with the next session. After the third session, when all sessions with extra information (Info (+)) were completed, participants were asked to complete the acceptance scale for both the lights and the beeps. After having completed all four sessions, participants were also presented with the customised questionnaire and the Yielding Behaviour questionnaire.

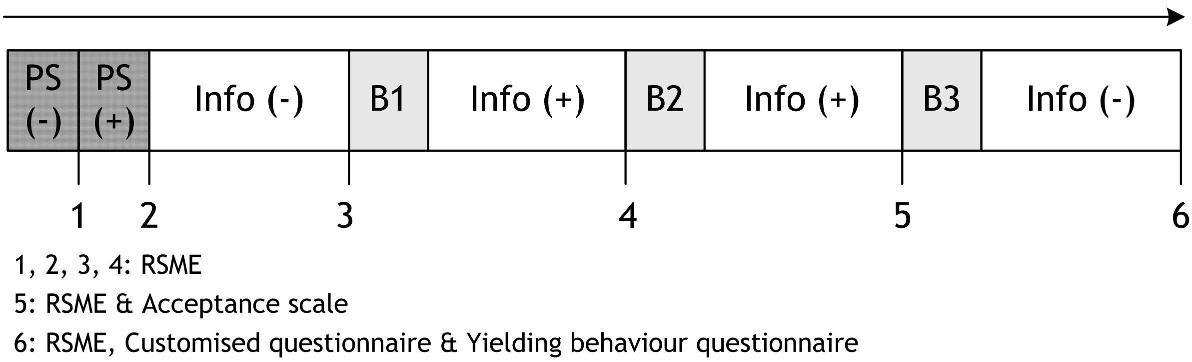


Figure 6.2: Order of sessions, breaks and questionnaires

6.2.7. Data collection and analyses

The main independent and dependent variables that were included in the analyses of the results are introduced in Table 6.3 and Table 6.4, respectively. Data concerning speed, throttle, braking and position for both the participant and the experimenter were sampled with 100 Hz. Dependent variables were initially calculated for each situation encounter. Depending on the analysis to be conducted, scores for these variables were aggregated per participant.

The experiment had a within-subjects design. Each participant encountered the same number of encounters with situations 1 through 5. The distribution of Situations 6 and 7 was randomised over participants to enable the approach strategy of the experimenter to be truly free. With Situation 6 and 7 occurring randomly, she would not know from which direction to expect the participant. Thus, not all participants will have encountered Situations 6 and 7 in the same proportion. The effects of the within-subject factors (Extra Info, Visiblity, ROW, AS, etc.) were analysed using the GLM ANOVA for repeated measures. An ANOVA for repeated measures assumes sphericity (i.e., equal variances of the differences between levels of the repeated measures factor). To test if the sphericity assumption is violated, Mauchly's test is conducted. The Greenhouse-Geisser is a commonly used correction for violations of the sphericity assumption. By adjusting the degrees of freedom using the Greenhouse-Geisser correction the repeated measures ANOVA becomes more conservative (Field, 2005). Due to the application of the Greenhouse-Geisser correction degrees of freedom for similar analyses can vary. Post hoc analyses for the within-subjects factor were performed with t-tests using the Bonferroni correction to control for the familywise error. Where too few values for a certain variable did not allow for a repeated measures ANOVA to be conducted, a Chi square analysis was conducted using the entire data set, rather than an aggregated data file. An alpha of .05 was consequently used to determine the significance of effects.

Table 6.3: Main independent variables

Variable	Explanation	Range
Situation	As described in Table 6.1	1-7
ROW	Did the participant have Right Of Way (ROW)?	0: no; 1: yes
AS	What was the Approach Strategy (AS) of the other road user?	1: slow down; 2: maintain speed
AC	What was the Approach Condition (AC) of the other road user?	1: Fixed_expected; 2: Fixed_unexpected; 3: Free
Extra Information	Was the participant provided with extra information (beeps and lights) during this session?	0: no; 1: yes
Visibility	How was the visibility of other road users approaching the intersection?	1: Low; 2: Medium; 3: High
Exposure	Has the participant been exposed to this type of session (with or without Extra Information) before?	0: no; 1: yes

The main dependent variables that were included in the analyses of the results are introduced in the following table.

Table 6.4: Main dependent variables

Variable	Explanation	Range
TTC_{min}	Minimum Time to Collision[1]	≥ 0s
Safety	The natural log of the difference between the time in seconds to the estimated collision point of the participant and the other road user[2], when the participant is 15m from the centre of the intersection. N.B. Values >3 indicate that one of the interaction partners stood still, and cannot really discriminate anymore.	≥ 0
DTI_Brake	The participant's mean distance to the intersection (DTI) in meters when the brake is first pressed.	0 -150m
Hard Braking	Indicates how often the participant pushed the brake for more than 60%	0 (never) – 1 (always)
DTI_Throttle	The participant's mean distance to the intersection (DTI) in meters when the throttle is first released.	0 -150m
Near miss	Indicates how often the difference in time to the estimated collision point of the participant and the other road user was less than 1.5 seconds	0 (never) – 1 (always)
Collision	Did a collision occur?	0: no; 1: yes
Efficiency	Sum of average speeds of both interaction partners (km/h) from when they were between 150 m. before the intersection to reaching the centre of the intersection	≥ 0 km/h
Speed_after	Participant's speed at the moment of leaving the intersection	≥ 0 km/h
Standstill	Indicates how often a participant's speed was < 1 km/h (proportionally over all encounters).	0 (never) – 1 (always)
Mean Yield	Indicates how often a participant yielded (proportionally over all encounters).	0 (never) – 1 (always)
Mental Effort	Subjectively perceived mental effort as indicated on the RSME	0-150
Usefulness	Mean score on items on subscale of Acceptance concerning Usefulness	
Pleasantness	Mean score on items on subscale of Acceptance concerning Pleasantness	

[1](van der Horst, 1990a)/ [2](de Winter et al., 2006)

As Table 6.4 includes many different dependent variables, it was decided to conduct the same type of analyses for the majority of these variables to consistently check for effects of the different independent variables introduced in Table 6.3, so as to answer the main research questions posed in Section 6.1.4. These analyses included different levels of the dependent variables (see Table 6.5). The first of three repeated measures analyses (A-I) only included encounters in Situation 1 (⬅) and 2 (⇢) to determine the effect of all three Visibility levels. The second repeated measures analysis (A-II) included encounters Situation 1 (⬅), Situation 2 (⇢), Situation 3 (➡) and Situation 4 (⇠) at the medium and high Visibility levels to determine the effects of Situation, Approach Strategy and Right of Way. Thus, the encounters at low Visibility levels were left out of A-II to be able to compare the encounters in all four situations. Both A-I and A-II also included Extra Information as a factor with two levels. A third repeated measures analysis (A-III) was included to determine the effect of Approach Condition: 1) Fixed_expected (Situation 1, ⬅ and Situation 2, ⇢); 2) Fixed_unexpected (Situation 3, ➡ and Situation 4, ⇠); 3) Free (Situation 6, ▶ and Situation 7, ◀). As Situation 6 (▶) and 7 (◀) only occurred in the high Visibility condition, this analysis only included encounters in the high Visibility condition. Appendix J to Appendix M provide summary tables of the results. Appendix N to Appendix P provide summary tables of the effects.

Table 6.5: Levels of dependent variables used in analyses

Number of levels per dependent variable:	Situation	AS	ROW	AC	Extra Info	Visibility
A-I	2	(2)	(2)	(1)	2	3
A-II	4	(2)	(2)	(2)	2	2
A-III	(6)	(2)	2	3	2	(1)

Note: Numbers in parentheses indicate that this dependent variable was not included in the analysis explicitly (each Situation is a different combination of AS and ROW). Analyses thus included either Situation as a dependent variable or AS and ROW.

6.3. Results

6.3.1. Main research question

Safety – TTC_{min}

First of all, analyses were conducted using minimum Time to Collision (TTC_{min}, Table 6.4) as suggested by Van der Horst (1990a). For A-I, the only significant effect was found for Visibility ($F_{1.612,38.693}$= 4.40; p< .05). No effects were found for either Extra Information or Situation. Post hoc analyses revealed that the medium Visibility level yielded a significantly lower TTC_{min} than the high Visibility level (mean TTC_{min} 0.856s vs. 0.978s, respectively). No other significant differences were found in this analysis. For A-II and A-III, no significant effects were found.

Safety – Safety index

Data analysis continued using the Safety index which is based on the speed of both road users as they approach the estimated collision point (Table 6.4). The results for A-I indicated a main effect of Situation and Visibility ($F_{1,24}$= 43.50; p< .001 and $F_{2,48}$= 9.79; p< .001 respectively). Figure 6.3 shows that a higher score for Safety is found in Situation 2 (⇢) indicating that this situation yielded safer interactions than Situation

1 (⬅). Post hoc tests revealed that when Visibility is low, a significantly higher Safety score is found as compared to the other two (i.e. higher) levels of Visibility. It should be noted that a Safety score larger than 3 can be the result of one of the interaction partners standing still and waiting for the other to pass, which was often the case in Situation 2 (⋯➡). Although the effect of Extra Information was not significant, the results did indicate a trend ($F_{1,24}$= 3.67; p< .10). Figure 6.3 indicates that this trend might be caused by a decreased safety score in Situation 2 (⋯➡) when Extra Information is provided.

The results for A-II indicated an effect of Situation ($F_{1.901,45.627}$= 34.66; p< .001). Post hoc analyses revealed a significantly higher Safety score for Situation 2 (⋯➡) and 4 (⬅⋯) versus the Safety scores for Situation 1 (⬅) and Situation 3 (➡). Thus it seems that the situations in which the other road user approached the intersection while slowing down yielded safer interactions than situations which involved the other approaching the intersection while maintaining speed. No significant effects were found for Visibility. Again, the effect of Extra Information was not significant, but did indicate a trend ($F_{1,24}$= 4.20; p< .10). Encounters without Extra Information seem to yield higher Safety scores.

A-III indicated a significant effect of Approach Condition ($F_{2,40}$=3.37; p< .05). The highest Safety score was found for Fixed_unexpected, followed by Fixed_expected and Free. This, perhaps counterintuitive, effect can be explained by the significant interaction effect between Approach Condition and Right of Way. When participants did not have right of way and were confronted with an unexpected Approach Strategy (i.e. Situation 4, ⬅⋯), the highest Safety score was found, which was in fact higher than 3, indicating that one of both interaction partner came to a standstill (in this case it is likely that the participant came to a standstill). For the other Approach Conditions (i.e. Fixed_expected and Free), higher Safety scores were found when participants did have right of way (i.e. Situation 2, ⋯➡ and 6, ▶).

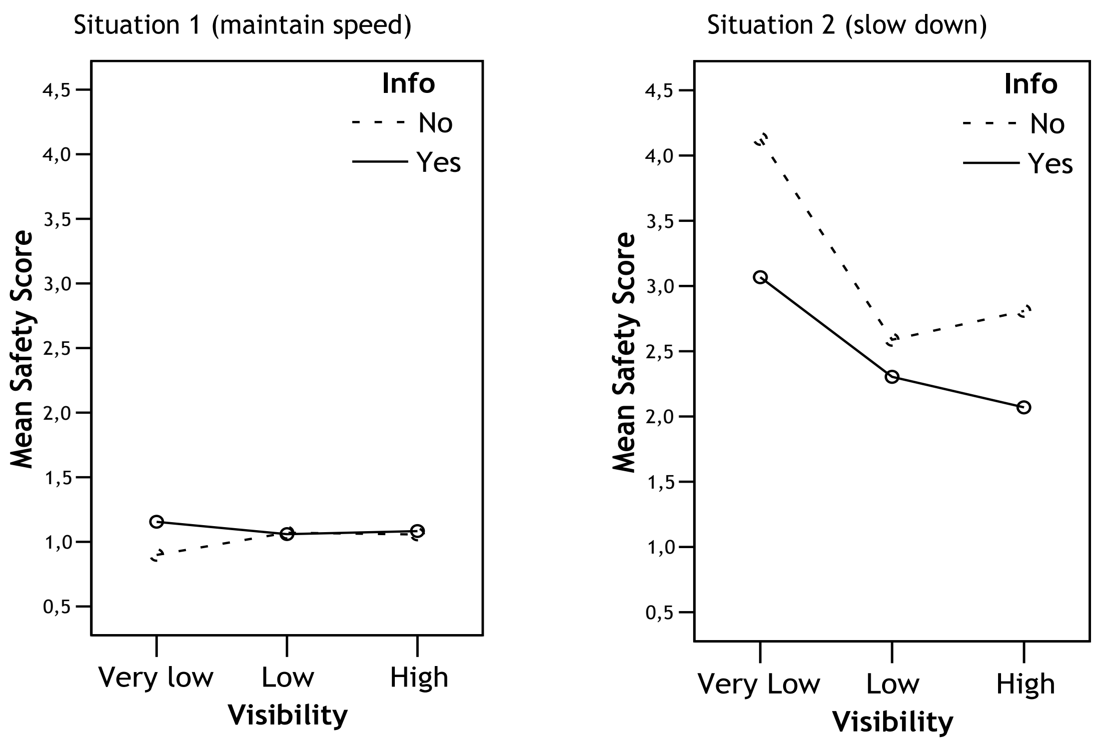


Figure 6.3: Effect of Extra Information and Visibility on Safety per Situation

Safety – DTI_Brake

Using the participant's Distance To Intersection when the brakes are first applied (DTI_Brake, Table 6.4) as the dependent variable three analyses were conducted (A-I, A-II and A-III). Although the results for A-I did not indicate any significant effects, A-II indicated an effect of Situation ($F_{3,15}$= 3.65; p< .05). Post hoc tests indicated that in Situation 4 (←··) participants tended to brake significantly closer to the intersection than in Situation 2 (··→). These results might seem counterintuitive as in Situation 2 (··→) participants had right of way, which they did not have in Situation 4 (←··). Further exploration of the data provided a possible explanation for the abovementioned effect. Presumably because they had right of way, the data showed that participants did not apply the brakes as often in Situation 2 (··→) as they did in Situation 4 (←··). However, when they did apply the brakes in Situation 2 (··→), they tended to do this relatively far from the intersection as the results of A-II indicated. The results also indicated that when the brakes were applied further away from the intersection, the participant's driving speed tended to be higher. This could imply that they applied the brakes to adjust their driving speed so as not to exceed the speed limit and not so much to avoid a collision with another road user. Thus, as braking behaviour seems to be open to multiple interpretations, it does not seem to be a really valid indicator of safety of the interaction.

A-III did not indicate a main effect of either Right of Way or Extra Information, but the interaction effect did turn out to be significant ($F_{1,3}$=16.42; p< .05). When participants had right of way, they tended to apply the brakes further from the intersection when they were provided with extra information than when they did not have right of way. However, it should be noted that the brakes were not applied in that many encounters, and these results consequently should not be interpreted as indicating a general tendency to apply the brakes earlier when having right of way.

Safety – Hard Braking

The proportion of situations in which the brake pedals were pressed for at least 60% (Hard Braking, Table 6.4) was used in subsequent analyses. A-I indicated that in Situation 1 (⬅) significantly more hard braking occurrences were found than in Situation 2 (⇢) ($F_{1,24}$= 26.98; p< .001), which can be explained by the right of way situation. In Situation 2 (⇢), the participant had right of way and the other road user behaved accordingly (slowed down) which reduced the need for (hard) braking. The results also showed that more hard braking occurrences are found as Visibility decreases ($F_{2,48}$= 3.25; p< .05). The final significant result for A-I was found for the interaction between Situation and Visibility ($F_{2,48}$= 3.25; p< .05). In the medium Visibility condition, Situation 1 shows the highest occurrence of hard braking, whereas Situation 2 shows the lowest occurrence. Hard braking occurrences in the low Visibility condition were always higher than in the high Visibility condition.

A-II also indicated an effect of Situation ($F_{3,72}$=13.86; p< .001). Post hoc tests showed that in Situation 2 (⇢), participants hardly ever applied the brake pedal with more than 60%, whilst in the other situations, participants did so in about 1 in 5 encounters.

A-III indicated that when the Approach Condition was Fixed_unexpected, participants tended to brake hard significantly more often than when confronted with the Fixed_expected or Free Approach Condition ($F_{1.278,25.568}$=12.05; p< .01). Although the effect of Right of Way was not significant, A-III did indicate a trend. When participants did not have right of way, they tended to brake hard more often ($F_{1,20}$=3.18; p< .10). The interaction effect between Right of Way and Approach Condition showed that the effect of Right of Way seems to depend on the Approach Condition ($F_{2,40}$=5.93; p <.01). Participants tended to brake hard more often when they did not have right of way, unless they were confronted with the Fixed_unexpected Approach Condition. In that case, having right of way does not seem to affect the number of hard braking occurrences.

Safety – DTI_Throttle

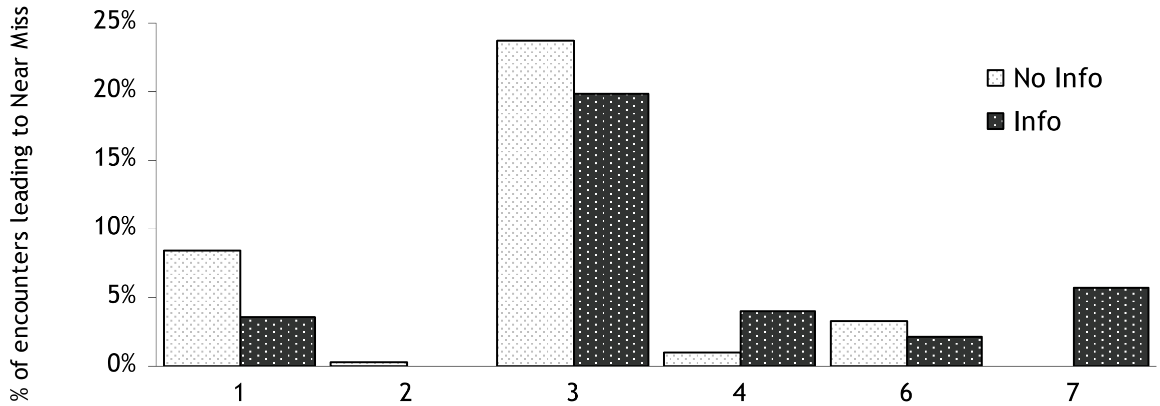
Analyses were also conducted using the participant's Distance To Intersection when the throttle was first released (DTI_Throttle, Table 6.4). All three analyses (A-I, A-II and A-III) only indicated a significant effect of Extra Information (resp. $F_{1,23}$= 12.04; p< .01; $F_{1,23}$= 5.71; p< .05 and $F_{1,18}$=10.97; p< .01). This effect indicated that in the Sessions where Extra Information was provided, participants tended to release the throttle when they were closer to the intersection than in Sessions where they were not provided with Extra Information (A-I: $Mean_{NoInfo}$=95m vs $Mean_{Info}$=90m; A-II: $Mean_{NoInfo}$=96m vs $Mean_{Info}$=91m). As participants were told that they would be informed about other road users approaching throughout an entire session, it is plausible that they postponed releasing the throttle based on that knowledge.

The effect of Right of Way in A-III was not significant, but did indicate a trend, which suggests that when participants had right of way, they tended to first release the throttle when they were closer to the intersection ($F_{1,18}$=4.18; p< .10).

Safety – Near Misses

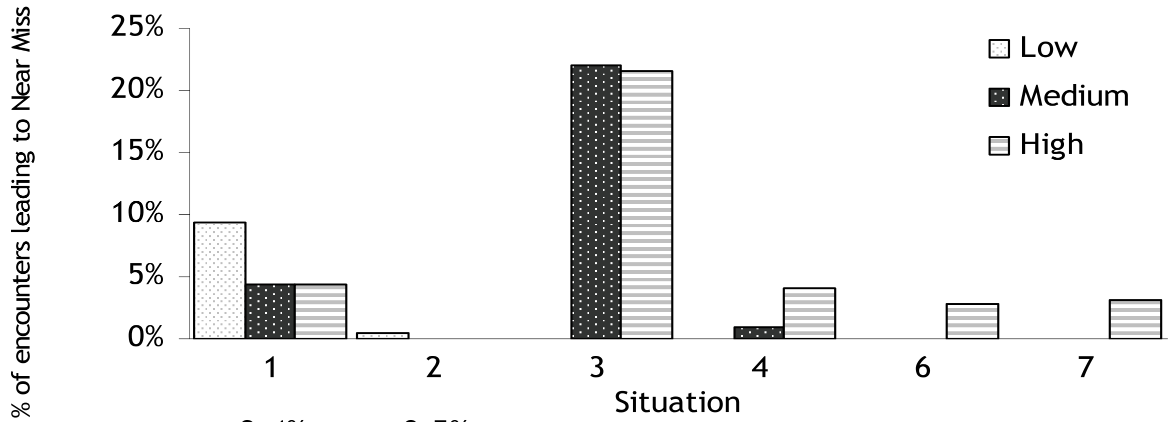
Analyses with the number of Near Misses followed a different approach as the total number of Near Misses was too low for a repeated measures analysis (i.e. 93 Near Misses on a total of 1729 encounters with another road user). Figure 6.4 and Figure 6.5 illustrate the distribution of Near Misses per situation and the effect of Extra Information and Visibility. To be able to determine effects similar to the A-I analysis, separate Chi square analyses were conducted for Right of Way, Approach Strategy, Visibility and Extra Information (including only encounters for Situation 1 & 2 and thus Visibility with 3 levels). The results for the analysis for Right of Way showed that when participants had right of way (Situation 2, ⇢) , they experienced a Near Miss in 0.2% of their encounters versus in 6.1% of encounters when they did not have right of way (Situation 1, ⬅; X^2(1, N = 1250) = 37.13; p <.001). The same effect was found for the analysis for Approach Strategy of the other road user: when the other road user slowed down (Situation 2, ⇢) a Near Miss occurred in 0.2% of the encounters versus 6.1% when the other road user maintained speed (Situation 1, ⬅; X^2(1, N = 1250) = 37.13; p <.001). Comparing only Situation 1 (⬅) and 2 (⇢), the results for the analysis for Visibility showed that when Visibility was low, 4.8% of encounters resulted in a Near Miss versus 2.2% and 2.1% for medium and high Visibility respectively (X^2(2, N = 1250) = 6.49; p <.05). The analysis for Extra Information indicated that when Extra Information was not provided, 4.2% of encounters resulted in a Near Miss, versus 1.8% when Extra Information was provided (X^2(1, N = 1250) = 6.23; p <.05).

Subsequently, separate Chi square analyses were conducted to determine effects similar to the effects determined by A-II. These analyses included only encounters in Situations 1, 2, 3 or 4 and Visibility levels 'medium' or 'high' as Situations 3 and 4 did not include encounters with Visibility level 'low'. The results for the analysis for Right of Way indicated an opposite effect of Right of Way compared to the Chi Square analysis including only Situation 1 and 2 mentioned in the previous paragraph: when participants did not have right of way, 3.8% of the encounters resulted in a Near Miss as opposed to 7.3% when participants did in fact have right of way (X^2(1, N = 1213) = 7.15; p <.01). The results did show a similar effect of Approach Strategy compared to the results of the Chi Square analysis mentioned in the previous paragraph: when the other road user maintained speed, relatively more encounters resulted in a Near Miss than when the other road user approached the intersection while slowing down (i.e. 10.2% vs. 0.8%; $X^2(1, N = 1213) = 51.03$; $p < .001$). The Chi Square analyses for Visibility or Extra Information did not indicate any effects. There were too few collisions to perform analyses using Collision as the dependent variable. In total, 2 collisions occurred, which were both in sessions without information and in Situation 3 (➡).



	1	2	3	4	6	7
No Info	8.5%	0.3%	23.8%	1.0%	3.3%	0.0%
Info	3.6%	0.0%	19.8%	4.0%	2.1%	5.7%

Figure 6.4: Percentage of Near Misses per Situation for encounters with and without Extra Information



	1	2	3	4	6	7
Low	9.4%	0.5%				
Medium	4.4%	0.0%	22.0%	1.0%		
High	4.4%	0.0%	21.6%	4.0%	2.8%	3.2%

Figure 6.5: Percentage of Near Misses per Situation for encounters for each level of Visibility

Efficiency – Efficiency index

The results of A-I using the Efficiency index (Table 6.3) yielded significant main effects for both Visibility and Information ($F_{1.617,38.805}$= 31.39; p< .001 and $F_{1,24}$= 12.41; p< .01 resp.) The interaction effect was not significant. Post hoc analyses revealed that Efficiency in the lowest Visibility condition was significantly lower than in two other Visibility conditions. With Extra information, interactions were significantly more efficient, particularly in Situation 2 (⇢) (Figure 6.6). The interaction effect for Situation*Extra information was indeed significant ($F_{1,24}$= 17.11; p< .001). The interaction effect between Visibility and Situation also turned out to be significant ($F_{2,48}$= 6.93; p< .01). In Situation 1 (⬅), the positive effect of Visibility on Efficiency is not as large as in Situation 2 (⇢). Perhaps this effect is caused by the participants' tendency to slow down for junctions with traffic from the right.

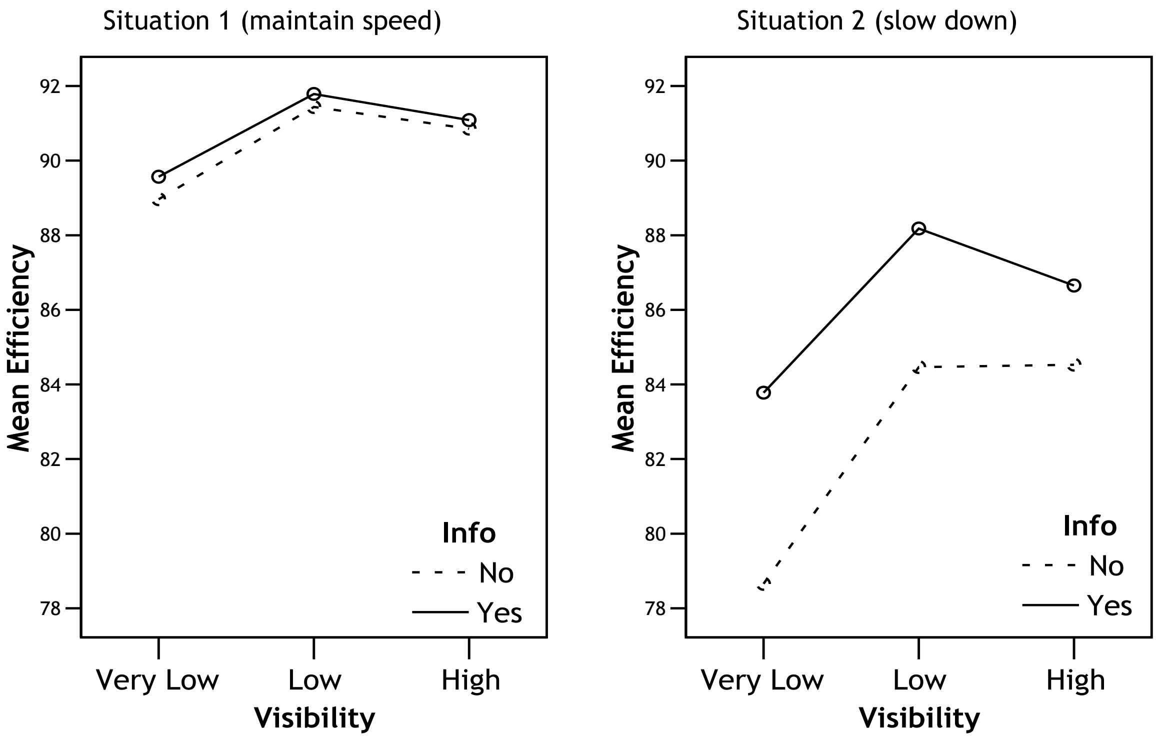


Figure 6.6: Interaction between Information and Visibility for Situation 1 & 2

For A-II, the effect of Visibility was not significant. A main effect of Extra Information was found again ($F_{1,22}$=7.97; p<.05). Providing extra information tended to increase Efficiency. Also, a main effect of Situation was found ($F_{1.983,43.637}$=151.03; p<.001). Post hoc analyses indicated that Efficiency in Situation 1 (⬅) and 3 (➡) did not differ significantly (Mean Efficiency= 91 & 93, resp.) but was significantly higher than in Situation 2 (⇢, Mean Efficiency = 86) and Situation 4 (⇠, Mean Efficiency = 71). Efficiency in the latter situation was also significantly less than in Situation 2 (⇢). Finally, A-III indicated a main effect for both Right of Way and Approach Condition. When participants had right of way, Efficiency was significantly higher than when they did not have right of way ($F_{1,18}$= 31.33; p<.001). Post hoc tests indicated that

Efficiency was significantly lower when the Approach Condition Fixed_unexpected compared with the Free and Fixed_expected Approach Condition ($F_{1.408,25.340}$= 28.94; p<.001). The results concerning the effect of providing extra information was not significant, but did indicate a trend that providing information might improve Efficiency. Also, an interaction effect was found between Right of Way and Approach Condition ($F_{2,36}$= 128.57; p<.001), which seems to be mainly caused by the difference between the Fixed_unexpected Approach Condition and the other two Approach Conditions. As Table 6.6 shows, in situations where the experimenter approached the intersection with a free or fixed but expected Approach Condition Efficiency does not seem to be affected that much by the participant having right of way or not. However, when the experimenter's Approach Condition was fixed but unexpected, Mean Efficiency was lower when the participant did not have Right of Way.

Table 6.6: Mean Efficiency for each combination of AC and ROW in A-III

		Approach Condition		
		F_E	F_U	Free
Right of Way	No	91	72	91
	Yes	87	94	90

Note: F_E: Fixed_expected; F_U: Fixed_unexpected

Efficiency – Speed_after

Speed when leaving the intersection (Speed_after, Table 6.4) might also provide an indication of the efficiency of the interaction, although it is only based on the participant's behaviour rather than on a combination of the behaviour of both interaction partners. A-I indicated main effects of Situation, Extra Information and Visibility. Participants tended to leave the intersection at a higher speed in Situation 2 (⇢) than in Situation 1 (⬅) ($F_{1,24}$= 33.14; p<.001; Mean difference= 3 km/h). Providing participants with Extra Information also tended to increase their speed as they left the intersection ($F_{1,24}$= 23.60; p<.001; Mean difference= 1 km/h). Post hoc tests on the main effect of Visibility indicated that Speed_after was significantly higher (Mean difference = 1 and 3 km/h respectively) in the Medium and High Visibility conditions as compared with the Low Visibility condition ($F_{2,48}$=26.51; p< .001). The interaction effect between Situation and Extra Information indicated that particularly in Situation 2 (⇢), Extra Information had an increasing effect on Speed_after ($F_{1,24}$= 11.36; p<.01). The interaction effect between Situation and Visibility indicated that in Situation 1 (⬅) the highest Speed_after was found in the High Visibility condition, whereas in Situation 2 (⇢) the highest speed after was found in the Medium Visibility condition ($F_{2,48}$= 6.81; p < .01). Finally, the interaction effect between Extra Information and Visibility indicated that the increasing effect of Extra Information on Speed_after decreases as Visibility increases ($F_{2,48}$= 5.22; p < .01).

The subsequent analysis, A-II, indicated that Speed_after in Situation 2 (··➔) is significantly higher than in the other three Situations included in this analysis ($F_{3,72}$= 17.63; p< .001, Mean difference ranging between 4 and 5 km/h). As in A-I, the results of this analysis indicated that providing participants with Extra Information tended to increase Speed_after ($F_{1,24}$= 7.09; p<.05; Mean difference= 1 km/h). As could be expected based on the results of A-I, A-II did not indicate a significant difference between the Medium and High Visibility conditions. The results did, however, indicate a significant interaction effect between Situation and Visibility ($F_{3,72}$= 4.80; p < .01). High Visibility only seems to increase Speed_after in Situation 1 (⬅) & 4 (⬅··), when participants encounter a road user approaching the intersection from the right.

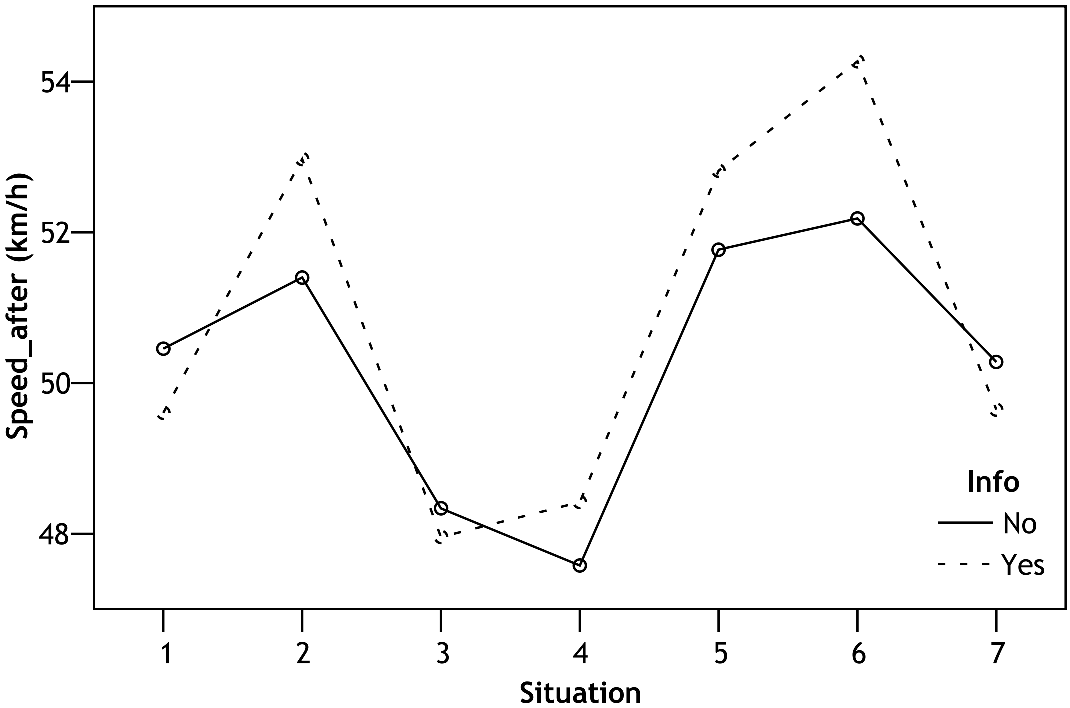


Figure 6.7: Mean Speed when leaving the intersection per situation

The results for the A-III showed a main effect for both Right of Way and Approach Condition. When participants had right of way, they tended to leave the intersection at a higher speed than when they did not ($F_{1,20}$=8.57; p<.01). Post hoc tests revealed that when the Approach Condition was Fixed_unexpected (Situation 3 and 4), participants tended to leave the intersection at a lower speed than when confronted with other approach strategies ($F_{1.279;25.576}$=17.99; p<.001; Figure 6.7). No significant differences were found between the Fixed_expected Approach Condition (Situation 1 and 2) and the Free Approach Condition (Situation 6 and 7). The effect of Extra Information turned out to be dependent on Right of Way ($F_{1,20}$=5.08; p<.05). When participants did have right of way, Extra Information tended to increase their speed as they left the intersection. When they did not have right of way, Extra Information led to a decrease of their speed when leaving the intersection.

Efficiency – Standstill

The total amount of time spent below 1 km/h (i.e. Standstill, Table 6.4) could also provide an indication of efficiency of the interaction, although standing still only occurred in about 5% of all encounters. Again, three analyses were conducted. A-I only indicated that in Situation 1 (⬅), when the participant did not have right of way, slightly more time was spent standing still compared with Situation 2 (⇢), when the participant did have right of way($F_{1,24}$= 5.42; $p< .05$). No effects were found for either manipulations of interaction space (Extra Information and Visibility).

A-II also only indicated an effect of Situation. Post hoc tests showed that in Situation 4 (⇠) participants tended to come to a standstill for a longer time (on average 0.4 seconds longer) than in the other three Situations included in this analysis ($F_{1.056,25.342}$=9.45; $p<.01$).

Similarly, A-III only indicated effects for Right of Way and Approach Condition (instead of Situation, A-III included Right of Way and Approach Condition as independent variables). As in A-I, the results indicated that when participants did not have right of way, they would spend more time standing still than when they did have right of way ($F_{1,20}$= 4.52; $p< .05$). Also, the Approach Condition Fixed_unexpected led to the highest mean amount of time spent standing still ($F_{1.075,21.495}$=6.17; $p< .05$), particularly when participants did not have right of way (i.e. Situation 4, ⇠, $F_{1.071,21.427}$=4.22; $p< .05$).

Yielding behaviour

Using Mean Yield (Table 6.4) as dependent variable the three repeated measures analyses were conducted. As could be expected, A-I indicated an effect of Situation ($F_{1,24}$= 3418.21 $p< .001$). When participants did not have right of way (Situation 1, ⬅; Mean Yield = .93) they tended to yield more often than when they did have right of way (Situation 2, ⇢; Mean Yield = .00), indicating that the right hand right of way rule largely influenced their yielding behaviour. Main effects were also found for both manipulations of interaction space (Extra Information and Visibility). When interaction space was increased by providing Extra Information or by increasing Visibility to the Medium or High level, participants tended to yield slightly more often (resp. $F_{1,24}$=6.69; $p<.05$ and $F_{1.516,36.393}$=3.87; $p<.05$). Interaction effects indicated that the effects of these manipulations were only found in Situation 1 (⬅), where the participant did not have right of way and thus was obliged to yield.

A-II also indicated an effect of Situation ($F_{1.247,29.020}$=110.03; $p<.001$). Post hoc tests showed that in Situation 2 (⇢) participants yielded significantly less than in the other situations (Mean Yield_2 = .00). In Situation 1 (⬅) and 3 (➡) participants tended to yield almost equally often (Mean Yield_1= .95 and Mean Yield_3= .92), which was almost each encounter. In Situation 4 (⇠), participants tended to yield significantly more often than in Situation 2 (⇢) and significantly less often than in Situation 1 (⬅)

and 3 (➡) (Mean $Yield_4$= .41). Furthermore, A-II did not indicate any effects for Extra Information and Visibility.

A-III indicated effects for Right of Way and Approach Condition. As in A-I, the results indicated that when participants did not have right of way, they tended to yield significantly more often than when they did have right of way ($F_{1,20=105.772}$; p<.001). When the Approach Condition was Fixed_expected (Mean $Yield_{F\_E}$= .47) participants tended to yield significantly less often than when the Approach Condition was Fixed_unexpected (Mean $Yield_{F\_U}$= .66) or Free (Mean $Yield_{Free}$= .55), although the differences aren't that large ($F_{1.323,26.470}$=7.89; p< .01). The interaction effect between Right of Way and Approach Strategy indicated that not having right of way led to more yielding when the Approach Condition was Fixed_expected or Free ($F_{1.323,26.470}$=204.64; p<.001). However, when the Approach Condition was Fixed_unexpected, participants tended to yield more often when they did have right of way (Situation 4, ⬅··).

Subjective mental effort

Figure 6.8 shows the distribution of the scores given on the Rating Scale Mental Effort (RSME) throughout the experiment. The first two are the scores given right after the practice trials. Particularly the first practice trial seems to yield high scores for subjective mental effort. Participants mentioned in their motivation for their (often high) score that they needed to get used to the car and the way it reacted.

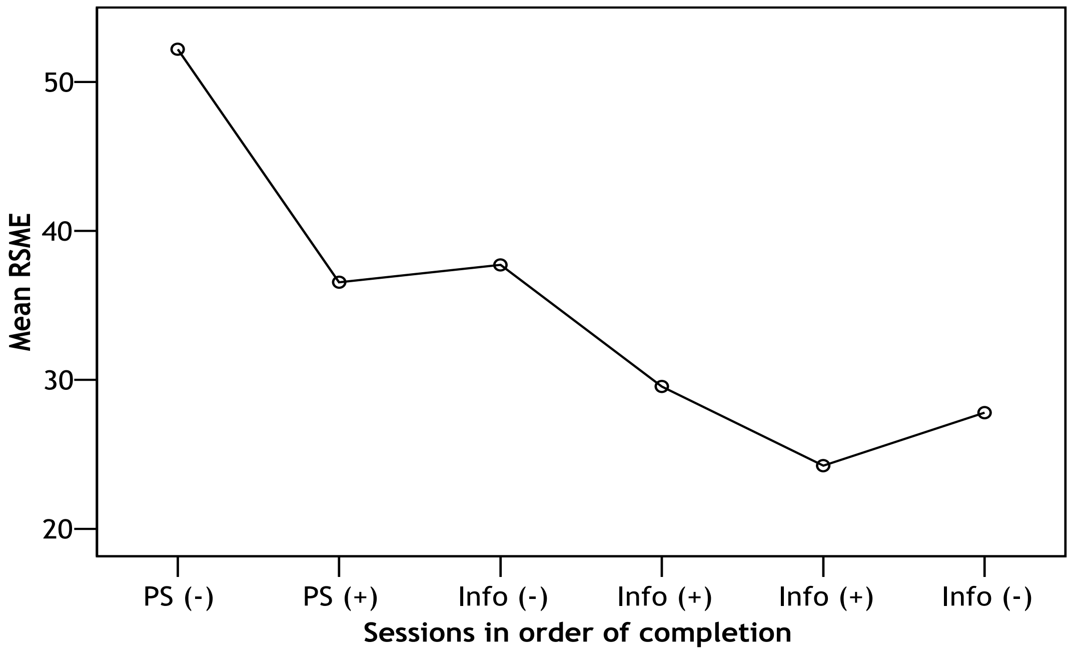


Figure 6.8: Mean RSME (per session)

A 2x2 Repeated Measures ANOVA was conducted to determine the effect of the Extra Information, which was presented in half of the driving sessions. This analysis also allowed us to determine the effect of Exposure to a certain type of session (i.e.

having extra information or not). The results indicated that participants reported a significantly higher score for mental effort in the sessions without the extra information (Mean $RSME_{NoInfo}$= 33 vs. Mean $RSME_{Info}$= 27; $F_{1,24}$=16.66; p <.001). Exposure to a certain type of session also yielded lower scores for mental effort (Mean $RSME_{NotExposed}$= 34 vs. Mean $RSME_{Exposed}$= 26; $F_{1,24}$=6.76; p <.05). The interaction effect between Exposure and Extra Information was not significant. Thus, the decreasing effect of Extra Information on subjective mental effort is independent of the effect of having been previously exposed to a session of a certain type.

Acceptance

To determine the consistency of the items on the Acceptance scale, reliability analyses were performed on the scores for the subscales "Usefulness" and "Pleasantness" for both the lights and the beeps. Cronbach's α ranged from .69 to .85, which, according to Van Der Laan et al., is sufficiently high. For more information on the Acceptance scale, the reader is referred to Chapter 3.

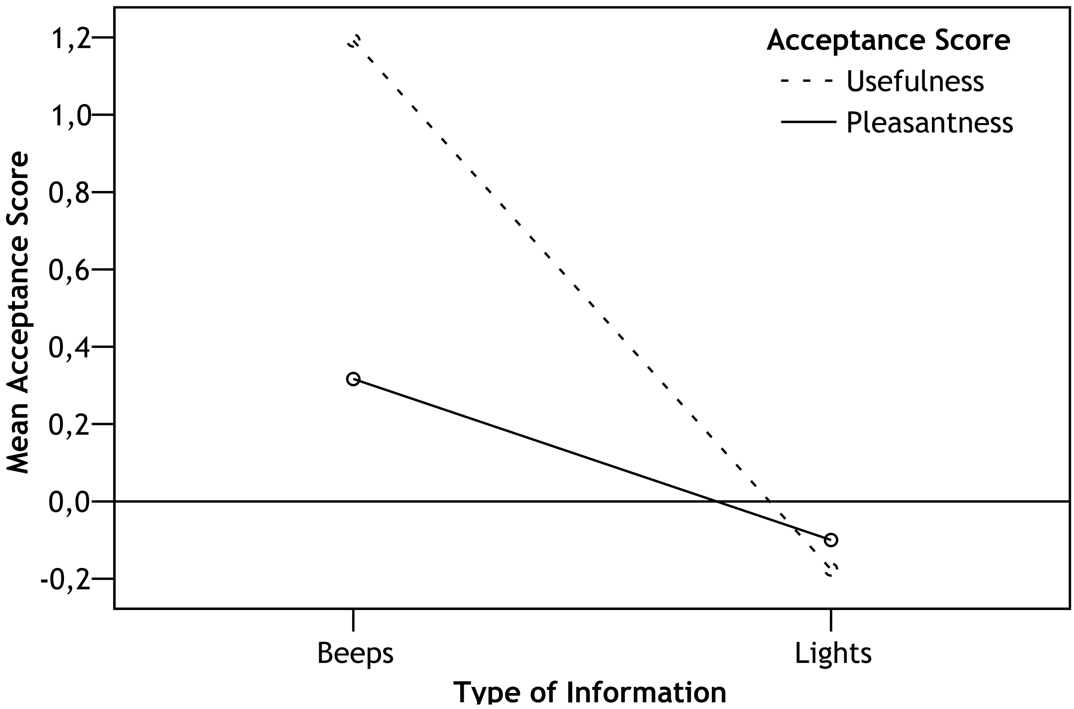


Figure 6.9: Interaction between Acceptance and Type of Extra information

A 2x2 Repeated Measures ANOVA was conducted to determine the effect of the type of Extra information (i.e. lights or beeps). The analysis also allowed us to determine if the Acceptance scores differed for the subscales "Usefulness" and "Pleasantness".

The results indicated that participants found the beeps both more Useful as well as more Pleasant compared with the lights ($F_{1,24}$=24.29; p <.001). A significant main effect was also found for the subscales of the Acceptance scale ($F_{1,24}$=12.10; p <.01). This effect will be discussed in the light of the also significant interaction effect ($F_{1,24}$=29.18; p <.001; Figure 6.9). Participants experienced the beeps as more Useful than Pleasant, whereas this difference was not found for the lights, which yielded lower (negative!) mean scores on both subscales.

6.3.2. Additional analyses

Repeatability of previous experiment

To determine if the effects of Right of Way (ROW) and Approach Strategy (AS) in the present experiment are similar to the previous experiment, an ANOVA for Repeated Measures was performed, using both ROW and AS with two levels. As this analysis is only aimed at making a comparison with the results of the previous experiment, only sessions were included where Extra Information was not provided.

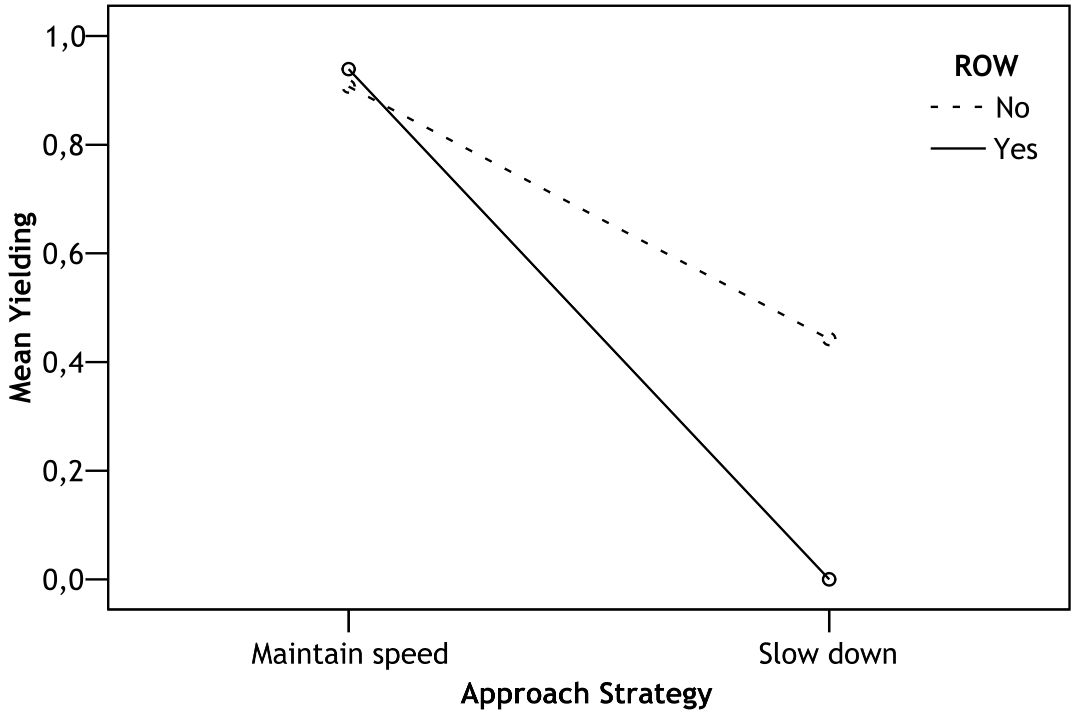


Figure 6.10: Mean Yielding for each combination of AS and ROW

As in the previous experiment, main effects were found for both Right of Way ($F_{1,25}$= 23.31; p< .001) and Approach Strategy ($F_{1,25}$= 233.09; p< .001). The interaction effect between ROW and AS was also significant again (Figure 6.10; $F_{1,25}$= 23.21; p< .001). Again, participants tended to take right of way when they were entitled to it and tended to yield when confronted with another road user maintaining speed while approaching the intersection. The interaction effect indicates that when participants had right of way, but where confronted with a road user maintaining speed, they mostly decided to yield instead of take right of way. The two experiments therefore give the same results.

Self-reported versus observed yielding behaviour

A GLM ANOVA for Repeated Measures was conducted to determine if self-reported yielding differed from observed yielding. Again, ROW and AS were entered as independent factors (with two levels) as was Type of Behaviour (Self-reported vs. Observed). The results did not indicate a significant difference between reported and observed behaviour, although a significant interaction effect was found between Type of Behaviour and Approach Strategy ($F_{1,24}$= 25.61; p< .001). When the Approach Strategy of the other road user was to maintain speed, participants tended to report a lower yielding frequency than they displayed. When the Approach Strategy of the other road user was to slow down, this tendency was found in the opposite direction. Thus, it seems that participants had less insight in their behaviour in the unexpected situations. Overall, they behaved less cautiously (i.e. took right of way more often) than they reported in the Yielding behaviour questionnaire when they observed the other road user slowing down, whereas they behaved in a more cautious way (i.e. yielded more often) when they observed the other road user maintaining speed. These effects seem to be larger in situations in which the other road user's Approach strategy is unexpected with respect to the right hand-right of way rule (Situation 3, ➡ & Situation 4, ⬅⋯).

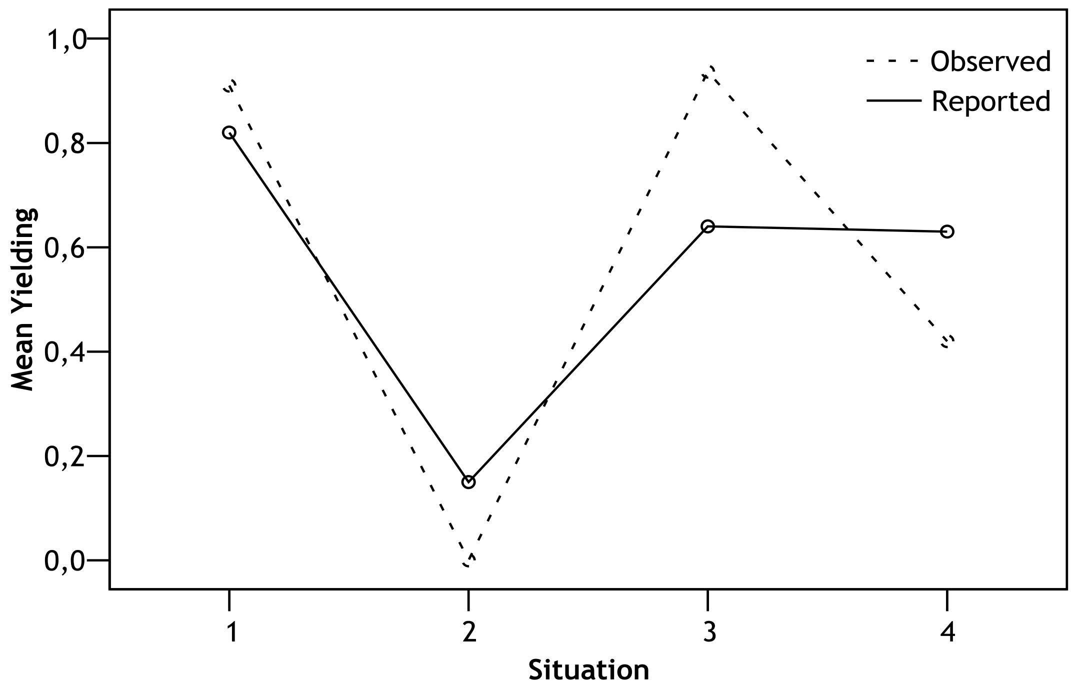


Figure 6.11: Comparing Reported and Observed behaviour

An interaction effect was also found between Type of Behaviour and Right of Way ($F_{1,24}$= 5.98; p< .05) indicating that in situations where participants had right of way, they reported that they would yield less often than they actually did in the driving simulator. Also, when participants did not have right of way the reverse effect is found. Figure 6.11 indicates that this interaction effect is largely due to the results found in the unexpected situations (Situation 3, ➡ & Situation 4, ⬅⋯).

Customised questionnaire

The first item on this questionnaire was concerned with the extent to which the participant regarded their driving in the simulator as representative for their driving in real life. The majority of participants indicated that their driving behaviour was quite representative for their normal driving. Table 6.7 shows that about two thirds of the participants indicated that they behaved differently in the sessions with extra information. They were asked to elaborate if they indeed did behave differently. Answers included phrases such as "more looking in sessions without information" and "in sessions with information: crossing the intersection more easily when not hearing beeps". These answers suggest clear behavioural reactions to the extra information provided.

Table 6.7: Results of Customised Questionnaire

Question	Answers				
How representative was your driving?	Not at all 4 %	Not really 0 %	Neutral 8 %	A little 32 %	Very much 56 %
Did your behaviour change as a result of the extra information?	Yes 64 %				No 36 %
What did you think of crossing the intersections with extra information?	Easier 75 %		No difference 21 %		Harder 4 %
When would you prefer to receive extra information?	Every Intersection 8 %	Choice 63 %	Not at all 21 %	Other 8 %	
How would you prefer to receive extra information?	Lights 4 %	Beeps 67 %	Both 21 %	Other 8 %	
About what would you prefer to receive extra information?	All approaching RU[1] 33 %	RU not complying with rules 38 %	RU approaching from right 13 %	Other 17 %	

[1] RU = Road Users

Participants also indicated unanimously, that the extra information worked as explained. Table 6.7 shows that 75% of participants indicated that crossing the intersections in the sessions with extra information was easier than in the sessions without extra information. This result is in line with the findings suggested by the RSME results (i.e. driving with extra information leads to less mental effort). Only one participant (i.e. 4%) indicated the opposite. When asked when they would prefer to receive the extra information, 63% indicated that they would prefer to choose when to receive the information versus receiving it always or never. Two participants indicated the "other" response and elaborated on that. These elaborations suggest that they too would prefer to choose when to receive extra information. Table 6.7 suggests a distinct preference for beeps versus lights. Two participants indicated that they would prefer to have a voice provide the extra information. Concerning the focus of the extra information, participants do not seem to agree as much. Perhaps this is caused by their lack of experience with all options mentioned.

Characteristics of less safe drivers

The experiment discussed in Chapter 5 indicated that participants involved in a collision tended to release the throttle closer to the intersection than participants who had not been involved in a collision (during encounters that did not result in a collision). To explore if a similar effect could be found for the present experiment, analyses were conducted using a different grouping variable, as only two participants were involved in a collision. In this case, less safe participants (n=4) were identified as participants who experienced a near miss during at least ten percent of their encounters with another road user (i.e. $NearMiss_{10Perc}$). A-I and A-II were conducted using DTI_Throttle as the dependent variable, and $NearMiss_{10Perc}$ as a grouping variable. Only encounters which did not result in a near miss were included in these analyses. The results for both A-I and A-II indicated a significant effect of $NearMiss_{10Perc}$ (resp. $F_{1,22}=7.36$; $p<.05$ & $F_{1,15}=26.31$; $p<.001$). Participants who had experienced a NearMiss in at least 10% of their encounters tended to first release the throttle when they were on average 17m (A-I: Situation 1, ←, and Situation 2, ⇢) or 31m (A-II: Situation 1 through 4) closer to the intersection than participants who had not experienced as many near misses, during “safe” encounters which did not eventually lead to a near miss.

Previous research using the Driver Behaviour Questionnaire (DBQ) has indicated that less safe drivers (i.e. drivers with a higher accident liability) tend to report more violations (Parker, Reason, Manstead, & Stradling, 1995). Analyses were conducted to determine if that finding could be supported by the results of the present experiment.

Based on Lajunen, Parker and Summala (2004), alpha reliability coefficients for the DBQ subscales were calculated for the four subscales (i.e. aggressive violations, ordinary violations, errors and lapses). Unfortunately, as Table 6.8 indicates, the alpha for the aggressive violations scale was extremely low.

Table 6.8: Alpha reliability coefficients using four DBQ subscales

	Cronbach’s alpha
Aggressive violations (3 items)	0.08
Ordinary violations (8 items)	0.79
Errors (8 items)	0.60
Lapses (8 items)	0.68

Deleting any one of the three items of this scale would not have resulted in a sufficiently high alpha either. Thus, it was decided to combine the aggressive violations scale with the ordinary violations scale to create a more general "violations scale". This 3-factor structure has been used before (e.g., Reason, Manstead, Stradling, Baxter, & Campbell, 1990). Also, item 8 was deleted from the "error scale" to improve the reliability coefficient. This item (i.e. "Fail to check rear-view mirror before pulling out, changing lanes, etc.") did not correlate highly with any of the other items on either the error scale or lapses scale (all $r < .3$) and was therefore dropped (Field, 2005). The resulting alpha reliability coefficients can be found in Table 6.9.

Table 6.9: Alpha reliability coefficients using three DBQ subscales

	Cronbach's alpha
Violations (11 items)	0.78
Errors (7 items)	0.74
Lapses (8 items)	0.68

A MANOVA was conducted using the scores for each of the eleven Violation items as dependent variables and $NearMiss_{10Perc}$ as the grouping variable to determine if participants that had experienced a Near Miss in at least 10% of their encounters also tended to report a higher score for committing Violations. The results, however, did not indicate a significant relationship. A similar analysis was conducted for the items for both Lapses and Errors as well, but, again, no significant results were found.

6.4. Discussion & Conclusions

Appendix J to Appendix M provide a simple overview of the results of the main analyses conducted to answer the main research question. Appendix N to Appendix P provide an overview of the effects found per manipulation. To recapitulate, the main research question dealt with the effect of the manipulations of interaction space on driving behaviour. An attempt was made to manipulate interaction space by providing extra information concerning the approach of other road users and by varying visibility of the intersection road.

6.4.1. Interaction space and safety

A large number of analyses included different measures of safety (Table 6.4). The hypothesis in Section 6.1.5 stated that increasing interaction space should lead to increased safety, as the increased interaction space allows road users more time to adapt their expectancies to the situation as it develops and select an appropriate course of action. Appendix N to Appendix P include results that support that hypothesis, but also results that seem to suggest the contrary. To start with the supporting results, the results for TTC_{min} show shorter values (safety ↓) in the medium Visibility condition compared with the high Visibility condition (interaction space ↓). More hard braking (safety ↓) also seemed to occur in the low Visibility condition (interaction space ↓). Also, more Near Misses (safety ↓) were found in encounters where the other road users' Approach Strategy was to maintain speed (interaction space ↓), in encounters where participants were not provided with Extra information (interaction space ↓), when Visibility was low (interaction space ↓) and when the Approach Condition was Fixed_unexpected (interaction space ↓). Results suggesting the contrary include the results for the Safety index. The lowest scores were found when Visibility was medium or high (interaction space ↑) and when the Approach Condition was Free (interaction space ↑). Participants tended to release the throttle and apply the brakes when they were closer to the intersection (safety ↓) when extra information was provided (interaction space ↑). Although the abovementioned results might seem contradictory, they can be explained by the differences between these measures. Near Misses and Hard Braking are perhaps measures more closely related to the critical aspects of (unsafe) situations as they correspond to a relatively late stage in the interaction process compared with measures such as DTI_Brake, DTI_Throttle and Safety. To explain, Near Misses and Hard Braking will generally occur closer to an estimated collision point than releasing the throttle and applying the brake and also past the 15m to the intersection used to determine the Safety index. Thus, Near Misses and Hard Braking might be indicators of a more critical stage in the interaction process and thus more direct indicators of interaction safety, whilst early brake and throttle manipulations might be more relevant related to efficiency.

This is consistent with the idea that the interaction process consists of a stage where there is a tendency towards proactive caution, which, depending on the way the situation develops, might be followed by a stage where there is a tendency to reactive caution. Further away from the estimated collision point, a driver is more likely to be in the "proactive stage" and act accordingly by releasing the throttle or gently applying the brakes. As the driver comes closer to the estimated collision point, it is plausible that the need for reactive caution is assessed and the brakes might need to be instantly applied with considerable force and the result could be a near miss. Assuming such a distinction between a proactive and reactive stage, the results of this experiment suggest that the measures of safety related to the latter stage are more prone to the applied manipulations of interaction space.

6.4.2. Interaction space and efficiency

Concerning the effect of increasing interaction space on efficiency of the interaction two opposing hypotheses were posed. The previous experiment suggested a possible trade-off relationship between safety and efficiency. Perhaps in situations that are experienced as sufficiently safe, "excess" safety is traded for increased interaction efficiency. If so, we would expect to find opposite effects for measures of efficiency compared to the effects we found for measures of safety. On the other hand, we could expect participants to use the increased interaction space to increase interaction efficiency, which would imply that increased efficiency should be found for situations with increased interaction space. The results for the different measures of efficiency seem to point in the direction of the latter hypothesis. The Efficiency index shows higher scores (efficiency ↑) when extra information is provided, particularly in Situation 2 (interaction space ↑), and in the medium and high Visibility conditions (interaction space ↑). Higher scores were also found in the Fixed_expected and Free Approach conditions compared with the Fixed_unexpected Approach condition. In accordance, participants' speed when leaving the intersection was higher (efficiency ↑) when extra information was provided (interaction space ↑) and in the Fixed_expected and Free Approach conditions. The final measure of efficiency also indicated less standing still by the participant in these Approach conditions. In conclusion, the results indicate that particularly the extra information enabled participants to create a more efficient interaction (compared to when they did not receive extra information), allowing participants to cross the intersection without decreasing speed that much. When efficiency was already rather high, as was the case in the situations where the other road user approached the intersection while maintaining speed, providing Extra Information did not seem to increase Efficiency any further.

6.4.3. Trade-off Safety vs. Efficiency

Section 6.1.5 suggested a trade-off relationship between safety and efficiency. But do the abovementioned results for the safety and efficiency measures indeed indicate such a relationship? If we were to divide the safety measures into two groups based on the results found (proactive vs. reactive), the effects found for the first group (i.e. Safety index and DTI_throttle) might indicate a trade-off with the effects found for the efficiency measures. For example, the results for the first analysis showed higher values for the Safety index when Visibility was low and a trend that higher values were found when information was not provided (Appendix N). Values for the Efficiency index in those encounters were found to be lower, suggesting the possible existence of a trade-off relationship, in this case, efficiency being traded in for safety.

The fact that evidence for such a relationship is not found for the measures of safety relating to the "reactive stage" can be explained. Take the least safe result of an interaction process: a collision between the interaction partners. In that case, the situation is highly unsafe, but also highly inefficient, as both partners will not be moving. Perhaps the same holds for Near Misses and Hard Braking, suggesting the existence of an optimum in the trade-off relationship between safety and efficiency, beyond which both suffer.

6.4.4. Approach Conditions

This experiment included three different approach conditions to determine the effect of the approach strategy being fixed, which was analysed in A-III. The results generally seem to indicate no differences between the approach condition in which the experimenter approached the intersection with a fixed (but expected) approach strategy and the approach condition in which the experimenter approached the intersection freely. This indicates that the behaviour of the experimenter in the "Fixed_expected"-condition can be considered similar to free interaction behaviour and also fairly realistic. However, it should be kept in mind that there was only a small number of encounters in the free approach condition on which these inferences could be based. The results also showed that interactions in the "Fixed_unexpected"-condition were often indicated as less safe and less efficient.

6.4.5. Yielding behaviour

In this experiment, increasing interaction space did not affect the decision to yield or not. Neither providing extra information, nor increasing visibility influenced yielding behaviour. When comparing participants' observed and reported behaviour, a tendency to underestimate yielding frequency is found when confronted with a road user maintaining speed while approaching the intersection (Situation 1, ⬅ and 3, ➡). Also, a tendency to overestimate yielding frequency is found when confronted with a road user slowing down while approaching the intersection (Situation 2, ⇢ and 4, ⇠). The largest discrepancies between observed and reported yielding behaviour are found for the unexpected situations (Situation 3, ➡ and 4, ⇠), indicating less insight among participants in how they would respond here.

6.4.6. Evaluation of measures used

Safety

As mentioned in Chapter 3, many different studies have used many different measures to indicate safety of a particular traffic situation or location. However, it seems that all measures have drawbacks as well as advantages. For example, considering the more quantitive measures, Minimum Time to Collision (TTC_{min}) cannot be calculated when there is even the smallest difference in time between one party's estimated departure from the intersecting area and the other party's arrival. The often suggested alternative, Post Encroachment Time (PET), unfortunately does not incorporate the speed of either party. Thus, a situation in which both parties approach each other at high speed might result in the same score for PET as a situation in which both parties approach each other while driving rather slowly. Intuitively, we would probably rate the latter situation as more safe. Taking the abovementioned drawbacks into account, de Winter et al. (2006) developed an alternative to indicate safety for a particular interaction situation which was used in the data-analysis of the experiments in Chapter 5 and 6 (i.e. the Safety index, Table 6.4).

However, the "problem" with the Safety index is that values above about 3 indicate that one of the interaction partners was practically standing still when the participant was 15m before the intersection. Obviously, when one interaction partner is standing still, the estimated difference in time before reaching the collision point will reach infinity. Thus, variation in values above 3 (or perhaps even above 2) does not seem a relevant indication of variation in safety. A more discriminating indication of safety might be the minimum Safety index found for a certain travelled distance.

The results of the present experiment showed hardly any effects for TTC_{min}, which could be due to the above mentioned drawback. The results for the Safety index did, however, provide us with some interpretable results as discussed in Section 6.4.1. The results showed higher scores for the Safety index for the low visibility condition, which might seem counterintuitive. However, this effect might be explained by the tendency of drivers to compensate for the extremely low visibility of the intersecting road by, for example, approaching the intersection at a lower speed and thus increasing the available interaction space (i.e. proactive caution).

Other measures which were suggested as indicators of the level of safety such as Distance To Intersection when the brakes are first applied and hard braking occurrences did not yield many significant effects.

Efficiency

As for safety, several measures were used to provide an indication of the efficiency of the interaction. Most analyses were focused on the sum of average speeds of both interaction partners, labelled "Efficiency". An interaction was thus considered to be efficient when both parties were able to cross the intersection in a short amount of time. When one of the interaction partners needs to come to a standstill, this will have a negative impact on the average speed of that driver and thus a negative effect on Efficiency.

Another measure assumed to provide an indication of interaction efficiency is the participant's speed when leaving the intersection. When speed is relatively high when leaving the intersection, this is presumed to indicate an efficient interaction. In contrast with the abovementioned measure (labelled “Efficiency”), this measure only included behavioural data of the participant and not of the experimenter. Theoretically, including behavioural data of both interaction partners would provide a better indication of efficiency. However, as the initial focus of the experiment was on yielding behaviour, the experimenter did not always leave the intersection as though she would keep on driving. Instead, when both parties had crossed the intersection, the experimenter would often just slowly drive out of sight of the participant. Thus, including the experimenter's speed when leaving the intersection, would have underestimated interaction efficiency.

The results showed that in Situation 2 (··➔), the participant left the intersection with a higher speed than in the other situations, indicating that this situation yielded the most efficient interactions. However, the results for Efficiency indicated that the situations where the other road user approached the intersection while maintaining speed (i.e. Situation 1, ⬅ and 3, ➡), were the most efficient. Thus, at first sight, these results seem to contradict each other. Keeping in mind that Situation 2 (··➡) is indicated as most efficient based only on the participant's behaviour, the effect can be explained. In Situation 2(··➡), when approaching the intersection, the participant will already perceive the other road user displaying an intention to yield. Consequently, he might decide to speed up again and proceed to cross the intersection (taking right of way), leaving it at a relatively high speed. In a situation where the participant would decide to yield, speed when leaving the intersection would be considerably lower, because of the shorter distance available to accelerate again after having yielded. Thus, it seems that speed when leaving the intersection could be a better indicator of interaction efficiency if it were to include behaviour of all road users involved.

It was assumed that the total amount of time spent below 1 km/h (i.e. practically standing still) could also provide an indication of efficiency of the interaction. The results showed that in Situation 4 (⬅··) the participants spent a significantly larger amount of time standing still compared to the other situations. Presumably, this is largely due to the effect of expectancy. In Situation 4 (⬅··), participants were confronted with a road user slowing down (instead of maintaining speed), while, according to the right of way regulation, the participant should be the one yielding. Participants consequently needed to slow down more than they normally would, before the other road user would decide to cross the intersection. No effect was found for providing the participants with Extra Information.

6.4.7. Providing extra information

Acceptance

A scale to assess the acceptance of the lights and beeps through which the Extra Information was presented, was completed by the participants after the third driving session (van der Laan, Heino, & De Waard, 1997). At that point, they had completed one session without extra information and two consecutive sessions with extra information.

The results indicated that participants experienced the beeps as both Useful and Pleasant, especially compared with the lights, which were rated negatively. Several participants indicated that they had not even noticed the lights flashing in the dashboard. They mentioned that they looked towards the intersecting roads, rather than on their dashboard. Also, the customised questionnaire suggested a distinct preference for the beeps for the majority of participants. This result is relevant for studies focusing on ways to display information in the car. The way information is presented should be tuned to the driving task. The results for the customised questionnaire did not show much agreement concerning the focus of the extra information, which might be explained by the participants' lack of experience with the options mentioned. Thus, further research endeavours could focus on what exactly road users should receive information about. Although the beeps yielded high acceptance scores, some participants indicated that they enjoyed looking for themselves rather than always being informed. The customised questionnaire also indicated that the majority of participants would prefer to choose when to receive information, rather than receiving it always or never. The beeps, besides being useful (and pleasant to a lesser extent) were said to make the driving task less interesting.

Subjective mental effort

To assess subjective mental workload, participants were asked to complete a form called "Rating Scale Mental Effort" (RSME) after each session, including the practice trials. The results indicated that when provided with extra information, participants experienced less mental workload than in sessions where they did not receive information. Of course, this effect could be biased, as the scale only provides an indication of subjective workload. Participants were presented with extra information which helped them to determine what the other road user was doing. As they generally rated the beeps as useful, it could be that participants consciously decided that a lower workload corresponds to the sessions where information was provided. Thus, for future studies, it might be interesting to include more objective (physiological) measures of mental workload as well (e.g., heart rate variability, de Waard, 1996).

The results also indicated an effect of exposure. Having been exposed to a similar session before, participants experienced lower levels of mental workload. Thus, as participants indicated after the practice sessions, they needed to get used to the simulator and the way it reacted.

6.4.8. Visibility

This experiment included three visibility conditions as opposed to the experiment discussed in the previous chapter, which included only two visibility conditions. These two visibility conditions offered participants a limited view of the other road user as they approached the intersection. Therefore, the present experiment included two 'new' visibility conditions which allowed for greater visibility of the intersection road, whilst the third visibility condition allowed for similar visibility as the first experiment.

The results for several measures (both for safety and efficiency) indicated a difference largely between the two 'new' visibility conditions (i.e. "medium" and "high") and the visibility condition that allowed for similar visibility as in the first experiment (i.e. "low"). This suggests that, at least in this experimental set-up, a threshold exists between the "low" and "medium" visibility condition beyond which a positive effect is found for (reactive) safety and efficiency. When the threshold has been reached, the results of the present experiment suggest that increasing visibility even more does not seem to have a significant added positive effect on reactive safety or efficiency.

6.4.9. Repeatability of previous experiment

Overall, the results showed similar effects for Right of Way and Approach Strategy, as found in the previous experiment discussed in Chapter 5. First of all, the results for Situation 1 (⬅) and 3 (➡) are similar; participants tended to yield most of the time, which was also the case in the experiment discussed in Chapter 5. In Situation 2 (··➡), participants did not yield at all, which is again probably due to the behaviour of the experimenter: she slowed down while approaching the intersection and sometimes even came to a standstill to allow participants to proceed. Although the behaviour of the experimenter in Situation 4 (⬅··) was similar to that in Situation 2 (··➡), mean Yielding in situation 4 (⬅··) is considerably higher. The difference between these situations is that in Situation 4 (⬅··) the experimenter had right of way, whereas in Situation 2 (··➡) the participant had right of way. Also, as a result of that, the experimenter did not wait as long in Situation 4 (⬅··) as in Situation 2 (··➡) for the participant to proceed. As soon as the experimenter could assume that the participant would yield, she would proceed to cross the intersection. The standard deviation of yielding in Situation 4 (⬅··)was considerably higher than for the other situations. This is largely due to the fact that participants tended to follow a consistent yielding strategy when confronted with the same situation. Some participants tended to yield in Situation 4, whereas others tended to proceed with crossing the intersection when they perceived the other road user slowing down. The abovementioned results were found for both driving simulator experiments.

6.4.10. Characteristics of less safe drivers

Concerning the identification of less safe drivers based on their behaviour, the results of the present experiment supported the findings of the previous experiment discussed in Chapter 5. Again, drivers who were involved in a near miss in at least 10% of their encounters were shown to first release the throttle when were closer to the intersection than their counterparts who were not involved in as many near misses.

Although previous research using the Driver Behaviour Questionnaire (DBQ) has been able to link drivers with a higher accident liability to an increase in self-reported violations (Parker, Reason, Manstead, & Stradling, 1995), the results for the DBQ in the present experiment did not indicate a significant relationship between drivers involved in a near miss in at least 10% of their encounters and self-reported violations. This might be (at least in part) due to the limited group of participants (N=26) in the present study compared to the large group (N= 1600+) used in the study of Parker et al.

6.4.11. Limitations

Although the experiment seemed to yield relevant and meaningful results, there are some limitations that should be taken into account when interpreting the results. First of all, all interaction situations in this experiment where relatively simple, compared to the interactions we would encounter at intersections in daily life. At each intersection, the participant would only encounter one road user (or none at all), but never more than one. Also, the only other road users they could encounter were car drivers. Several participants indicated that they learned that this was the case (through experience) and consequently expected only one car driver at each intersection. After having dealt with the first car driver, they would immediately assume that no other road user would approach the intersection. Thus, without really looking to see if that assumption was justified, they would proceed to cross the intersection. This effect of expectancy will undoubtedly have influenced participants' interaction behaviour, in a way that it is less representative for their normal interaction behaviour, than if they would have encountered a greater variety of situations.

Besides the situation, the environment was also quite simple, the intersections all looked relatively the same and only Visibility was varied by placing buildings at different distances to the intersection. However, keeping the situations as simple as we did, allowed us to create an experimental design in which effects of separate aspects could be assessed, which would otherwise have been impossible.

The results indicate that the Extra Information, and in particular the beeps, did help participants to create more safe and more efficient interactions. However, it would be premature and unwise to conclude that we have proved that the Extra Information "works" in general to create safe and efficient interactions. All that can be concluded is that the particular way in which we provided extra information, worked in the simple and small range of situations that were presented to the participants. For example, imagine what would happen if not one, but two road users would approach the intersection at the same time or even shortly after each other. How would the participant be able to distinguish between the two approaches? It should be noted that the aim of this experiment was not to test an application that is meant to help road users at intersections, but merely to determine the effect of providing information on road users' interactive behaviour. The results of the experiment do, however, provide encouragement for further research in this direction.

7. Discussion and Conclusions

The research presented in this thesis is focused on modelling interaction behaviour in traffic and, more precisely, the interaction between car drivers at intersections without any designated priority. Because of the increase in ADAS possibilities, there is a greater need for an increased understanding of the interaction process. Most models of driving behaviour incorporated only one active road user, which makes them not so useful for interaction behaviour. In an attempt to construct a model of interactive driving behaviour, expectancy was explored as a key concept using qualitative research techniques.

The research questions posed in Chapter 1 were the following:

- What is the role of expectancy in interaction behaviour at intersections?
- What is the influence of expectancy on traffic safety at intersections?
- What are the implications of human interaction behaviour for ADAS?

This chapter will discuss the main findings of the research conducted throughout this thesis and consider the implications of these findings in several contexts. Sections 7.1, 7.2 and 7.5 are related to each of the abovementioned research questions. Section 7.3 discusses the model of interaction behaviour in driving and the alterations made based on the results of the research for this thesis. Section 7.4 evaluates the research methods used throughout this thesis. Section 7.6 discusses the limitations of the research and suggests directions for further research. The final section provides the conclusions that can be derived from this thesis.

7.1. Expectancy

The key concept throughout this thesis has been “expectancy”, which is assumed to allow road users to anticipate the behaviour of other road users and to successfully interact with other road users in time. In Chapter 2 a distinction was made between long and short term expectancies, which were both incorporated in the proposed model (Section 2.4.1). A long term expectancy corresponds to a general idea about what to expect in a certain typical situation, whereas a short term expectancy is based on that general idea but includes information from the currently perceived situation to create a more specific expectation about the current situation. Furthermore, Chapter 2 discussed research suggesting that unjustified expectancies can have a negative impact on traffic safety. The distinction between long and short term expectancies, as well as the relationship with traffic safety has been researched throughout this thesis.

7.1.1. Expectancies in interaction situations at intersections

The qualitative research reported in Chapter 4 indicated three categories of aspects mentioned in road users' expectancies of interaction situations at intersections:

1) References to right of way
2) References to other road users
3) References to the location of road users

- ❖ Past location: the direction road users are coming from
- ❖ Present location: the present position road users are at
- ❖ Future location: the direction towards which road users are moving

The driving simulator experiments discussed in Chapter 5 and 6 combined the abovementioned categories in the interaction situations used in the experiment. The participants encountered situations in which they had right of way, or not, (ad 1) depending on the direction (ad 3) from which another road user (ad 2) approached the intersection. Intersection situations without any designated priority were assumed to elicit a long term expectancy concerning who (ad 2) would or should yield (ad 1), whereas the location (ad 3) of the other road user (ad 2) was assumed to provide information necessary to further specify the long term expectancy into a short term expectancy.

7.1.2. Uncertainty of expectancies

In the introduction to Chapter 5, the concept of uncertainty was discussed in the context of short term expectancies. When a long term expectancy conflicts with the perceived aspects of the situation, the resulting short term expectancy is likely to be associated with a higher level of uncertainty. This uncertainty, associated with the *short* term expectancy, is elicited as the long term expectancy and situational information are combined and a conflict is being detected. Although not the focus of this research, it is acknowledged that a *long* term expectancy can also be associated with a certain level of uncertainty, depending on how specific the long term expectancy is. For example, a long term expectancy could be about something as general and abstract as the right of way rule, but could also be about something more specific, such as the timing of traffic lights at one particular intersection. A rather general long term expectancy might elicit a certain amount of "a priori"-uncertainty, as it provides less input (a priori) to create a specific short term expectancy. The concept of uncertainty as discussed in Chapter 5 could consequently be labelled "ad hoc"-uncertainty, as it elicits uncertainty as the situation develops.

The qualitative data analysis of the expectancies indicated two distinct clusters of references to right of way, which can be related to the distinction between a priori and ad hoc uncertainty (Section 4.4.2). The first cluster refers to uncertainty concerning what *should* happen in a particular situation (the general rule) and the second cluster to uncertainty concerning what is *likely* to happen (the action). Determining what should happen is often based on rather general long term expectancies, which might involve a certain level of a priori uncertainty. After combining the long term expectancy with the information provided by the situation, a short term expectancy is elicited concerning what is likely to happen. This expectancy might be associated with a certain level of ad hoc uncertainty.

7.1.3. Proactive vs. reactive interaction behaviour

The results obtained by the different studies throughout this thesis seem to indicate two types of interaction behaviour, namely *proactive* and *reactive* interaction behaviour. The distinction between proactive and reactive control has also been made by, for example, Fuller (1984) and Hollnagel (1993). As mentioned in Chapter 2, Fuller pointed out that a driver can either make an anticipatory avoidance response (i.e. proactive) or a delayed avoidance response (reactive). The first is generally made before being certain that it is really necessary to ensure safety. If an anticipatory avoidance response is not made, a delayed avoidance response might eventually become necessary. However, in that case, less time is left to make an adequate avoidance response.

Hollnagel's Contextual Control Model (COCOM) provides a more detailed account of the distinction between proactive and reactive control (Hollnagel, 1993). He identified four control modes, which vary in the degree of forward planning and reactivity to the environment. The first two modes, "strategic" and "tactical", are based on long term planning and procedural short term planning respectively and can be considered more proactive, as they allow road users to anticipate future events. Behaviour in the latter two modes, "opportunistic" and particularly the "scrambled" mode, is much less planned but highly reactive to the immediate environment (Stanton, Ashleigh, Roberts, & Xu, 2001). The mode is determined by several factors; the knowledge and experience of the individual, the rate of change of the process and the subjective (and objective) time available. The first two factors can be related to the concept of expectancy discussed above, as expectancy also depends on prior knowledge and experience (reflected in the long term expectancy) and adapts to changes that occur in the process (reflected in the short term expectancy).

The latter factor, the available time, can be linked to the concept of "interaction space", which will be discussed further on in this chapter.

According to Hollnagel, people tend to move between control modes in linear fashion, which is corroborated by Stanton, Ashleigh, Roberts and Xu (2001). This suggests a continuous scale ranging from proactive control to reactive control. People should attempt to achieve strategic or at least tactical control which allows for a certain amount planning and anticipation, increasing the potential of reaching the desired outcome. The reactive modes, the opportunistic mode and particularly the scrambled mode should be avoided as these modes provide rather limited opportunities to recover from errors (Fuller, 2005).

During the phase of the interaction process in which proactive control is most likely, the environment will provide less of the specific information needed to adapt the long term expectancy into a detailed short term expectancy than during the phase of the interaction process, in which reactive control is more likely. For example, one road user might not even see any other road users but proactively release the throttle based on the knowledge that the intersection ahead is often rather busy. In such a situation, the short term expectancy used to select the proactive throttle action is not so much more specific than the long term expectancy concerning how busy such an intersection can be. In contrast, during the reactive phase, the environment provides many more elements that allow the long term expectancy to become a rather specific short term expectancy.

The results of Chapter 6 used a variety of measures to indicate the level of interaction safety, which seem to support the distinction between a proactive phase and a reactive phase. A detailed discussion of these measures can be found in Chapter 3. Furthermore, the results suggested that the transition from the proactive phase towards the reactive phase is not only affected by the amount of situational information available, but also by the interaction space available, which is in line with Hollnagel's (1993) idea about the time available determining the control mode. The concept of interaction space will be further discussed in Section 7.2.2. The Safety index and initial throttle and braking behaviour seemed to be indicators of the proactive phase, referring to behaviour more towards the start of the interaction situation, where the remaining interaction space is still relatively large. TTC_{min}, near misses and hard braking seemed to be indicators of a reactive phase, referring to behaviour more towards the end of the interaction situation, which generally coincides with limited interaction space.

7.2. Traffic safety implications

7.2.1. Uncertainty and interaction safety

In the qualitative research in Chapter 4 uncertainty surfaced as an important concept in expectancies of road users in interaction situations at intersections. Based on these results a hypothesis was formulated stating: "uncertainty concerning right of way and where a road user is going is more likely to lead to dangerous situations" (Section 4.4.5). This hypothesis was tested in the driving simulator studies discussed in Chapters 5 and 6.

The results of the driving simulator experiments did not provide unequivocal evidence to support the abovementioned hypothesis. The experiment included two types of situations that were assumed to elicit uncertainty. The results for one of those situations seemed to support the hypothesis, whereas the results for the other situation did not. When participants were confronted with a road user approaching the intersection from the left who maintains speed (behaviour which conflicts with the right of way regulation), the results indicated that this situation were less safe than the situations that were not designed to elicit uncertainty. However, when participants were confronted with a road user approaching the intersection from the right who slows down (again behaviour which conflicts with the right of way regulation), the results indicated no safety problems at all. It is likely that these effects are, at least, partly due to the behaviour of the other road user, who slowed down to a complete standstill. Follow-up research would need to focus on this aspect to determine the safety effects in a more natural interaction situation. This situation could include the other road user only slowing down as much as is necessary to determine if the participant would yield, before speeding up again to take priority. It should, however, be said that the decrease in safety in the situation where the other road user did not slow down coming from the left also gave rise to very clear compensatory behaviour by the participants. They yielded very often, which meant that safety did not deteriorate as much as it could have done if they had stood on their rights.

It seemed that an extra mechanism was needed to explain these ambiguous results, which is why the concept of interaction space was introduced and purposely manipulated in Chapter 6. The effects of interaction space are discussed in the next section.

7.2.2. Interaction space

The results above showed that of the two situations designed to elicit uncertainty only one tended to yield more dangerous situations. The difference between these two situations could be found in the interaction space, which is defined as the *time* available for both road users to negotiate their way across the intersection. The approach strategy “maintain speed” leaves less time for road users to adapt their expectancies to fit the current situation and consequently select an appropriate response. The situation that was meant to elicit uncertainty and yield less safe interactions, involved the other road user maintaining speed and thus a smaller interaction space than the uncertain situation which involved the other road user slowing down. This could explain the safety effects discussed in the previous section (Section 7.2.1). When the other road user slowed down and stopped, the interaction space became more or less unlimited in space-time and hence inherently safe, but also very inefficient in terms of the time needed by both interaction partners to clear the intersection. If the other road user had initially slowed down and then speeded up (perhaps on seeing her 'mistake' of incorrectly yielding right of way), as suggested in the proposal for further work at the end of Section 7.2.1, the interaction space would again have become small and uncertainty would have increased. Studies of this situation would provide interesting possibilities for further insights.

To further explore the concept of interaction space the experiment discussed in Chapter 6 included several attempts to manipulate interaction space (Table 7.1). First of all, as mentioned above, the different approach strategies of the other road user were assumed to have an effect on the interaction space (maintain speed vs. slow down). A second method used to manipulate interaction space focused on the visibility of the intersecting road. By placing buildings closer to the intersection, visibility and thus the interaction space was assumed to decrease (ceteris paribus). The third method used to manipulate interaction space involved providing the participants with extra information concerning the approach of other road users on the intersecting road, which was assumed to increase the interaction space.

Table 7.1: Manipulations of interaction space and their assumed effects

Interaction space	Approach Strategy	Visibility	Extra information
		High	
↑	Slow down		Yes
		Medium	
↓	Maintain speed		No
		Low	

The results suggested that if there is any additional interaction space it is used to increase efficiency. Primarily, interaction space is used to increase safety, thus safety generally has priority over efficiency. Additionally, the results indicated a trade-off relationship between proactive caution and efficiency: when participants tended to be rather cautious in the proactive phase, these interactions tended to be less efficient. Interactions where participants tended to rely on reactive control tended to be more efficient.

More studies of this interaction space-time are recommended to explore how drivers' strategies are influenced by the different parameters manipulated here, but also others that were not included in the present studies. This would need more parameters of the behaviour of both vehicles and drivers to be recorded than was the case in the experiments in this thesis, and would require more exploration of interactions with a more 'natural' behaviour of the experimenter's vehicle. Questions to study could include:

Does proactive slowing down occur both when information about approaching traffic is very poor and also when there is excellent visibility and/or information?

To what extent do drivers fall into different groups concerning how they respond?

When does proactive behaviour change to reactive and how is that affected by visibility and/or information about closing vehicles?

7.2.3. Compensatory mechanism

The experiments discussed in Chapter 5 and 6 studied the effects of different combinations of the approach strategy used by the other road user approaching the intersection (slow down or maintain speed) and the participant having right or way or not (which depended on the direction the other road user approached the intersection from). The results for both experiments indicated that participants had a general tendency to behave according to the right-hand right of way rule and also had a general tendency to give way when confronted with an interaction partner maintaining speed as the intersection is approached. The results also indicated that deviating behaviour of the other road user can cause the participant to compensate for that behaviour by abandoning the rule. This tendency towards compensating for deviating behaviour was particularly found when the other road user approached the intersection maintaining speed but not having right of way. These results are in line with a questionnaire study including similar interaction situations focusing on reported yielding behaviour (Björklund & Åberg, 2005).

The experiment reported in Chapter 6 included a short questionnaire asking participants to report their estimated yielding behaviour in reaction to schematically depicted situations of interactions at intersections (similar to the Björklund & Åberg approach). The results were compared with their actual yielding behaviour as observed in the driving simulator experiment. The largest discrepancies between observed and reported yielding behaviour were found in the situations which were assumed to elicit uncertainty as they involved the other road user's approach strategy being unusual in the context of the right of way situation. Participants tended to overestimate their own yielding behaviour in situations involving another road user maintaining speed, whereas an underestimation occurred in situations involving another road user slowing down. This implies that road users are not aware of how influential the compensatory mechanism can be.

7.2.4. Identifying less safe drivers

The results of the experiments discussed in Chapters 5 and 6 suggest that less safe drivers, that is, drivers who are involved in more near misses or collisions, can be identified by the distance to the intersection they decide to first release the throttle, which is considered to show less proactive interaction behaviour (Section 7.1.2).

An explanation of this effect might include that road users who display less proactive caution consequently need to rely more on their abilities during the reactive phase of the interaction process. The consequences of less safe behaviour during the reactive phase are likely to be more severe than during the proactive phase, due to the decreased interaction space. Other interaction partners will also have less opportunity to perform compensatory actions. An ADAS application is needed to help less safe drivers to increase their proactive caution. Unfortunately, the present implementation of providing extra information was shown to have a negative effect on proactive caution.

7.3. Modelling interaction behaviour in driving

The results have indicated an important role for the amount of interaction space in determining interaction safety and interaction efficiency. Factors that were able to affect the amount of interaction space included road users' approach strategies, visibility of the intersecting road and informing participants about other road users approaching the intersection (Table 7.1).

Based on the findings and notions discussed above, the model postulated in Chapter 2 requires some adaptation to better describe interaction behaviour in driving. The adapted model should incorporate aspects such as interaction space, uncertainty relating to expectancies, and the distinction between a proactive and a reactive phase in the interaction process. The model in Figure 7.1 shows several alterations compared to the model presented in Chapter 2. The environment is now depicted by a separate box to enable a feedback loop from the 'end' of the interaction process, indicating that the environment is influenced by what happens with the different vehicles interacting in the interaction space. As in the previous version of the model, all road users perceive the environment through a 'window' which produces a filtered perception of the environment. Due to these windows, the two road users will receive different information from the environment as they are at different positions in the situation. The results found for the different visibility conditions support the concept of a window. Subsequently the road users react through their vehicle to the situation they have perceived. Actions of all road users, which can be influenced by environmental aspects (e.g., visibility) and by ADAS (e.g., providing extra information), result in a certain amount of interaction space which has its effects on both interaction safety and efficiency as indicated by the results throughout this thesis. Figure 7.1 shows interaction space as an oval that changes size due to influences of other road users and their vehicles. Figure 7.1 also indicates that the effects of the amount (i.e. size) of the interaction space on safety and efficiency does not need to be equal. It is possible that the interaction space increases safety and decreases efficiency or the other way round or it may increase or decrease both. The result of the (developing) situation can subsequently be perceived in the environment through the windows. For reasons of clarity only two road users are presented here, but it is possible to add more road users.

In the earlier version of the model, ADAS was represented by an asterisk in the vehicle and environment boxes, as ADAS may or may not be present in either of the road users' vehicles and/or the environment. On further consideration, it seems much more important to show where ADAS has its effect, rather than where it is physically located. The asterisks have therefore been moved to the parts of the model where they can have an effect. The information about approaching traffic, provided in a rudimentary form in the experiment discussed in Chapter 6, affects the size of the window through which the road user receives information from the environment. Also, to an extent, the road user is affected by the information as it directs attention (see the new asterisk there in the model in Figure 7.2). Other ADAS developments might provide effects on the road users themselves (their attention, perception, working memory and through their experience on their long term memory, - see the asterisks added there in Figure 7.2), or on the interaction with their vehicles (e.g., ABS).

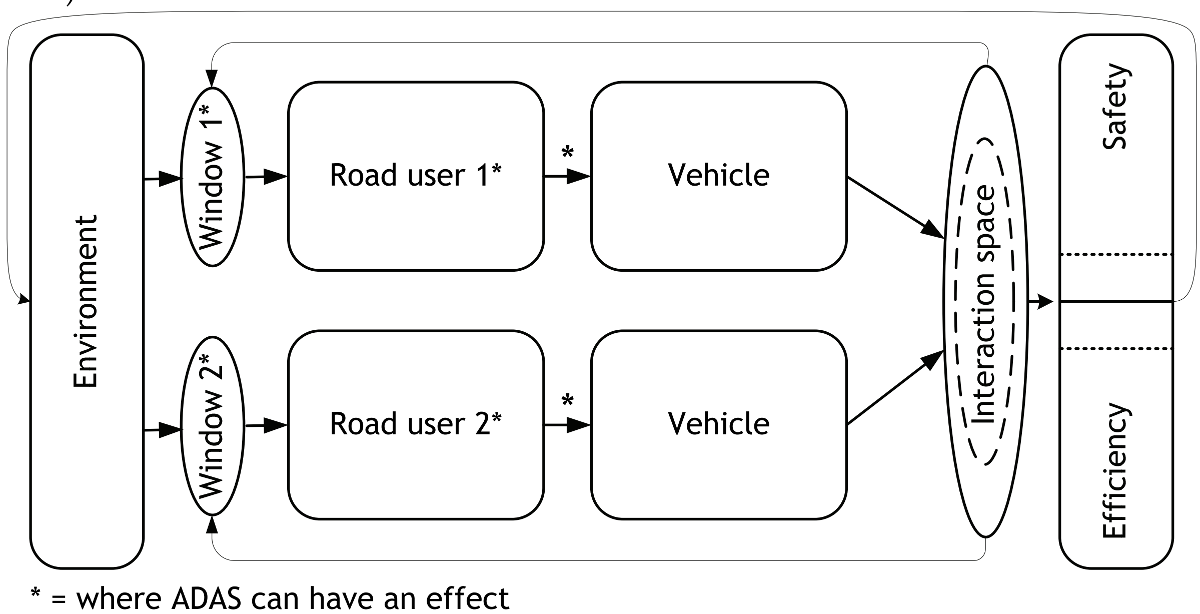


Figure 7.1: Interaction process (see text for explanation)

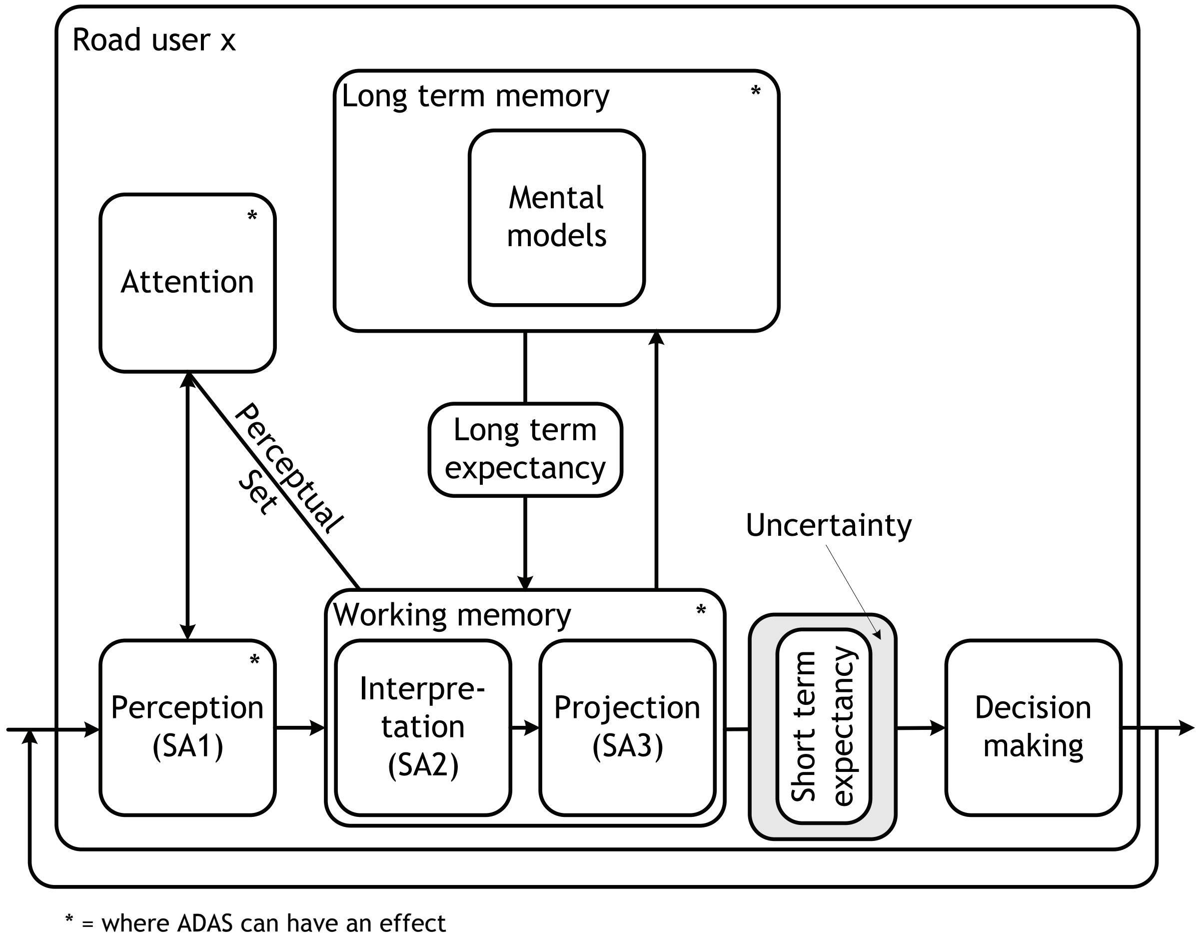


Figure 7.2: Information processing in driving (see text for explanation)

The second model (Figure 7.2) looks more closely at the road user in the first model but was slightly altered. The box marked "short term sensory processing" was omitted in the recent version of the model as this level of detail was not considered essential for such a model. For purposes of simplification we now assume short term sensory processing is a sub-process of the perception stage. The information from the outside world, which was filtered by the window in the first model, is perceived and– at least in part – determined by the focus of attention. In turn, the focus of attention on particular aspects of the situation is determined by what is included in working memory at a certain moment in time. The perception stage in this model corresponds to the first level of situation awareness (SA). This is where expectancy comes in. Based on the mental models of certain situations in traffic that a road user keeps in his long term memory and the situational aspects that are perceived, a long term expectancy is elicited. Subsequently, the perceived aspects of the situation are interpreted in the framework of this long term expectancy. This stage corresponds to the second level of SA. When the situation has been interpreted, the road user can make a projection of the state of the situation in the future (level 3 of SA) which will result in a short term expectancy. In this model, the short term expectancy is surrounded by a shell of (ad hoc) uncertainty that may vary in thickness depending on how uncertain the road user is about this particular short term expectancy. When the uncertainty shell is thin, road users can quite accurately plan their actions ahead (i.e., proactive mode), whereas when the shell of uncertainty is thick, road users need to rely more heavily on their reactive skills (i.e. reactive mode). As a more uncertain short term expectancy is likely to be elicited in the reactive mode, a larger interaction space will be required to adequately adapt the expectancy to the current situation and select an adequate response than with a relatively certain expectancy. However, a thicker shell of uncertainty would also make the expectancy more susceptible to potential conflicts between the expectancy and the developing situation, which might trigger a quicker adjustment of the expectancy. Based on the short term expectancy, a decision is made about which action is appropriate in the situation at hand. This decision could also be not to do anything yet, or to search for more evidence to support a certain expectancy. The action can be made through the road user’s vehicle, which brings us back to the first model. Whilst the situation develops, road users will need to assess their environment continuously and adapt their expectancies to the changing environment in order to be able to adequately (i.e., safely and efficiently) react to the situation.

In conclusion, this model incorporates the concept of expectancy which is assumed to be necessary to account for the way road users are able to anticipate situations. In addition, the effects of uncertainty and proactive and reactive control have been discussed. The amount of interaction space can be affected by aspects within the environment (e.g., visibility of the intersecting road), by aspects related to ADAS (e.g., providing information about other road users approaching the intersection) and by behavioural aspects (e.g., approach strategies). In turn, it seems the amount of interaction space is related to interaction safety (primarily during the phase in the interaction process in which reactive control is likely) and efficiency. As the interaction space increases, traffic safety (reactive) and efficiency also seem to increase.

In future studies we will need to elaborate on how interaction space works and whether it can be better optimised than in the present situation, by better infrastructure design, ADAS and driver training. We will also need to study not only how it works and can be optimised in 'normal' interactions, but how it functions and can be optimised in 'worst case scenarios'. In the meantime it is suggested that infrastructure designers and ADAS-designers should introduce or modify existing guidelines to take account of this more dynamic concept of interaction space, which is not easily catered for with rigid rules for all intersections. They will need to consider visibility lines, the choice of clear road markings to indicate right of way, as opposed to leaving interaction to the default right-hand rule, so reducing uncertainty. Furthermore, traffic calming measures can control speed at intersections, to provide the optimal space-time which is required for an effective interaction.

7.4. Research Methods

Several different methods were applied throughout the research conducted for this thesis. Although evaluating these methods was not the main research topic, the following section will briefly discuss aspects related to the use of (linked) driving simulators. A discussion of the explorative techniques used in the research prior to the driving simulator experiments can be found in Chapter 4.

7.4.1. Linked simulators

The driving simulator experiments discussed in this thesis included the use of two linked driving simulators which allowed the participants to interact with other road users being controlled by another human rather than being pre-programmed to react in a certain way. As this was quite an innovative approach, the first driving simulator experiment included both the traditional use of a driving simulator and the linked driving simulators which allowed the experimenter to control the behaviour of the other road user encountered by participants (Chapter 5). Comparing the results for the different experimental set-ups indicated that the traditional driving simulator obtained less variation in yielding behaviour than the linked simulators. The variation between similar situations which is also found in real life traffic situations seems to be more realistically reproduced using the linked simulators.

Furthermore, the results using the linked simulators showed more safety critical situations than when using the single simulator. This can, at least partly, be accounted for by the increased variation in behaviour of the encountered road user. Increased variation could have induced uncertainty, which, in the reactive mode, can lead to decreased safety as the road user will have limited opportunity to select an appropriate response. As real life interaction situations are also quite variable, these results imply that future studies aimed at assessing safety effects in interaction situations would benefit from the use of linked simulators.

The second driving simulator experiment used only linked simulators (Chapter 6). In addition to the type of situations studied in the first experiment, which included a "semi-programmed" experimenter as the participants' interaction partner, the second experiment included situations in which the experimenter could approach the intersection freely as she was not instructed to approach the intersection in a certain way. This allowed for an even more "natural" interaction situation than the way the linked simulators were used in the first experiment, although this also made it difficult to attribute findings to specific aspects of the situation. The results indicated that the behaviour in the condition in which the experimenter could approach the intersection did not really differ from the behaviour in the "semi-programmed" situations. This implies that the results using the semi-programmed experimenter can be considered fairly realistic, although it should be kept in mind that only a small number of encounters included the experimenter behaving freely. Studying the most natural interaction behaviour in a driving simulator would include having two participants interact freely with each other in the linked simulators. The results of the second experiment might suggest that this would not yield significantly different results from an experiment using a semi-programmed experimenter. However, other benefits could arise from having participants directly interact with each other, depending on the study objectives.

Simulator sickness

Both driving simulator experiments contended with simulator sickness occurring in about one in three to four participants. The first experiment (Chapter 5) involved many curves and the driving sessions were rather long (about 45 minutes of driving without a break), which might have contributed to simulator sickness occurring (Wertheim, 1996). In an attempt to avoid simulator sickness in the follow-up experiment, the number of curves was reduced and participants were allowed more breaks after shorter driving sessions. Unfortunately, a similar proportion of participants had to drop out due to simulator sickness. The second experiment was conducted in June during a rather hot period, in a room without air conditioning, which could explain why participants still tended to become sick. Furthermore, high fidelity of the simulated traffic environment might also have contributed to the occurrence of simulator sickness (Kennedy, Hettinger, & Lilienthal, 1990).

7.4.2. Behavioural measures used

As mentioned before, the experiment in Chapter 6 included a variety of behavioural indicators relating to safety or efficiency. A more detailed discussion of these measures can be found in Sections 3.3.2 and 6.4.6. Based on the results, two recommendations can be made. Firstly, the minimum score on the Safety index might be an improvement over the Safety index we used in the experiments for this thesis as this would indicate the most critical Safety index score throughout the encounter, rather than the Safety index score at a certain distance to the intersection. Furthermore, it has been argued that to provide a meaningful indication of the efficiency of an interaction situation, measures should incorporate behavioural aspects of *both* road users. Thus, for further research on interaction efficiency it is recommended to combine the speed when leaving the intersection for both road users to create a better measure of interaction efficiency. Unfortunately, the experimenter's behaviour did not allow for such a measure in the experiment reported in Chapter 6.

7.5. Implications for ADAS

To determine what the implications of interaction behaviour are for Advanced Driver Assistance Systems (ADAS), the experiment reported in Chapter 6 involved providing extra information concerning the approach of other road users on the intersecting road. Participants were informed about the speed and direction other road users were coming from using beeps and flashing lights. It is stressed that this was not an attempt towards an actual intersection support system, but merely an attempt to determine the effect of informing drivers (an aspect often found in ADAS) on interaction behaviour.

The extra information did not affect participants' decision to yield, but did affect other behavioural aspects concerning the approach to the intersection. For example, the safety indicators relating to the phase in the interaction situation in which the proactive mode is likely to be active (Safety index and throttle behaviour) indicated a decrease in safety as a result of providing extra information. However, a lower proportion of near misses occurred in the session with extra information indicating an increase in safety in the phase of the interaction in which the reactive mode is likely to be active. Thus, providing extra information seemed to weaken performance in the proactive mode and improve performance in the reactive mode. Furthermore, the efficiency indicators (Efficiency index and the participants' speed when leaving the intersection) indicated an increase in efficiency as an effect of extra information.

When asked about their experience with the extra information, participants indicated that they found the beeps to be quite useful, particularly compared to the lights, which they regarded as unpleasant and not useful at all. Participants indicated that the presentation of lights in the speedometer often went unnoticed as they tended to look towards the intersecting roads for relevant information rather than on their speedometer. This tendency could be taken as a suggestion for human machine interface design not to place information intended to aid a user at a location where the user would need to search for it before being able to perceive it. Instead, using a modality not dependent on search behaviour such as audition or touch could be a solution.

Furthermore, participants indicated that although they experienced the beeps as quite helpful, they did not experience them as pleasant to the same extent. Several participants even indicated that they experienced the driving task to be less interesting when provided with extra information. This observation corresponds to the findings regarding the decrease in subjective mental effort in sessions with extra information. Although a decrease in workload implies a road user would be better able to adequately react to unexpected situations (more resources to adapt the expectancy), it should be kept in mind that a workload that is too low is also undesirable (Yerkes & Dodson, 1908). Although the research in this thesis only employed a tool to assess *subjective* mental workload, future attempts to assess workload in combination with new functionalities for a driver would benefit from including other (objective) measures as well (e.g., de Waard, 1996; Östlund et al., 2004).

Another consideration involves the effect ADAS will have on expectancies of drivers, which could cause behavioural adaptation. The effect of behavioural adaptation can range from positive, through neutral, to negative, where the negative effects are considered most important to be able to predict in the context of traffic safety (Dragutinovic, Brookhuis, Hagenzieker, & Marchau, 2004). Future research endeavours to develop an ADAS aimed at supporting the interacting driver should take the concept of behavioural adaptation in to account when discussing the potential safety effects.

7.6. Further research suggestions and relevance

7.6.1. Limitations

Although the driving simulator experiments yielded quite interesting results, there were some limitations. Firstly, the interaction situations always involved just one other car driver approaching the intersection, whereas in daily traffic one would often simultaneously encounter more than one road user at an intersection and also different types of road users (e.g., pedestrians, cyclists, motorists). This limitation also illustrates why the particular implementation of providing information used in the experiment discussed in Chapter 6 can not be used as an ADAS supporting intersection behaviour. Because the situations always included only one road user approaching on the intersecting road, it was always clear to the participants what the information provided implied. However, this particular implementation would not work as well in real-life interaction situations which tend to involve more than one interaction partner. Thus, further research focusing on interaction behaviour between more than just two road users is required to be able to develop an adequate ADAS that can support interaction behaviour at intersection.

Furthermore, this thesis only included road users with at least five years of driving experience as we assumed they would have similar expectancies due to their experience. To determine how we could improve interaction behaviour through education it would be necessary to gain insight into the way road users develop and adapt their (long term) expectancies as they gain experience. Longitudinal studies focused on the driving experiences in the first years after licensing could provide some interesting insights (e.g., de Craen, in prep.; Ivers et al., 2006).

Although throughout the driving task interaction does not only occur at intersections, the current research only focused on interaction behaviour at intersections without any designated priority. The understanding of the interaction process could be expanded by also including other driving tasks that involve interaction in future research. For example, studying interaction behaviour at other types of intersections (e.g., Laberge, Creaser, Rakauskas, & Ward, 2006), studying different manoeuvres at intersections (e.g., Yan, Radwan, & Guo, 2007) or even during overtaking manoeuvres on the motorway (e.g., Houtenbos, Hegeman, & van Driel, 2005) could provide a useful additive to the research on interaction behaviour.

7.6.2. Visibility of the intersection

The variations in both driving simulator experiments concerning the visibility of the intersecting road proved that the extent to which the intersecting road is visible has an effect on interaction behaviour. Manuals on road design have previously acknowledged such effects and consequently incorporated the concepts of intersection sight distance and stopping sight distance in their road design guidelines (e.g., CROW, 2002).

The experiment in Chapter 6 included three levels of visibility (low, medium and high). The results implied the existence of a threshold in the relationship between visibility and interaction behaviour (between low and medium). The effects on safety indicators rarely differed between the medium and high visibility conditions but did show effects when compared with the low visibility condition. The existence of such a threshold could be of interest to infrastructural designers, who could incorporate that knowledge in their designs of intersections.

7.6.3. Sustainable Safety

The Sustainable Safety vision was introduced in 1992 and aimed to prevent traffic crashes or at least diminish crash severity primarily by focusing on infrastructural aspects (Koornstra, Mathijssen, Mulder, Roszbach, & Wegman, 1992). It is acknowledged that the road design should meet road users' expectations, which is operationalised through the principle of *predictability*. The principle of predicitability states that the infrastructural design and the resulting behaviour of road users should support the expectations road users have, which can be achieved by applying consistency and continuity in road design. Previous research on predictability has focused on road sections without intersections, whereas more research will need to be conducted to provide more information about predictability at intersections, particularly where transitions between different road types are involved (Aarts & Davidse, 2007). This study therefore breaks new ground in giving more specific meaning to predictability, which is very close to the concept of expectancy used here.

Another relevant principle within Sustainable Safety introduced in "Advancing in Sustainable Safety" is *forgivingness*, which aims to limit injuries by creating a forgiving road environment and allowing road users to anticipate road user behaviour (Wegman & Aarts, 2006). Research on the social aspect of forgivingness will need to focus on the way road users interpret each others' behaviour and the impact that has on their interactive behaviour. For example, a taxi driver approaching an intersection while maintaining speed may be interpreted as driving aggressively, whereas an old lady driving in a small car portraying the same behaviour, might be interpreted as driving absent-mindedly. Although this study always presented participants with identically looking interaction partners, varying the appearance of interaction partners could provide more insight into how forgivingness can be affected.

7.7. Conclusions

The research discussed in this thesis has provided increased insights into the role of long and short term expectancies in interaction behaviour at intersections. The results provided support for the distinction between a proactive and reactive mode of control in driving behaviour and indicated the related effects on safety and efficiency of the interaction situation. Furthermore, the results indicated that road users differ in the extent to which they seem to prefer the proactive or the reactive mode. Road users that tend to rely on their reactive skills were shown to encounter more unsafe interaction situations (near misses and collisions). However, overall, road users where shown to be able to cope rather well with situations where other road users' behaviour conflicted with the right of way regulations, illustrating that road users are indeed quite capable of compensating for deviating behaviour of other road users.

This thesis has made a start on research in a much neglected area, that of interaction behaviour in traffic. It has shown that there is a world of insight to be gained in the subtleties of how road users react to each other and how normally successful those interactions are. The use of linked simulators provides a very promising method to start mining this rich field of study much more systematically and intensively. Since ADAS intervenes in this subtle and complex world of prediction and feedback, reaction and learning, we need to know a great deal more about how this all works if we are to avoid making expensive mistakes in introducing it, or to avoid missing opportunities which it can offer.

References

Aarts, L. T., & Davidse, R. J. (2007). *Herkenbare vormgeving van wegen : eindrapport van de herkenbaarheidsprojecten in het SWOV-programma 2003-2006*. R-2006-18. Leidschendam: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.

Aarts, L. T., & van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis & Prevention, 38*(2), 215-224.

Abelson, R. P. (1981). Psychological status of the script concept. *American Psychologist, 36*, 715-729.

Alexander, G. J., & Lunenfeld, H. (1986). *Driver Expectancy in Highway Design and Traffic Operations*. Publication No. FHWA-TO-86-1. Washington, D.C: Federal Highway Administration.

Allen, B. L., Shin, B. T., & Cooper, P. J. (1977). *Analysis of traffic conflicts and collisions.* Hamilton, Ontario, Canada: Dept. of Civil Engineering, McMaster University.

Björklund, G., & Åberg, L. (2005). Driver behaviour in intersections: Formal and informal traffic rules. *Transportation Research Part F-Traffic Psychology and Behaviour, 8*(3), 239-253.

Bliersbach, G., & Dellen, R. G. (1980). Interaction conflicts and interaction patterns in traffic situations. *International Review of Applied Psychology, 29*, 475-490.

Brookhuis, K. A., de Waard, D., & Janssen, W. H. (2001). Behavioural impacts of advanced driver assistance systems: an overview. *European Journal of Transport and Infrastructure Research, 1*(3), 245-253.

Carroll, J. M., & Olson, J. R. (1987). *Mental models in human-computer interaction; research issues about what the user of software knows; Workshop on Software Human Factors: Users' mental Models* Washington National Academy Press.

Carsten, O., & Brookhuis, K. (2005). The relationship between distraction and driving performance: towards a test regime for in-vehicle information systems. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 75-77.

Chauvin, C., & Saad, F. (2000). Interaction and communication in dynamic control tasks: ship handling and car driving., *International Conference on Traffic and Transport Psychology*. Berne, Switzerland: Swiss Council for Accident Prevention, Berne.

Chin, H.-C., & Quek, S.-T. (1997). Measurement of traffic conflicts. *Safety Science, 26*(3), 169-185.

Cnossen, F., Meijman, T., & Rothengatter, T. (2004). Adaptive strategy changes as a function of task demands: a study of car drivers. *Ergonomics, 47*(2), 218-236.

CROW. (2002). *Handboek wegontwerp wegen buiten de bebouwde kom : erftoegangswegen*. Ede: CROW kenniscentrum voor verkeer, vervoer en infrastructuur.

de Craen, S. (in prep.). *Calibration in young drivers; results of a longitudinal study.* PhD thesis, Delft University of Technology, Delft.

de Waard, D. (1996). *The measurement of drivers' mental workload.* University of Groningen, Groningen.

de Waard, D., Steyvers, F., & Brookhuis, K. A. (2004). How much visual road information is needed to drive safely and comfortably? *Safety Science, 42*(7), 639-655.

de Waard, D., van der Hulst, M., & Brookhuis, K. A. (1999). Elderly and young drivers' reaction to an in-car enforcement and tutoring system. *Applied Ergonomics, 30*(2), 147-157.

de Winter, J. C. F., Houtenbos, M., Wieringa, P. A., Mulder, J. A., Kuipers, J., & de Groot, S. (2006). *Individual characteristics affecting intersection behaviour in a driving simulator.* Proceedings of the 25th European Conference on human decision making and manual control (EAM), Valenciennes, France.

Dewar, R. E. (2002). Roadway Design. In: R. E. Dewar & P. L. Olson (Eds.), *Human factors in traffic safety* (pp. 381-420). Tucson, AZ: Lawyers & Judges Publishing Company, Inc.

Dewar, R. E., Olson, P. L., & Alexander, G. J. (2002). Perception and Information Processing. In: R. E. Dewar & P. L. Olson (Eds.), *Human factors in traffic safety* (pp. 13-42). Tucson, AZ: Lawyers & Judges Publishing Company, Inc.

Dragutinovic, N., Brookhuis, K. A., Hagenzieker, M. P., & Marchau, V. A. W. J. (2004). *Importance of Behavioural Adaptation in Assessing Effectiveness of ADAS.* 10th World Conference on Transport Research, Istanbul: WTCR.

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic-Systems. *Human Factors, 37*(1), 32-64.

Engström, J. A., & Hollnagel, E. (2005). Towards a conceptual framework for modelling drivers' interaction with in-vehicle systems. In: L. Macchi, C. Re & P. C. Cacciabue (Eds.), *Proceedings of the international workshop on modelling driver behaviour in automotive environments* (pp. 197-204). Ispra, Italy: European Commission, Directorate-General Joint Research Centre (JRC) / Luxembourg, Office for Official Publications of the European Communities Eur-OP.

Field, A. (2005). *Discovering statistics using SPSS* (2nd ed.). London: Sage Publications Ltd.

Finn, P., & Bragg, B. W. E. (1986). Perception of the risk of an accident by young and older drivers. *Accident Analysis & Prevention, 18*(4), 289-298.

Fuller, R. A. (1984). A conceptualization of driving behaviour as threat avoidance. *Ergonomics, 27*(11), 1139-1155.

Fuller, R. A. (2005). Towards a general theory of driver behaviour. *Accident Analysis and Prevention, 37*(3), 461-472.

Hale, A. R., Stoop, J., & Hommels, J. (1990). Human error models as predictors of accident scenarios for designers in road transport systems. *Ergonomics, 33*(10/11), 1377-1387.

Hancock, P. A., & de Ridder, S. N. (2003). Behavioural accident avoidance science: understanding response in collision incipient conditions. *Ergonomics, 46*(12), 1111-1135.

Harbluk, J., Noy, Y. I., & Matthews, M. L. (1999). *Situation Awareness: What is it and why it matters for ITS.* ITS: Smarter, Smoother, Safer, Sooner - Proceedings of the 6th world congress on ITS, Toronto.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of experimental and theoretical research. In: P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 139-183). Amsterdam: North Holland.

Herslund, M.-B., & Jørgensen, N. O. (2003). Looked-but-failed-to-see-errors in traffic. *Accident Analysis & Prevention, 35*, 885-891.

Hoedemaeker, M. (1999). *Driving with intelligent vehicles: Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers.* PhD Thesis, Delft University of Technology, Delft.

Hoffman, R. B., Molino, J. A., & Vaughan, W. I. (2003). *Driving Simulator Sickness Management at Turner – Fairbank Highway Research Center.* DSC North America 2003 Dearborn, Michigan.

Hole, G. J., & Tyrrell, L. (1995). The Influence of Perceptual Set on the Detection of Motorcyclists Using Daytime Headlights. *Ergonomics, 38*(7), 1326-1341.

Hollnagel, E. (1993). *Human Reliability Analysis: Context and Control*: Academic Press.

Hollnagel, E. (1998). *Cognitive Reliability and Error Analysis Method: CREAM* (1st ed.). Oxford: Elsevier Science Ltd.

Hollnagel, E., Nåbo, A., & Lau, I. V. (2003). *A systemic model for driver-in-control.* Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Iowa University, Iowa City.

Hollnagel, E., & Woods, D. D. (2005). *Joint cognitive systems : Foundations of Cognitive Systems Engineering* Retrieved February 20th 2007.

Houtenbos, M. (2004). *Modelling Interaction Behaviour in Driving: The role of expectations in interaction behaviour between car drivers.* TRAIL Congress, Rotterdam.

Houtenbos, M. (2005). Modelling Interaction Behaviour in Driving. In: H. M. Jagtman & J. W. F. Wiersma (Eds.), *The Research Agenda of Risk and Design Anno 2005: 20 Years Chair in Safety Science at the TUDelft 1985-2005* (pp. 31-34). Delft.

Houtenbos, M., de Winter, J. C. F., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2006a). Interaction behaviour: Using two linked driving simulators to assess the effect of expectancy. In: S. Sillem (Ed.), *The Research Agenda of Risk and Design Anno 2006* (pp. 67-75). Delft: Risk Centre.

Houtenbos, M., de Winter, J. C. F., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2006b). Interaction behaviour: Using two linked driving simulators to assess the effect of expectancy. In: H. J. van Zuylen (Ed.), *TRAIL in MOTION: Proceedings of 9th International TRAIL Congress 2006* (pp. 129-144). Rotterdam: TRAIL Research School.

Houtenbos, M., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2004). Modelling Interaction Behaviour in Driving. In: D. de Waard, K. A. Brookhuis & C. M. Weikert (Eds.), *Human Factors in Design* (pp. 35-45). Maastricht, the Netherlands: Shaker Publishing.

Houtenbos, M., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2005a). Modelling interaction behaviour: focus on expectancy. In: L. Macchi, C. Re & P. C. Cacciabue (Eds.), *Proceedings of the international workshop on modelling driver behaviour in automotive environments* (pp. 280-286). Ispra, Italy: European Commission, Directorate-General Joint Research Centre (JRC) / Luxembourg, Office for Official Publications of the European Communities Eur-OP.

Houtenbos, M., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2005b). The role of expectations in interaction behaviour between car drivers. In: G. Underwood (Ed.), *Traffic and Transport Psychology : Theory and Application* (1st ed., pp. 303-314). Kidlington, Oxford: Elsevier.

Houtenbos, M., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2005c). *The role of expectations in interaction behaviour between car drivers.*, FERSI Young Researchers Seminar, The Hague, The Netherlands.

Houtenbos, M., Hegeman, G., & van Driel, C. (2005). *Determining opportunities for overtaking assistance:Combined efforts of a user needs survey and an interaction model.* 12th World Congress on ITS, San Francisco.

Houtenbos, M., Jagtman, H. M., Hagenzieker, M. P., Wieringa, P. A., & Hale, A. R. (2005). Understanding road users' expectations: an essential step for ADAS development. *European Journal of Transport and Infrastructure Research, 5*(3), 253-266.

Huguenin, R. D. (1988). The Concept of Risk and Behavior Models in Traffic Psychology. *Ergonomics, 31*(4), 557-569.

Hydén, C. (1987). *The development of a method for traffic safety evaluation : the Swedish Traffic Conflicts Technique. .* Bulletin No. 70. Lund: Lund University, Department of Traffic Planning and Engineering.

Ivers, R. Q., Blows, S. J., Stevenson, M. R., Norton, R. N., Williamson, A., Eisenbruch, M., et al. (2006). A cohort study of 20 822 young drivers: the DRIVE study methods and population. *Injury Prevention, 12*(6), 385-389.

Jackson, K. M., & Trochim, W. M. K. (2002). Concept mapping as an alternative approach for the analysis of open-ended survey responses. *Organizational Research Methods, 5*(4), 307-336.

Jagtman, H. M. (2004). *Road Safety by Design: a decision support tool for identifying ex ante evaluation issues of road safety measures.* PhD Thesis, Delft University of Technology, Delft.

Jahn, G., Oehme, A., Krems, J. F., & Gelau, C. (2005). Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(3), 255-275.

Jamson, S. (2006). Would those who need ISA, use it? Investigating the relationship between drivers' speed choice and their use of a voluntary ISA system. *Transportation Research Part F-Traffic Psychology and Behaviour, 9*(3), 195-206.

Kaptein, N. A., Theeuwes, J., & van der Horst, R. (1996). Driving Simulator Validity: Some Considerations. *Transportation Research Record*(1550), 30-36.

Kennedy, R. S., Hettinger, L. J., & Lilienthal, M. G. (1990). Simulator sickness. In: G. H. Crampton (Ed.), *Motion and space sickness* (pp. 317-341). Boca Raton, FL: CRC Press.

Knapp, K. (1998/1999, December-January). Driver expectancy, traffic control and roadway design. *Technology News,* pp. 1-2.

Koornstra, M. J., Mathijssen, M. P. M., Mulder, J. A. G., Roszbach, R., & Wegman, F. C. M. (Eds.). (1992). *Naar een duurzaam veilig wegverkeer; Nationale Verkeersveiligheidsverkenning voor de jaren 1990/2010. [Towards sustainably safe road traffic; National road safety outlook for 1990/2010]. (In Dutch)*. Leidschendam: SWOV Institute for Road Safety Research.

Laberge, J. C., Creaser, J. I., Rakauskas, M. E., & Ward, N. J. (2006). Design of an intersection decision support (IDS) interface to reduce crashes at rural stop-controlled intersections. *Transportation Research Part C: Emerging Technologies, 14*(1), 39-56.

Lajunen, T., Parker, D., & Summala, H. (2004). The Manchester Driver Behaviour Questionnaire: a cross-cultural study. *Accident Analysis and Prevention, 36*(2), 231-238.

Layton, R. D. (2004). *Stopping sight distance and decision sight distance*. Salem, Oregon: Oregon Department of Transportation.

Lunenfeld, H., & Alexander, G. J. (1984). Human Factors in Highway Design and Operations. *Journal of Transportation Engineering, 110*(2), 149-158.

Martens, M. H. (2000). *Automatic Visual Information Processing and Expectations in Traffic*. SE-581 95. Linköping, Sweden: Swedish National Road and Transport Research Institute VTI.

Martens, M. H. (2004). Stimuli fixation and manual response as a function of expectancies. *Human Factors, 46*(3), 410-423.

Martens, M. H., & Fox, M. (2007). Does road familiarity change eye fixations? A comparison between watching a video and real driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 10*(1), 33-47.

Michon, J. A. (1985). A critical view of driver behavior models: What do we know, what should we do? In: L. Evans & R. C. Schwing (Eds.), *Human Behavior and Traffic Safety* (pp. 485-520). New York: Plenum Press.

Michon, J. A. (1989). Explanatory pitfalls and rule-based driver models. *Accident Analysis & Prevention, 21*(4), 341-353.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: an expanded sourcebook* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Näätänen, R., & Summala, H. (1976). *Road User Behavior and Traffic Accidents.* Amsterdam: North Holland.

Naniopoulos, A. (2000). *Advanced driver assistance systems and traffic safety.* Workshop on Advanced Driver Assistance Systems (ADAS) and their impact on road safety and traffic efficiency, organised by NTUA and AUTh, Athens, 18 October.

Neisser, U. (1976). *Cognition and reality*. San Fransisco: W.H. Freeman.

Neisser, U. (1978). Anticipations, images and introspection. *Cognition, 6*, 169-174.

Nilsson, L. (1993). Contributions and limitations of simulator studies to driver behaviour research. In: A. M. Parkes & S. Franzén (Eds.), *Driving future vehicles* (pp. 401-407). London: Taylor and Francis.

Noy, Y. I. (1999). *The Need for Integration of Ergonomics in Transportation Policy, invited keynote address.*, International Symposium on Automotive Technology and Automation, Proceedings of the 32nd ISATA.

Nunes, L. M., & Recarte, M. A. (2005). Speed, Traffic Complexity and Visual Performance: A Study on Open Road. In: G. Underwood (Ed.), *Traffic and Transport Psychology : Theory and Application* (1st ed., pp. 339 - 354). Kidlington, Oxford: Elsevier.

Oborne, D. J. (1976). Examples of Use of Rating-Scales in Ergonomics Research. *Applied Ergonomics, 7*(4), 201-204.

OECD Scientific Expert Group. (1990). *Behavioural adaptation to changes in the road transport system*. Paris: OECD.

Olson, P. L., & Sivak, M. (1986). Perception-response time to unexpected roadway hazards. *Human Factors, 28*(1), 91-96.

Östlund, J., Nilsson, L., Carsten, O., Merat, N., Jamson, H., Jamson, S., et al. (2004). *HASTE Deliverable 2: HMI and Safety-Related Driver Performance*. HASTE-D2.

Ozkan, T., Lajunen, T., Chliaoutakis, J. E., Parker, D., & Summala, H. (2006). Cross-cultural differences in driving behaviours: A comparison of six countries. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(3), 227-242.

Parker, D., Reason, J. T., Manstead, A. S. R., & Stradling, S. G. (1995). Driving Errors, Driving Violations and Accident Involvement. *Ergonomics, 38*(5), 1036-1048.

Perkins, S. R., & Harris, J. I. (1967). *Traffic conflict characteristics accident potential at intersections.* 47th Highway Research Board (HRB) Congress, Washington, D.C.

Ranney, T. A. (1994). Models of Driving Behavior - a Review of Their Evolution. *Accident Analysis and Prevention, 26*(6), 733-750.

Räsänen, M., & Summala, H. (1998). Attention and expectation problems in bicycle-car collisions: an in-depth study. *Accident Analysis & Prevention, 30*(5), 657-666.

Rasmussen, J. (1983). Skills, rules, knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics, 13*(3), 257-266.

Reason, J. T., & Brand, J. J. (1975). *Motion Sickness*. London: Academic Press.

Reason, J. T., Manstead, A., Stradling, S., Baxter, J., & Campbell, K. (1990). Errors and Violations on the Roads - a Real Distinction. *Ergonomics, 33*(10-11), 1315-1332.

Renge, K. (2000). Effect of driving experience on drivers' decoding process of roadway interpersonal communication. *Ergonomics, 43*(1), 27-39.

Rothengatter, T. (1997). Psychological aspects of road user behaviour. *Applied Psychology-an International Review-Psychologie Appliquee-Revue Internationale, 46*(3), 223-234.

Russell, E. R. (1998). *Using Concepts of Driver Expectancy, Positive Guidance and Consistency for Improved Operation and Safety*. Paper presented at the Conference Name|. Retrieved Access Date|. from URL|.

Saad, F., Delhomme, P., & van Elslande, P. (1990). Drivers' speed regulation when negotiating intersections. In: M. Koshi (Ed.), *Transportation and Traffic Theory* (pp. 193-212): Elsevier.

Saad, F., Mundutéguy, C., & Darses, F. (1999). *Managing interactions between car drivers: an essential dimension of reliable driving.*, Proceedings of Seventh European Conference on Cognitive Science Approaches to Process Control (CSAPC '99), Villeneuve d'Ascq.

Schank, R. C., & Abelson, R. P. (1977). *Scripts, Plans, Goals and Understanding:*
An Inquiry into Human Knowledge Structures. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Shor, R. E. (1964). Shared patterns of nonverbal expectations in automobile driving. *Journal of Social Psychology, 62*, 155-163.

Simulators and Traffic Psychology. (1996). Proceedings of the Human Factors and Ergonomics Society Europe Chapter Annual Meeting, Haren, The Netherlands.

Stanton, N. A., Ashleigh, M. J., Roberts, A. D., & Xu, F. (2001). Testing Hollnagel's Contextual Control Model: Assessing Team Behavior in a Human Supervisory Control Task. *International Journal of Cognitive Ergonomics, 5*(2), 111-123.

Stanton, N. A., & Young, M. S. (2002). Developing a psychological model of the driver. In: *Behaviour Research in Road Safety: Eleventh seminar* (pp. 135-140): Department for Transport, London.

Stemler, S. E. (2004). A comparison of consensus, consistency, and measurement approaches to estimating interrater reliability [Electronic Version]. *Practical Assessment, Research & Evaluation*, 9. Retrieved February 15, 2007 from http://PAREonline.net/getvn.asp?v=9&n=4

Summala, H., Pasanen, E., Räsänen, M., & Sievänen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention, 28*(2), 147-153.

Svensson, A., & Hydén, C. (2006). Estimating the severity of safety related behaviour. *Accident Analysis and Prevention, 38*(2), 379-385.

Tenenhaus, M., & Young, F. W. (1985). An Analysis and Synthesis of Multiple Correspondence-Analysis, Optimal-Scaling, Dual Scaling, Homogeneity Analysis and Other Methods for Quantifying Categorical Multivariate Data. *Psychometrika, 50*(1), 91-119.

Theeuwes, J. (1996). Visual search at intersections: An eye-movement analysis. In: A. G. Gale (Ed.), *Vision in Vehicles* (Vol. V, pp. 125 - 134): Elsevier Science B.V.

Theeuwes, J., & Godthelp, H. (1995). Self-explaining roads. *Safety Science, 19*(2-3), 217-225.

Theeuwes, J., & Hagenzieker, M. P. (1993). Visual search of traffic scenes: on the effect of location expectations. In: A. G. Gale (Ed.), *Vision in Vehicles IV* (pp. 149-158). Amsterdam: Elsevier.

Twisk, D. A. M., & Hagenzieker, M. P. (1993). *Feitelijk en beoogd fietsgedrag in relatie tot veiligheid: uitgangspunten voor het ontwerpen van een veilige infrastructuur voor fietsers*. R-93-24. Leidschendam: Institute for Road Safety Research SWOV.

van Arem, B., van Driel, C. J. G., & Visser, R. (2006). The Impact of Cooperative Adaptive Cruise Control on Traffic-Flow Characteristics. *IEEE Transactions on Intelligent Transportation Systems, 7*(4), 429-436.

van der Horst, A. R. A. (1990a). *A Time-Based Analysis of Road User Behaviour at Intersections.* ICTCT, Krakow.

van der Horst, A. R. A. (1990b). *A time-based analysis of road user behaviour in normal and critical encounters.* PhD Thesis, Delft University of Technology, Delft.

van der Hulst, M. (1999). *Adaptive control of safety margins in driving.* Doctoral Thesis, Rijksuniversiteit Groningen, Groningen.

van der Kloot, W. A. (1997). *Meerdimenionale schaaltechnieken voor gelijkenis- en keuzedata: Ruimtelijke modellen voor psychologie, marktonderzoek en andere wetenschappen*. Utrecht: Uitgeverij Lemma BV.

van der Laan, J. D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies, 5*(1), 1-10.

van der Molen, H. H. (1983). *Pedestrian ethology: unobstrusive observations of child and adult road-crossing behaviour in the framework of the development of a child pedestrian training programme.* Haren (The Netherlands): Traffic Research Center, University of Groningen.

van Driel, C., & van Arem, B. (2005). *Integrated driver assistance from the driver's perspective: results from a user needs survey*. CE&M research report 2005R-002. VVR-002.

van Elslande, P., & Fauncher-Alberton, L. (1996). *When expectancies become certainties: A potential adverse effect of experience.* Traffic and transport psychology : theory and application : proceedings of the international conference on traffic and transport psychology, Valencia, Spain.

Vogel, K., Kircher, A., Alm, H., & Nilsson, L. (2003). Traffic sense--which factors influence the skill to predict the development of traffic scenes? *Accident Analysis & Prevention, 35*(5), 749-762.

Ward, N. J., Parkes, A., & Crone, P. R. (1995). Effect of background scene complexity and field dependence on the legibility of head-up displays for automotive applications. *Human Factors, 37*(4), 735-745.

Wegman, F. C. M., & Aarts, L. T. (Eds.). (2006). *Advancing sustainable safety : National Road Safety Outlook for 2005-2020.* Leidschendam: SWOV Institute for Road Safety Research.

Wertheim, A. H. (1996). Human performance in a moving environment. In: K. A. Brookhuis, D. de Waard & C. M. Weikert (Eds.), *Simulators and Traffic Psychology* (pp. 7-23). Groningen: The Centre for Environmental and Traffic Psychology.

Wertheim, A. H. (1998). Working in a moving environment. *Ergonomics, 41*(12), 1845-1858.

Wickens, C. D. (1992). *Engineering Psychology and Human Performance* (2nd ed.). New York: HarperCollins Publishers Inc.

Wickens, C. D., & Hollands, J. G. (2000). *Engineering Psychology and Human Performance* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Wieringa, P. A., & Stassen, H. G. (1999). Human-machine systems. *Transactions of the Institute of Measurement and Control, 21*(4-5), 139-150.

Wilde, G. J. S. (1982). The theory of risk homeostasis: implications for safety and health. *Risk Analysis, 2*(4), 209-225.

Williams, M. J. (1981). Validity of the traffic conflicts technique. *Accident Analysis & Prevention, 13*(2), 133-145.

Yan, X., Radwan, E., & Guo, D. (2007). Effects of major-road vehicle speed and driver age and gender on left-turn gap acceptance. *Accident Analysis & Prevention, 39*(4), 843-852.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459-482.

Zhang, L., & Prevedouros, P. D. (2003). Signalized intersection level of service incorporating safety risk. In: *Traffic Flow Theory and Highway Capacity 2003* (pp. 77-86).

Zijlstra, F. R. H. (1993). *Efficiency in work behaviour : a design approach for modern tools* Delft University of Technology, Delft.

Zijlstra, F. R. H., & Van Doorn, L. (1985). *The construction of a subjective effort scale*. Delft, the Netherlands: Delft University of Technology.

Summary

Most of the research on traffic behaviour has been focused on the individual road user, despite the fact that road users rarely encounter traffic situations in which they are not confronted with other road users. An associated finding is that most models of the driving task represent the driving task from the perspective of one individual road user, rather than incorporating the interactive nature of traffic behaviour. To achieve an understanding of the way road users are able to gear their behaviour to one another this thesis included the following research questions (Chapter 1):

- ❖ What is the role of expectancy in interaction behaviour at intersections?
- ❖ What is the influence of expectancy on traffic safety at intersections?
- ❖ What are the implications of human interaction behaviour for ADAS?

Chapter 2 provided a theoretical framework for the research discussed in subsequent chapters and centred on the concept of expectancy. Literature focussing on this concept has implied that when expectancies are not justified, road users may not perceive the relevant information at all or too late, resulting in a delayed and potentially less adequate response. This would obviously have a negative impact on interaction safety at intersections. Furthermore, a range of models of driving behaviour were discussed and scrutinised for their applicability to interaction behaviour. A model of driving behaviour explicitly incorporating the effect of behaviour of one road user on the behaviour of another was found to be lacking, which led to the development of a new model that attempts to describe the interaction process on a cognitive level. This model was eventually revised in Chapter 7 based on the results obtained through the research for this thesis.

Chapter 3 discussed the range of research methods applied throughout the research conducted for this thesis. These varied from more qualitative techniques such as

concept mapping and qualitative data analysis, while the research was still rather explorative, to more quantitative methods involving the use of (linked) driving simulators as the research progressed.

Chapter 4 dealt with the research of a more explorative nature and was particularly aimed at exploring the concept of expectancies in interaction situations (at intersections). The chapter started with an account of the concept mapping studies followed by a more detailed (qualitative) analysis of the expectancies generated by the participants in the concept mapping studies. The concept maps were created through a concept generation phase, in which respondents' expectancies in presented interaction situations were elicited, followed by a concept sorting phase, in which respondents were asked to categorise the different expectancies based on their similarities. The resulting concept map provided insight into the different types of aspects occurring in expectancies in interaction situations. The expectancies were also analysed in greater detail using qualitative data analysis techniques. Combining the results of both techniques indicated three categories of aspects mentioned in expectancies: references to (1) right of way, (2) other road users and (3) the location of other road users, be it someone's past, present or future location. These were used to focus the driving simulator experiments discussed in Chapter 5 and 6.

Chapter 5 discussed the first of two driving simulator experiments. To study interaction behaviour, two driving simulators were linked to allow the participant in the first simulator to interact with the experimenter driving in the second simulator. As this was quite an innovative approach, the linked simulators were only used in one half of the experiment, whilst the other half was conducted using only one driving simulator and included pre-programmed interaction partners. The experiment focused on the effects of manipulations of uncertainty concerning right of way and the (future) location of the other road user. These manipulations entailed another road user approaching an intersection (without any designated priority) from either the left or the right while either maintaining speed or slowing down. The results indicated that both the right hand right of way rule as well as the approach strategy of the other road user had a significant effect on participants' decision to yield. Although participants generally yielded when they did not have right of way, they also tended to yield when they did have right of way if they were confronted with another road user approaching the intersection maintaining speed. This behaviour shows that road users can indeed compensate for deviating behaviour of their interaction partners, indicating that unexpected behaviour does not necessarily result in a critically unsafe interaction situation.

The research for Chapter 6 again employed two linked driving simulators since the variation between similar situations (which is also found in real life traffic situations) seemed to be more realistically reproduced using the linked simulators. The results of the previous experiment suggested that the time available to both interaction partners to successfully cross the intersection (i.e. interaction space) could help to explain the effects of uncertainty of expectancies on traffic safety. This second experiment was aimed at further studying the concept of interaction space and the effects on both interaction safety and efficiency. The intersection situations encountered by the participants were similar to the first experiment although this time visibility of the intersection was varied to manipulate the amount of interaction space. Another attempt to manipulate the amount of interaction space included participants being informed of approaching road users through beeps and lights. The results implied a distinction between behaviour indicating proactive caution and reactive caution. Increasing interaction space tended to affect the latter behaviour to a greater extent as well as positively affecting interaction efficiency. The results also indicated that participants felt the information about approaching road users was useful and lead to a lower level of mental workload.

Chapter 7 discussed the main findings of the research conducted throughout the thesis and considered the implications of these findings in several contexts. Concerning the role of expectancy in interaction behaviour at intersections (Research Question 1), the results of the various research seemed to support the a priori distinction made between long term expectancies (i.e. a general idea of what is likely to happen in certain situations) and short term expectancies (i.e. a more specific idea of what is likely to happen in the current situation at hand). Uncertainty, a concept related to expectancy, seemed to show a similar distinction; one can be uncertain concerning what should happen (a priori uncertainty) and concerning what is likely to happen (ad hoc uncertainty). The distinction between proactive and reactive interaction behaviour seemed to correspond to similar distinctions made in previous models of driving behaviour, which were also discussed.

Concerning the influence of expectancy on traffic safety at intersections (Research Question 2), uncertainty surfaced as an important concept. Although the literature discussed in Chapter 2 suggested that increased uncertainty and unjustified expectancies would lead to a decrease in traffic safety, the research did not indicate just that. It seemed that an extra mechanism was needed to explain the ambiguous results found, which is why the concept of interaction space was studied in Chapter 6. The results suggested that additional interaction space is used to increase efficiency, indicating that safety has the first priority. Additionally, the results indicated a trade-off relationship between proactive caution and efficiency. Another notable finding indicated that less safe drivers (relatively often involved in collisions and/or near misses) could be identified by the moment they chose to release the accelerator as they approached the intersection (later than safer drivers).

Based on the research discussed above, the model postulated in Chapter 2 was revised and presented in Chapter 7. The concepts of uncertainty and interaction space were added and the representation of ADAS in the model was altered. To enhance understanding of the interaction process in driving it was suggested to focus future research on the way interaction space works and whether it can be better optimised than in the present situation, either through better infrastructure design, ADAS or driver training.

Chapter 7 also discussed the merits of using linked driving simulators when studying interaction behaviour, allowing for more natural interaction situations compared to when using a traditional (single) driving simulator where behaviour of the interaction partners is pre-programmed. Suggestions for future studies include having two participants interact with each other, rather than having the participant interact with the experimenter as was the case for the research conducted for this thesis.

The implications of the results have also been discussed in the context of ADAS (Research Question 3). The extra information participants were provided with in the driving simulator experiment in Chapter 6 did not affect participants' decision to yield but did affect other behavioural aspects concerning the approach to the intersection. Providing extra information seemed to elicit a shift from proactive control towards reactive control. Furthermore, the results suggested the design of human machine interfaces should use a modality not dependent on search behaviour such as audition or touch, rather than vision.

Chapter 7 ends with the overall conclusion that the research presented in this thesis has shown that road users are able to cope rather well with situations where other road users' behaviour conflicted with the right of way regulations, illustrating that road users are indeed quite capable of compensating for deviating behaviour of other road users. Also, the use of linked simulators proved to be a rather promising method to study interaction behaviour systematically but also intensively. As ADAS will also influence interaction behaviour it is stressed that a greater understanding of all aspects of interactive behaviour in traffic is required to be able to exploit the potential of ADAS to the fullest.

Samenvatting

Onderzoek naar verkeersgedrag heeft zich in het verleden vooral gericht op de individuele weggebruiker, ondanks het feit dat weggebruikers zelden verkeerssituaties ervaren waarin ze niet geconfronteerd worden met andere weggebruikers. De meeste modellen van de rijtaak blijken deze rijtaak echter weer te geven vanuit het perspectief van één enkele weggebruiker, in plaats van de interactieve aard van verkeersgedrag in het model verwerken. Om te kunnen begrijpen hoe weggebruikers in staat zijn hun gedrag op elkaar af te stemmen is een aantal onderzoeksvragen geformuleerd (Hoofdstuk 1):

- Welke rol spelen verwachtingen in interactiegedrag op kruispunten?
- Hoe beïnvloeden verwachtingen de verkeersveiligheid op kruispunten?
- Wat zijn de implicaties van menselijk interactiegedrag voor geavanceerde bestuurder ondersteunende systemen (ADAS)?

Hoofdstuk 2 biedt een theoretisch kader voor het onderzoek dat wordt besproken in de daaropvolgende hoofdstukken en richt zich voornamelijk op verwachtingen. Literatuur gewijd aan verwachtingen impliceert dat ongerechtvaardigde verwachtingen kunnen leiden tot het niet of te laat waarnemen van relevante informatie, met als gevolg een vertraagde en eventueel ook minder adequate reactie. Het moge duidelijk zijn dat dit negatieve consequenties voor de verkeersveiligheid op kruispunten kan hebben. In Hoofdstuk 2 wordt tevens een reeks modellen van rijgedrag besproken en onderzocht op de toepasbaarheid op interactiegedrag. Een model van rijgedrag dat expliciet het effect van het gedrag van de ene weggebruiker op het gedrag van de andere meeneemt, werd niet gevonden. Dit heeft geleid tot de ontwikkeling van een nieuw model dat poogt het interactieproces op een cognitief niveau te beschrijven. Dit model werd uiteindelijk in Hoofdstuk 7 aangepast op basis van de resultaten van het onderzoek dat voor dit proefschrift werd uitgevoerd.

Hoofdstuk 3 bespreekt de reeks verschillende in dit proefschrift toegepaste onderzoeksmethoden. Deze varieerden van meer kwalitatieve technieken (zoals "concept mapping" en kwalitatieve data analyse) voor het onderzoek dat meer verkennend van aard was tot meer kwantitatieve methoden (zoals het gebruik van gekoppelde rijsimulatoren) naarmate het onderzoek vorderde.

Hoofdstuk 4 handelt over het onderzoek van verkennende aard en was voornamelijk gericht op het bestuderen van verwachtingen in interactiesituaties (op kruispunten). Het hoofdstuk begint met een beschrijving van de concept mapping studies gevolgd door een gedetailleerdere kwalitatieve analyse van de verschillende verwachtingen verwoord werden door de deelnemers aan de concept mapping studies. De concepten of verwachtingen werden gegenereerd door proefpersonen te vragen naar hun verwachtingen naar aanleiding van getoonde interactiesituaties. Vervolgens werd proefpersonen gevraagd de verschillende verwachtingen in categorieën in te delen op basis van gelijkenis. De resulterende "concept map" biedt een grafische weergave van de verschillende clusters verwachtingen. De verwachtingen werden ten slotte in detail bestudeerd middels kwalitatieve data analyse technieken. De resultaten van bovengenoemde onderzoekstechnieken duidden op drie categorieën aspecten genoemd in de verwachtingen: verwijzingen naar (1) voorrang, (2) andere weggebruikers en (3) de locatie van andere weggebruikers (in het verleden, heden en toekomst). Deze categorieën zijn vervolgens gebruikt bij het ontwerpen van de rijsimulator experimenten besproken in Hoofdstuk 5 en 6.

Hoofdstuk 5 bespreekt het eerste rijsimulator experiment. Om interactiegedrag te kunnen bestuderen, zijn twee simulatoren aan elkaar gekoppeld zodat de proefpersoon in de eerste simulator kan interacteren met de proefleider in de tweede simulator. Vanwege de innoverende aard van deze aanpak is besloten de gekoppelde simulatoren slechts voor de helft van het experiment te gebruiken en voor de andere helft gebruik te maken van een enkele rijsimulator en voorgeprogrammeerde interactiepartners. Het experiment richtte zich op de manipulatie van de mate van onzekerheid met betrekking tot voorrang en de (toekomstige) locatie van de andere weggebruiker. De mate van onzekerheid werd gemanipuleerd door een andere weggebruiker het ongeregelde kruispunt te laten naderen van links ofwel van rechts, terwijl deze dezelfde snelheid aanhoudt ofwel snelheid mindert. De resultaten geven aan dat de "verkeer van rechts heeft voorrang"-regel evenals de naderingswijze van de andere weggebruiker beide een significant effect hadden op de beslissing van proefpersonen om voorrang te verlenen. Hoewel proefpersonen doorgaans voorrang verleenden als ze zelf geen voorrang hadden, bleken proefpersonen ook voorrang te verlenen als ze wel voorrang hadden maar geconfronteerd werden met een weggebruiker die geen snelheid minderde tijdens het naderen van het kruispunt. Dit gedrag toont aan dat weggebruikers kunnen compenseren voor afwijkend gedrag van interactiepartners. Onverwacht gedrag hoeft dus niet noodzakelijk tot een kritieke en onveilige interactiesituatie te leiden.

Het onderzoek voor Hoofdstuk 6 maakte wederom gebruik van twee gekoppelde rijsimulatoren aangezien de variatie tussen vergelijkbare interactiesituaties (zoals die ook in werkelijke verkeerssituaties wordt gevonden) realistischer leek te worden gereproduceerd bij gebruik van de gekoppelde rijsimulatoren. De beschikbare tijd en ruimte voor beide interactiepartners om het kruispunt succesvol over te steken kan de resultaten van het voorgaande experiment met betrekking tot de effecten van onzekerheid van verwachtingen mogelijk verklaren. Vandaar dat het vervolgexperiment gericht is op het nader bestuderen van het concept "interactieruimte" en de effecten op interactieveiligheid en -efficiëntie. De kruispuntsituaties in dit tweede experiment zijn vergelijkbaar met de situaties zoals gebruikt in het eerste experiment, hoewel ditmaal de zichtbaarheid van de kruispunten bewust gevarieerd is om de interactieruimte te manipuleren. Een tweede poging de interactieruimte te manipuleren betreft het informeren van proefpersonen met betrekking tot naderende weggebruikers middels piepjes en lichtjes. De resultaten geven aan dat er een onderscheid te maken valt tussen gedrag dat blijk geeft van proactieve behoedzaamheid en van reactieve behoedzaamheid. Het vergroten van de interactieruimte leek meer invloed te hebben op reactieve behoedzaamheid en leek tevens de interactie-efficiëntie te verhogen. De proefpersonen gaven tevens aan de informatie met betrekking tot naderende weggebruikers nuttig te vinden en ervaarden tijdens de ritten waarin ze geinformeerd werden ook een lagere mentale belasting.

Hoofdstuk 7 bespreekt de belangrijkste bevindingen van het onderzoek dat voor dit proefschrift is uitgevoerd evenals de implicaties van deze bevindingen in verschillende contexten. Wat betreft de rol van verwachtingen in interactiegedrag op kruispunten (Onderzoeksvraag 1), lijken de resultaten het a priori aangebracht onderscheid tussen lange termijn verwachtingen (een algemeen idee van wat er in een bepaalde situatie zou kunnen gebeuren) en korte termijn verwachtingen (een meer specifiek idee van wat er in de huidige situatie zou kunnen gebeuren) te ondersteunen. Met betrekking tot onzekerheid, een concept gerelateerd aan verwachtingen, blijkt een vergelijkbaar onderscheid te maken; men kan onzeker zijn met betrekking tot wat er zou moeten gebeuren (a priori onzekerheid) en met betrekking tot wat er waarschijnlijk zal gebeuren (ad hoc onzekerheid). Het onderscheid tussen proactief en reactief interactiegedrag lijkt aan te sluiten bij onderscheid dat gemaakt wordt in bestaande modellen van rijgedrag die ook worden besproken.

Wat betreft de invloed van verwachtingen op de verkeersveiligheid op kruispunten (Onderzoeksvraag 2), bleek onzekerheid een belangrijke rol te spelen. Hoewel op basis van de literatuur besproken in Hoofdstuk 2 viel te verwachten dat meer onzekerheid en ongerechtvaardigde verwachtingen zouden leiden tot een verslechterde verkeersveiligheid, bleek dit niet direct uit de resultaten van dit onderzoek. Er blijkt een extra mechanisme nodig te zijn om de ambigue resultaten te kunnen verklaren, derhalve is het concept “interactieruimte” in Hoofdstuk 6 bestudeerd. De resultaten geven aan dat veiligheid de eerste prioriteit heeft en additionele interactieruimte wordt gebruikt om de efficiëntie te verhogen. Bovendien wijzen de resultaten op een wisselwerking tussen proactieve behoedzaamheid en efficiëntie. Een ander opmerkelijk resultaat is de bevinding dat minder veilige bestuurders (die in het experiment relatief vaak betrokken waren bij een botsing of bijna botsing) konden worden geïdentificeerd op basis van het moment waarop ze besloten het gaspedaal voor het eerst los te laten. Zij bleken dit dichterbij het kruispunt te doen dan veiligere bestuurders.

Op basis van het onderzoek dat hierboven besproken werd, is het model dat in Hoofdstuk 2 geponeerd is aangepast in Hoofdstuk 7. De concepten onzekerheid in interactieruimte zijn toegevoegd en de manier waarop ADAS in het model werd weergegeven is gewijzigd. Om meer begrip te krijgen van het interactieproces in het verkeer wordt voorgesteld om toekomstig onderzoek te richten op de werking van de interactieruimte en de mogelijkheden het beter te optimaliseren dan in de huidige situatie, bijvoorbeeld door beter ontwerp van de infrastructuur, ADAS of training.

Hoofdstuk 7 gaat ook in op de voordelen van het gebruik van gekoppelde rijsimulatoren bij het bestuderen van interactiegedrag. Het biedt de mogelijkheid om meer natuurlijke interactiesituaties te bestuderen dan wanneer men een traditionele (enkele) rijsimulator zou gebruiken, waar het gedrag van de interactiepartner vooraf bepaald en geprogrammeerd is. Er wordt ook voorgesteld om in toekomstig onderzoek twee proefpersonen met elkaar te laten interacteren, in plaats van een proefpersoon met een proefleider zoals in het huidige onderzoek het geval was.

De implicaties van de resultaten worden vervolgens besproken in de context van ADAS (Onderzoeksvraag 3). Het aanbieden van extra informatie bleek geen invloed te hebben op de beslissing voorrang te verlenen, maar wel op andere aspecten van het gedrag bij het naderen van het kruispunt. Zo bleek het aanbieden van extra informatie te leiden tot een verschuiving van proactieve controle naar reactieve controle. Op basis van de resultaten wordt bovendien geadviseerd bij het ontwerpen van een dergelijke mens machine interface gebruik te maken van een modaliteit die onafhankelijk is van zoekgedrag (zoals geluid of gevoel, in plaats van zicht).

Hoofdstuk 7 besluit met de algemene conclusie dat het onderzoek dat in dit proefschrift gepresenteerd is heeft aangetoond dat weggebruikers relatief goed in staat zijn om te gaan met situaties waarin het gedrag van andere weggebruikers conflicteert met de voorrangsregel. Kortom, weggebruikers lijken behoorlijk in staat te compenseren voor afwijkend gedrag van andere weggebruikers. Tevens wordt geconcludeerd dat het gebruik van gekoppelde rijsimulatoren een veelbelovende methode is om zowel systematisch als tot in detail interactief verkeersgedrag te bestuderen. Vanwege de invloed van ADAS op interactiegedrag wordt er ten slotte veel belang aan gehecht aan een beter begrip van alle aspecten van interactief verkeersgedrag teneinde optimaal te kunnen profiteren van hetgeen ADAS kan bieden.

About the author

Maura Houtenbos was born in Seria, Brunei on November 23rd in 1977. After obtaining her gymnasium diploma from Rijnlands Lyceum in Wassenaar in 1996, she attended the Vrije Hogeschool in Driebergen. In 1997 she started studying Psychology at VU University Amsterdam. She specialised in cognitive psychology and completed her studies with an internship at TNO Human Factors in Soesterberg. During this internship she was introduced to applied traffic psychology and conducted driving simulator experiments focusing on lane keeping behaviour and eye movements.

In September 2002 she started her PhD research at Delft University of Technology within the BAMADAS (Behavioural Analysis and Modelling for the Design and Implementation of Advanced Driver Assistance Systems) research program. Also in September 2002, she started as a part-time researcher at SWOV Institute for Road Safety Research participating in studies on, for example, young drivers, enforcement and credibility of speed limits and safety aspects of new vehicle types. Since February 2007, Maura is a fulltime researcher at SWOV Institute for Road Safety Research.

Photo: Peter de Graaff

Appendix A - Acceptance scale

Tijdens de afgelopen 2 ritten bent u geïnformeerd over andere bestuurders die het kruispunt naderden middels een knipperend lichtje en piepjes. Zou u kunnen aangeven wat u van deze extra informatie vond tijdens het rijden?

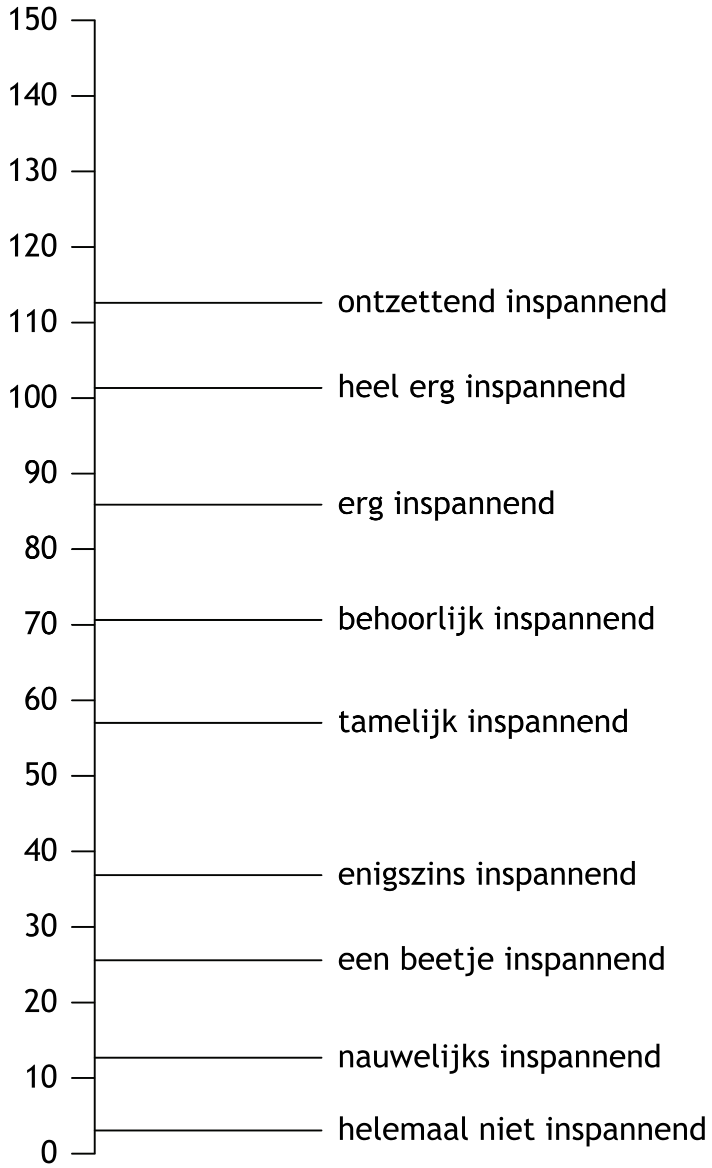
Er zijn telkens 5 antwoordmogelijkheden. Als u een term volledig van toepassing vindt, zet dan een kruisje in het vakje dat het dichtst bij die term staat. Als u een term in bepaalde mate van toepassing vindt zet dan aan die kant, dus links of rechts van het middelste vakje, een kruisje. Als u er geen uitgesproken mening over hebt, zet dan een kruisje in het midden.

Ik vond de extra informatie tijdens het naderen van de kruispunten:

nuttig						zinloos
plezierig						onplezierig
slecht						goed
leuk						vervelend
effectief						niet effectief
irritant						aangenaam
behulpzaam						waardeloos
ongewenst						gewenst
waakzaamheidverhogend						slaapverwekkend

Appendix B - Rating Scale Mental Effort (RSME)

Wilt u op de onderstaande, verticale lijn met een kruisje aangeven hoe inspannend u de rit vond?



Appendix C - Driver Behaviour Questionnaire(DBQ)

Hoe vaak doet u de volgende dingen?

Voor elk van de volgende gedragingen wordt u gevraagd aan te geven óf, en zo ja hoe vaak, u dit heeft gedaan. Baseer uw oordeel op wat u zich herinnert van het afgelopen jaar. Geef uw oordeel door steeds een van de hokjes aan te kruisen.

De hokjes zijn genummerd van 0 tot 5, deze nummers betekenen het volgende:
0=Nooit 1=Bijna nooit 2=Soms 3=Redelijk vaak 4=Vaak 5=Bijna altijd

		0	1	2	3	4	5
1	Bij het achteruitrijden raakt u iets, wat u daarvoor nog niet gezien had.	O	O	O	O	O	O
2	Terwijl u van plan was om naar bestemming A te rijden, “schrikt” u wakker en ontdekt dat u op weg bent naar bestemming B, misschien omdat de laatste bestemming voor u de meest gebruikelijke is.	O	O	O	O	O	O
3	U stapt in de auto, hoewel u vermoedt dat u meer heeft gedronken dan de wettelijk toegestane hoeveelheid	O	O	O	O	O	O
4	U sorteert verkeerd voor bij de nadering van een rotonde of kruising.	O	O	O	O	O	O
5	Terwijl u achter een andere auto wacht om rechtsaf een drukke weg op te kunnen draaien, besteedt u zoveel aandacht aan het verkeer op die weg, dat u bijna de auto voor u raakt.	O	O	O	O	O	O
6	Wanneer u vanaf een drukke weg een zijweg inslaat, ziet u niet dat daar voetgangers aan het oversteken zijn. .	O	O	O	O	O	O
7	Om uw ergernis aan een andere weggebruiker kenbaar te maken, toetert u.	O	O	O	O	O	O
8	U kijkt niet in uw binnenspiegel wanneer u wegrijdt of van rijbaan verandert.	O	O	O	O	O	O
9	U remt te hard op een gladde weg, of stuurt de verkeerde kant op als u in een slip raakt.	O	O	O	O	O	O
10	U rijdt zo ver een kruispunt op, dat een weggebruiker die voorrang heeft, u wel voor moet laten gaan.	O	O	O	O	O	O
11	U negeert de snelheidslimiet binnen de bebouwde kom.	O	O	O	O	O	O
12	U wilt iets aanzetten, bijvoorbeeld uw ruitenwissers, maar zet in plaats daarvan iets anders aan, bijvoorbeeld uw lichten.	O	O	O	O	O	O
13	Bij het rechtsaf slaan raakt u bijna een fietser die rechts naast u is komen rijden.	O	O	O	O	O	O

14	U mist een waarschuwingsbord voor "nadering voorrangsweg" en kunt maar net een botsing voorkomen met verkeer dat voorrang heeft.	O	O	O	O	O	O
15	Bij een verkeerslicht wilt u optrekken in de derde versnelling.	O	O	O	O	O	O
16	U wilt iemand inhalen, maar ziet niet dat deze persoon aangeeft linksaf te willen slaan.	O	O	O	O	O	O
17	Een andere bestuurder heeft u boos gemaakt en u zet de achtervolging in, met de bedoeling hem of haar een lesje te leren.	O	O	O	O	O	O
18	U blijft op een rijstrook rijden waarvan u weet dat die binnenkort ophoudt. Op het laatste moment drukt u zich tussen het verkeer op de andere rijstrook.	O	O	O	O	O	O
19	U vergeet waar u uw auto heeft geparkeerd op een parkeerterrein.	O	O	O	O	O	O
20	U haalt een langzame bestuurder rechts in	O	O	O	O	O	O
21	Bij een verkeerslicht trekt u zo snel mogelijk op, met de bedoeling sneller te zijn dan de auto naast u.	O	O	O	O	O	O
22	U leest de borden niet goed, en neemt vanaf een rotonde de verkeerde afslag.	O	O	O	O	O	O
23	U rijdt zo dicht achter de auto voor u dat het moeilijk zou zijn op tijd te stoppen in geval van nood.	O	O	O	O	O	O
24	Hoewel u weet dat het verkeerslicht al op rood is gesprongen, steekt u een kruispunt over.	O	O	O	O	O	O
25	Een bepaald type bestuurder maakt u kwaad, en u maakt dit op alle mogelijke manieren duidelijk.	O	O	O	O	O	O
26	U realiseert zich dat u zich de weg die u net heeft afgelegd niet duidelijk herinnert.	O	O	O	O	O	O
27	Bij het inhalen onderschat u de snelheid van een u tegemoet komend voertuig.	O	O	O	O	O	O
28	U negeert de snelheidslimiet op een snelweg	O	O	O	O	O	O

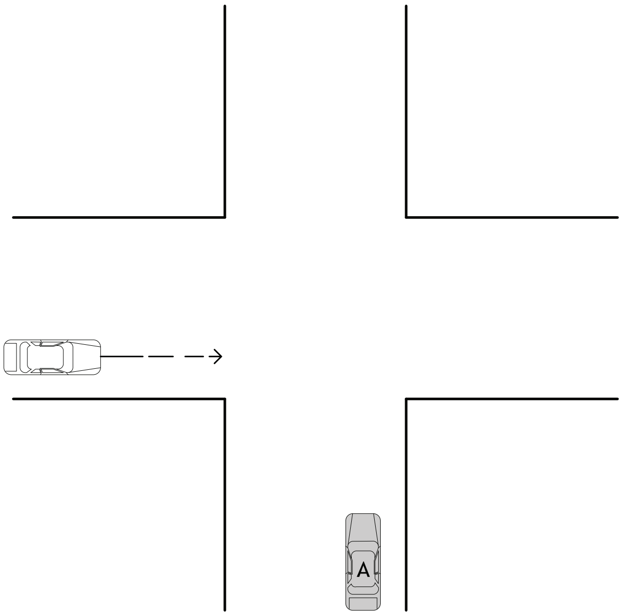
Appendix D - Yielding Behaviour Questionnaire

Geef voor onderstaande situaties aan hoevaak u in de afgebeelde situatie voorrang zou nemen. Stelt u zich telkens voor dat u de bestuurder bent van auto A.

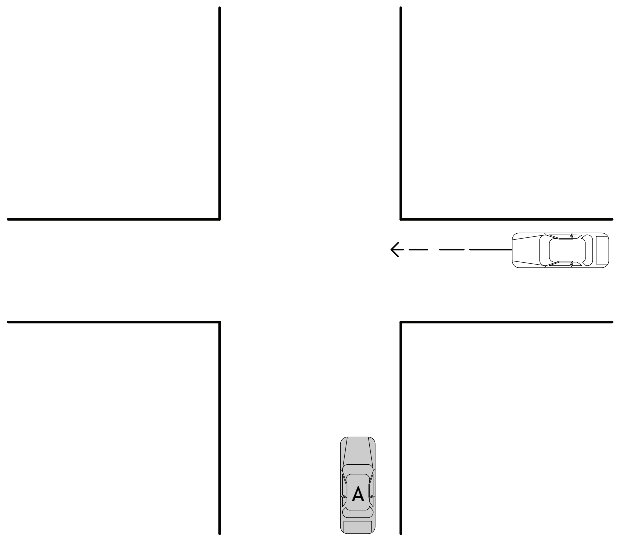
In alle afgebeelde situaties komt een andere weggebruiker ofwel van links, ofwel van rechts. De pijl (onderbroken of doorgetrokken) geeft aan of de andere weggebruiker afremt of niet.

←———— = Remt niet af

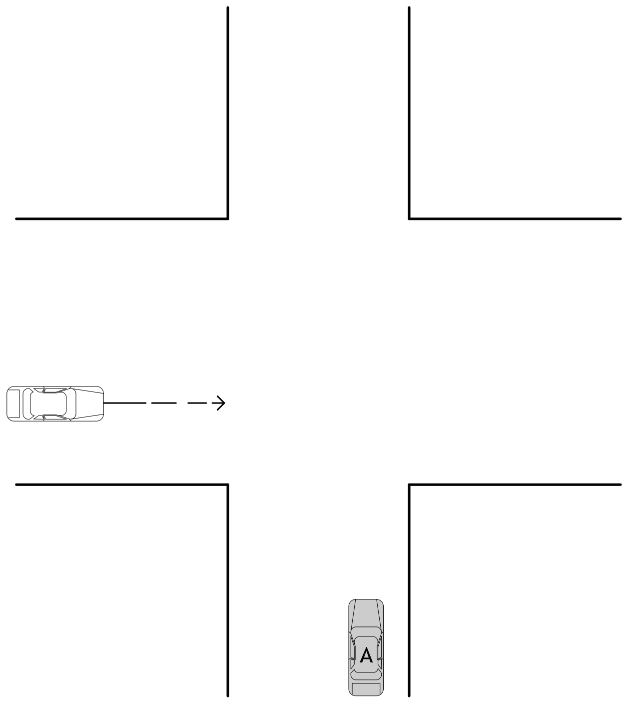
←— —— = Remt wel af



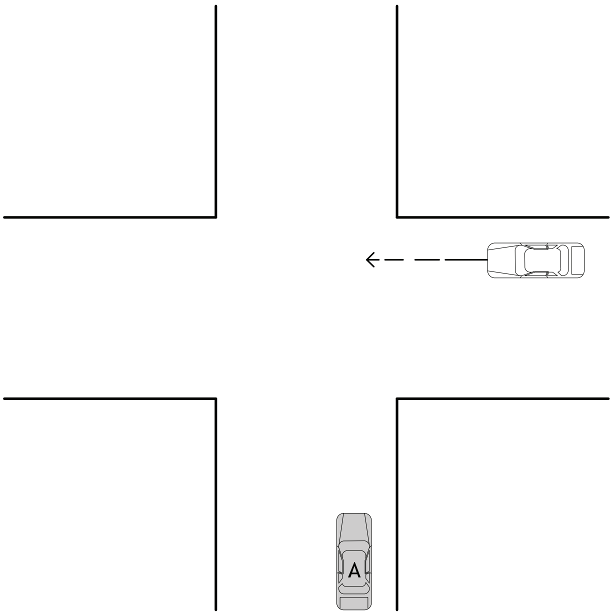
- ○ Nooit
- ○ Zelden
- ○ Soms
- ○ Regelmatig
- ○ Altijd



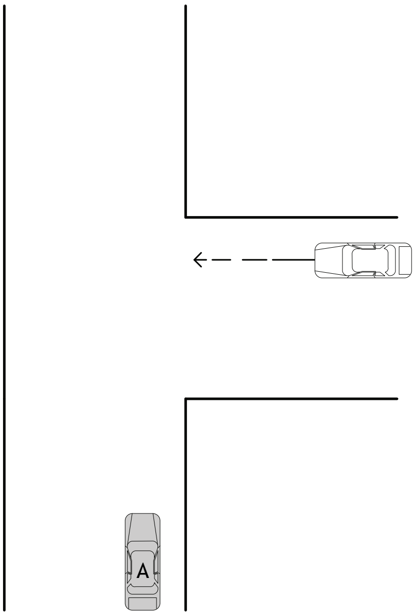
- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



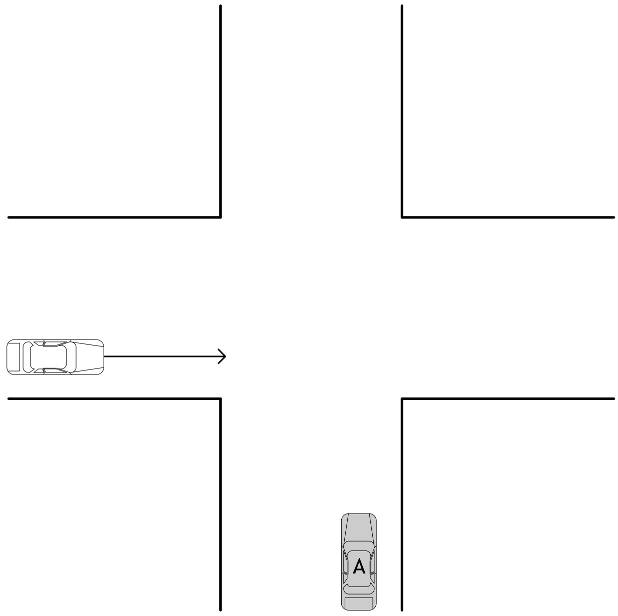
- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



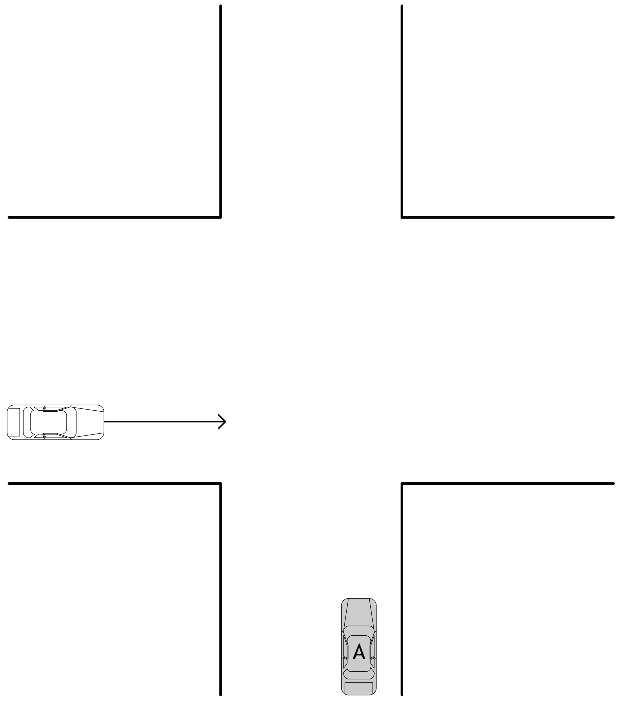
- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



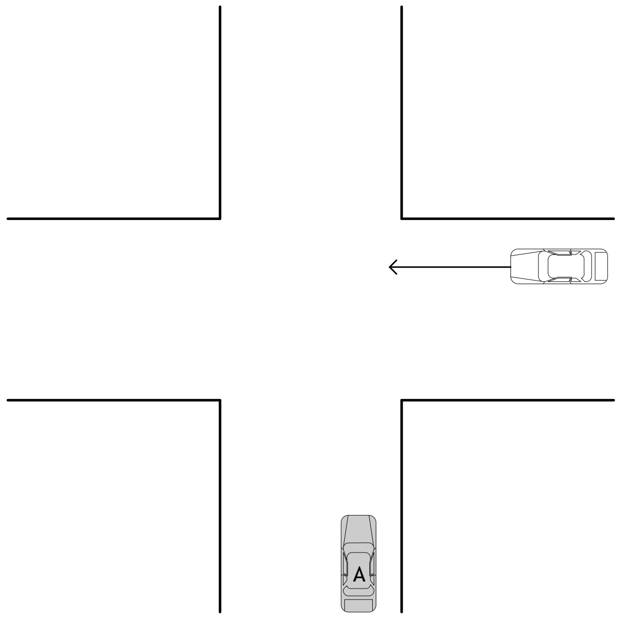
- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



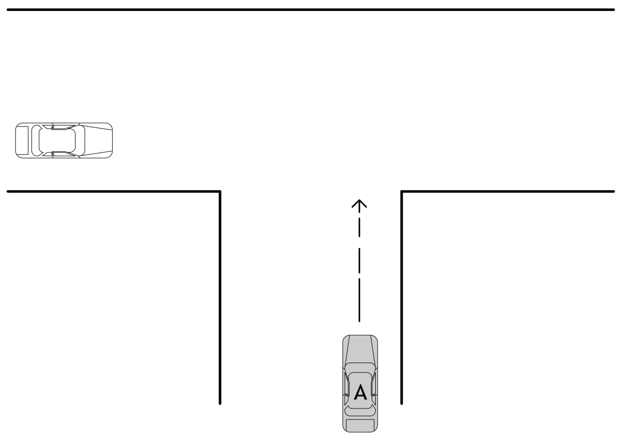
- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



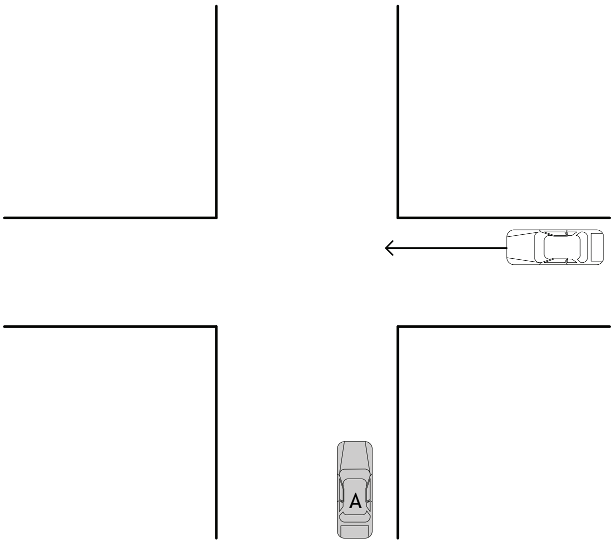
- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd



- Nooit
- Zelden
- Soms
- Regelmatig
- Altijd

Appendix E - Rating of stimuli

Situation \ Aspect	1	2	3	4	5	6	CS
0	more	one	many	yes	0	yes	3
1	one	one	many	yes	2	yes	2
2	more	more	many	yes	0	both	4
3	one	one	many	no	2	no	1
4	one	one	few	yes	1	yes	1
5	one	one	many	yes	0	no	2
6	more	one	few	yes	0	yes	2
7	more	more	few	no	5	yes	2
8	one	one	many	no	2	yes	1
9	one	one	many	no	3	no	1

1. Number of interaction partners.
   - ❖ Rated “one” or “more” corresponding to a “less” or “more” complex situation

2. Number of different types of interaction partners
   - ❖ Rated “one” or “more” corresponding to a “less” or “more” complex situation
   - ❖ The types or interaction partners were cyclists, pedestrians or car drivers. Each situation involves at least one car driver as an interaction partner

3. Number of branches of the intersection that interaction partners could possibly come from
   - ❖ Rated “few” or “many” corresponding to a “less” or “more” complex situation
   - ❖ A T-junction is an example of “few”, whereas a 4-way intersection would be rated as “many”

4. Is it an intersection without any designated priority?
    - A priority intersection or an intersection with traffic lights corresponds to a less complex situation, whereas an intersection without any designated priority is considered a more complex situation.

5. How many pieces of static information regarding right of way can be found in the still picture?
    - Zebras, triangular markings and traffic signs would each be rated as one piece of static information regarding right of way.
    - No inferences are made about the effect of the amount of static information on complexity. However, this rating aspect was included to select situations that included both relatively little static information and situations that included relatively many pieces of static information.

6. Should the 'respondent’s car' give right of way according to traffic rules?
    - This aspect was also included to select situations that show the greatest variation.

Appendix F - Stimuli used for concept generation

Situation 0

Situation 1

Situation 2

Situation 3

Situation 4

Situation 5

Situation 6

Situation 7

Situation 8

Situation 9

Appendix G - Variables included in the coding scheme

Section 1 - Items focusing on identification of the response

Name	Clarification	Coding
Situation	Identification of the traffic scene the response was related to.	0-9 (see Appendix F)
RandomCode	Random code generated to identify each response (after coding), allowing the researcher to code the responses without being aware of the Group, StimulusType or Respondent that was related to the response.	Any random integer ranging from 0 to 9999
Chopped	Due to a problem transferring the response to the database some responses seem to be chopped off. This item indicates if that applied to a particular response.	No/Yes/Uncertain

Section 2 - Items focusing on the road users involved in the expectancy

Name	Clarification	Coding
Involved	Indicates if the respondent included him-/herself in the expectancy and if other road users were included. N.B. When other road users were not explicitly mentioned but implied by phrases such as "yielding", "busyness" or "wait for the road to clear" this was interpreted as "others" being included in the expectancy.	Only self/ Only other(s)/ Self & Others/ Uncertain
NumParties	Indicates the number of parties explicitly mentioned in the expectancy (including self). N.B. "Traffic" (in general) was considered as 1 party, whereas "traffic from the left and right" as 2 parties.	Integer
RUSpec	Phrases which refer to specific road users included in the expectancy. N.B. This item was coded for different types of road users, namely: Cars, cyclists, pedestrians and others.	E.g., for RUSpec_Cars: "the red car" or for RUSpec_Pedestrians: "the pedestrian on my right"
RUGen	Indication of the types of road users (in general) which were included in the expectancy.	Cars in general/ Cyclists in general/ Pedestrians in General/ Traffic in general/ Other

Section 4 - Items indicating aspects[1] mentioned in the expectancy

Name	Clarification	Coding examples
OtherRU	Phrases which refer to all other road users explicitly mentioned in the expectancy, and is thus a specification of NumParties (although "self" is not specified here).	"the red car"/"the approaching traffic"
ROW	Phrases relating to right of way	"intersection with main road"/ "yielding"/ "having right of way"
Position	Phrases indicating positions of other aspects mentioned in the expectancy (in particular road users)	"at the intersection"/ "behind the other vehicle"
Dir_Towards	Phrases indicating the direction a road user is moving towards.	"approaching an intersection"/ "continuing on my way"/ "turning left"
Dir_From	Phrases indicating the direction a road user is coming from.	"leaving a home zone"/ "coming from the left"
Infrastructure	Phrases indicating elements of the infrastructure mentioned in the expectancy.	"the intersection"/ "a home zone"/ "a speed bump"
Informal	Phrases indicating an informal rule.	"most cyclists don't indicate direction when they turn, which elicits quite some irritation"/ "possibly cross the road without yielding"
Timing	Phrases relating to speed differences between road users in their approach of the intersection or relating to their timing while approaching the intersection.	"braking to allow the car to precede"/ "by then, the blue car will be gone"

[1] For reasons of clarity, this table only contains a selection of all coded aspects. This selection includes all aspects which were found in at least 20% of the responses.

Section 5 - Items focusing on yielding behaviour

Name	Clarification	Coding examples
Who_ROW	Does the respondent indicate who will yield? N.B. When the respondent indicates a road user *taking* right of way, this is also taken as an indication of who will yield.	No/Yes
Who	If so (see above), who?	Self/Other/Both
Spec_other	Specification of which “other” yields to whom.	“the car to me”
Spec_both	Specification of who yields to whom.	“self to the cyclist and the cyclist to the pedestrian”

Section 6 - Items focusing on uncertainty and vigilance

Name	Clarification	Coding examples
Uncertainty	Phrases that indicate uncertainty	“possibly”/ “probably”/ “could stop”
Vig_high	Phrases that indicate increased vigilance	“look out”/”watch out for”
Vig_low	Phrases that indicate decreased vigilance	“nothing will happen”/ “no threat”

Appendix H - An illustrative selection of (translated) statements

1. If the car from the right will drive on, then he could get into trouble with the car that is approaching him from the right.
11. If the curb is clearly continuous, then I will watch out for pedestrians.
22. If the cycling woman rides on, she could get into trouble with the van.
33. If I'm waiting for traffic from the right because I am turning left, in the mean time, I will check to see if the traffic from the left will indeed allow me to precede.
44. If the position of the wheels of the Fiat Punto is like here, then he will drive straight on the road.
55. If I have not reached the intersection yet, then the car from the left will take right of way.
66. If the red and the blue car do not hinder each other at all, then both cars will continue on their path unhindered.
77. If the white car will proceed, then I expect that the cyclist on the left will slow down and continue after the white car has passed.
88. If it all looks as calm as here, then I will expect the green car from the left to crosse the intersection without being hindered.
99. If the first black car drives away from the other two, then I will not expect an unsafe situation.

Appendix I - Overview of relatively high and low counts per situation

Situation	Overview
0 (CS=3)	Relatively high counts: ROW: what *should* happen - Rules (p.55) ROW: what *will* happen - Action (p.55) Road users coming from the right (p. 56) Road users needing to wait (p. 57) Uncertainty (p. 58)
1 (CS=2)	Relatively high counts: Road users in general (p. 53) Static elements present (p. 55) Road users coming from the right (p. 56) Uncertainty (p. 58)
2 (CS=4)	Relatively high counts: Only specific road users (p. 53) Continuing on one's way (p. 54) Specific manoeuvres (p. 54) ROW: what *should* happen - Rules (p.55) ROW: what *will* happen - Action (p.55) Uncertainty (p. 58) Uncertainty concerning actions of other road users (p. 58) Relatively low counts: The direction road users are coming from (p.56)
3 (CS=1)	Relatively high counts: Only specific road users (p. 53)
4 (CS=1)	Relatively high counts: Road users in general (p. 53) Static elements present (p. 55) Relatively low counts: Uncertainty (p. 58)
5 (CS=2)	Relatively high counts: Nothing will happen (p. 57)
6 (CS=2)	-

7 (CS=2)	Relatively high counts: Taking into account that behaviour might not be according to ROW rules (p.57) Equal counts: Specific road users and road users in general (p. 53) Relatively low counts: The direction road users are coming from (p. 56) Uncertainty (p. 58)
8 (CS=1)	Relatively high counts: Nothing will happen (p. 57) Equal counts: Specific road users and road users in general (p. 53)
9 (CS=1)	Relatively high counts: Uncertainty (p. 58)

Note: CS refers to the Complexity Score (Appendix E)

Appendix J - Summary of results (A-I)

A-I		TTC_{min}	Safety	DTI_Brake	DTI_Throttle	Hard Braking	Efficiency	Speed_after	Standstill	Mean Yield
Situation (2)	F		43.50			26.98		33.14	5.42	3418.21
	df		1,24			1,24		1,24	1,24	1,24
	p	n.s.	< .001	n.s.	n.s.	< .001	n.s.	< .001	< .05	< .001
Extra Information (2)	F		3.67		12.040		12.41	23.60		6.693
	df		1,24		1,23		1,24	1,24		1,24
	p	n.s.	< .10	n.s.	< .01	n.s.	< .01	< .001	n.s.	<.05
Visibility (3)	F	4.398	9.79			3.25	31.39	26.51		3.87
	df	1.612, 38.693	2,48			2,48	1.617, 38.805	2,48		1.516, 36.393
	p	<.05	< .001	n.s.	n.s.	<.05	< .001	< .001	n.s.	< .05
Situation x Extra Information	F						17.11	11.36		
	df						1,24	1,24		
	p	n.s.	n.s.	n.s.	n.s.	n.s.	< .001	< .01	n.s.	n.s.
Situation x Visibility	F					3.25	6.93	6.82		
	df					2,48	2,48	2,48		
	p	n.s.	n.s.	n.s.	n.s.	<.05	< .01	< .01	n.s.	n.s.
Extra Information x Visibility	F							5.22		
	df							2,48		
	p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	< .01	n.s.	n.s.

Appendix K - Summary of results (A-II)

A-II		TTC_{min}	Safety	DTI_Brake	DTI_Throttle	Hard Braking	Efficiency	Speed_after	Standstill	Mean Yield
Situation (4)	F		34.66	3.65		13.82	151.03	17.63	9.45	110.03
	df		1.901,45.627	3,15		3,72	1.983,43.637	3,72	1.056,25.342	1.247,29.020
	p	n.s.	< .001	< .05	n.s.	<.001	<.001	< .001	< .01	< .001
Extra Information (2)	F		4.20		5.71		7.97	7.09		
	df		1,24		1,23		1,22	1,24		
	p	n.s.	< .10	n.s.	< .05	n.s.	< .05	< .05	n.s.	n.s.
Visibility (2)	F									
	df									
	p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Situation x Visibility	F							4.80		
	df							3,72		
	p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	< .01	n.s.	n.s.

Appendix L - Summary of results (A-III)

A-III		TTC_{min}	Safety	DTI_Brake	DTI_Throttle	Hard Braking	Efficiency	Speed_after	Standstill	Mean Yield
Approach Condition (AC:3)	F		3.37			12.05	28.94	17.99	6.12	7.89
	df		2,40			1.278, 25.568	1.408, 25.340	1.279, 25.576	1.075, 21.495	1.323, 26.470
	p	n.s.	< .05	n.s.	n.s.	<.01	<.001	< .001	< .05	<.01
Right of Way (ROW:2)	F				4.18	3.18	31.33	8.54	4.52	105.77
	df				1,18	1,20	1,18	1,20	1,20	1,20
	p	n.s.	n.s.	n.s.	< .10	< .10	< .001	< .01	< .05	< .001
Extra Information (2)	F				10.97					
	df				1,18					
	p	n.s.	n.s.	n.s.	< .01	n.s.	n.s.	n.s.	n.s.	n.s.
AS x ROW	F		35.89			5.93	128.57		4.22	204.64
	df		2,40			2,40	2,36		1.071, 21.427	1.323, 26.470
	p	n.s.	< .001	n.s.	n.s.	< .01	< .001	n.s.	< .05	< .001
AS x Extra Information	F									
	df									
	p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
ROW x Extra Information	F			16.42				5.08		
	df			1,3				1,20		
	p	n.s.	n.s.	< .05	n.s.	n.s.	n.s.	< .05	n.s.	n.s.

Appendix M - Summary of all results (Near Miss)

A-I		6	A-II			A-III		
ROW (2)	Chi Sq.	37.13	ROW (2)	Chi Sq.	7.15	ROW (2)	Chi Sq.	
	(df, N)	1,1250		(df, N)	1,1213		(df, N)	
	p	< .001		p	< .01		p	n.s
AS (2)	Chi Sq.	37.13	AS (2)	Chi Sq.	51.03	AC (2)	Chi Sq.	34.14
	(df, N)	1,1250		(df, N)	1,1213		(df, N)	2,812
	p	< .001		p	< .001		p	< .001
Info (2)	Chi Sq.	6.23	Info (2)	Chi Sq.		Info (2)	Chi Sq.	
	(df, N)	1,1250		(df, N)			(df, N)	
	p	< .05		p	n.s		p	n.s
Vis (3)	Chi Sq.	6.49	Vis (2)	Chi Sq.				
	(df, N)	1,1250		(df, N)				
	p	< .05		p	n.s			

Appendix N - Summary of effects (A-I)

A-I		TTC_{min}	Safety	DTI_Brake	DTI_Throttle	Hard Braking	Efficiency	Speed_after	Standstill	Mean Yield
Situation	1		lower			more, most for Medium Vis		lower	more	more
	2		higher			less, least for Medium Vis		higher	less	less
Extra Information	no		(higher)		farther		lower	lower		slightly less, only in Sit 1
	yes		(lower)		closer		higher, particularly in Sit 2	higher, particularly in Sit 2, but less when visibility is increased		slightly more, only in Sit 1
Visibility	low		higher			more	lower			slightly less, only in Sit 1
	medium	shorter	lower			in between	higher			slightly more, only in Sit 1
	high	longer	lower			less	higher			slightly more, only in Sit 1

Note: Effects in parentheses indicate trends ($p < .10$) rather than significant effects ($p < .05$)

Appendix O - Summary of effects (A-II)

A-II		TTC_{min}	Safety	DTI_Brake	DTI_Throttle	Hard Braking	Efficiency	Speed_after	Standstill	Mean Yield
Situation	1		lower			more	higher	lower	less	almost always
	2		higher	farther		less	lower	higher	less	almost never
	3		lower			more	higher	lower	less	almost always
	4		higher	closer		more	lower (also lower than Sit 2)	lower	more	in between
Extra Information	no		(higher)		farther		lower	lower		
	yes		(lower)		closer		higher	higher		
Visibility	medium									
	high							higher for Sit 1 & 4		

Note: Effects in parentheses indicate trends ($p < .10$) rather than significant effects ($p < .05$)

Appendix P - Summary of effects (A-III)

A-III		TTC_{min}	Safety	DTI_Brake	DTI_Throttle	Hard Braking	Efficiency	Speed_after	Standstill	Mean Yield
Approach Condition (AC)	F_E		in between, but higher than F_U when ROW = yes			less	higher	higher	less	slightly less, but more when ROW=no
	F_U		higher, but only when ROW = no			more	lower	lower	more, particularly when ROW=yes	slightly more, particularly when ROW=yes
	Free		lower, but higher than F_U when ROW = yes			less	higher	higher	less	slightly more, particularly when ROW=no
Right of Way (ROW)	no			closer when Extra Info = yes	(farther)	(more, but not when F_U)	lower	lower	more	more
	yes			farther when Extra Info = yes	(closer)	(less, but not when F_U)	higher, particularly when F_U	higher	less	less
Extra Information	no				farther		lower			
	yes				closer		higher			

Note: Effects in parentheses indicate trends ($p < .10$) rather than significant effects ($p < .05$)

Appendix Q - Summary of all effects (Near Miss)

A-I		6	A-II			A-III		
ROW	no	more	ROW	no	less	AC	F_E	less
	yes	hardly any		yes	more		F_U	more
							Free	less
AS	slow down	hardly any	AS	slow down	hardly any	ROW	no	
	maintain speed	more		maintain speed	more		yes	
Extra Information	no	more	Extra Information	no		Extra Information	no	
	yes	less		yes			yes	
Vis	low	more	Visibility	medium				
	medium	less		high				
	high	less						

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