Assisted Overtaking
An Assessment of Overtaking on Two-lane Rural Roads

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Assisted Overtaking
An Assessment of Overtaking on Two-lane Rural Roads

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Preface

Finally, the time has come to write the first page of this dissertation. The most read page by family, colleagues and friends, looking for their own name. Well, I hope I will not forget anybody to thank and that you find your name when you expect it to be in this preface.

When I started in 2003, Henk van Zuylen, Karel Brookhuis and Serge Hoogendoorn were my supervisors. Through the years, you all have assisted me with good ideas and with structuring and realising my own ideas. Henk, you were the promoter, the man to fear, nevertheless it wasn’t too bad. Actually, I think it went quite well. Karel, everytime when I had a wild idea, you transformed it a feasible plan and assisted with the realisation. Thank you for your Groningse nuchterheid. Serge, you have spent the most time on reading my papers and chapters, for which I am grateful. Thank you for your advice, also concerning music. Henk, Karel en Serge I shocked the three of you when I told you that I was pregnant. However, I hope I have taken any doubts away. Due to your trust and confidence, I was able to finish the dissertation research fairly on time.

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On the 28th February 2008, Maura Houtenbos en Cornelie van Driel are the paranimfen, to assist me during that day. The reason why I asked you, is because you two have given me much assistance during the dissertation. We helped each other with finding literature, with presentations, with testing of questionnaires and experiments, with statistical questions, with computer program questions and frustrations and with proof-reading of papers and the dissertation. Thanks, thanks, thanks!

During the five years that I was a Ph.D. student, I experienced interest and confidence of all my friends. Friends from secondary school, from the University of Twente, the econometrics friends, my in-laws, I would like to thank you for asking about the subject and telling me, when I needed it. I was able to do it and that I would finish it once. Special thanks for Jessica that you did find the time for proof-reading parts of this dissertation, even during this busy and exiting phase of your life.

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### Table of contents

1 Introduction .................................................................................................................................................. 1
  1.1 Background .............................................................................................................................................. 2
      1.1.1 The overtaking safety problem ........................................................................................................ 2
      1.1.2 The solutions applied to improve overtaking safety ....................................................................... 4
      1.1.3 Advanced driver assistance systems to improve overtaking performance ..................................... 6
  1.2 Objectives and applied research methods ............................................................................................. 6
  1.3 Research Scope ......................................................................................................................................... 8
  1.4 Contribution and relevance .................................................................................................................. 10
      1.4.1 Scientific contribution ....................................................................................................................... 10
      1.4.2 Practical and social relevance ........................................................................................................ 10
  1.5 Dissertation outline .................................................................................................................................. 11

2 Empirical Facts of Overtaking Behaviour Observations with an Instrumented Vehicle ................................ 13
  2.1 Introduction ............................................................................................................................................. 14
  2.2 Definition of the overtaking manoeuvre ................................................................................................. 15
  2.3 Review of empirical overtaking behaviour studies .................................................................................. 17
  2.4 Method: overtaking data collection with an instrumented vehicle .......................................................... 20
      2.4.1 The instrumented vehicle, its instruments and the road section ......................................................... 20
      2.4.2 Measures to observe ......................................................................................................................... 21
      2.4.3 Observation strategy ......................................................................................................................... 21
      2.4.4 Data collection and analysis of overtaking manoeuvres .................................................................. 22
  2.5 Results of empirical overtaking data collection ....................................................................................... 24
  2.6 Summary and discussion of overtaking observations results ................................................................. 29
      2.6.1 Discussion of international applicability of Dutch observation results ............................................ 30
      2.6.2 Discussion of usability of findings for overtaking assistant design ................................................. 30
      2.6.3 Use of existing assistance systems during overtaking ..................................................................... 33

3 Overtaking Task Analysis and Matching Assistance Needs ........................................................................... 35
  3.1 Introduction ............................................................................................................................................. 36
  3.2 Driver behaviour models applied to overtaking ....................................................................................... 37
      3.2.1 Hierarchical frameworks of driving tasks ....................................................................................... 37
      3.2.2 Driver models based on the risk homeostasis theory ...................................................................... 38
      3.2.3 Information flow control models .................................................................................................... 39
      3.2.4 Task analysis ................................................................................................................................... 39
  3.3 The overtaking task analysis .................................................................................................................... 40
      3.3.1 Phase 1: Decide whether to overtake or not .................................................................................... 42
      3.3.2 Phase 2: Prepare to overtake ............................................................................................................ 43
      3.3.3 Phase 3: Changes lane ...................................................................................................................... 44
      3.3.4 Phase 4: Pass ................................................................................................................................... 45
      3.3.5 Phase 5: Return to the right lane ..................................................................................................... 45
      3.3.6 Total overtaking manoeuvre .......................................................................................................... 46
3.4 Assistance needs and ranking per subtask ................................................................. 46
  3.4.1 Assistance needs for decision to overtake (phase 1) ........................................ 48
  3.4.2 Assistance needs for overtaking preparation (phase 2) .................................... 49
  3.4.3 Assistance needs for lane change (phase 3) ...................................................... 50
  3.4.4 Assistance needs for passing (phase 4) ............................................................. 50
  3.4.5 Assistance needs for lane change back to right lane (phase 5) ....................... 50

3.5 International differences in overtaking rules and execution ..................................... 51
  3.5.1 Overtaking wishes, permissions and opportunities ......................................... 51
  3.5.2 Indicator usage ............................................................................................... 53
  3.5.3 Safe headway keeping ................................................................................. 54
  3.5.4 International applied alternative overtaking strategies ................................... 54

3.6 Summary and discussion of the overtaking task analysis ....................................... 55

4 Overtaking Assistant Design ....................................................................................... 57
  4.1 Introduction ........................................................................................................... 58
  4.2 Method: the basic design cycle ............................................................................. 59
  4.3 Basic design cycle: function ................................................................................ 61
    4.3.1 Informing, intervening or automating driver assistance systems ...................... 61
    4.3.2 Necessary assumptions for a feasible overtaking assistant design ................. 62
  4.4 Basic design cycle: analysis ................................................................................ 63
    4.4.1 User needs ..................................................................................................... 63
    4.4.2 Automotive industry needs .......................................................................... 64
    4.4.3 Legal needs (standards) ............................................................................. 65
    4.4.4 Designer’s needs ....................................................................................... 65
    4.4.5 Resulting set of needs ............................................................................... 66
  4.5 Basic design cycle: synthesis ............................................................................... 66
    4.5.1 Measurement .............................................................................................. 67
    4.5.2 Compute (estimate) ................................................................................... 68
    4.5.3 Advice and HMI ....................................................................................... 71
    4.5.4 Essential measurement devices of the overtaking assistant ......................... 72
    4.5.5 Conceptual design of the overtaking assistant ............................................ 73
  4.6 Basic design cycle: simulation .............................................................................. 75
    4.6.1 Relaxing assumptions for a feasible overtaking assistant design ..................... 76
  4.7 Basic design cycle: evaluation ............................................................................. 78
    4.7.1 Design adjustments after first evaluation (driving simulator experiment) .... 78
    4.7.2 Design adjustments after second evaluation study (micro simulation study) 79
    4.7.3 Adjusted of conceptual overtaking assistant to satisfy needs ..................... 80
  4.8 Summary and discussion of conceptual overtaking assistant design .................... 81

5 A Driving Simulator Experiment on Overtaking Assistance ......................................... 83
  5.1 Introduction ........................................................................................................... 84
  5.2 Pre-assessment of overtaking performance indicators ......................................... 85
    5.2.1 Pre-assessment selected objective indicators overtaking assistant effects ... 85
    5.2.2 Pre-assessment selected subjective indicators overtaking assistant effects ... 89
  5.3 Method: overtaking assistant assessment with a driving simulator .................... 94
1 Introduction

At the start of the 21st century, overtaking on two-lane rural roads is a major traffic safety problem. On the other hand, overtaking manoeuvres are desired to improve drivers’ comfort and traffic system efficiency. Overtaking prohibitions might help to increase the safety of overtaking, however these have their limitations. Overtaking lanes increase drivers’ comfort, however, their effect on traffic system efficiency is limited. The costs for both solutions are high. At the same time driver assistance systems are being developed to assist drivers with parts of driving often aiming to increase traffic safety. The main objective of this dissertation is to thoroughly analyse overtaking on two-lane rural roads and to study the opportunities of an overtaking assistant with respect to traffic system efficiency, drivers’ comfort and safety.
1.1 Background

Overtaking is a driving manoeuvre that involves moving to another lane, passing a slower preceding vehicle and moving back to the original lane. On two-lane roads, overtaking drivers (overtakers) have to make use of the opposing traffic lane to perform the overtaking manoeuvre. Especially when driving speeds are high, it is difficult to estimate the available time to perform the manoeuvre. Indeed, overtaking on roads with oncoming traffic is one of the most difficult driving tasks (McKnight and Adams, 1970). In fact, not all overtaking manoeuvres are performed correctly and safely.

1.1.1 The overtaking safety problem

The World Health Organization (WHO) estimates that throughout the world, over one million people are killed annually and as many as 50 million are injured in road crashes (WHO, 2004). The USA has almost 43,000 fatalities each year, which cost 230.6 billion dollars (NHTSA, 2004). Within Europe, 40,000 people die annually due to traffic accidents and 1.7 million are injured, with direct costs of 45 billion Euros and estimated indirect costs of 160 billion Euros (Commission of the European Communities, 2003). These statistics show that traffic safety is a serious problem that costs society a lot of money.

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Figure 1.1 Fatal crashes in OECD member countries and head-on crashes in the USA, both on rural roads and other roads.

At the end of the twentieth century about 60% of all fatal crashes in Organisation for Economic Co-operation and Development (OECD) member countries occurred on rural roads (OECD, 1999). In the USA 75% of all head-on crashes of which overtaking might be the cause, occur on two-lane undivided rural roads (NCHRP, 2003). Figure 1.1 displays these two statistics graphically. It should be noted that not all head-on crashes have overtaking as the cause and, contrary, overtaking could also be the cause of other accidents, like side swipe accidents. On the South African arterials (often designed as two-lane roads), overtaking was identified as the main factor behind human error that causes 75% of the analysed accidents (Vogel and Bester, 2005). With regard to human error during overtaking, it was found that among other variables, for overtaking tendencies, driving skills moderated the effects of

---

1 Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.
safety skills, that is, high (assumed) driving skills constitute a serious risk factor if they are not accompanied with high levels of safety precaution (Sumer et al., 2006).

In the seventies, a study of overtaking and passing vehicle accidents found that 43% of all traffic accidents on two-lane highways involved overtaking or passing manoeuvres (Kemper et al., 1972). Back then, overtaking was identified as being the fifth most common cause of road traffic accidents (IDBRA, 1973). Overtaking is defined as the movement of the subject vehicle to another lane, the pass of at least one (slower) preceding vehicle and the movement back to the lane where the manoeuvre started. Passing is sometimes used as a synonym for overtaking. However, in this dissertation, passing does not include the movement back to the lane where the manoeuvre started.

Not only do most of the overtaking accidents occur on two-lane rural roads, they are also often very serious. An American study found that crashes with oncoming traffic account for 20% of all fatal crashes on two-lane rural roads, representing about 4500 fatalities annually (Persaud et al., 2004). Within Europe, 25% of the above-mentioned fatal crashes in OECD member countries are head-on collisions. Additional country specific overtaking accident data on two-lane rural roads, including severity are shown in Table 1.1.

Table 1.1 Overview of country specific overtaking accidents findings

<table>
<thead>
<tr>
<th>Country</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark (Larsen, 2004)</td>
<td>Between 1986 and 1995, in Denmark an average of almost 130 fatalities have been recorded each year in connection with head-on collisions, which is more than 20% of all fatalities.</td>
</tr>
<tr>
<td>Finland (Katila and Keskinen, 2000)</td>
<td>When traffic accidents are divided into the groups ‘same driving direction’, ‘intersection’ and ‘opposing driving direction’, 72% of accidents can be grouped in the last category.</td>
</tr>
<tr>
<td>The Netherlands (AVV Transport Research Centre, 2002)</td>
<td>Overtaking on two-lane rural roads causes an average of 26 fatalities each year (3%) on two-lane rural flow roads, representing 5% of all kilometres of roads in the Netherlands.</td>
</tr>
<tr>
<td>The Netherlands (Institute for Road Safety Research, 2003)</td>
<td>One third of all accidents between trucks and cars on roads outside build-up areas with a limit of 50, 80 or 100 km/h are frontal, indicating that overtaking might be the cause.</td>
</tr>
<tr>
<td>Nottinghamshire, UK (Clarke et al., 1997)</td>
<td>Of 970 analysed accidents, 8% were caused by overtaking, representing 20% of the total fatalities. One of five most frequent accident scenarios is overtaking on a hill where overtaking is prohibited.</td>
</tr>
<tr>
<td>Nottinghamshire, UK (Clarke et al., 1999)</td>
<td>Misjudgement of speed of and distance to oncoming vehicles accounts for on average 8% of overtaking accidents. Highest dangers for overtakers come from oncoming vehicles that are not seen and from unexpected actions of overtaken vehicles.</td>
</tr>
<tr>
<td>United Kingdom (DETR, 2000)</td>
<td>The number of accidents caused by overtaking manoeuvres is only 3.5%, but it is assumed that these accidents are overrepresented in fatality statistics, because of the high speeds with which they occur.</td>
</tr>
</tbody>
</table>

2 In this case, highways represent all paved roads.
In summary, overtaking is a main cause of serious accidents on two-lane rural roads. To reach the ambitious European goal of reducing the fatalities within the European Union by 50% between 2000 and 2010 (Commission of the European Communities, 2003) it is worthwhile to search for possibilities to reduce overtaking accidents as well.

1.1.2 The solutions applied to improve overtaking safety

To solve the overtaking safety problem, structural overtaking prohibitions are applied in many countries. Most countries install prohibitions at locations with limited sight distances due to e.g. curves and hills. Some countries install prohibitions for the unsafety of the manoeuvre itself, on straight roads with perfect views. The Dutch Sustainable Safety Program of the Netherlands includes overtaking prohibitions as a possible means to increase safety of two-lane flow roads3 (CROW, 2002b, Wegman and Aarts, 2005).

Overtaking prohibitions

Overtaking prohibitions are often installed by means of a (double) continuous centre line, accompanied with a sign at the start of each road section as shown in Figure 1.2. Some countries use yellow paint for the centre lines. The Dutch Safety Program referred to above recommends installing prohibitions using physical barriers between the driving directions, however most authorities choose double continuous centre lines, which is cheaper and easier to cross in case of emergency.

However, the question is whether overtaking prohibitions will reduce overtaking accidents when it is possible to violate these prohibitions. Although overtaking frequency reduces due to overtaking prohibitions, in a Dutch study 20% of normally performed overtaking manoeuvres were still observed on sections with an overtaking prohibition (Hegeman, 2004b). A possible reason is that car drivers are more or less inclined to violate overtaking prohibitions, since passenger cars have a higher speed limit on these roads (100 km/h) than trucks and cars with trailers (80 km/h). Koorey (2007) found that when drivers cannot overtake slower vehicles owing to a lack of passing opportunities, they are likely to become frustrated, which can lead to an increase in unsafe passing manoeuvres, which can in turn lead to crashes. Traffic violations in general are positively correlated with accident involvement (Parker et al., 1995). Moreover, when overtaking is prohibited, other drivers do not expect overtaking manoeuvres, which might make the ones performed anyway, more dangerous (Houtenbos et al., 2005b). Another Dutch study that confirms this assumption found that a road is safe when expected behaviour corresponds with real behaviour (Davide et al., 2002). This implies that overtaking while prohibited is presumed to be more unsafe than overtaking at locations where it is permitted, all else being equal.

To reduce overtaking prohibition violations, the European Transport Safety Council designated overtaking offences as one of the important areas of misconduct that need to be addressed for traffic enforcement to maintain its credibility in the future (ETSC, 1999). Furthermore, dangerous overtaking is among the most important behaviours targeted by the

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4 Assisted Overtaking

3 The Sustainable Safety Program defines three road types: access roads, distributor roads and flow roads. Two-lane flow roads outside build-up areas have a speed limit of 100 km/h and there should not be any roads/accesses entering a flow road at the same level.
police in Europe (Makinen et al., 2003). Another solution to reduce overtaking prohibition violations is to introduce alternative solutions for the overtaking safety problem.

**Overtaking lanes**

Overtaking lanes are extra traffic lanes alternating for the two driving directions, to give drivers the temporary opportunity to safely overtake slower preceding vehicles, without using the opposing traffic lane. Overtaking lanes have the potential to increase traffic efficiency and drivers' comfort. This concept is successfully applied in many countries, for example in Australia (Charlton et al., 2001, Charlton, 2007) and Sweden (Bergt et al., 2005). Great Britain uses short stretches of dual carriageway on many major routes to enable overtaking of slow-moving vehicles. Figure 1.2 demonstrates an example of such an overtaking lane, where driving directions are divided by means of a cable barrier. It has also been suggested that alternating passing lanes and median barriers on multilane roads should be implemented in the USA to minimise the likelihood of crashing with an oncoming vehicle (NCHRP, 2003).

![Figure 1.2 Three solutions to reduce overtaking fatalities: overtaking prohibition, overtaking lane and overtaking assistance.](image)

An overtaking lane gives drivers a safe opportunity to overtake other vehicles and well designed overtaking lanes could significantly reduce the number of accidents caused by overtaking (May, 1991). Regarding efficiency, overtaking lanes may improve the capacity of the road from maximum 3600 pcu/h for two lanes to a maximum of 4000 pcu/h for the three driving lanes together (CROW, 2002a, 2002b). This increased capacity also results in less aggressive driving behaviour (Shinar and Compton, 2004), which is an indication of higher driver comfort. Indeed, delays caused by slow moving vehicles in front are a source of irritation for more than half of the motorists, which was found in a Dutch study (Levelt and Rappange, 2000).

The downside of an overtaking lane in one direction is that overtaking must be prohibited for the other direction, with all the resulting disadvantages discussed above. The net result of alternating overtaking lanes does not yield more overtaking manoeuvres in one direction compared to a situation without an extra lane where overtaking is permitted (Harms, 2006). In a capacity estimation simulation study, the presence of passing zones was not found to have an effect on capacity (Kim and Elefteriadou, 2007). Furthermore, the use of overtaking lanes in the Netherlands is questionable, because it is a small country with relatively short road segments and high intersection density. The minimum design length of an overtaking lane is 1200 m (BTCE, 1997). Moreover, such an extra driving lane requires extra space, which is of limited availability in the Netherlands.
Thus far, overtaking prohibitions and overtaking lanes are the two solutions that have been implemented internationally to prevent overtaking accidents on two-lane rural roads. Another promising development regarding safety enhancement of traffic is driver assistance systems. Expectations are high that these systems will contribute to solving many kinds of traffic safety problems (European Comission, 2002). Since overtaking causes safety problems, the possibilities of driver assistance systems with regard to overtaking should be explored as well.

1.1.3 Advanced driver assistance systems to improve overtaking performance

Driver assistance systems have been developed for more than two decades, in which existing systems have been continuously improved and new systems have entered the market. In 1994, lane change crashes and merge crashes were indicated as potential “target crashes” of high technology Intelligent Vehicle Highway System (IVHS) crash avoidance systems (Wang and Knipling, 1994). The development of an overtaking assistant is in line with proposals for other driver assistance systems, to assist drivers with the difficult overtaking task. Developments in this direction began in 2003 (Louwerse, 2003, Hegeman, 2004a). In-car aids were recommended that can measure the range and speed of the oncoming and preceding vehicle and provide a warning if the driver initiates an unsafe manoeuvre (Gray and Regan, 2005). In 2007, BMW introduced a so-called passive overtaking assistant on the market, which warns drivers of unsafe overtaking situations (Loewenau et al., 2006) given the road infrastructure. Figure 1.2 displays the interface of this passive overtaking assistant.

A possible disadvantage of driver assistance during overtaking that it may encourage overtaking manoeuvres and create extra risk when the overtaken vehicle makes an unexpected action. One advantage of driver assistance systems for increasing overtaking safety compared to overtaking prohibitions and overtaking lanes, is that these systems assist drivers in better performing the overtaking manoeuvre itself, instead of preventing drivers from overtaking or preventing conflicts with oncoming traffic. The safety of the overtaking manoeuvre itself will be improved, presumably without causing negative capacity effects or discomfort. Furthermore, driver assistance systems will work everywhere identically. Drivers equipped with such a system can use it on any two-lane rural road. Finally, from a cost perspective, driver assistance systems could be a cheaper solution than overtaking prohibitions and overtaking lanes.

There is hardly any scientific overtaking knowledge available to enable the development of an overtaking assistant. Detailed knowledge of the performance of the overtaking manoeuvre, separating it into subtasks and defining the possible assistance needs for each subtask, will enable the development of a first design of an overtaking assistant. When such an assistant is designed, the effects of it should be tested both on users and on surrounding traffic before it is introduced into the market.

1.2 Objectives and applied research methods

This dissertation has the following main objective:
To thoroughly analyse overtaking performance on two-lane rural roads and study the opportunities of an overtaking assistant with respect to traffic system efficiency drivers’ comfort and safety.

Overtaking performance on two-lane rural roads is the main subject of this dissertation. Overtaking is a manoeuvre performed by drivers with the intention to pass (slower) preceding vehicles. Two-lane rural roads are roads with one driving lane for each driving direction and hence drivers always have to use the lane of the oncoming vehicles to perform the overtaking manoeuvre. The OECD gives a definition for rural roads as those which are outside urban areas that are not motorways or unpaved roads (OECD, 1999). In this dissertation, rural indicates that speed limits are high, often 80 or 100 km/h. In the Netherlands, these roads are sometimes called provincial roads or flow roads; in American English they are referred to as highways. In this dissertation the roads studied will be called two-lane rural roads.

The general objective of this dissertation research is divided into five main research questions. The first research question is:

1. How are overtaking manoeuvres performed on two-lane rural roads?

By means of an instrumented vehicle, overtaking manoeuvres performed on two-lane rural roads are observed in great detail. Different overtaking strategies are distinguished and measures as overtaking duration, indicator use, headway before and after the manoeuvre, time spent in the left lane, are analysed.

The second research question is:

2. What are the subtasks of overtaking and what are their matching assistance needs?

A task analysis of overtaking exposes all subtasks of the overtaking manoeuvre and matching assistance needs are distinguished. Together with the answer of the first research question, this information is used to answer the third research question:

3. How should an overtaking assistant be designed?

The basic design cycle is applied to make a functional design of the overtaking assistant. The assessment phase of the design cycle answers the following two research questions, together resulting in an adjusted design that will be accepted or rejected. The fourth research question is:

4. What are the individual driver effects of an overtaking assistant on overtaking efficiency, safety and comfort?

A first design of the overtaking assistant is implemented in a driving simulator and effects on overtaking frequency, indicator use, headway prior to the manoeuvre, overtaking duration and headway at the end of the manoeuvre are studied. In addition to these objective performance measures, subjective effects are also studied, including changes in workload and activation.
levels and acceptance of the system. With this experiment, the effects of one overtaking assistant are tested, however it is also important to look at the effects when more drivers are equipped with an overtaking assistant. The fifth research question is:

5. What are the effects of the overtaking assistant on collective flow characteristics in terms of traffic system efficiency, drivers’ comfort and safety?

To study possible network effects of an overtaking assistant, detailed knowledge on the situation without overtaking assistant is required. Observations of traffic flows, speeds and overtaking frequencies on two different Dutch roads give a detailed insight into traffic performance in general and overtaking frequencies specifically on two-lane rural roads. This information is used to create a reference situation for the micro simulation study that is performed to study effects of different overtaking assistant designs and different penetration rates. Effects on traffic system efficiency, drivers’ comfort and safety are studied.

1.3 Research Scope

This dissertation focuses on overtaking on two-lane rural roads. The results are not readily applicable to roads with more than one driving lane per driving direction or to roads with divided driving directions. Some results may be generalised to such situations. However, the focus lies on roads with speed limits of 80 or 100 km/h. This means that vulnerable road users, such as cyclists and pedestrians, are not taken into account and results will only be partly applicable to roads with lower speed limits, since these roads often include vulnerable road users.

Passenger vehicles are the focus for the development of the overtaking assistant. This vehicle type accounts for more than three-quarters of all driven vehicle kilometres in the Netherlands (SCP, 2003). Since passenger cars have a higher speed limit than trucks and vehicles with trailers on two-lane rural roads, they probably also have higher overtaking demands. Hence, an overtaking assistant will probably be most useful for passenger cars.

The observations and experiments of this research have taken place in the Netherlands. Because Dutch roads are fairly unique in the sense of high flows, relatively short road segments and narrow lanes, the application of the findings outside the Netherlands is explicitly discussed. The overtaking task analysis is carried out for the Dutch situation and international application of this analysis is verified with an international questionnaire. The driving simulator that is used to test the developed overtaking assistant is among the world’s most realistic simulators. Applications of the results of this study in other countries are discussed. The microscopic traffic simulation study of network effects of an overtaking assistant includes a section on inter-regional differences in overtaking and the difficulties this gives for microscopic traffic simulation models in general.

The overtaking assistant is designed as an informing assistant, rather than an intervening or automating system. An informing assistant is the least thorough and in our opinion the best to start with. An informing system could be followed by an intervening system, which for example prevents drivers from overtaking. An intervening system during overtaking is more
difficult, because there is no clear control that should be intervened. With regard to automating systems, in general, drivers do not like the loss of control over driving (De Waard and Van der Hulst, 1999).

This research focuses on functional aspects of an overtaking assistant. Less attention is paid to aspects related to the user interface of such systems, although it is recognised that a proper design of the user interface is of importance for system acceptance and efficacy. The technical feasibility of the system is briefly discussed. The aim of this research is not to produce a ready-for-sale overtaking assistant, however to explore the possibilities and usability of such a system.

Finally, the focus of this dissertation is directed at overtaking difficulties regarding other vehicles or drivers and less on infrastructural limitations, such as hills or sharp curves causing sight limitations.

**Framework: BAMADAS**

This dissertation is part of the Dutch research programme BAMADAS (Behavioural Analysis and Modelling for the Design and Implementation of Advanced Driver Assistance Systems). This program started in 2002 and is sponsored by NWO-Connekt. BAMADAS intends to improve the knowledge regarding road vehicle driver behaviour in interaction with advanced driver assistance systems. To reach this aim, four Ph.D. projects, one post-doc project and one added project sponsored by the Cornelis Lely-association, have been defined, which are displayed in Table 1.2.

The BAMADAS framework directed this dissertation research to driver assistance systems solutions for overtaking problems. The focus was less on infrastructural elements, because these have been studied within the MIDAS project. Cooperation with the ASTIM project has resulted in a paper on interaction during overtaking (Houtenbos et al., 2005a). Cooperation with the TOMAS project has resulted in a follow-up driving simulator experiment of the simulator experiment described in this dissertation, to study behavioural adaptation (Dragutinovic, in prep.).

<table>
<thead>
<tr>
<th>Table 1.2 The BAMADAS program</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BAMADAS</strong></td>
</tr>
<tr>
<td>ASTIM:</td>
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<tr>
<td>TOMAS:</td>
</tr>
<tr>
<td>ROADAS:</td>
</tr>
<tr>
<td>MIDAS:</td>
</tr>
<tr>
<td>RULES:</td>
</tr>
<tr>
<td>SPACE:</td>
</tr>
</tbody>
</table>
1.4 Contribution and relevance

The main contribution of this dissertation is extending the knowledge of overtaking on two-lane rural roads and how assisted overtaking can improve traffic system efficiency, drivers’ comfort and safety. Observations of natural overtaking manoeuvres give insight into overtaking performance and the strategies that drivers apply. Together with the results of a detailed overtaking task analysis, identifying all subtasks of overtaking and matching assistance needs, this has led to the development of an overtaking assistant. The overtaking assistant assists the most difficult subtask of overtaking: judging whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. Individual tests of the functioning and acceptance of the overtaking assistant in a driving simulator experiment contributes to improvement suggestions for the design of the assistant and brings it closer to market introduction. Tests of the assistant on the traffic system by means of a microscopic traffic simulation study, contributes into more insight into the possibilities of the system with respect to traffic system efficiency, drivers’ comfort and safety. It shows that drivers can benefit from the assistant without negatively affecting other road users.

1.4.1 Scientific contribution

An extensive and broad study of overtaking on two-lane rural roads as described in this dissertation has not been done before. Detailed observations of naturalistic overtaking manoeuvres improve the knowledge of the overtaking process. This enables modelling of overtaking within microscopic traffic simulation models. These models will gain from all collected empirical data of two-lane rural roads, enabling further development and validation. The combination of empirical studies of overtaking frequency and overtaking behaviour leads to a complete view of the overtaking process. This leads to the extension of existing theories on overtaking frequency. An overtaking frequency formula with only two dependent variables is developed, with an $R^2$ of 0.67. Finally, the insight into the possibilities of driver assistance system to improve overtaking is valuable for further development of these systems.

1.4.2 Practical and social relevance

The outcome of this research is relevant for the European Commission, who set up the rules for the development and testing of driver assistance systems such as an overtaking assistant. These rules should, on the one hand, give the possibility to develop systems and on the other hand, protect drivers for too wide variety of possibly unsafe systems. Public authorities and road operators are recommended to keep track of developments such as the overtaking assistant. These systems can contribute to solving problems on their own roads, which could save money spent on other, expensive and possibly less effective solutions. The outcome of this dissertation is also useful for the automotive industry who wants to develop driver assistance systems that contribute to the safety and comfort of drivers.

Observations of current traffic situations on two-lane rural roads, including overtaking frequencies, give public authorities and road operators information about how many drivers are affected by overtaking prohibitions and what the impact of this measure is on the capacity. Effects of an overtaking lane are made clear as well, in comparison with effects of an overtaking assistant. The latter shows that it was possible to exclude overtaking as accident
cause, without lowering the capacity of the roads or lowering comfort of drivers. Money spent on the implementation of prohibitions or overtaking lanes can be saved as soon as overtaking assistance systems become available.

The implementation of driver assistance systems such as the overtaking assistant is generally considered to go slow, considering the potential benefits of these systems. Intelligent Car Initiative of the European Commission provides a further push with respect to smarter, safer and cleaner vehicles (European Commission, 2006). This dissertation contributes to the objective of the Intelligent Car Initiative by creating awareness and acceptance of assistance systems by examining and publishing the effects of such systems.

Finally, in the Netherlands, around 1000 fatalities happen annually, costing society 12.3 billion Euros, 2.7% of the gross national product (Institute for Road Safety Research, 2005). To reach the ambitious goal of the Dutch government to have a maximum number of 580 fatalities in 2020 (VROM, 2006) any improvement of traffic safety has to be given a chance. The overtaking assistant has the potential to reduce traffic fatalities.

1.5 Dissertation outline

The main objective of this dissertation is divided into five research questions which are answered in eight chapters. Collection of empirical data of overtaking behaviour (Chapter 2) describes this behaviour in great detail. Further insight of the overtaking manoeuvre itself is gathered with a task analysis (Chapter 3). Both chapters form the basis for the design of the overtaking assistant (Chapter 4). The effects of the designed assistant are studied on the individual (driver) level by means of a driving simulator experiment (Chapter 5). To study the effects at the network level, it is firstly necessary to collect empirical data of unassisted traffic performance on two-lane rural roads, including overtaking frequencies (Chapter 6). This data served as a reference situation to study the collective flow characteristics effects of the overtaking assistant (Chapter 7). The main results of this dissertation are summarised in the discussion and conclusions chapter (Chapter 8). Figure 1.3 gives a visual overview of the relations between the chapters of this dissertation.
Objective: Thoroughly analyse overtaking performance on two-lane rural roads and study the opportunities of an overtaking assistant with respect to traffic system efficiency, drivers' comfort and safety.

Figure 1.3 Dissertation outline
2 Empirical Facts of Overtaking Behaviour
Observations with an Instrumented Vehicle

Almost fifty overtaking manoeuvres performed on two-lane rural roads are observed using an instrumented vehicle. A distinction is made between the overtaking strategies accelerative, flying, piggy backing and 2+. The average duration of an overtaking manoeuvre is found to be 7.8 s. This duration is independent of overtaking strategy and of the observed overtaken vehicle’s speed. Fairly short perception-reaction times are observed; indicating that the decision to overtake is made before an opportunity is present. Almost two-third of the observed drivers used their indicator at the start of the manoeuvre, whereas at the end, only one-third uses the indicator correctly. Based on the measurements, there are opportunities for an overtaking assistant that advises drivers about available overtaking gaps.
2.1 Introduction

This chapter collects empirical data of overtaking manoeuvres performed on two-lane rural roads. It aims to answer the first research question of this dissertation: how are overtaking manoeuvres performed on two-lane rural roads?

An instrumented vehicle is used to collect overtaking data for different overtaking strategies and for different preceding vehicle speeds. The observed overtaking measures are perception-reaction time, indicator usage, headway at the start of the manoeuvre, duration, headway at the end of the manoeuvre, and time left until the first oncoming vehicle arrives. The collected data are used to study differences in overtaking performance between drivers and for different overtaking strategies. This is important information for the ability to design a uniform overtaking assistant that aims to assist all drivers. Assisted overtaking manoeuvres should approach the safely performed un-assisted manoeuvres as the ones observed in this study, and exclude unsafe manoeuvres and thereby exclude overtaking accidents.

Figure 2.1 displays the outline of this chapter. Section 2.2 defines the overtaking manoeuvre distinguishing four different overtaking strategies. A review of existing overtaking performance knowledge is described in Section 2.3, including an overview of empirical data collection methodologies. The instrumented vehicle is chosen to collect overtaking data, explained in the method section (2.4). This section includes a description of the measures to observe, the applied observation strategy, the data collection and the data analysis. The observation results can be found in Section 2.5. The final section of this chapter discusses the international applicability of the Dutch observation results, the usability of the findings for the design of an overtaking assistant and the use of existing assistance systems during overtaking.
2.2 Definition of the overtaking manoeuvre

An overtaking manoeuvre is defined in this dissertation by moving of the subject vehicle to another lane, passing of at least one (slower) preceding vehicle and moving back to the lane where the manoeuvre started. The manoeuvre is performed on two-lane roads, where the opposing traffic lane needs to be used, which in the Netherlands is the left lane. The vehicle that performs the overtaking manoeuvre is defined as the overtaker and the preceding vehicle is overtaken is defined as the overtakeen vehicle. The term passing is also often used, although this mostly indicates an overtaking manoeuvre on one-directional roads without moving back to the lane where the manoeuvre started (right lane). In this study passing is used to indicate the part of the overtaking manoeuvre that drivers spend in the left lane, where they truly pass the preceding vehicle, excluding the lane change parts.

For the empirical overtaking data collection, it is important to define the start and the end of an overtaking manoeuvre. Other authors have used divergent definitions (see for an overview 2007). For this study, the start of the overtaking manoeuvre is defined as the moment the left front wheel of the overtaker touches the centre line. The end of the overtaking manoeuvre is defined as the moment the left back wheel has fully crossed the centre line again. Figure 2.1 visualises these chosen definitions, which are chosen since these moments can precisely be derived from collected empirical overtaking data and are equal for all observed overtaking manoeuvres.

Some subtasks of the overtaking manoeuvre are already performed before the start of the overtaking manoeuvre as defined above. Before overtakers move to the centre line, they prepare for the overtaking manoeuvre by e.g. changing to a lower gear or turning the indicator on. Also, the base position of drivers is not with their left front wheel touching the centre line, which means that a part of the lateral movement already takes place before the defined start of the overtaking manoeuvre. Since base positions on a driving lane differ between drivers, it is difficult to measure the real start of the overtaking manoeuvre. Hence, a position clearly measurable and similar for all overtakers is set as the start of the overtaking manoeuvre.

\[
\begin{align*}
\text{Start overtaking manoeuvre} & = & \text{left front wheel touches the centre line} \\
\text{End overtaking manoeuvre} & = & \text{left back wheel has passed the centre line}
\end{align*}
\]

Figure 2.2 Visualisation definitions start and end of the overtaking manoeuvre

Apart from the choice how to define the start and end of the overtaking manoeuvre, different overtaking strategies can be distinguished. Earlier studies distinguished the strategies accelerative (normal), flying and piggy backing (Wilson and Best, 1982). These three strategies, together with the added 2+ strategy can be described as follows:
Assisted Overtaking

Accelerative: The overtaker approaches the preceding vehicle. The overtaker has to adjust his/her speed to the speed of the preceding vehicle (car-following), waiting for a sufficiently large gap in the opposing traffic stream. When this gap arrives, the overtaker overtakes the preceding vehicle, while accelerating to a higher speed.

Flying: The overtaker drives at his/her desired speed. It observes the preceding vehicle and is directly able to overtake the preceding vehicle, which might require some speed adjustments, however, car-following is not necessary.

Piggy backing: A vehicle overtakes the preceding vehicle and the overtaker follows this vehicle. So the overtaker stays behind the vehicle in front, while they both overtake a slower preceding vehicle.

2\': The overtaker overtakes more than one preceding vehicles at once. So the minimal number of vehicles that are being overtaken is two. This strategy may involve accelerative, flying or piggy backing strategy.

Figure 2.3 Trajectories of involved vehicles for accelerative and flying overtaking strategies

To visualise these four overtaking strategies the trajectories of the involved vehicles are shown per overtaking strategy in Figure 2.3 and Figure 2.4. These are example figures, for example, flying overtaking might require some acceleration.
The main difference between accelerative overtaking and flying overtaking is that accelerative overtaking is always preceded by car-following, whereas the flying overtaking is preceded by free driving. Now that the start and end of overtaking manoeuvres have been defined and the overtaking strategies have been explained, this chapter continues with an overview of empirical studies on overtaking behaviour. This review is used to select the most suitable methodology to collect detailed, empirical overtaking manoeuvre data.

2.3 Review of empirical overtaking behaviour studies

In the past, different studies were performed to collect empirical overtaking data, using different observation methodologies. Much effort in overtaking observations was made during the 1930s, then again during the 1980s and at the start of the 21st century, the interest in overtaking behaviour has grown again (see for an overview Jenkins, 2004). Table 2.1 gives an overview of the overtaking behaviour results relevant for this study, together with the applied observation methodologies.
### Table 2.1 Summary of overtaking manoeuvre studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Observation methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crawford (1963)</td>
<td>Test track</td>
<td>Overtaking duration: 6.7 s, accepted gap: 11.5 s. Advice to cut-in in case time to finish becomes critical</td>
</tr>
<tr>
<td>Stolz (Stolz, 1967)</td>
<td>Instrumented vehicle</td>
<td>Overtaking duration: 13 s and was independent of speed of preceding vehicle</td>
</tr>
<tr>
<td>Summala (1980)</td>
<td>Pneumatic tube</td>
<td>Minimum time headway of vehicles in a platoon increased from 0.1 to 0.5 s when overtaking was prohibited</td>
</tr>
<tr>
<td>Wilson and Best (1982)</td>
<td>Observers along road</td>
<td>The overtaking strategies accelerative, flying, piggy backing, lane sharing, cutting in, braking to follow are distinguished. 14% of accepted gaps were judged to be too small (threshold 400 m)</td>
</tr>
<tr>
<td>Harris et al. (1986)</td>
<td>Camera observations</td>
<td>Piggy backing strategy often applied to overtake HGV Vehicles with high power and low weight overtake safest</td>
</tr>
<tr>
<td>Polus (1987)</td>
<td>Instrumented vehicles</td>
<td>Perception-reaction time mean 1.74 s standard deviation (SD) 1.35 s, headway before mean 23.7m SD 11.4m, time travelling in opposing lane mean 8.9 s SD 2.6 s, headway after mean 29.7m SD 9m</td>
</tr>
<tr>
<td>Clarke (1997)</td>
<td>Accident analysis</td>
<td>Accident types: 16% head-on, 10% swipe, 3% cut-in. Explanatory factors: poor observation, misjudgement, inexperience</td>
</tr>
<tr>
<td>Tapio (2003)</td>
<td>Helicopter / remote sensing</td>
<td>Median accepted gap to overtake a truck: 11.5 s and to overtake a passenger car: 9.9 s. On wider shoulder lanes, the corresponding medians were 12.4 s and 11.8 s. Time-to-collision with next oncoming vehicle at the end of manoeuvre 3.8 s for oncoming trucks and 4.8 s for oncoming passenger cars</td>
</tr>
<tr>
<td>Benedetto et al. (2004)</td>
<td>Simulator study</td>
<td>Overtaking duration: 11.2 s +/- 2.6 s. Four phases in overtaking trajectories: perception-reaction time, the time for occupying the left lane; the time during which the overtaking car drives in the left lane; and, the clearance time distance between passing and oncoming vehicle at the end of the overtaking. These were similarly performed by different drivers</td>
</tr>
<tr>
<td>Satyakumar (2004)</td>
<td>Instrumented vehicle (moving observer)</td>
<td>Linear acceleration during overtaking. Relation between acceleration and initial speed is parabolic</td>
</tr>
<tr>
<td>Lee (2004)</td>
<td>Instrumented vehicle</td>
<td>Rear mirror is used twice as often during move to left lane compared to during move to the right lane. Overtaking duration: 6.5 s, 44% used indicator. All analysed lane changes took place on roads with at least two driving lanes in one driving direction (no oncoming traffic)</td>
</tr>
<tr>
<td>Baumann (2004)</td>
<td>Instrumented vehicle</td>
<td>Eye glance behaviour is related to the intention to change lane.</td>
</tr>
<tr>
<td>Tijerina et al. (2005)</td>
<td>Instrumented vehicle</td>
<td>Move left to right: chance driver uses rear mirror is significantly higher than use of right side mirror. Move right to left: chance use the rear mirror is significantly higher than for move left to right. Chance use left side mirror for move right to left is significantly higher than use right mirror for move left to right.</td>
</tr>
</tbody>
</table>
Table 2.1 shows which observation methodologies have been applied and which measures of the overtaking manoeuvre have been studied in the past. Accepted gap is one of the studied measures, for which 11.5 s was found in 1963 and in 2003, values varying between 9.0 s and 12.4 s for different oncoming vehicle types and different lane width. The duration of an overtaking manoeuvre has also been subject of several studies, for which the values 6.5 s, 6.7 s, 11.2 s, and 13 s were found. The most probable explanation for the differences between these findings is the different definitions applied for the start and end of the manoeuvre. For the remaining gap at the end of the manoeuvre applied 3.8 s and 4.8 s were found, the first when the oncoming vehicle was a truck, the latter when this was a passenger car. All these findings will be used to verify the observation results of the current overtaking data collection.

Other interesting findings are those related to overtaking strategies. The three overtaking strategies accelerative, flying and piggy backing as defined in Section 2.2 have been also distinguished in other studies. In addition to these strategies, several erroneous strategies, where overtakers clearly made a mistake during the overtaking manoeuvre are observed as well. This knowledge, together with overtaking accidents knowledge, give information about how drivers could fail during overtaking, indicating what part of the manoeuvre might require assistance.

Some of the reviewed studies have been performed specifically to give advice on the design of assistance systems. The findings of the comprehensive examination of natural lane-changes have been used to give the design advices for a lane change collision avoidance system. This advice included the use of a visual presence-detection indicator display to provide information about following vehicles in the adjacent lane anytime a vehicle is detected; and to consider the left mirror and rear view mirror locations for providing lane change information to drivers (Lee et al., 2004). Two other instrumented vehicle studies have been also performed to give design recommendations for a lane change assistant, e.g. to position the human-machine-interface (HMI) (Baumann, 2004, Tijerina et al., 2005). These three examples of detailed overtaking behaviour observations make clear that the results can be used for the design of overtaking assistance systems. But, in all three cases, the results were used to give design advices for existing systems and not (yet) to design a new assistant.

The three above mentioned studies applied instrumented vehicles to collect their empirical data. Table 2.1 displays that many other data collection methodologies can be applied, where the best methodology depends on the aim of the study. In our case, data collection on natural overtaking manoeuvres as performed by drivers on the road is most important. Given the aims and findings of the reviewed studies, passive use of an instrumented vehicle or the moving observer method is selected as the best method for this aim. Passive use means that the instrumented vehicle will be used to record overtaking manoeuvres of other vehicles which overtake the instrumented vehicle. Compared to the situation where participants drive the instrumented vehicle, it is expected that recording the movements of drivers who do not know they are recorded, will yield observations of truly unaffected overtaking manoeuvres. The next section explains the use of the instrumented vehicle in detail.
2.4 Method: overtaking data collection with an instrumented vehicle

There are many different instrumented vehicles. The one used in this study is described in Section 2.4.1, including a description of its instruments and the road section on which the observations have taken place. Next, the measures to observe, the observation strategy, the expected results and the data collection and analyses are described successively.

2.4.1 The instrumented vehicle, its instruments and the road section

The instrumented vehicle is a Renault 19 as shown in Figure 2.5. This passenger car has one camera positioned at the rear window and one at the front window. Both were focused in such a way that the right and left traffic lane were within viewing angle. The views of the camera were sufficiently sharp over 100 m which means that within this reach at least license plates of the vehicles were distinguishable. A GPS system was positioned in the car, together with a laptop, running a tailored software tool that registered the real time for all manually entered data. All noticeable events were recorded, including the overtaking manoeuvres, the speed of the instrumented vehicle and weather conditions.

Figure 2.5 The instrumented vehicle and its camera positions

In addition, a video observation of overtaking manoeuvres was carried out on the N305 as shown in Figure 2.6 and is called Flevoland road in this dissertation. The road forms the main connection between Almere and Zeewolde with an average annual daily traffic flow (AADT) of 12,000 vehicles.

Figure 2.6 N305 Gooise Weg, Flevoland, the Netherlands

The Flevoland road was selected because many overtaking manoeuvres were expected on this road. In the first place because of its relatively long road stretches of about 5 km without
Chapter 2 – Empirical facts overtaking behaviour

intersections and sight restrictions. In the second place because it forms the main connection between Almere and Zeewolde, with many commuters, wanting to arrive on time at work or at home. In the last place because the municipality of Flevoland indicated overtaking as a main safety problem of this road (Verkeer en Waterstaat Flevoland, 2003).

2.4.2 Measures to observe
To decide on the overtaking performance data to collect, ready available video data were studied of a study into road design (Steyvers and Streefkerk, 2002). These data included overtaking manoeuvres performed by drivers in an instrumented vehicle, driving on a two-lane rural road in the Netherlands. Analysis of the video recording, together with the literature findings reported in Section 2.3, has led to the following list of measures to collect:
- Overtaking strategies;
- Speed of the preceding vehicle;
- Accepted gap in the oncoming traffic stream (measured front of the vehicle of the overtaker till the front of the vehicle of the first oncoming vehicle);
- Perception-reaction time (defined as the time between passage of last oncoming vehicle and start movement to the left lane);
- Indicator usage;
- Duration of the overtaking manoeuvre;
- Distance headway between overtaker and overtaken vehicle at the start of and at the end of an overtaking manoeuvre;
- Time-To-Collision (TTC)

The last listed measure, TTC, is defined as the time required for two vehicles to collide if they continue at their present speed and on the same path (Hayward, 1972). For the observations of overtaking, TTC is defined as the time between the moment the back left wheel of the overtaker has crossed the centre line until the oncoming vehicle is at the same level as the instrumented vehicle (see Table 2.2). Strictly speaking, this should be called Post-Encroachment Time (PET) defined as the time between the moment that the first road user leaves the path of the second and the moment that the second road user reaches the path of the first (Van der Horst, 1990). Since TTC is a more common and widely spread term than PET, it was decided to use the term TTC throughout this dissertation research.

2.4.3 Observation strategy
The instrumented vehicle was driven by a member of the research team while overtaking manoeuvres of drivers were recorded. Figure 2.7 illustrates the observation strategy. The observations were performed for four different speeds of the instrumented vehicle: 70, 80, 90 and 100 km/h. Speeds below 70 km/h were considered unsafe on a road with a speed limit of 100 km/h. Above this limit, the chance of overtaking observations were considered to be too low. 10 km/h difference between the chosen speeds is considered necessary to distinguish between the different speeds. These speeds were also chosen in another similar study observing overtaking manoeuvres with two instrumented vehicles (Polus et al., 2000).
The observation of overtaking behaviour is exploratory and aims to observe the manoeuvre as detailed as possible, with the ultimate aim to gather necessary information for the design of an overtaking assistance system. Special attention is paid to differences in overtaking strategies and the influence of the speed of the overtaken vehicle (i.e. the instrumented vehicle) on the duration of the overtaking manoeuvre.

### Data collection and analysis of overtaking manoeuvres

The observations were carried out on Tuesday 19 November 2004, between 11.00 and 16.00 hours. It was a sunny, cold day while in the afternoon it became cloudy, with some rain.

The main data sources for the measures of interest are the video recordings of the two cameras and the manually recorded data. This latter includes information on overtaking strategy, speed of the instrumented vehicle and any remarkable events during the overtaking manoeuvre, together with the registration time. This enabled easily linkage with the video recordings that also includes the registration time.

The front and back view video data are used to extract perception-reaction time, indicator usage, headway at the start of an overtaking manoeuvre, overtaking duration, headway at the end of an overtaking manoeuvre and TTC. These measures are extracted from the video tapes by means of analysis of the essential sequences of pictures from the video tapes. For this extraction, clear definitions of start and end of the measures are necessary. Table 2.2 explains the moments at which the overtaking measures are obtained from the video recordings.

To extract distances from the video tapes, the video images need to be calibrated on objects with known sizes, to compensate for perspective distortion. Because all vehicles carry a license plate and these almost always have the same dimensions, the license plate is used for this calibration process. License plates are measured and recorded with the cameras. The real size of the license plate was matched with the size of the recordings of the license plate. All video tapes are calibrated with these data. Headways are subsequently obtained by ticking the size of the license plate at the picture where the headway is displayed. The accuracy of this method becomes less when distances are larger. A test observation over a distance of 100 metres, confirms an accuracy of 1 m.
Table 2.2 Chosen definitions for the performance measures extracted from the video

<table>
<thead>
<tr>
<th>Visualisation</th>
<th>Description and what measured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overtaker at same level as last oncoming vehicle:</td>
</tr>
<tr>
<td></td>
<td>- Start perception-reaction time</td>
</tr>
<tr>
<td></td>
<td>Left front wheel touches centre line:</td>
</tr>
<tr>
<td></td>
<td>- End perception-reaction time</td>
</tr>
<tr>
<td></td>
<td>- Indicator usage at the start of the manoeuvre</td>
</tr>
<tr>
<td></td>
<td>- Headway at the start of the manoeuvre:</td>
</tr>
<tr>
<td></td>
<td>from front overtaker to back preceding vehicle</td>
</tr>
<tr>
<td></td>
<td>- Start of the duration of the overtaking manoeuvre</td>
</tr>
<tr>
<td></td>
<td>Left back wheel has crossed centre line:</td>
</tr>
<tr>
<td></td>
<td>- Indicator usage after the manoeuvre</td>
</tr>
<tr>
<td></td>
<td>- End of the duration of the overtaking manoeuvre</td>
</tr>
<tr>
<td></td>
<td>- Start of the TTC</td>
</tr>
<tr>
<td></td>
<td>First oncoming vehicle at same level as overtaker:</td>
</tr>
<tr>
<td></td>
<td>- End of the TTC</td>
</tr>
</tbody>
</table>

It has not been possible to extract accepted gap data. For most observed manoeuvres, the first oncoming vehicle was not visible at the moment the overtaker started the overtaking manoeuvre. And, when the first oncoming vehicle was visible, the distance to this vehicle was too large to obtain an accurate measurement of this distance. Hence, no accepted gap data could be collected.

Data analysis is performed using SPSS 12.0 and Excel 2003, including descriptive statistics, Kolmogorov-Smirnov tests for normality and independent t-tests. Linear regression is used to study whether the duration of the overtaking manoeuvre depends on the speed of the overtaken vehicle, is studied simultaneously with linear regression. Correlations between headway at the start of and at the end of an overtaking manoeuvre are studied by means of Spearman’s correlation coefficient $r_s$. Application of the more common Pearson correlation coefficient was not possible, since the headway at the start of an overtaking manoeuvre had violated the assumption that this parameter is normally distributed. The Spearman’s correlation requires ranking of the variable from small to large. The results are presented in histograms, scatterplots, pie diagrams and boxplots. With the application of these data analysis methodologies, the aim of a detailed description of overtaking manoeuvres is reached.

For statistical analysis of the recorded overtaking manoeuvre measures, a representative sample of the overtaking population is required. Since the distribution of any overtaking manoeuvre related variable is unknown (e.g. duration of the manoeuvre), it is not possible to calculate the required sample size. In general, a sample size less than or equal to 30 is
24

indicated as ‘small’. Based on this, it was decided to collect as much overtaking manoeuvres as possible on one observation day.

2.5 Results of empirical overtaking data collection

In total 48 overtaking manoeuvres were recorded. Respectively 13, 24, and 11 overtaking manoeuvres were observed while driving 70, 80 and 90 km/h. The instrumented vehicle was not overtaken when it drove at 100 km/h. Thirty-one manoeuvres were accelerative and the other strategies flying, piggy backing and 2* were applied respectively 6, 6 and 5 times. Note that not all measures could obtained for all observed manoeuvres. For example, the total overtaking time could be calculated for 43 of the 48 observed manoeuvres, which makes the total shown in Figure 2.10 equal to 43 and not to 48.

The first presented result is the perception-reaction time. Figure 2.8 shows that the bin with perception-reaction times ranging from 0 – 0.5 s is the tallest. The 0 bin represents perception-reaction times smaller than 0 s, which means that the left front wheel of the overtaker already crossed the centre line before the back of the last oncoming vehicle is at the same level as the back of the overtaker.

Most observed perception-reaction times are smaller than 1 s, indicating that a driver observes an appropriate gap in the oncoming stream in advance: as soon as the gap arrives, the overtaking manoeuvre can start. This makes the chosen name perception-reaction time somewhat misleading, because most drivers perceive the overtaking opportunity before it is actually present; in fact, they anticipate it.

The second collected measure of overtaking performance is the distance headway at the start of an overtaking manoeuvre. The mean observed distance headway between the overtaker and the preceding vehicle at the start of the manoeuvre is 17.8 m with a standard deviation of 9.8 m. Flying overtaking and piggy backing have significantly longer headways compared to accelerative overtaking manoeuvres (flying: $t_{45} = 2.503, p<.05$, piggy backing: $t_{45} = 2.805, p<$
Almost one fourth of the observed manoeuvres had a distance headway of less than ten metres, which equals, at the driven speeds, a time headway of less than 0.5 s. For some manoeuvres, the overtaker had not even totally crossed the centre line at the moment the front of the vehicle is next to the preceding vehicle. The shortest measured distance headway at the start of an overtaking manoeuvre is 7.7 m (accelerative strategy, instrumented vehicle drove 80 km/h). This corresponds with a net time headway of 0.35 s.

The indicator was used almost twice as often at the start of an overtaking manoeuvre than at the end of a manoeuvre, excluding manoeuvres for which the indicator usage was not visible on video. Before the manoeuvre starts, almost two-thirds of the observed drivers used their indicator as shown in Figure 2.9. For the movement back to the right lane, less than half of all drivers used their indicator.

![Figure 2.9 Observed indicator usage (a) at the start of the overtaking manoeuvre and (b) at the end of the overtaking manoeuvre](image)

A descriptive measure of the overtaking manoeuvre, subject of many earlier overtaking behaviour studies, is the duration of the manoeuvre. The mean duration of all observed overtaking manoeuvres in this study was 7.8 s with a standard deviation of 1.9 s. Figure 2.10 shows a boxplot of the duration of the overtaking manoeuvre per overtaking strategy of which the median of all 4 overtaking manoeuvre strategies lies between 6 and 8 s. The 25 and 75 percentiles of accelerative and flying overtaking are closer to the median than for the piggy backing and 2+ strategies. This involves that the duration of accelerative and flying overtaking is less spread or more similar than for the other two strategies.

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4 This is the standard way to report statistical results. The $t$ indicated the applied test (Student’s $t$-test in this case) 45 are the degrees of freedom, 2.503 is the resulting $t$-statistic and $p<.05$ is the significance value.
Figure 2.10 Left: boxplot of duration of an overtaking manoeuvre per overtake strategy; Right: mean and standard deviation of duration per speed and strategy

Cases 12, 14 and 25 are outliers, meaning that they are more than 2 standard deviations away from the median. Apart from the overtaking strategy, the speed of the vehicle that is overtaken was also expected to influence the overtaking manoeuvre duration. To verify this, the mean and standard deviation of the duration per strategy and per speed of the preceding vehicle have been calculated and are displayed in the right part of Figure 2.10. Compared to an accelerative overtaking manoeuvre, with the speed of the vehicle that is overtaken equal to 80 km/h, both a variation in speed between 70 and 90 km/h and a variation in strategy show no significant difference in the duration of the overtaking manoeuvre at the 95% confidence level. However, the duration of an overtaking manoeuvre for the flying strategy turned out to be significantly shorter than 2 strategy ($t_5 = 2.494, p < 0.05$).

To gain insight into the distinctive parts of the overtaking manoeuvre, the duration of the move to the left, the time it takes to get past the preceding vehicle, the time the overtaker drives in the left lane after it has passed the preceding vehicle and the duration of the move back to the right lane are compared as well. Figure 2.11 and Figure 2.12 show these durations, separated for the speed of the preceding vehicle and the applied strategy. Again, no significant differences by the preceding vehicles’ speed or overtaking strategy for all distinguished parts, are found.

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SD = standard deviation

The total included manoeuvres for the calculation of the mean and standard deviation of the duration of the total passing manoeuvre is not equal to the total observed overtaking manoeuvres, because for some manoeuvres not all necessary moments to calculate the duration could be observed.
Figure 2.11 Duration of overtaking manoeuvres (move to the left (ml), passing, driving in the left lane until the move to the right lane (pass-mr) and the move to the right lane (mr)) for the 3 strategies accelerative, flying and piggy backing, while the preceding vehicle was driving 70 km/h (above) or 80 km/h (below)

The next overtaking performance measure analysed is the distance headway at the end of the overtaking manoeuvre between the overtaken vehicle and the overtaker. The mean of this measure is 32.5 m with a standard deviation of 12.2 m.

Possible correlation between the distance headway at the start of an overtaking manoeuvre and at the end of an overtaking manoeuvre is studied as well, by means of the non-parametric Spearman’s correlation coefficient \( r_s \). Figure 2.13 displays a scatterplot of the ranked (ascending order) distances, presenting a more or less random spread of the overtaking manoeuvres. This means that there is no significant correlation between the ranked distance headway at the start of an overtaking manoeuvre and at the end of a manoeuvre (\( r_{39} = .29, \text{ ns} \)).
Figure 2.12 Duration of overtaking manoeuvres (move to the left (ml), passing, driving in the left lane till the move to the right lane (pass-mr) and the move to the right lane (mr)) for the three strategies accelerative, flying and piggy backing, while the preceding vehicle was driving 90 km/h.

Figure 2.13 Scatterplot of ranked (ascending order) distance headways at the start of the overtaking manoeuvre and at the end of the overtaking manoeuvre per overtaking strategy.

Finally, TTC is analysed, defined as the time left between the end of the overtaking manoeuvre and the passage of the first oncoming vehicle as presented in Table 2.2. For most
observed manoeuvres in this study, it took more than 10 s before the first oncoming vehicle arrived. Five overtaking manoeuvres were performed with a TTC less than 3 s, an often used critical value below which drivers become to feel uncomfortable (Hoogendoorn, 2000). The lowest measured TTC was 1.2 s.

### 2.6 Summary and discussion of overtaking observations results

To answer the first research question of this dissertation research: *how overtaking manoeuvres are performed on two-lane rural roads?* almost fifty overtaking manoeuvres on two-lane rural roads were observed using an instrumented vehicle. Table 2.3 gives an overview of the observed measures, together with earlier findings on these measures.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Results this study</th>
<th>Earlier findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accepted gap</td>
<td>-</td>
<td>Mean 11.5 s (Crawford, 1963), median 11.5 s to overtake truck, 9.9 s to overtake car (Tapio, 2003)</td>
</tr>
<tr>
<td>Perception-reaction time</td>
<td>50% between 0 s and 0.5 s</td>
<td>3.86 s (Benedetto et al., 2004)</td>
</tr>
<tr>
<td>Headway at the start of an overtaking manoeuvre</td>
<td>Mean 7.8 m standard deviation (SD) 9.8 m, Minimum 7.7 m</td>
<td>0.1 s till 0.5 s (Summala, 1980)</td>
</tr>
<tr>
<td>Indicator usage</td>
<td>At start: 64% yes, 19% no, 17% not visible</td>
<td>44% used indicator (Lee et al., 2004)</td>
</tr>
<tr>
<td>After: 35% yes, 52% no, 13% not visible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headway at end of overtaking manoeuvre</td>
<td>Mean 32.5 m SD. 12.2 m</td>
<td>Mean 29.7 m SD. 9m (Polus et al., 2000)</td>
</tr>
<tr>
<td>Overtaking duration</td>
<td>Mean 7.8 s SD 1.9 s</td>
<td>Mean 6.5 s (Lee et al., 2004), mean 11.2 s SD 2.6 s (Benedetto et al., 2004), mean 8.0 s SD 2.6 s (Polus et al., 2000), mean 6.7 s (Crawford, 1963)</td>
</tr>
<tr>
<td>TTC with first oncoming vehicle</td>
<td>About 10% below 3 s, smallest observed: 1.2 s</td>
<td>3.8 s when opposing is truck, 4.8 s when opposing is car (Tapio, 2003)</td>
</tr>
</tbody>
</table>

Despite the inability to observe accepted gaps, the instrumented vehicle is thought to be a satisfying observation instrument to observe most measures of interest. The two methodologies applied in studies in which accepted gaps have been observed are a test track (Crawford, 1963) and helicopter observations (Tapio, 2003). In particular the latter is believed to be a good overtaking observation methodology, however application of this methodology very much depends on the available research resources. Whether Finnish results in Tapio (2003) or results from other countries are also applicable to the Netherlands is discussed in the next section, about international overtaking differences. Section 2.6.2 discusses the results with regard to the overall aim of this dissertation research, the usefulness of the observations for the development of an overtaking assistance system to improve traffic system efficiency, drivers’ comfort and safety of overtaking. Finally, the functioning of other ready existing driver assistance systems during overtaking is discussed.
2.6.1 Discussion of international applicability of Dutch observation results

Dutch roads in general are among the safest of the world (Koornstra et al., 2002, Wegman et al., 2006). However, two-lane rural roads with speed limits of 80 or 100 km/h are the Dutch least safe roads, with the safety of overtaking as a main concern. However, the safety problem of overtaking is larger in countries where most roads are two-lane rural roads, e.g. in Poland (Cielecki and Pursula, 1994) and Finland (Enberg and Pursula, 1991). Therefore, when developing improvements of overtaking safety, in this case an overtaking assistant, applicability should not be limited to the Netherlands. When the design of an overtaking assistant will be based on overtaking performance of Dutch drivers, it should be verified if drivers in other countries perform overtaking manoeuvres in a similar way.

Table 2.3 displays similarities between the Dutch findings and other findings. The differences are mostly caused by different definitions of the measures, e.g., the duration of the observed overtaking manoeuvres by Lee et al. (2004) did not include the move back to the right lane and were performed on a road without oncoming traffic. These definition differences make it hard to compare the findings. The results do not give clues for differences. Differences in overtaking rules and performance are presented in the next chapter, including results from an international questionnaire.

The scope, method and collected measures in this study are best comparable with the study performed by Polus (2000) in South Africa. Although all observed measures in the Netherlands are smaller than the ones in South Africa, time spent in the left lane and headway at the end of the manoeuvre are fairly similar. An explanation for the shorter overtaking duration in the Netherlands could be the difference in the traffic flows on the roads where the experiments took place. The hourly flows of the two observed roads in South Africa were 100 veh/h and 200 veh/h respectively. The observed road in the Netherlands had an hourly flow above 500 veh/h. From the literature it is known that passing time increases with a decreasing flow (Hanley and Forkenbrock, 2005). The South African conclusion that perception-reaction times are significantly shorter in case there is an oncoming vehicle in-sight supports this finding.

Apart from the observed measures, comparison of internationally applied overtaking strategies is interesting as well. Three of the four defined overtaking strategies in this study, accelerative, flying and piggy backing, are also observed in an Italian overtaking study, using a driving simulator (Benedetto et al., 2004). The 2+ strategy is not distinguished before, although it is assumed that in other countries drivers sometimes overtake two or more slower preceding vehicles at once as well.

2.6.2 Discussion of usability of findings for overtaking assistant design

Detailed observations of overtaking manoeuvres have been collected to get a better understanding of how drivers perform overtaking manoeuvres, which in turn is the basis for developments of solutions to improve this performance. Solutions can be found within the area of driver assistance systems, more specific the possibility of an overtaking assistant. This section discusses the usability of the findings of overtaking observations for the design of an overtaking assistant.
The overtaking manoeuvres observed are performed by drivers who currently overtake preceding vehicles driving 70, 80 or 90 km/h. These drivers might not represent the whole driver population and only those who dare to overtake. A study into differences in overtaking of relatively fast (average 73 km/h) and slow (either 20 km/h or 30 km/h) vehicles found larger distributions of overtaking time and distance for the slow vehicles (Van Nes, 1986). This implies that a subpopulation of drivers does not overtake faster vehicles. When an overtaking assistant is designed to assist all drivers, it should be taken into account that e.g. the spread of the distribution of overtaking duration will be larger than collected overtaking data in this Chapter.

Different overtaking strategies could require different overtaking assistance. For the four observed strategies, only small differences are found in the performance, indicating that it would be possible to develop a single overtaking assistant generally applicable to all overtaking strategies. The measured mean duration of an overtaking manoeuvre is observed to be 7.8 s ± 1.9 s. The 2’ strategy takes significantly longer than piggy backing. With the 2’ strategy, at least two vehicles are overtaken. All other differences in duration for the speed driven by the vehicle that is overtaken and the different overtake strategies are not significant, however this finding should be interpreted with caution, since the sample size is very limited.

In addition to performance differences between strategies, the moment the decision to overtake is made might be difficult. For example, in case of flying overtaking, drivers need to decide to overtake in a fairly short time period, such that speed adaptation is not necessary, while during accelerative overtaking manoeuvres, drivers might have to wait several minutes until an overtaking opportunity is available. This difference has implications for the activation of the overtaking assistant. For accelerative overtaking manoeuvres, drivers could switch an overtaking assistant on at the moment they are waiting for an opportunity. For the flying overtaking case, there is no time to switch the system on and it should give information about overtaking possibilities on the fly.

To activate the overtaking assistant, indicator usages is a possibility. For example, the lane change assistant of Mitsubishi Proudia works only if the indicator is on (European Commission, 2000) and another tested inter-vehicle cooperation system also relied on indicator usage (Ammoun et al., 2007). However, the present observations showed that only 64% of the observed overtaking manoeuvres the indicator was used at the start of the manoeuvre. When the overtaking assistant relies on indicator usage, not all manoeuvres will be assisted. On the other hand, a design based on indicator usage could possibly lead to more frequent use of the indicator, when drivers know the lane change assistant works only when using the indicator. Nevertheless, if the aim is to exclude overtaking as accident cause, it is not possible to rely on indicator usage. Based on their low indicator usage findings, Lee et al. (2004) recommends not to rely on indicator usage for the functioning of assistance systems. A technical problem to activate the assistant by the indicator is that the moment the indicator is switched on is rather late to activate an overtaking assistant. By law, the indicator should already be switched on, when there is an overtaking possibility. At that moment, many subtasks of the overtaking manoeuvre have already been performed, as will be shown in Chapter 3.
Assisted Overtaking

The observed short perception-reaction time prior to an overtaking manoeuvre indicates that drivers’ decision to overtake is made before a sufficiently large gap is actually present. With regard to overtaking assistance, this implies the necessity to advice the driver about an overtaking possibility well before an appropriate gap is available. Thus, the overtaking assistant needs to be switched on before an appropriate gap is present. This means that the system should either be always on, or be switched on by a driver who intends to overtake. This is in line with recommendations of the American comprehensive examination of naturalistic lane-changes study (Lee et al., 2004).

Time headways at the start of an overtaking manoeuvre as short as 0.35 s are observed, where 2 s is the recommended safe headway. To increase the headway at the start, the overtaking assistant should control a safe distance between the two vehicles. In this respect, combinations with distance keeping systems, as for example included in an adaptive cruise control, are desirable. Such a system can be set at a headway of, for example, 1 s. If overtakers in the present observation study would have been equipped with a distance keeping system set at 1 s, it would have interfered in 29 out of 48 observed manoeuvres. Although none of these overtaking manoeuvres led to an accident, research has shown that close followers commit two times as many traffic offences than other drivers (Evans and Wasielewski, 1982, 1983, Rajalin et al., 1997). However, a direct connection between close following and accident involvement has not yet been established.

The mean headway measured at the end of an overtaking manoeuvre was 32.1 m ± 12.5 m, which is longer than the headways at the start. Crawford (1963) advised that if a dangerous situation develops, the best thing to do is to cut-in slightly, in front of the vehicle that is overtaken. The argument is that the vehicle that is overtaken has a lower speed than the overtaker, which involves a lower risk between these two vehicles than between the oncoming vehicle and the overtaker. Indeed, of 972 analysed overtake related road accidents, 158 were head on collisions and only 29 cut-in (Clarke et al., 1997). The danger of cut-in accidents will be further reduced if the overtaken vehicle is informed about the overtaking manoeuvre. This would require an advanced assistant that is able to communicate with other vehicles.

In summary, based on the observation findings, an ideal overtaking assistant should:
- Advice drivers about overtaking gaps before they are available;
- Not rely on indicator usage;
- Keep a safe time gap with the overtaker and the preceding vehicle at the start of the manoeuvre;
- Advice drivers when it is safe to move back to the right lane; and
- Widely applicable, enabling assistance for all overtaking strategies and all drivers.

It will be difficult to design a system including all these functions at once. More useful is to analyse the possibilities of readily existing systems first, whether these are already available to assist with some of the requirements of the overtaking assistant. The remaining needs which cannot yet be assisted by other existing systems are the most interesting ones to develop an overtaking assistant for. The next section discusses the possible effects of readily existing driver assistance systems for overtaking.
2.6.3 Use of existing assistance systems during overtaking

Existing driver assistance systems could have influence on overtaking behaviour, both in a positive and negative way. The most common and wide spread assistance systems at the moment are route navigation systems. BMW has combined the functioning of a route navigation system with a pass prediction assistant (Loewenau et al., 2006). This system advises the driver about infrastructural, unsafe overtaking circumstances.

An example of a successfully introduced and yet often used driver assistance system is cruise control. Adaptive cruise control (ACC) includes distance keeping systems, which control the headway. Since observed headways at the start of an overtaking manoeuvre were below one second which is often the minimum adjustable headway of ACC, the system will interfere at the start of the overtaking manoeuvre. When drivers prefer smaller headways at the start of an overtaking manoeuvre, they either have to switch off the ACC or the ACC has to adjust to smaller headways at the start of overtaking manoeuvres. Both seem unacceptable from a safety point of view, however larger headways at the start of the manoeuvre increase the overtaking duration, thereby possible increasing the risk of a collision with the first oncoming vehicle. Also, headways smaller than 1 s at the start of overtaking manoeuvres are likely to be less dangerous than during normal following conditions. When overtakers are actively trying to find an overtaking gap, temporary shorter headways might be acceptable, because perception-reaction times will be short as well. In summary, distance keeping assistance systems are (already) available and hence, this is not the most important task to develop an overtaking assistant for.

To prevent accidents with oncoming traffic, features of a collision avoidance system (CAS) could assist the overtaker. Generally, it would be best if overtaking manoeuvres for which the time to complete the manoeuvre is critical, are banned. But, in case the overtaker has started a manoeuvre, a CAS can warn drivers when the distance with the oncoming vehicle becomes critical. The advice to cut-in in front of the overtaken vehicle might prevent dangerous situations with oncoming traffic. A CAS is based on TTC. TTC is an important cue in detecting potentially dangerous situation in traffic (Van der Horst, 1990). Three seconds is the conservative amount of warning time required by drivers according to tests with a CAS at the Vehicle Research Test Centre (Lee et al., 2004). For an oncoming vehicle and overtaker driving at 100 km/h, the TTC becomes smaller than 3 s if the distance between the two vehicles is about 167 m.

Taking all the possibilities of existing assistance systems together, the only main subtask of overtaking not yet covered is the judgment of the available time gap before the first oncoming vehicle arrives. This subtask of overtaking is assumed to be the most difficult, since distances are large and speeds are high. These two reasons have led to the conclusion that an overtaking assistant that provides support with finding suitable overtaking gaps in the opposing traffic stream is the most interesting. The next chapter presents a detailed task analysis of overtaking.
3 Overtaking Task Analysis and Matching Assistance Needs

An overtaking task analysis is performed to thoroughly analyse this driving task and to distinguish matching drivers’ assistance needs. In the proposed scheme, overtaking on two-lane rural roads is divided into five phases, including over twenty subtasks. For these subtasks, ten matching assistance needs are established. The assistance need for the subtask to judge whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre is the only with a ‘crucial’ ranking and for which no assistance systems are yet available. Hence, there are opportunities for an overtaking assistant designed for this task. A questionnaire among drivers in 17 different countries shows that overtaking rules do not differ much, which enables international applicability of the overtaking assistant. However, overtaking execution in these countries varies a lot and the assistant could help reducing these variations.
3.1 Introduction

This chapter specifies all subtasks of overtaking manoeuvres on two-lane rural roads and indicates possible needs for assistance for each subtask. The chapter furthermore verifies whether these subtasks and needs are similar across countries. The chapter thus aims to answer the second research question of this dissertation: **what are the subtasks of overtaking and what are their matching assistance needs?**

A task analysis is the behavioural model that is chosen to analyse the overtaking manoeuvre. *Driver behaviour models* have been applied before to give design recommendations for assistance systems (e.g. Lee et al., 2004, e.g. Cody, 2005). However, never was a task analysis used to specify the assistance needs during overtaking on two-lane rural roads with the aim to select the subtask that needs assistance most. Since the automotive industry operates as a global market, an international scope is needed for the development of driver assistance systems. To study international differences in overtaking rules and execution, a questionnaire among drivers in different countries is performed. When overtaking rules are similar, overtaking subtasks are assumed to be similar and so are the assistance needs.

Figure 3.1 presents the outline of this chapter. The next section reviews driver behaviour models applied to analyse overtaking, in order to choose the most suitable model for this study. Section 3.3 explains the overtaking task analysis and Section 3.4 the established, matching assistance needs. Section 3.5 reports the findings of a questionnaire among drivers in 17 countries about the international applicability of the overtaking task analysis. The chapter ends with a summary and discussion of the findings.

Research question 2: What are the subtasks of overtaking and what are their matching assistance needs?

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![Figure 3.1 Outline of Chapter 3: overtaking task analysis and matching assistance needs](image-url)
3.2 Driver behaviour models applied to overtaking

Through the years, many driver behaviour theories are developed. Consequently, many models describing these theories are developed as well. This section does not attempt to describe all models, but only the ones applied to model overtaking. In accordance with existing literature, the most suitable model to thoroughly analyse overtaking and to distinguish those parts that need assistance, is chosen. For clarity, the discussed models in this chapters represents a theory or a part of a theory (Michon, 1985). The microscopic traffic simulation models discussed in Chapter 7 are other type of models.

3.2.1 Hierarchical frameworks of driving tasks

The number of developed driver models is almost as high as the number of different driver types. Only a few are applied to describe overtaking. The ones that try to structure the driving task include overtaking as well. An often used hierarchical structure of the driving task is (further) developed by Michon (1985). He distinguishes three levels of skills and controls as displayed in Figure 3.2. The strategic level (planning), the tactical level (manoeuvring), and the operational level (control) together cover all taken decisions during driving.

![Figure 3.2 The hierarchical structure of the road user task. Performance is structured at three levels that are comparatively loosely coupled. Internal and external outputs are indicated (adapted from Michon, 1985)](image_url)

Rasmussen (1983) distinguishes three levels of performance of skilled operations: skill based, rule based and knowledge based performance. Hale et al. (1990) combines the hierarchical structure of driving tasks with the levels of performance of skills and control in a matrix and divided the decisions taken in the driving process over the nine resulting cells as presented in Table 3.1. Overtaking decisions are positioned in the middle cell, at the manoeuvre task and rule-based level.
Indeed, the decision to overtake is a manoeuvre task of driving taken at the rule-based level, but the execution of overtaking includes many control tasks such as steering, acceleration and monitoring, which are mostly performed at the skill-based level. Although the classification presented in Table 3.1 is useful to position the overtaking task within the whole of driver tasks, a more detailed model is necessary for the analysis of overtaking, to distinguish those subtasks that possibly need assistance.

### 3.2.2 Driver models based on the risk homeostasis theory

The theory of risk homeostasis states that an individual has an inbuilt target level of acceptable risk which does not change. For driving, this implies that measures to improve safety do not increase personal safety of drivers; instead, drivers with new, safety improving systems adjust their driving behaviour to keep their present safety at the same level (Wilde, 1982). For example, drivers wearing a seatbelt tend to drive faster (Wilde, 2002). Wilde developed the zero risk model based on this risk homeostasis theory. Summala and Näätänen (1988) applied the zero risk theory to the overtaking case, concluding that the decision to overtake is not a rational decision. Drivers’ motives for overtaking, for example hurry, influence the expectancy of overtaking opportunities. This implies that solutions to improve safety of overtaking could have an effect if they affect the expectancy of drivers of overtaking opportunities. In our view, driver assistance systems are able to influence these expectancies and therefore have potential to improve the safety of overtaking.

A related model to the zero risk model is the threshold model of Näätänen and Summala (1976) that assumes that drivers generally do not experience feelings of risk until a certain threshold. With respect to overtaking this could for example be interpreted as drivers performing overtaking manoeuvres as long as no oncoming vehicles are within sight.

The zero risk model can also be considered as a utility maximisation model which presupposes that humans are fully informed rational decision makers. That drivers do not take rational decisions, especially not in case of overtaking is illustrated by Janssen and Tenkink (1987). They state that the way an overtaking manoeuvre is performed depends on the size of the discrepancy between the desired speed and that of the preceding vehicle.

These three examples of models related to the risk homeostasis theory are suitable to describe the decision to overtake, however, less suitable when one wants to describe the details of the overtaking manoeuvre itself. Hence, the search for a suitable model is continued.
3.2.3 Information flow control models
Information flow control models are functional psychological models. Kidd and Laughery (1964) have constructed a fairly complicated information flow control model that simulated all major tasks a driver is faced with. The idea is that a driver flows through the model by answering questions such as vehicle from the right? (yes/no) and restricted view? (yes/no). When the answer to both these questions is no, the driver continues at the same speed. The resulting model can be regarded as a decision tree. What drivers need to do to continue at the same speed is not explained in the information flow control model. This is the main drawback to apply this modelling approach to analyse overtaking to find the assistance needs. To identify the subtasks of overtaking, it is necessary to know what drivers need to do at decision points.

3.2.4 Task analysis
In principle, a task-analysis is no more than a systematic bare enumeration, or catalogue, of the components of a task; whilst a task may be defined as a goal oriented collection of activities subject certain structural and environmental limitations (Michon and Van der Molen, 1977). A task analysis aims to train task performers or to pinpoint the problem areas of the task performance. An extensive task analysis exists of three parts: task requirements, performance objective and ability requirements (Brookhuis, 1989). Applications of task analyses are limited, mainly because empirical bases of behaviour classifications are often only possible at a less detailed level, for example to show the difference between perceptual and loco motional parts of task performance. An extensive task analysis of all subtasks of the driving task was performed by McKnight and Adams (1970), which resulted in 45 major tasks, composed of more than 1700 elementary tasks. Passing was one of the 45 major tasks, existing of more than twenty elementary tasks. This passing is similar to overtaking, when the optional subtask to return to the right lane is included. Elements involved in the overtaking task, such as cars, infrastructure and drivers have changed substantially in the last thirty years, which makes an update of McKnight and Adams’ task analysis to current circumstances necessary. This updated version enables to distinguish assistance needs and, in turn, to design an overtaking assistant.

Another effort with driver task analysis is made by Summala (1997), resulting in a driver task cube that outlines basic dimensions of the driver’s task to model behavioural adaptation. This driver task cube is displayed in Figure 3.3 and includes overtaking manoeuvres as a lower-level goal largely determined by the targeted speed level.

In addition to these theoretical task analysis developments, more practical applications of task analysis are done especially in the field of driver assistance system design. An American lane change observation study includes a kind of task analysis, for the design of a lane change collision avoidance system for one-directional roads (Lee et al., 2004). Another American study of the development of a lane change blind spot warning system also establishes assistance needs based on performed driving tasks during lane changes (Cody, 2005). Finally, Fastenmeier and Gstalter (2007) state that a driving task analysis is recognised to be a good tool in traffic safety research and practice.
Task analysis is the only driver behaviour model that is suitable to develop driver assistance systems. This is one of the reasons why a task analysis is chosen in the present study to distinguish those subtasks of overtaking that need assistance most. Another reason is that a task analysis gives the possibility to pinpoint all subtasks of overtaking, enabling to select those subtasks that possible need assistance.

3.3 The overtaking task analysis

This section creates a presumed model of overtaking. The presented task analysis divides the overtaking task in five phases, each existing of several subtasks being either basic control tasks, general driving tasks or situational behaviours. Figure 3.4 presents the divided phases and the subtasks involved. In this flow diagram the overtaker flows through the arrows. At each decision point (yes/no) the arrow divides and, depending on the right answer, the overtaker can continue or has to wait. The dotted lines represent alternative paths. This section explains each phase in more detail and when possible, the subtasks are quantified as well, to give an indication of when and how fast drivers execute the subtasks. This is necessary knowledge for the design of an overtaking assistant, to know how much time there is to assist drivers.
Chapter 3 – Overtaking task analysis and matching assistance needs

Figure 3.4 The overtaking task analysis, presenting all subtasks of overtaking
The first phase is the decision whether to overtake or not, where drivers verify overtaking wish or need, whether overtaking is permissible and opportunity with respect to infrastructural overtaking opportunities. A driver’s overtaking wish depends on the desired speed, the speed of the preceding vehicle, whether the driver is in hurry and other driving behavioural and attitudinal factors. Chapter 6 will show that the theoretical overtaking demand that generates an overtaking wish for each speed difference is roughly ten times higher than the observed overtaking frequency. To give an example, for a flow of 700 vehicles in one direction, with an average speed of 90 km/h, a standard deviation of 8 km/h and an opposing flow of 400 vehicles, the theoretical overtaking demand calculated with Wardrop’s catch-up formula (equation 6.1) for the busy direction is 273, while the observed overtaking frequency was 25 /km-h. For this example, the number of drivers with an overtaking wish will lie somewhere between 25 and 273 for in total 700 drivers.

When drivers have an overtaking wish, it needs to be verified whether overtaking is permissible. Information on overtaking permissions is generally gathered at the start of the road section, and stored in short-term memory (Houtenbos et al., 2005a). When drivers feel an overtaking wish, they generally scan the roadside again for overtaking regulation signs. Since allowance of overtaking is not affected by drivers, the purpose of the quantification of this subtask is limited. Chapter 6 will show that overtaking manoeuvres are still observed on no overtaking zones and that the percentage of violators is dependent on the distribution of traffic in both driving directions: drivers who get fewer opportunities to overtake (high opposing flows), are more inclined to ignore an overtaking prohibition. Violations with regulation could also occur at the end of the manoeuvre, while the manoeuvre was started at a location where it was allowed to overtake. The non-compliance to overtaking prohibition is indicated in Figure 3.4 with a dotted line from no to opportunity?

When it is wished and allowed to overtake, the third subtask of the first phase of overtaking manoeuvres is to look for an overtaking opportunity, which at this stage includes only verification of more or less static, infrastructural factors, such as hills, curves, intersections, railroad crossings, bridges and tunnels. Dynamic opportunity factors, such as potential oncoming vehicles, are judged in the next phase. With regard to the infrastructure, there should be no overtaking limitations for the whole overtaking distance. McKnight and Adems (1970) assumed that this overtaking distance is judged by the driver on the basis of the preceding vehicle’s speed. However, analysis of the observed overtaking manoeuvres described in Chapter 2 showed that the duration of an overtaking manoeuvre is independent of the preceding vehicle’s speed. McKnight and Adems (1970) further state that the overtaking
distance depends on the duration of the manoeuvre which is dependent on the acceleration capability of the car, which in turn depends on the load of the car (passengers, cargo, trailer). Additionally relevant are familiarity with the car and proper operation of the car.

In addition to the required overtaking distance, the driver also has to allow adequate safety margins for the return to the right lane. The gap in front of the preceding vehicle should be verified as being large enough. The opportunity judgement of this phase leads to the establishment whether the overtaking manoeuvre can be safely completed within the available overtaking distance.

3.3.2 Phase 2: Prepare to overtake

When the tasks of the first phase of the overtaking manoeuvre are checked and positive, the first task of the second phase is to judge the gap with the first oncoming vehicle. This is a fairly difficult task, for different reasons. Firstly because it is not included in other tasks of driving (McKnight and Adams, 1970), implying that drivers do not have the kind of routine in the performance of this task as in case of steering or changing gears. Secondly, drivers can make reasonable judgements of overtaking distance, but have difficulty judging oncoming vehicles’ speed (McLean, 1989). Even errors of own speed estimations are sufficiently great that drivers should consult speedometers (Evans, 1991). Estimates of oncoming vehicles’ speed are influenced by their own car speed and the speed limit (McKnight and Adams, 1970).

When the gap with oncoming vehicles is sufficient, all surrounding traffic is observed, starting with deviations of the preceding vehicle. Activities of the preceding vehicle such as signalling to indicate a left turn, preparing an overtaking manoeuvre, sudden deceleration, weaving or wandering, should lead to the decision not (yet) to overtake. When the preceding vehicle is accelerating, it would also be better to wait with the overtaking manoeuvre. However, this is found to be difficult to detect: when a driver is following a car ahead at a distance of 30 m, a minimum change of 3.7 m is needed before the driver will become aware that the distance is increasing or decreasing, that is, a change in relative velocity (Mortimer, 1988). Finally, in addition to the preceding vehicle and oncoming vehicles, the driver should take notice of traffic from behind, possibly also performing an overtaking manoeuvre.

Important during the second phase is to maintain a proper following distance prior to the lane change. On two-lane rural roads, a time headway of 2 s as used in most European countries is regarded as adequate (cited in Lamm et al., 1999). However, during the overtaking
observation study described in Chapter 2, only one driver kept more than 2 s headway (flying overtaking). More than half of the drivers kept headways shorter than 1 s. Rajalin (1997) interviewed drivers who were driving with short headways and they often gave *preparing to overtake* as a reason for close following.

The final task of the second phase is indicator usage. Although obligatory in the Netherlands, about 20% of the observed drivers described in Chapter 2 did not use their indicator at the start of the overtaking manoeuvre.

The time frame in which the second phase is performed is called the *perception-reaction time*. Wilson et al. (1989) present an extensive description of perception-reaction time. The in Chapter 2 observed perception-reaction times are measured as the time that elapses when the last oncoming vehicle has passed the overtaker and the moment the overtaker’s front left wheel touches the centre line. Twenty-one of the 26 observed perception-reaction times were shorter than 1 s.

For the establishment of overtaking assistance needs, the second phase is important. Accident analysis has shown that the majority of overtaking accidents arise from a decision to start the overtake in unsuitable circumstances (Clarke et al., 1999).

### 3.3.3 Phase 3: Changes lane

The actual start of the manoeuvre in terms of movements is included in the third phase, where the overtaker changes lane. This phase starts with steering, accelerating and monitoring to let the vehicle enter the centre of the new lane. In case of a flying overtaking, acceleration is not necessary. The in Chapter 2 observed average duration of the third phase of the overtaking manoeuvre is 1.5 s with a standard deviation of 0.5 s.
3.3.4 Phase 4: Pass

In the fourth phase, the overtaking vehicle is in the opposing traffic lane and passes the preceding vehicle. During an accelerative overtaking manoeuvre, the pass of the preceding vehicle is a continuation of acceleration, possibly requiring a gear change. According to McKnight and Adems (1970), the two tasks during the pass of the preceding vehicle are to signal the preceding vehicle if necessary and flick headlights at night. Both are not commonly used in the Netherlands and therefore not included in Figure 3.4. The overtaker passes the preceding vehicle while monitoring the gap with possible oncoming vehicles. In theory, acceleration till the desired speed is enough, but most drivers continue accelerating as long as they are in the left lane and adjust the speed to the desired speed when back to the right lane. If sudden acceleration is needed, the driver needs press the accelerator to the floor to finish the manoeuvre quickly. But, if the opportunity to complete the pass is uncertain, the pass could be aborted and the driver returns to the right lane, behind the preceding vehicle and the overtaking manoeuvre may start again at phase one.

When the sight distance permits, several vehicles can be passed in one overtaking manoeuvre. This is defined in Chapter 2 as the 2+ strategy and applied to about 10% of the observed overtaking manoeuvres described in Chapter 2. The average time spent in the left lane, that is, the duration of the fourth phase of the overtaking manoeuvre is 4.2 s with a standard deviation of 2.3 s.

3.3.5 Phase 5: Return to the right lane

The fifth and final phase of the overtaking manoeuvre is the return to the right lane. Similar to the start of the manoeuvre, the indicator should be used to indicate a lane change. For the
observed overtaking manoeuvres described in Chapter 2, more than half of the overtakers did not use the indicator at the end of the manoeuvre.

The steering action to position the vehicle in the centre of the right lane can start if both headlights of the overtaken vehicle are observed in the rear view mirror. But if the gap with the oncoming vehicle becomes critical, that is, smaller than 4 s (Van der Horst and Hogema, 1993), the driver can decide to move back to the right lane sooner, for example, when both headlights are observed in the right sight mirror. The risk of a (severe) accident when cutting in in front of the overtaken vehicle is smaller than with oncoming vehicles, because the speeds are in the same direction and, presumably, the overtaker’s speed is higher. Back in the right lane, drivers need to control the speed again. If the overtaking vehicle enters the right lane behind a new preceding vehicle with a speed lower than the desired speed, the overtaker’s speed has to be adjusted to this speed. The average duration of the fifth phase of the observed overtaking manoeuvres described in Chapter 2 is 2.7 s with a standard deviation of 0.7 s.

### 3.3.6 Total overtaking manoeuvre

The presented task analysis divides the overtaking manoeuvre into five phases, in total consisting of more than 20 subtasks. The execution of all these subtasks for the observed manoeuvres in Chapter 2 takes 7.8 s with a standard deviation of 2.5 s. The next section continues with a description of the established matching assistance needs.

### 3.4 Assistance needs and ranking per subtask

The presented overtaking task analysis serves as a basis for the design of an overtaking assistant. It exposes all subtasks of the overtaking manoeuvre which may need assistance. For this purpose, the needs for assistance per subtask are established and ranked either crucial (★★★★), wished (★★) or nice (★). This ranking is based on literature findings, completed with own perspectives. The needs, together with their ranking and potential availability in existing assistance systems are displayed in Table 3.2. In total ten assistance needs are established of which some are present more than once during the overtaking manoeuvre. For the subtasks steering, accelerating, monitoring, maintaining speed, continuing acceleration or deceleration and indicator on/off, no assistance needs are established, because these are assumed to be such general driving tasks that assistance is wished only at the intervention level or automation level (explained in the next chapter), where assistance systems take over control. The established assistance needs are discussed in the following subsections, also verifying whether readily available assistance systems could serve those needs. An overview of all systems that could possibly assist during overtaking is presented in Figure 3.5. The established needs with the highest ranking for which no assistance systems are yet available are the ones most suitable to design an overtaking assistant for. The overtaking assistant design is described in the next chapter, where the needs are linked with functional requirements and usability requirements of the overtaking assistant. Note that for the establishment of the assistance needs in this chapter, it is assumed that the overtaking assistant will be a prescriptive informing system, rather than an intervening system or an automating system. This was already explained in the research scope (Chapter 1) and will be clarified further in Chapter 4.
### Table 3.2: Assistance needs, ranking and availability in existing assistance systems for all subtasks of the overtaking task

<table>
<thead>
<tr>
<th>Subtask</th>
<th>No.</th>
<th>Assistance need</th>
<th>Information on:</th>
<th>Ranking1</th>
<th>Ready (possible) available in assistant?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verifying overtaking wish</td>
<td>1</td>
<td>Possible speed gain</td>
<td></td>
<td>●</td>
<td>Not available</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Speed limits</td>
<td></td>
<td>●</td>
<td>Intelligent speed adaptation / route navigation systems</td>
<td></td>
</tr>
<tr>
<td>Checking whether overtaking is permissible</td>
<td>3</td>
<td>Overtaking prohibitions</td>
<td></td>
<td>★</td>
<td>Route navigation systems</td>
<td></td>
</tr>
<tr>
<td>Checking infrastructural opportunities</td>
<td>4</td>
<td>Curves/hills/sight distance</td>
<td></td>
<td>★★★</td>
<td>Route navigation systems</td>
<td></td>
</tr>
<tr>
<td>Keeping sufficient gap with oncoming vehicle</td>
<td>5</td>
<td>Available overtaking gap size</td>
<td></td>
<td>★★★</td>
<td>Not available</td>
<td></td>
</tr>
<tr>
<td>Monitoring deviations of preceding vehicle</td>
<td>6</td>
<td>Intended behaviour preceding vehicle</td>
<td></td>
<td>★★★</td>
<td>Vehicle-to-vehicle communication</td>
<td></td>
</tr>
<tr>
<td>Checking other obstructing traffic</td>
<td>7</td>
<td>Intended behaviours other traffic</td>
<td></td>
<td>★★★</td>
<td>Vehicle-to-vehicle communication</td>
<td></td>
</tr>
<tr>
<td>Maintain safe headway with preceding vehicle</td>
<td>8</td>
<td>Headway size</td>
<td></td>
<td>★</td>
<td>Adaptive Cruise Control / Forward collision warning system</td>
<td></td>
</tr>
<tr>
<td>Change to lower gear</td>
<td>9</td>
<td>Fuel usage / revs</td>
<td></td>
<td>●</td>
<td>Fuel-efficiency support tool</td>
<td></td>
</tr>
<tr>
<td>Switch indicator on</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steering, accelerating, monitoring</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitor deviations of preceding vehicle</td>
<td>6</td>
<td>Intended behaviour preceding vehicle</td>
<td></td>
<td>★★★</td>
<td>Vehicle-to-vehicle communication</td>
<td></td>
</tr>
<tr>
<td>Checking other obstructing traffic</td>
<td>7</td>
<td>Intended behaviours other traffic</td>
<td></td>
<td>★★★</td>
<td>Vehicle-to-vehicle communication</td>
<td></td>
</tr>
<tr>
<td>Switch indicator on</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continue</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change gear</td>
<td>9</td>
<td>Fuel usage / revs</td>
<td></td>
<td>●</td>
<td>Fuel-efficiency support tool</td>
<td></td>
</tr>
<tr>
<td>Pass preceding vehicle</td>
<td>6</td>
<td>Intended behaviour preceding vehicle</td>
<td></td>
<td>●</td>
<td>Vehicle-to-vehicle communication</td>
<td></td>
</tr>
<tr>
<td>Monitor gap with oncoming vehicle</td>
<td>10</td>
<td>Remaining gap with oncoming vehicle</td>
<td></td>
<td>★</td>
<td>Extended collision avoidance systems</td>
<td></td>
</tr>
<tr>
<td>Pass other vehicles</td>
<td>10</td>
<td>Remaining gap with oncoming vehicle</td>
<td></td>
<td>★</td>
<td>Extended collision avoidance systems</td>
<td></td>
</tr>
<tr>
<td>Switch indicator on</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steering, accelerating monitoring</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch indicator off</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check whether speed equals speed</td>
<td>2</td>
<td>Speed limits</td>
<td></td>
<td>●</td>
<td>Route navigation systems</td>
<td></td>
</tr>
<tr>
<td>Maintain speed</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continue acceleration/deceleration</td>
<td></td>
<td>None, general driving task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Ranking: ● = nice, ★ = wished, ★★★ = crucial. 2 For a description of these assistance systems see (Bishop, 2005)
3.4.1 Assistance needs for decision to overtake (phase 1)
The first established assistance need is information on time gain possibilities that assist drivers with the subtask to verify whether there is an overtaking wish or not. When drivers know the limited travel time gain of an overtaking manoeuvre, they might decide not to overtake. To give an example, over a distance of 5 km, staying behind a vehicle driving 80 km/h compared to overtaking it and driving 100 km/h saves 15 s. However, the incentive for overtaking is often to gain comfort rather than to save travel time. Anyway, information to assist with the overtaking wish is assumed to be less suitable for in-vehicle assistance systems and the rank of this assistance need is nice, since this information does not influence the ease of the overtaking manoeuvre itself.

Figure 3.5 Available assistance systems that could serve assistance needs in overtaking

A second assistance need for the first phase of overtaking is information on speed limits. Such information is included in intelligent speed adaptation systems, that is assumed to prevent drivers from exceeding the speed limits (Carsten, 2002). Speed limit information has also been added to some available route navigation systems (e.g. TomTomInternationalBV, 2007). In-vehicle speed information also prevents drivers from maintaining to a speed limit of 80 km/h while the real limit is 100 km/h. This also reduces the overtaking demand for other drivers. Fast drivers’ overtaking wish could also reduce when confronted with the speed limit
in their vehicle. In both cases, speed limit information influences the number of overtaking manoeuvres. The rank given to speed limit information is *nice*, since this information does not influence the ease of the overtaking manoeuvre itself.

The third assistance need is information on overtaking prohibitions, which could be added to route navigation systems or lane departure warning systems. The latter warns drivers when they leave their driving lane unintended. When this system is able to distinguish overtaking prohibitions indicated by double continuous centre lines, it could warn drivers that overtaking is not permitted. Again, this assistance need is ranked as *nice*.

For the judgement whether there is an overtaking opportunity regarding curves, hills and sight distance, extension of route navigations systems is an option. BMW works on dynamic pass prediction tools that informs drivers about overtaking unsafe infrastructure (Loewenau et al., 2006). The required information is obtained by GPS. Dynamic environmental limitations, such as fog or heavy rain, should ideally be included as well. This assistance need, to get information on infrastructural limitations of overtaking opportunities, is ranked as *crucial*, based on the knowledge that overtaking accidents often occur due to infrastructural sight limitations (Lamm et al., 1999).

### 3.4.2 Assistance needs for overtaking preparation (phase 2)

The fifth established assistance need is information on available gap size, to assist with the subtask to judge whether the next gap in the oncoming traffic stream is sufficiently large to safely perform the manoeuvre. This is a fairly difficult subtask of overtaking (Gray and Regan, 2005). Drivers can make reasonable estimates of the distance to an oncoming vehicle, but have more difficulties with judging the speed of that vehicle (Farber et al., 1967). The accepted passing distance adopted by drivers tends to remain constant regardless of the oncoming vehicle’s speed. Furthermore, drivers are found to be able to do little more than detect whether the headway is decreasing or increasing (cited in Hoffmann and Mortimer, 1996). Accuracy of judgments increases as headway decreased and when the gap is closing. These literature findings on overtaking gap estimation have led to the highest ranking of the assistance needs as *crucial*. No existing assistance systems have functionalities to give information on available gap size.

Assistance need number six involves information on intended behaviour of preceding vehicles. Vehicle-to-vehicle communication systems are being developed, to inform drivers about changes in driving behaviour of preceding vehicles and possible also for other surrounding traffic (Bishop, 2005). This also covers assistance need for information on deviations (e.g. swerving or left turning) of other surrounding traffic, the next subtask in this phase of the overtaking manoeuvre. Both assistance needs are ranked as *crucial*, since the largest dangers during overtaking come from preceding vehicles or from unseen vehicles at the start of the manoeuvre (Clarke et al., 1999).

To assist overtakers with maintaining a safe gap with the preceding vehicle, information on gap size may help, currently provided by Adaptive Cruise Control (ACC). Most ACCs intervene with the driving task to keep a safe gap, adjustable by drivers. The minimum safe headway that can be set is often 1 s (Hoedemaeker, 1999). As soon as drivers use the brake
pedal or the clutch, the system switches off, the gas pedal overrules the system. In case of overtaking, this means that the ACC does not work just before overtaking and during overtaking, since drivers will touch pedals for example to start accelerating. Hoedemaeker (1999) found that overtaking on two-lane rural roads is more dangerous when driving with ACC. Proposed forward collision warning systems are more suitable to assist drivers to keep a safe following distance prior to overtaking. When driving with forward collision warning, it is expected that the percentage of driving distance spent in rear-end collision mode is reduced by up to 34% (Regan et al., 2006). The ranking of this assistance need is nice because information on headway size is useful prior to overtaking, when headways could be fairly short. This need did not get a higher ranking because in our view, shorter headways for drivers awaiting an overtaking opportunity could be temporarily permitted. Observed average perception-reaction times were just below 1 s (Lamm et al., 1999) and provide confidence that temporary shorter headways of for example 1 s are safe when drivers are preparing an overtaking manoeuvre.

3.4.3 Assistance needs for lane change (phase 3)
Assistance with the task to check other obstructing traffic was already discussed in the previous subsection. This could be included in vehicle-to-vehicle communication systems. There are no other assistance needs distinguished for the lane change phase.

3.4.4 Assistance needs for passing (phase 4)
The ninth assistance need involves information on fuel usage or revs to assist drivers when to change gear. A fuel-efficiency support tool has been developed for this, including the functionality not to overload drivers with information while they are busy with other tasks of driving (Van der Voort, 2001). This assistance need is ranked as nice.

The tenth and last established assistance need for the overtaking task is information on the remaining gap with oncoming vehicles. Current available collision avoidance systems warn drivers of possible collisions when the remaining time gap with the possible collision object is 3 s or less (Lee et al., 2004). Such warnings during overtaking are supposed to increase the danger of the situation, where drivers probably are able to safely complete the manoeuvre. An additional advice whether it is possible to move back to the right lane would be more useful to reduce the possibility of too small time-to-collisions (TTCs) with oncoming vehicles. Assistance for the subtask to monitor the gap with oncoming vehicles is ranked as wished.

3.4.5 Assistance needs for lane change back to right lane (phase 5)
For the final phase of the overtaking manoeuvre, the change back to the right lane, no special assistance needs are determined.

In summary, existing driver assistance systems have the potential to assist with most established assistance needs for the different subtasks of the overtaking task. For one of the assistance needs ranked as crucial no assistance systems were found to assist with this subtask. This is the need for information whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. The next chapter presents the design of an overtaking assistant that assists with this subtask of overtaking. But before such
an assistance device can be designed, it is necessary to verify whether the presented overtaking task analysis is applicable internationally.

### 3.5 International differences in overtaking rules and execution

The presented task analysis is based on Dutch overtaking manoeuvres. Whether this task analysis is also applicable to other countries depends on differences in overtaking rules and executions. To explore these differences, a small scale questionnaire amongst drivers in 17 countries has been performed. The included countries are presented in Table 3.3. The questionnaire was handed out at two traffic and transport related conferences, resulting in respondents with traffic related jobs. The reported results are the respondents’ answers, based on their driving experiences in their own country. They all hold a driving license for at least 5 years. It is stressed that the presented results are subjective, as experienced by respondents. Most countries are represented by 1 respondent, which makes statistical analyses by country impossible. The presented results of the questionnaire are meant to give an indication of international similarities and differences in overtaking rules and executions.

**Table 3.3 Countries included in the small scale overtaking questionnaire with the number of respondent in brackets**

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Respondent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia (1)</td>
<td></td>
</tr>
<tr>
<td>Austria (1)</td>
<td></td>
</tr>
<tr>
<td>Belgium (1)</td>
<td></td>
</tr>
<tr>
<td>Brazil (1)</td>
<td></td>
</tr>
<tr>
<td>China (1)</td>
<td></td>
</tr>
<tr>
<td>Great Britain (2)</td>
<td></td>
</tr>
<tr>
<td>Germany (1)</td>
<td></td>
</tr>
<tr>
<td>Italy (3)</td>
<td></td>
</tr>
<tr>
<td>New-Zealand (3)</td>
<td></td>
</tr>
<tr>
<td>Norway (3)</td>
<td></td>
</tr>
<tr>
<td>Portugal (1)</td>
<td></td>
</tr>
<tr>
<td>Spain (1)</td>
<td></td>
</tr>
<tr>
<td>Sweden (1)</td>
<td></td>
</tr>
<tr>
<td>United States of America (4)</td>
<td></td>
</tr>
</tbody>
</table>

The questionnaire is displayed in Appendix A and includes questions about overtaking rules and execution on two-lane rural roads. Speed limits on these roads in the included countries vary between 80 and 100 km/h. Almost all countries have a lower limit for (large) trucks, the lowest being 70 km/h in Sweden and Italy. All respondents indicated to have a desired driving speed at or just above the speed limit. Respondents of most countries indicates to experience large differences in driven speeds on these roads, except for respondents from Australia and China, who experienced similar speeds for all drivers.

#### 3.5.1 Overtaking wishes, permissions and opportunities

The threshold speed difference to provoke an overtaking wish for the respondents varies between 5 and 40 km/h. These are large differences: one respondent with a desired speed of 100 km/h will overtake preceding vehicles when these are driving 95 km/h, the other, with the same desired speed, when preceding vehicles are driving 60 km/h.

Table 3.4 presents how an overtaking prohibition is indicated in the included countries. Finland New-Zealand and the USA use yellow paint (instead of white) for the (double) continuous centre line to indicate overtaking prohibitions. Other countries do use yellow paint for temporarily overtaking prohibitions, for example in case of road works. As a physical barrier, Sweden mainly uses cable barriers (Bergt et al., 2005).
### Table 3.4 Indication overtaking prohibitions

<table>
<thead>
<tr>
<th>Country</th>
<th>Sign</th>
<th>(Double) continuous centre line</th>
<th>Physical barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Always</td>
<td>Always</td>
<td>Not</td>
</tr>
<tr>
<td>Austria</td>
<td>Always</td>
<td>Always</td>
<td>Not</td>
</tr>
<tr>
<td>Belgium⁷</td>
<td>Always</td>
<td>Always</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Brazil</td>
<td>Always</td>
<td>Always</td>
<td>Sometimes</td>
</tr>
<tr>
<td>China</td>
<td>Always</td>
<td>Always</td>
<td>Not</td>
</tr>
<tr>
<td>Great Britain</td>
<td>Sometimes</td>
<td>Always</td>
<td>Sometimes/Rarely</td>
</tr>
<tr>
<td>Finland</td>
<td>Always</td>
<td>Always</td>
<td>Rarely</td>
</tr>
<tr>
<td>Germany</td>
<td>Always</td>
<td>Always</td>
<td>Rarely</td>
</tr>
<tr>
<td>Italy</td>
<td>Always</td>
<td>Always</td>
<td>Rarely</td>
</tr>
<tr>
<td>the Netherlands</td>
<td>Always</td>
<td>Always</td>
<td>Sometimes</td>
</tr>
<tr>
<td>New-Zealand</td>
<td>Not</td>
<td>Always</td>
<td>Sometimes/Rarely</td>
</tr>
<tr>
<td>Norway</td>
<td>Always</td>
<td>Always</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Poland</td>
<td>Always</td>
<td>Always</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Portugal</td>
<td>Always</td>
<td>Always</td>
<td>Rarely</td>
</tr>
<tr>
<td>Spain</td>
<td>Always</td>
<td>Always</td>
<td>Rarely</td>
</tr>
<tr>
<td>Sweden</td>
<td>Sometimes</td>
<td>Always</td>
<td>Often</td>
</tr>
<tr>
<td>USA²</td>
<td>Often</td>
<td>Always</td>
<td>Often/Sometimes</td>
</tr>
</tbody>
</table>

⁷ Double continuous lines are not used in Belgium

² The state of Texas uses barriers that cannot be crossed

Reasons for overtaking prohibitions in all countries are mostly restricted views. Prohibitions are occasionally installed in case of bad surface, temporary high traffic flows and bad weather. Austria has overtaking prohibitions near bus stops and Italy has some tunnels with overtaking prohibitions.

Some countries install overtaking prohibitions for the sole purpose of avoiding unsafe overtaking manoeuvres. For example in the Netherlands Self Explaining Roads as part of the Dutch Sustainable Safety Program (see frame) include overtaking prohibitions on all two-lane rural roads (Wegman and Aarts, 2005).

In the Netherlands, an overtaking prohibition for special vehicle types, for example trucks or vehicles with trailers, is indicated with road signs, at the beginning of each road section. No-overtaking zones for all traffic are always indicated with at least one continuous line between two driving directions. Until the eighties these zones were positioned only in curves or on hills, where it is difficult to see possible oncoming vehicles. The "Sustainable Safety Program", launched in 1992, including the self-explaining roads concept, includes overtaking prohibitions on all two-lane rural roads with a speed limit of 80 km/h (distributor road) and 100 km/h (flow road). This program is supposed to be a strong advice for road authorities: they are recommended to install the prohibition on their roads, but they are not obligatory to apply the sustainable safety design. If they do, there should be at least two continuous lines between the two driving directions to indicate the overtaking prohibition. A physical barrier is preferred, since prohibitions indicated with one or two continuous centre lines are easily violated.
Table 3.5 presents compliance with overtaking prohibitions according to the respondents. Compliance to overtaking prohibitions that are installed only for safety reasons (no sight distance restrictions, no bad surface, no bad weather, no road works), is estimated to be low in all countries. Furthermore, all respondents think that the chance of being caught when violating an overtaking prohibition is small, with a maximum chance of 10% estimated for America. However, in the Czech Republic, not included in this questionnaire, overtaking is in the list of most ticketed traffic violations (Zaidel, 2000). The fine when caught for overtaking violations varies between $50 and $1000 in the USA and between €30 and €100 in European countries. Finland applies income-dependent fines. English drivers and young drivers in the Netherlands get a notification on their driving license, with the risk of loosing their license. In the USA and Sweden drivers also have the risk to loose their driving license after committing overtaking violations.

Table 3.5 Compliance with overtaking prohibitions, according to the respondents

<table>
<thead>
<tr>
<th>Compliance</th>
<th>Austria, China, Great Britain, Finland, Germany, New-Zealand, Norway, Sweden</th>
<th>America, Australia, Belgium, Netherlands, Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Brazil, Italy, Poland, Spain</td>
<td></td>
</tr>
</tbody>
</table>

When overtaking is permitted, the judgment whether it is safe to overtake given the infrastructure is rather subjective. Most respondents indicated to observe overtaking manoeuvres at locations where, according to them, it is not safe to do so.

Table 3.6 Indicator usage during overtaking in practise

<table>
<thead>
<tr>
<th>Country</th>
<th>At start manoeuvre</th>
<th>During manoeuvre</th>
<th>At end manoeuvre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Sometimes</td>
<td>Never</td>
<td>Rarely</td>
</tr>
<tr>
<td>Austria</td>
<td>Sometimes</td>
<td>Often</td>
<td>Often</td>
</tr>
<tr>
<td>Belgium</td>
<td>Sometimes</td>
<td>Never</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Brazil</td>
<td>Often</td>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>China</td>
<td>Often</td>
<td>Never</td>
<td>Often</td>
</tr>
<tr>
<td>Great Britain</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Finland</td>
<td>Often</td>
<td>Rarely</td>
<td>Often</td>
</tr>
<tr>
<td>Germany</td>
<td>Often</td>
<td>Often</td>
<td>Often</td>
</tr>
<tr>
<td>Italy</td>
<td>Rarely</td>
<td>Often</td>
<td>Rarely</td>
</tr>
<tr>
<td>the Netherlands</td>
<td>Rarely</td>
<td>Often</td>
<td>Rarely</td>
</tr>
<tr>
<td>New-Zealand</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>Rarely</td>
</tr>
<tr>
<td>Norway</td>
<td>Often</td>
<td>Never</td>
<td>Often</td>
</tr>
<tr>
<td>Poland</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Portugal</td>
<td>Sometimes</td>
<td>Never</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Spain</td>
<td>Often</td>
<td>Rarely</td>
<td>Often</td>
</tr>
<tr>
<td>Sweden</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>USA</td>
<td>Sometimes</td>
<td>Never</td>
<td>Sometimes</td>
</tr>
</tbody>
</table>

3.5.2 Indicator usage

According to the rules for most countries, drivers should use their indicator for every lane change. With regard to overtaking, this means the indicator should be used at the start of the manoeuvre, to indicate a lane change to the opposing traffic lane and at the end of the
manoeuvre, to indicate a lane change back to the right lane (left lane in Great Britain and New Zealand). This rule applies for most countries, except for Austria, Germany and Sweden that have the rule to keep the indicator on when driving in the opposing traffic lane. Although the rules with respect to indicator usage are fairly similar, the usage in practise differs, as presented in Table 3.6.

Apart from the indicator, the start of an overtaking manoeuvre can also be indicated by means of other signs. For example, in Finland and Spain, it is obligatory when it is dark to flash the headlights to warn possible oncoming vehicles. This is also often done in Italy and Brazil, sometimes in the USA and rarely in Germany, Norway and Portugal. All other countries do not use this sign.

3.5.3 Safe headway keeping

None of the included countries seem to have rules for distance keeping during overtaking manoeuvres. In theory, at the start of the manoeuvre, drivers should apply the *two-second rule*: keep at least 2 s headway with preceding vehicles. This rule is known in Belgium, Finland, the Netherlands, New-Zealand and Austria. Chapter 2 showed that during the overtaking observations on Dutch roads, one observed headway at the start of the overtaking manoeuvre was larger than 2 s. More than half of the observed headways were smaller than 1 s.

With regard to the headway between the overtaker and the overtaken vehicle at the end of the manoeuvre, it turns out that only New-Zealand has a rule for this: *the overtaker should at least have 100 m free road way ahead to finish an overtaking manoeuvre*. Respondents indicate that their chosen time to go back to the right lane is the moment that both headlights of the overtaken vehicle are visible in the rear-view mirror or the right sight mirror.

3.5.4 International applied alternative overtaking strategies

The questionnaire also includes questions about applied overtaking strategies in practice. The in Chapter 2 defined overtaking strategies accelerative, flying, piggy backing and 2+ are applied in all countries. All respondents indicate to start accelerating already in the right lane and continue accelerating during the whole manoeuvre, until they are back to the right lane again. After this, they adjust the speed to their desired speed, possibly requiring some deceleration. A few respondents indicate to stop accelerating as soon as the desired speed is reached. They rarely use maximum acceleration capacity.

In addition to these strategies, several other overtaking executions are applied as well. Table 3.7 gives an overview of the applied overtaking executions as observed by the respondents either often or sometimes. If a country is not listed in a row of Table 3.7, this execution was either rarely or never applied in that country.

---

7 In The Netherlands, this is 'only' a rough and ready rule. Police officers decide for each individual case, whether drivers applied an appropriate following distance. In practice, fines are only given for headways smaller than 0.5 s Veilig Verkeer Nederland. (2007). Retrieved 27 April 2007, from http://www.pvvh.nl/smartsite.shtml?id=55217
Table 3.7 Applied ‘wrong’ overtaking executions

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Often or sometimes applied in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three vehicles side by side on two traffic lanes</td>
<td>Austria, Belgium, Brazil, China, Great Britain, Germany, Italy, New-Zealand, Poland, Portugal, USA</td>
</tr>
<tr>
<td>The preceding vehicle slows down to assist the overtaker</td>
<td>Spain</td>
</tr>
<tr>
<td>The oncoming vehicle slows down to assist the overtaker</td>
<td>Great Britain, Spain</td>
</tr>
<tr>
<td>The preceding vehicle moves to the emergency lane</td>
<td>Australia, Brazil, New-Zealand, Poland, Spain, Sweden</td>
</tr>
<tr>
<td>Due to misjudgements of the overtaker, other involved vehicles have to take invasive actions</td>
<td>Belgium, Great Britain, Poland, Portugal, Spain</td>
</tr>
<tr>
<td>The overtaker cuts in in front of the overtaken vehicle</td>
<td>Brazil, Great Britain, Portugal, New-Zealand, USA</td>
</tr>
</tbody>
</table>

In conclusion, the questionnaire points out that rules with regard to overtaking are fairly similar in the 17 included countries. Overtaking execution, however, differs substantially especially regarding driven speeds on two-lane rural roads, the threshold speed difference to provoke overtaking manoeuvres, indicator usage and application of alternative overtaking executions. An explanation for these differences may be the difference in attention paid to overtaking during driving lessons. In the Netherlands, overtaking is not included as one of the obligatory special manoeuvres of Dutch driving lessons. A guide how to instruct The new driving, a initiative to drive safely and environmental friendly, does include a section on the overtaking manoeuvre, involving terms such as appropriate overtaking, correct gear and sufficient space (NOVEM, 2006). Great Britain has included safe overtaking in their Pass Plus program, a recommended follow-up course after drivers have obtained their driving licence, to get driving experience with an own car (DSA, 2007). Also in Eastern European countries, where overtaking is a large problem, because of the relatively many two-lane rural roads, the attention for overtaking in driving lessons grows. Nevertheless, whatever the reasons for the different overtaking executions are, assistance with overtaking may help to prevent wrong executions.

The results from the questionnaire do not give indications that overtaking in different countries includes different subtasks then the ones included in Figure 3.4, apart from the additional task in some countries to flash their headlights at the start of the manoeuvre. Similar subtasks of overtaking around the world also indicate similar assistance needs. Hence, an overtaking assistant giving information on whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre is assumed to be useful for at least all drivers from the countries included in the questionnaire.

3.6 Summary and discussion of the overtaking task analysis

To answer the second research question of this dissertation: “What are the subtasks of the overtaking manoeuvre and what are their matching assistance needs?” a thorough task analysis of the overtaking manoeuvre was carried out. The overtaking manoeuvre was divided
Assisted Overtaking

into five phases including twenty subtasks. Some of these subtasks, for example steering, accelerating, monitoring, keeping proper distance, are also performed during normal driving. In the meantime, extra subtasks such as judging speed and distance to oncoming vehicles, judging the space in front of the preceding vehicle, judging the overtaking distance and overtaking time are performed as well, which makes it a complex driving task.

For the more than twenty subtasks of the overtaking task, ten assistance needs were established. For most of them, assistance systems are already available, sometimes requesting small adjustments to make them useful during overtaking. For the assistance need for information on whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre, which was ranked as crucial no assistance system is yet available.

The verification whether the task analysis based on Dutch overtaking information is internationally applicable is done by means of a questionnaire. Drivers of 17 countries answered questions on overtaking rules and execution. Large differences between the countries were found in the threshold to provoke overtaking manoeuvres (5 to 40 km/h), compliance to overtaking prohibitions and indicator usage in practise. The overtaking strategies accelerative, flying, piggy backing and 2’ are applied in all countries included in the questionnaire. In addition, other overtaking executions are observed in almost all countries, such as three vehicles side by side on two traffic lanes. Despite execution differences, overtaking rules and thus overtaking subtasks are similar between countries.

To improve traffic safety, driver assistance systems are considered as promising tools (Brookhuis, 2005). In the introduction chapter it was shown that overtaking is a major accident cause worldwide. By means of the overtaking task analysis presented in this chapter, the subtask to judge whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre is selected as the most difficult subtask of overtaking for which assistance need is crucial. In the next chapter, an overtaking assistant is developed, assisting with this subtask.
4 Overtaking Assistant Design

A conceptual design of an overtaking assistant is presented that informs drivers on two-lane rural roads whether gaps in the oncoming traffic stream are sufficiently large to safely perform overtaking manoeuvres. The proposed design contains a green sign to indicate a safe overtaking gap, preceded by 3 s blinking red during which drivers can prepare the manoeuvre. When the gap to the next oncoming vehicle becomes critical, that is, smaller than the threshold for safe overtaking, the green sign starts blinking. The green sign keeps blinking until 3 s before a next oncoming vehicle is at the same level as the overtaker. Then, a red sign lights up, meaning that the oncoming gap is too small to safely perform an overtaking manoeuvre. When two overtaking gaps follow each other with one oncoming vehicle in between, blinking green is followed by blinking red.
4.1 Introduction

This chapter presents an overtaking assistant design that is developed to assist drivers on two-lane rural roads with overtaking gaps acceptance. It aims to answer the third research question of this dissertation: *how should an overtaking assistant be designed?*

A so-called *basic design cycle* approach is applied to design the overtaking assistant. The basic design cycle starts with a general functional description of what problem is aimed to solve with the design. The cycle successively consists of the analysis, synthesis, simulation and evaluation phase. The final step of the basic design cycle is the decision whether to continue with the designed system or to stop further development.

Figure 4.1 presents the outline of this chapter. The next section explains the applied design approach, the basic design cycle. The following sections describe the main phases of this cycle applied to the overtaking assistant in more detail. The evaluation phase is performed by means of a driving simulator experiment and a micro simulation study, described in Chapter 5 and Chapter 7 respectively. The resulting design improvements from these studies are summarised in Section 4.7 of this chapter. The final Section 4.8 summarises the resulting conceptual overtaking design plus a proposed alternative design and discusses the feasibility of the production of an overtaking assistant.
4.2 Method: the basic design cycle

Designing is the process of originating and developing a plan for a product, structure, system, or component. The aim in this dissertation research is to improve overtaking on two-lane rural roads, to exclude it as an accident cause. The chosen solution to reach this aim is to design a system, an overtaking assistant. The previous chapters showed that particularly the subtask of overtaking to judge whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre, needs assistance. This finding roughly defines the function of the overtaking assistant, which is the first step of the basic design cycle as displayed in Figure 4.2.

![Diagram of the basic design cycle](image)

*Figure 4.2 Basic design cycle applied to design the overtaking assistant (adapted from Roozenburg and Eckels, 2001)*

The *function* is the start of the design cycle, covering the intended behaviour of the new system. The function does not need to be totally specified, however global statements about the function are needed to guide the designer. Section 4.3 includes the function description of the overtaking assistant, together with some necessary assumptions enabling the conceptual design of an overtaking assistant.

The *analysis* phase of the design cycle is used to get a detailed view of the problem and to formulate all the criteria the system should satisfy. The resulting list of criteria is often called the *set of needs*. This set is a collection of mandatory characteristics, the definition of the
system. It is used to generate feasible designs, which in turn are scored on their performance. In addition to this, it is a synthesis between the objective needs on the one hand and the practical possibilities on the other. As for most systems to design, the set of needs should include all needs from all stakeholders involved. The stakeholders in case of the overtaking assistant are:
- Users (car drivers);
- Producers (automotive industry);
- Governments and law-institutions who set limitations or guidelines;
- Designers, who design the system;
- Researchers, who study the possible impacts of the system.

Section 4.4 discusses the needs of all these stakeholders and how they are dealt with during the design. The result is a set of needs of all stakeholders against which the designed system is verified in the evaluation phase of the basic design cycle of the overtaking assistant.

The synthesis phase generates a conceptual design of the overtaking assistant, combining separate elements to one new whole. In the basic design cycle, the synthesis is the moment where the new system, in this case the overtaking assistant, is described explicitly. However, at this stage, it is only a conceptual design that needs to be developed further. Section 4.5 includes the synthesis phase, describing the elements of the overtaking assistant and its functions. This section ends with a conceptual overtaking design proposal.

In the simulation phase the behaviour and characteristics of the new design are thought through before it is actually produced. For the overtaking assistant, the simulation phase includes a verification of how the assistant will act during different circumstances. The assumptions made in the function phase of the design cycle are verified in this phase of the cycle, which is presented in Section 4.6.

The evaluation phase defines the value of quality of the conceptual design. The evaluation of the overtaking assistant exists of two studies, starting with a driving simulator experiment described in detail in Chapter 5. The results of the simulator experiment lead to improvements of the proposed overtaking assistant. The updated design is subsequently tested in a microscopic traffic simulation study, to analyse the effects of different assistant settings and different penetration rates on traffic system efficiency, drivers’ comfort and safety, described in detail in Chapter 7. The consequences for the overtaking assistant design of both studies are summarised in Section 4.7. The resulting design is ultimately tested against the needs and limitations formulated as a result of the analysis phase.

The final phase of the design cycle is the decision phase, where it is decided whether the proposed system will be produced, whether optimisation of the system is necessary or whether the proposed system must be rejected. The last should be the conclusion when other solutions for the aim where the project was designed for, are more effective.

---

8 Simulation here is defined as reasoning the product to get an idea of how it will function in reality. This is a different meaning than the more general meaning of simulation as meant in other parts of this dissertation e.g. in chapter 7.
Yet, all main elements of the basic design cycle as displayed in Figure 4.2 are explained. Furthermore, an optimisation arrow is displayed at the right side of the figure. This arrow indicates that the design process is iterative and after different optimisation cycles, the design can be acceptable for production. In Figure 4.2 a dashed extension of the original optimisation arrow is added, because in our view, during the design of a system, the function could change as well. Some of the best inventions resulted from a design process originally aimed to reach another goal. The final section of this chapter discusses whether the designed system reaches its original goal.

4.3 Basic design cycle: function

A global description of the function of the intended overtaking assistant design is that it should give drivers information on whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. Important for the design is the choice for an information system rather than an intervention or automation system and that the information will be prescriptive rather than descriptive. These choices are firstly explained, followed by a list of necessary assumptions made to enable a first design of the overtaking assistant.

4.3.1 Informing, intervening or automating driver assistance systems

Driver assistance can vary from giving information to full automation of the driving task. Different classifications of assistance systems exist (e.g. Minderhoud, 1999, European Comission, 2002, Bishop, 2005, Van Driel, 2007). Here, the following classification is used:

- Informing systems. The system gives information about the actual and/or possible future position of the vehicle on the roadway or in relation to other vehicles. Drivers can choose if and how to use the information. Informing systems can be split in two groups:
  - Descriptive information systems. These systems describe the situation and drivers are free to interpret it as they want. For example a system that gives the information that the headway with the preceding vehicle is 2 s;
  - Prescriptive information systems. These systems prescribe what to do in the given situation. For example a system that gives a warning when the headway with preceding vehicles becomes smaller than 2 s. These prescriptive information systems are often called warning systems;

- Intervening assistance systems. The system intervenes with parts of the driving task, but the driver can always overrule this intervention. For example a headway keeping system, that keeps the headway at 2 s and gives back the control when drivers touch a pedal;

- Automating assistance systems. These systems take over (parts of) the driving task, without driver cooperation. For example a headway control system that keeps headways at 2 s.

Whether the overtaking assistant should be informing, intervening or automating, depends on the level of the driving task at which overtaking decisions are taken. In Chapter 3, the driving task was divided into the strategic level, the tactical level and the control level after Michon (1985). These driving task levels cannot be directly linked to the three driver support levels informing, intervening and automating. Minderhoud (1999) proposes a control model of the
driving task, that describes the driving task as a continuously repeated sequence of state perception, followed by predictions of the expected future state and a control decision after which the control action is carried out and a new state is formed. This control model of the driving task does enable linkage between driving tasks and the three intervention levels of driver assistance systems. Van Driel (2007) developed the connection between assistance level and driving tasks levels, connecting the control level of driver assistance systems with the supported driving task and those that remain within the hands of the driver. For example, the informing support system was connected to the task state perception, while the remaining tasks are not assisted. Table 4.1 captures the distinguished driving tasks and the levels of assistance displaying the connection between the two. The proposed overtaking assistant is an informing system, assisting with the future state prediction, which is a new application area for informing systems. This is included in Table 4.1 as a dashed area.

Table 4.1 Assisted driving tasks for the three assistant levels (adapted from Van Driel, 2007)

<table>
<thead>
<tr>
<th>Cyclic human driving tasks</th>
<th>Assisted tasks at the assistance levels:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>State perception</td>
<td>Informing</td>
<td>Intervening</td>
<td>Automating</td>
</tr>
<tr>
<td>Future state prediction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control decisions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control action</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New state</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Given the level of intervention of the three assistance levels and the task that the overtaking assistant aims to assist, that is, judging whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre, the overtaking assistant is made to be prescriptive informing. The next step in the development is to make a list of additional assumptions to enable a feasible overtaking assistant design.

4.3.2 Necessary assumptions for a feasible overtaking assistant design
Assumptions regarding the conditions under which the overtaking assistant should provide support are needed to enable a conceptual design, without losing the main goal out of sight. Based on the findings of the previous two chapters, the following list of assumptions is made:

1. Only accelerative overtaking is considered, the overtaking strategies flying, piggy backing, and 2+ overtaking manoeuvres (see Chapter 2 for a description) are not considered yet. Accelerative overtaking is the most common applied strategy of which piggy backing and 2+ overtaking are derived strategies. Compared to flying overtaking, the need for assistance with accelerative overtaking is assumed to be larger, since drivers might have been following a preceding vehicle for some time;

2. The environment is assumed to be ideal for overtaking: no curves or hills. This is to prevent the environment making the conceptual design of the assistant too complex. Also, developments with regard to passive overtaking assistance, which involves systems that warn drivers of unsafe environmental overtaking circumstances, already take place in the automotive industry (Loewenau et al., 2006);
3. Speeds of oncoming vehicles are assumed to remain constant during the overtaking manoeuvre. The overtaking assistant should be able to measure speeds of oncoming vehicles before the overtaking manoeuvre starts, but cannot predict possible speed changes. Oncoming vehicle are assumed to be free driving, since they have no vehicles in front. For these vehicles the assumption of constant speed is the most likely.

4. Accelerations of overtakers are assumed constant and limit by the maximum speed of the vehicle. The observations described in Chapter 2 showed that the duration of the overtaking manoeuvre is independent of the preceding vehicle’s speed, which makes the assumption of constant acceleration plausible.

These assumptions enable a first conceptual design of the overtaking assistant. The simulation phase will relax these assumptions, that is, the behaviour of the assistant during the situations that are excluded by these assumptions is verified.

4.4 Basic design cycle: analysis

The analysis phase establishes a detailed view of the problem to be solved by the system being designed. For this detailed view the results of the previous two chapters are used. Chapter 1 showed that overtaking on two-lane rural roads causes often serious accidents and other solutions as overtaking lanes and overtaking prohibitions might help to reduce the number of overtaking accidents. However, these solutions do not affect the safe performance of the manoeuvre itself. Potential to increase traffic system efficiency, drivers’ comfort and safety of the overtaking manoeuvre itself may be found in the driver assistance solution. Chapter 2 has given more information about current overtaking performance which, together with the task analysis presented in Chapter 3, resulted in the choice to design an overtaking assistant assisting with the task to judge whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre.

The next step is to create a set of needs for the overtaking assistant that includes needs of all stakeholders involved, obtained from the findings of the previous chapters, other literature findings and on own perspective. Table 4.2, presented in the final subsection of this section, summarises the needs of all stakeholders that are discussed in the preceding subsections.

4.4.1 User needs

The overtaking assistant is designed to assist drivers with overtaking gap acceptance. Crucial for the success of such systems is that drivers feel a need for this kind of assistance and are willing to use it. Identification of user needs is essential for both assistant design and assistant assessment (Zhang et al., 1998). A user needs survey of needs for assistance during driving also looks at needs for assistance during overtaking on two-lane rural roads, which is presented by Van Driel (2007). Of the group of over 1000 respondents, 61% indicates a need for warning of oncoming traffic, for example on winding and hilly roads or when the vehicle in front restricts the view, and 43% of the respondents indicates a need for an indication for a safe overtaking possibility (Van Driel, 2007). The survey does not contain further questions about more specific needs of such a system. To get more information about user needs for the overtaking assistant, a questionnaire has been included in the driving simulator experiment described in Chapter 5, to test the conceptual design of the assistant.
The first user need included in Table 4.2 is that the system should be prescriptive. Informing systems can be either descriptive or prescriptive. A descriptive overtaking assistant will for example give information on the size of the available gap, while a prescriptive overtaking assistant tells the driver whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. Prescriptive information is preferred when decisions need to be taken under time pressure. In case of overtaking, the decision moment whether to overtake or not can be rather short. When an overtaking gap is critical, it is important that drivers use it as soon as it is present (Crawford, 1963). Hence, prescriptive informing is preferred above descriptive.

The second listed need of users is that the system should be visual rather than auditory or haptic. Haptic feedback is considered to be unsuitable for prescriptive overtaking assistance, since no haptic controls are involved at the moment the decision to accept the next gap is taken. Visual cues, information or guidance are often preferred over auditory advices (Brookhuis and De Waard, 1999, Wheatley and Hurwitz, 2002, Regan et al., 2006). However, visual assistance do distract drivers in a different way (Carsten and Brookhuis, 2005), which is likely to be undesired during or preceding overtaking. Most route navigation systems use a combination of visual and auditory advices. In case of the overtaking assistant, visual information is supposed to be more effective when presented in line of sight.

The request for an on/off switch is logical for a prescriptive design, since drivers do not need overtaking information all the time, but only when they have an overtaking desire. Of the 24 participants of the driving simulator experiment described in the next chapter, 23 indicated to prefer an assistant with an on/off switch. For flying overtaking, a design that continuously gives overtaking advice might be more suitable, which is discussed in more detail in Section 4.6.1.

The need to select overtaking gaps at least as efficient as drivers do without assistance, reflects that drivers want to gain from the system. Also for situations when drivers thought in advance that a gap is too small, but realise afterwards that it was large enough. The overtaking behaviour study described in Chapter 2 showed that overtakers without assistance immediately use a gap when it is present. The observed time between the passage of the last oncoming vehicle and the start of the overtaking manoeuvre was in most cases less than 1 s. Drivers apparently select the overtaking gap before it is present, to use it optimally. An overtaking assistant therefore needs information about the overtaking possibility before the gap is present, to inform drivers about an oncoming overtaking possibility, so that drivers can start to perform all the subtasks of the overtaking manoeuvre before the move to the left lane.

4.4.2 Automotive industry needs

The automotive industry is the stakeholder that needs to sell the overtaking assistant. Their general aim is to sell cars. The automotive industry will include only the overtaking assistant in their car options package when it does not negatively affect the sale of the vehicles equipped with it, at least brings in what it costs and does not negatively influence the reputation of the car brand.
4.4.3 Legal needs (standards)
The commission of the European communities recommends that in-vehicle information and communication systems provided by the European motor manufacturing and supply industries, including importers, should comply with the statement of principles (European Commission, 2006). Principle in this context must be interpreted as need or standard that needs to be satisfied. The statement of principles is applicable to the human machine interface (HMI) of in-vehicle information and communication systems. It includes principles for overall design, installation, information presentation, interaction with displays and controls, system behaviour and principles on information about the system. To avoid making the design of new driver assistance systems complex, it is better to make a conceptual design first and verify whether it complies with the statement of principles afterwards. This is for example done in the European AWAKE project, that utilises its findings to adapt/extend those principles to the area of driver monitoring (AWAKE, 2000).

For the conceptual design of the overtaking assistant, the European statement of principles is not strictly followed. Instead, it is more or less covered in the need that the system should not put users and surrounding traffic at danger. At a later stage, when feasibility of an overtaking assistant is proven, the assistant should be verified again against all stated principles. Note that these principles mainly relate to the human machine interface (HMI) part of driver assistance systems. As Figure 4.3 presents, driver assistance systems exist of multiple parts. Moreover, in our design of the overtaking assistant, less attention is paid to the HMI. It is recognised that HMI is an important part of driver assistance systems in general (Minderhoud, 1999, Van Driel, 2007) that requests a separate design method such as the method for user interface Analysis and redesign, ANDES (Smit, 1993). In general, system architectures are being developed for integrated adaptive HMI Solutions (Amditis et al., 2006)

4.4.4 Designer’s needs
The last discussed stakeholder generating needs for the overtaking assistant is the designer of the system. Designers have a certain goal that they want to reach with their proposed design. The resulting design should comply with their expectations of what the design should do. Needs 1 to 10 in Table 4.2 are all designer needs. The first four designer needs have all been confirmed by participants who gained experiences with the conceptual design of the overtaking assistant with a driving simulator as described in Chapter 5.

The need that the assistant should never advise a safe overtaking opportunity when there is no safe opportunity, seems rather trivial, but ensures that the system should never give a positive overtaking advice without the necessary variables to calculate this. In other words, the default advice of the system should be that there is no overtaking opportunity.

The need that the system should be able to assist all possible drivers implies that when different driver types perform overtaking manoeuvres differently, the system should be adjustable for each driver type. To give an example, when male drivers need a different amount of time to perform an overtaking manoeuvre than female drivers, the threshold for a safe overtaking gap should be adjustable for male and female drivers.
Needs with respect to traffic system efficiency, drivers’ comfort and safety reflect the aim that improvement of one of these elements of driving should not be in favour of the others.

4.4.5 Resulting set of needs

Table 4.2 shows the resulting needs for the overtaking assistant for all stakeholders together. This set is not the complete set of needs for a market-ready overtaking assistant. It is the set which makes the design of a conceptual overtaking assistant possible, leaving the design space rather free. When the feasibility of the conceptual overtaking assistant is proven, it is necessary to verify what remains to be fulfilled for a market-ready overtaking assistant.

Table 4.2 Set of needs for the overtaking assistant

<table>
<thead>
<tr>
<th>Needs. The system should:</th>
<th>Stakeholder(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Be prescriptive informing</td>
<td>Designer / user</td>
</tr>
<tr>
<td>2 Give visual information rather than auditory or haptic</td>
<td>User</td>
</tr>
<tr>
<td>3 Have an on/off switch</td>
<td>Designer / user</td>
</tr>
<tr>
<td>4 Select overtaking gaps as efficient as drivers do without assistance</td>
<td>Designer / user</td>
</tr>
<tr>
<td>5 Announce an overtaking manoeuvre a few seconds before it is present</td>
<td>Designer / user</td>
</tr>
<tr>
<td>6 Never advise a safe overtaking opportunity when it is not</td>
<td>All</td>
</tr>
<tr>
<td>7 Be able to assist all driver types</td>
<td>Designer</td>
</tr>
<tr>
<td>8 Not effect driver comfort negatively</td>
<td>Designer</td>
</tr>
<tr>
<td>9 Not affect driver safety negatively</td>
<td>Designer</td>
</tr>
<tr>
<td>10 Not affect network efficiency negatively</td>
<td>Designer</td>
</tr>
<tr>
<td>11 Not affect the sales numbers of vehicle equipped with it, negatively</td>
<td>Automotive industry</td>
</tr>
<tr>
<td>12 Balance the costs</td>
<td>Automotive industry</td>
</tr>
<tr>
<td>13 Not influence the manufacturer’s reputation or image negatively</td>
<td>Automotive industry</td>
</tr>
<tr>
<td>14 Not put users and surrounding traffic at danger (the system needs to agree with the state of principles as described in Section 4.4.3)</td>
<td>Authorities</td>
</tr>
</tbody>
</table>

The in Table 4.2 listed needs are taken into account during the next phases of the basic design cycle. In the evaluation phase, the resulting conceptual design of previous phases is tested against the needs in Table 4.2.

4.5 Basic design cycle: synthesis

The synthesis phase of the design cycle of the overtaking assistant generates a conceptual design. The system should do the following in the imagined situation:

A potential overtaker is following a preceding vehicle, which is driving below the desired speed of the potential overtaker. The road is a two-lane rural road, with one driving lane in each driving direction. Oncoming vehicles are present, approaching with random gaps between them. The potential overtaker feels an overtaking wish and switches the overtaking assistant on, that always starts with the advice not to overtake. A few seconds before an overtaking opportunity is present, the system indicates to the driver that there will be an overtaking opportunity within a few seconds. The system the advice that it is safe to overtake as soon as the opportunity is present. This advice remains as long as the gap with the first oncoming vehicle is sufficiently large to safely perform the overtaking manoeuvre. When the
gap till the first oncoming vehicle becomes too small to execute an overtaking manoeuvre, the system switches to the advice not to overtake.

An overtaking assistant complying with this description includes all basic elements of a driver assistance system. These are presented in Figure 4.3, with an indication of their relations. The traffic/environment in case of the overtaking assistant exists of a two-lane rural road with one driving lane in each driving direction, a slow(er) preceding vehicle and oncoming traffic. Sensors detect and collect the necessary measures to calculate the state of the system. This state results in an advice for the driver, which is communicated by means of the human machine interface (HMI). This HMI performs the two-way communication between the driver and the assistant and for example includes an on/off switch.

![Figure 4.3 Elements of advanced driver assistance systems](image)

The overtaking assistant needs to compute the advice, given the measured traffic situation. These three main tasks, to measure, to compute and to advise are presented in Figure 4.4 and explained in the next three subsections.

![Figure 4.4 The three main tasks of the overtaking assistant](image)

4.5.1 Measurement

To give an advice whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre, the overtaking assistant continuously has to make the following comparison:

\[
TAO \geq TRO + T_{\text{delay}}
\]  \hspace{1cm} (4.1)

With

- \( TAO \) Time available for overtaking [s]
- \( TRO \) Time required for overtaking manoeuvres [s]
Tsafety: A safety margin [s]

The time required for overtaking plus the safety margin are estimated by the assistant based on the information provided by its sensors, further explained in Section 4.5.4. The time available for overtaking has to be estimated continuously, since it changes over time. The time available for overtaking is defined as the time between the last oncoming vehicle has passed the overtaker and the moment the front of next oncoming vehicle is at the same level as the front of overtaker at its current position (behind the preceding vehicle). The assistant needs to estimate the distance between the overtaker and the oncoming vehicle and the speed of both. In formula:

\[ TAO(t) = \frac{x(t)}{v_{opp}(t) + v_{ot}(t)} \]  \hspace{1cm} (4.2)

With:
- \( v_{opp} \) Speed of the first oncoming vehicle at time \( t \) [m/s]
- \( v_{ot} \) Speed of the overtaker at time \( t \) [m/s]
- \( x \) The distance between the oncoming vehicle and the overtaker at the time moment the preceding oncoming vehicle has just past the overtaker [m]

The measurement of the variables to estimate the time available for overtaking should be at a high sample rate, for example at 10 Hz, since both speeds and distance will rapidly change. However, for more or less constant accelerations, the frequency of estimation could be lower, because time available for overtaking can then be estimated.

### 4.5.2 Compute (estimate)

Analytical computation of the time required for overtaking is possible with the kinematics equation for a uniform accelerative movement:

\[ x(t) = x(0) + v(0)t + \frac{1}{2}at^2 \]  \hspace{1cm} (4.3)

With
- \( x(t) \) Position at time \( t \) [m]
- \( x(0) \) Initial position at the start of the measurement (time = 0 s) [m]
- \( v(0) \) Initial speed at the start of the measurement [m/s]
- \( t \) Time [s]
- \( a \) Acceleration [m/s²]

Equation (4.3) is worked out by means of the example overtaking situation displayed in Figure 4.5, where the gap between oncoming vehicle 3A and 3B is considered.

At time moment \( t = 0 \) s, the following equations hold:

\[ x_{opp}(0) = 0 \] \hspace{1cm} (4.4)

\[ x_{prec}(0) = h_{prec} \] \hspace{1cm} (4.5)
With

\( x_{ot} \) Position of the overtaker [m]

\( x_{prec} \) Position of the preceding vehicle [m]

**Figure 4.5 General overtaking situation.** 1 = overtaker, 2 = preceding vehicle, 3A and 3B = oncoming vehicles. At \( t = 0 \) (time) distance between 3A and 3B is a possible overtaking gap, at \( t = t' \) the overtaker has just crossed the centre line (end of the overtaking manoeuvre).

At time moment \( t' \) the overtaker has finished its manoeuvre and then the position of the overtaker and the overtaken vehicle are defined as:

\[
x_{ot}(t') = x_{ot}(0) + v_{ot}(0)t' + \frac{1}{2}a_{ot}t'^2
\]

\[
x_{prec}(t') = x_{prec}(0) + v_{prec}(0)t' + \frac{1}{2}a_{prec}t'^2
\]

Combination of equations (4.5) and (4.7) and the assumption that preceding vehicles drive at constant speed leads to:

\[
x_{prec}(t') = h_{before} + v_{prec}(0)t'
\]

During the overtaking manoeuvre, the overtaker travels the same distance as the preceding vehicle, plus the headway between the two vehicles before the overtaking manoeuvre starts and at the end of the overtaking manoeuvre. This means that the position of the overtaker at time \( t' \) is also equal to:

\[
x_{ot}(t') = h_{before} + x_{prec}(t') + h_{after}
\]

Combination of equation (4.4), (4.6), (4.9) and (4.8) gives:

\[
0 + v_{ot}(0)t' + \frac{1}{2}a_{ot}t'^2 = h_{before} + v_{prec}(0)t' + h_{after}
\]
Because the overtaker is following the preceding vehicle before the overtaking manoeuvre starts, their speeds are assumed to be equal, which makes the equation for \( t' \) independent of speed. The final equation for the time required for overtaking is:

\[
\tau = T_{RO} = \sqrt{\frac{2(h_{\text{b}} + h_{\text{a}})}{a_{\text{a}}}} \quad (4.11)
\]

As stated in equation (4.1) a safety margin should be added to the time required for overtaking, otherwise the front of the oncoming vehicle will be at the same level as the front of the overtaker at the moment the overtaker has moved back to the right lane. This is assumed to unsafe for both the overtaker and the oncoming vehicle. Four seconds safety margin was calculated to be used for collision avoidance systems to warn drivers of a potential collision (Van der Horst and Hogema, 1993). Based on comprehensive lane change studies, 3 s was proposed (Lee et al., 2004). During an overtaking situation, drivers have full attention and reaction times are assumed to be short. Hence, the lowest safety margin corresponding to 3 s is chosen to add to the time required for overtaking. Now it is possible to fill in equation (4.1):

\[
\frac{x(0)}{v_{\text{opp}}(0) + v_{\text{a}}(0)} \geq \sqrt{\frac{2(h_{\text{b}} + h_{\text{a}})}{a_{\text{a}}}} + 3 \quad (4.12)
\]

As soon as equation (4.12) holds, the overtaking assistant should give drivers the advice that an overtaking opportunity is present.

Equation (4.12) shows that the overtaking assistant has to know the speed of the oncoming vehicle, its own speed, the headway with the preceding vehicle at the start and end of the manoeuvre, the acceleration level and the distance between the oncoming vehicle and the overtaker at the moment the preceding oncoming vehicle is at the same level as the overtaker. Subsection 4.5.4 discusses what devices are necessary to obtain all these variables, but first an example overtaking situation is elaborated.

**An example**

Let us assume a situation as displayed in Figure 4.6, where:
- Vehicle 2 is the preceding vehicle \( v_{\text{prec}} = 22m/s \approx 80km/h \); 
- Vehicle 1 is the potential overtaker with \( v_{\text{a}} = v_{\text{prec}} = 22m/s \approx 80km/h \); 
- Vehicles 3a and 3b are oncoming vehicles with \( v_{\text{opp}} = 28m/s \approx 100km/h \); 
- \( a_{\text{a}} = 2.5m/s^2 \); 
- \( x_{\text{a-opp}} = 400m \); 
- \( h_{\text{b}} = 1.5x = 33m \); 
- \( h_{\text{a}} = 2*v_{\text{a}} = 44m \).
The question is whether the gap between the two oncoming vehicles 3A and 3B is sufficiently large for the overtaker, to safely overtake the preceding vehicle. The time required for overtaking and the time available for overtaking are (equation (4.12)):

\[ TRO = \sqrt{\frac{2(33 + 44)}{2.5}} = 7.8s \]

\[ TAO = \frac{400}{28 + 22} = 8.0s \]

Without the safety margin, the overtaker has just enough time to overtake the preceding vehicle. However, with an added safety margin of 3 s the time required for overtaking manoeuvres becomes 10.8 s which is larger than the time available for overtaking of 8.0 s. For the overtaker, it is better to wait for another, larger gap in the oncoming traffic stream to perform the overtaking manoeuvre. Thus, the overtaking assistant should advise not to overtake.

### 4.5.3 Advice and HMI

After the overtaking assistant has estimated all necessary state variables and performed all of the required computations, it has to advise the driver whether or not it is safe to overtake. The device used to communicate this advice is called human machine interface (HMI).

Examples of integrated HMI in vehicles are the speedometer and the fuel consumption meter. An HMI of driver assistance systems can be integrated in the dashboard, or designed as a head up display, as long as it is within the natural glance pattern of drivers (Lee et al., 2004). The overtaking assistant should not put demands on the driver that are too high to combine with the actual driving task. This interface should be designed such that one glance at the system is enough to understand the given advice. Another HMI need, also included in Table 4.2, is that it has an on/off switch, to prevent the system to give advices at moments drivers cannot handle them.

In this dissertation research, only a conceptual design of the overtaking assistant is made, with less attention for HMI. The main requirements of HMI are that the overtaking assistant needs to be easy to design and easy to implement it in the evaluation studies. When it is decided to continue the development of an overtaking assistant, HMI needs more attention. In general to design a good HMI, designers need to know what users want and how they want this. Often,
designers do not know this, because they are humans themselves and think to know what humans want (Norman, 1986).

Another aspect related to HMI is that possible conflicts with other driver assistance systems need to be prevented. When different devices are on at the same time, for example a navigation system and an overtaking assistant, advices from both systems should be given in a hierarchical order, also proposed by Christoffel (2006). Probably, the advice of the overtaking assistant will have the least priority, since overtaking is almost never necessary, but done only to improve drivers’ comfort. This means that the overtaking assistant should wait with an advice when another device simultaneously gives an advice. For example, if a navigation system wants to inform drivers to turn left at the next junction, this message should be prioritised over a message that it is safe to overtake.

After the explanation of how the overtaking assistant measures, computes and advises, the next subsection describes which devices are necessary to obtain the required information.

4.5.4 Essential measurement devices of the overtaking assistant
The overtaking assistant must be able to measure the variables that are needed to calculate the time required for overtaking. Important for the selection of the necessary devices to obtain the required variables, is the moment variables should be measured. The overtaking assistant should inform drivers about overtaking gaps some seconds before they are actually present (covered by the fourth need listed in Table 4.2), since only then the overtaker can use the gap optimally. Taking this information into account, necessary devices should be able to obtain the speed of the overtaker, the headway before and after the manoeuvre, the speed of and distance to oncoming vehicles.

Speed of the overtaker is obtained from the speedometer. For the acceleration that will be applied, an assumption should be made, related to the maximum acceleration capacity of the vehicle. No special device is required for this.

Devices to measure headway at the start and end of the overtaking manoeuvre are abundantly available. Examples are the ALASCA laser scanner that provides wide field-of-view obstacle detection in the short and medium range, with range information on the order of centimetres (Bishop, 2005) and 24 GHz radar sensors, now applied to recognize vehicles to the rear of the host vehicle in adjacent lanes, covering both the blind spot and an upstream range out to 50 m (Bishop, 2005). Although headway at the start of the overtaking manoeuvre can be measured prior to the overtaking manoeuvre, the headway between the overtaken vehicle (was preceding vehicle) and the overtaker, cannot be measured in advance. This leads to the suggestion to estimate both, by multiplying speed of the overtaking vehicle with the generally recommended safe time headway of 2 s (Lamm et al., 1999). Using this estimation based on the speed at the start of the overtaking manoeuvre, the headway at the end of the manoeuvre will probably be underestimated, since overtakers will accelerate during the manoeuvre. However, in practice headways before and after the manoeuvre were found to be smaller than 2 s described in Chapter 2. This strengthens the assumption that the estimated headways approach reality.
Speed of the first oncoming vehicle and intermediate distance is the most difficult to measure. In the above given example, this distance was 400 m. To our knowledge, anno 2007, no devices are available to look far enough ahead to measure distance to and speed of oncoming vehicles over this distance. The most far reached distance is about 150 m (Invent-online, 2007). Moreover, since the assistant aims to inform drivers about an overtaking opportunity before it is actually present, the preceding vehicle will be driving in front of the overtaker, blocking the view of eventually radar or laser systems. Other techniques are necessary to measure the speed of and distance to the oncoming vehicles. A promising development with regard to this is vehicle-to-vehicle communication. In the MILTRANS project, a systems with a range up to 1 km is being developed (Gunton, cited in Bishop, 2005). Another study tested the communication possibilities of inter-vehicle cooperation, with a maximum communication range of 350 m (Ammoun et al., 2007).

In summary, speed and headway information of the overtaker can be easily obtained, however, necessary information of oncoming vehicles is a problem. Vehicle-to-vehicle communication developments are awaited to detect oncoming vehicles on time. To enable further development of the overtaking assistant, it is decided to continue with the conceptual design of the overtaking assistant and to deal with technological problems at a later stage, when the concept is proven to be fruitful. Developments in industry have proven to be fast. For example in case of the adaptive cruise control for which in a study performed in 1999 sensor technology was indicated to be the largest bottleneck (Hoedemaeker, 1999) and about 8 years later, many vehicles are equipped with it.

4.5.5 Conceptual design of the overtaking assistant

The result of the analysis phase and synthesis phase of the basic design cycle is a conceptual design of the overtaking assistant. The proposed design is adapted for a driving simulator experiment that is executed in the evaluation phase of the basic design cycle of the assistant. Availability problems described above of the necessary device to detect oncoming vehicles are not relevant for the driving simulator experiment, since oncoming vehicles can be programmed in such a way that the driving simulator knows where they are and what their speed is. This means that with the experiment, only the concept of the overtaking assistant can be tested, and not the functioning of the required devices.

Figure 4.7 presents the conceptual overtaking assistant design. The chosen interface of the design is a kind of traffic light with a red and green sign. When the assistant is off, both signs are off. When the assistant is switched on, the red sign lights up, indicating that it is not safe to overtake. The green sign lights up when it is safe to overtake, meaning that the gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. The red sign starts blinking 3 s before an overtaking opportunity and the green sign blinks 3 s before the next oncoming vehicle arrives, after this blinking phase, the red sign lights up again. When the next gap is sufficiently large, the green blinking phase is followed by the red blinking phase.
Figure 4.7 Top: interface of the overtaking assistant with a red sign (above) and a green sign (below). Bottom: visualisation of the functioning (solid = red, dashed = green)

A traffic light-like design of the interface of the overtaking assistant was chosen because of the familiarity of drivers with this interface. All drivers know the negative meaning of the red light and the positive meaning of the green light. This increases the fast understanding of the system required for the simulator experiment where participants need to understand the system quickly. Also, the chosen interface needed to be easily implemented in a driving simulator experiment, to test the conceptual design. A traffic light was fairly easy to design and implement.

The bottom of Figure 4.7 presents an example situation with a potential overtaker, a preceding vehicle and several oncoming vehicles. At a chosen time $t = 0$ s, the potential overtaker has been following the preceding vehicle for a while and wants to overtake it. The overtaker switches the assistant on and the red sign lights up. After 6 s there will be a gap of 10 s in the oncoming traffic stream that the assistant interprets as sufficiently large to safely perform an overtaking manoeuvre. At $t = 3$ s, the red sign of the assistant starts blinking and does this 3 times (off-on-off-on-off-on, this takes 3 s) and at $t = 6$ s, the green sign lights up. At $t = 13$ s,
green starts blinking three times (off-on-off-on-off-on, this takes also 3 s) and at \( t = 16 \) s, the red sign lights up again.

In Figure 4.7, a gap of 10 s in the oncoming traffic stream was assumed to be sufficiently large to safely perform an overtaking manoeuvre. Ten seconds is the threshold gap for this conceptual design of the overtaking assistant; all gaps larger than 10 s are treated as overtaking opportunities, that is, the assistant turns green and for gaps smaller than 10 s the assistant remains red. The choice for a threshold gap of 10 s is firstly based on the calculations as presented in the previous section and secondly on the observation results of Chapter 2. The average duration of observed overtaking manoeuvres was 7.8 s. This is the time from the moment the left front wheel touches the centre line until the left rear wheel has crossed the centre line again. Using equation (4.1), a reaction time should be added to get the time required for overtaking and, as presented in equation (4.12) a safety margin should be added as well. The blinking red phase prior to the green phase of the overtaking assistant is intended to announce an overtaking manoeuvre, to cover perception-reaction time. A safety margin of 2.2 s was added to the observed average overtaking duration which results in the threshold gap of 10 s. Before this conceptual design is tested in a simulator experiment, a pilot study with the simulator is needed to fine tune this chosen threshold setting.

The 3 s blinking red indicates drivers to start preparing the overtaking manoeuvre. Referring to the overtaking task analysis as described in Chapter 3, all subtasks of the second phase of the overtaking manoeuvre should be performed during the 3 s blinking red sign. These subtasks are: to check behaviours of the preceding vehicle and other surrounding traffic; to maintain a safe gap with the preceding vehicle; to change to a lower gear if necessary, and to turn the indicator on.

The 3 s blinking green warns drivers that the next oncoming vehicle will arrive within 3 s and that they need to hurry to finish their manoeuvre. The evaluation phase described in Section 4.7 will expose some problems with the blinking green phase and alternatives are proposed in that section.

The presented conceptual overtaking assistant design assumes that drivers switch the assistant on only at moments they have an overtaking desire. This involves that drivers will monitor the system when it is on and indeed use the 3 s blinking red to prepare their overtaking manoeuvre. Only then, the green phase is guaranteed to be long enough to perform the manoeuvre. This choice is further discussed in the evaluation phase of the design cycle, presented in Section 4.7.

### 4.6 Basic design cycle: simulation

The next phase of the basic design cycle is the simulation phase to verify expected behaviour and characteristics of the overtaking assistant. With regard to behaviour, the proposed overtaking assistant is expected to never advise that it is safe to overtake while it is not. The system should in general advise not to overtake and only when the circumstances are such that the system is able to measure, compute and advise about overtaking opportunities and permissions, the system will give the advice that it is safe to overtake.
The described expected behaviour accounts for the bounded circumstances where the conceptual overtaking assistant was designed for. Section 4.3 included several assumptions to leave any special situation out of the design space. The next subsection verifies the expected behaviours of the proposed, conceptual overtaking assistant design when these assumptions are relaxed.

4.6.1 Relaxing assumptions for a feasible overtaking assistant design

The first assumption was that the assisted overtaking manoeuvre was accelerative and not flying, piggybacking or 2", being the four possible overtaking strategies described in Chapter 2. An element of the proposed design that could be affected by the applied overtaking strategy, is the chosen threshold setting (the minimum time gap for which the assistant shows a green sign). However, the duration of the observed overtaking manoeuvres described in Chapter 2 did not vary with overtaking strategy, indicating that the same threshold could be used for the different strategies. In other words, the system does not need to know which overtaking strategy will be applied. However, although the observed 2" overtaking manoeuvres did have similar duration as the other strategies, it is plausible that when four or five preceding vehicles are overtaken in one manoeuvre, the duration of the whole manoeuvre will grow. To give overtaking advice to drivers that want to overtake more preceding vehicles in one manoeuvre, an advanced design is necessary. The system should be able to compute the remaining available overtaking time and compare this with the required overtaking time. It is difficult to estimate when the preceding vehicle is changing, that is, when the first preceding vehicle is passed, the vehicle in front will be the new preceding and so on. A possible solution is to design the overtaking assistant with an extra phase, next to a safe phase and a not safe phase that indicates that the remaining available overtaking time is just sufficient to overtake one vehicle. This could be included in the proposed design by an extension of the blinking green phase to the required time to overtake one vehicle. Another possibility is to make a descriptive overtaking assistant of which an example design is presented in Figure 4.8. Here, the overtaking assistant is a dynamic time bar, reflecting the remaining time until the next oncoming vehicle arrives.

---

**Figure 4.8 An alternative overtaking assistant design**
The manual on/off switch of the currently designed overtaking assistant, might be a problem in case of flying overtaking when time to switch the system on is limited. Furthermore, the system always start with the advice not to overtake to give the system time to measure all necessary variables to calculate the gap. When drivers want to use the system to verify whether flying overtaking is possible, the proposal that the assistant always starts with the advice not to overtake will be confusing and might cause dangerous situations. An overtaking assistant that is always on is a solution for this problem. Such a design could be feasible when the system is well integrated in the dashboard and not attracting drivers’ attention too much. It will then become descriptive information system rather than prescriptive, giving drivers the opportunity to verify whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre.

The second assumption included no infrastructural overtaking limitations. In practise, curves, hills and intersections limit overtaking opportunities. Cooperation with other (existing) driver assistance systems enables application of the overtaking assistant to all environments. An example of such a system is the pass prediction device developed by BMW, that informs drivers about infrastructural unsafe overtaking circumstances and for how many kilometres it remains unsafe (Loewenau et al., 2006). Negative overtaking advices of such systems should be taken over by the overtaking assistant, to prevent conflicting advices.

The third assumption, that the speed of oncoming vehicles will remain constant during the overtaking manoeuvre, is necessary to enable calculation of the time available for overtaking. Although speeds of oncoming vehicles are supposed to be measured during the overtaking manoeuvre, it is not possible to change a positive advice during the manoeuvre. An option is to let the green sign blink to warn drivers that the time available for overtaking becomes shorter due to acceleration of the oncoming vehicle. Or, again, the alternative descriptive design of which an example is presented in Figure 4.8 solves this problem, where the decreasing time bar will decrease faster when oncoming vehicles accelerate.

The fourth assumption, that acceleration of the overtaker will be linear and limited by the maximum speed of the vehicle, was mainly assumed to ease to computation of the time required for overtaking. A more precise calculation of time required for overtaking is not necessary, since large safety margins are added anyway. Furthermore, observations of the duration of overtaking manoeuvres complemented the analytical computation of time required for overtaking.

In summary, verification of the assumptions shows that the proposed overtaking assistant is able to correctly inform drivers for all circumstances when cooperating with other driver assistance systems. However, in favour of the assumptions a better choice instead of the prescriptive design is a descriptive overtaking assistant, giving drivers information on the size of the available overtaking gap. Figure 4.8 presents an example design of a descriptive overtaking assistant, showing drivers the time left till the next oncoming vehicle. This system will not have an on/off switch, in stead, time gap information is continuously displayed. When information is lacking or when it is in conflict with other driver assistance systems, the system should not display any information.
4.7 Basic design cycle: evaluation

The phase after the analysis, synthesis and simulation phase of the basic design cycle is the evaluation phase, where the conceptual design is tested. To evaluate the conceptual design of the overtaking assistant, a driving simulator experiment and a microscopic traffic simulation study are performed. The former tests the effects of the assistant at an individual level, the latter tests its effects when more vehicles are equipped with an overtaking assistant. These study results are discussed in detail in Chapter 5 and 7. This section discusses the consequences of the results of these studies with respect to the assistant design. In turn, the adjusted design is tested against the needs of the analysis phase of the design cycle, summarised in Table 4.2.

4.7.1 Design adjustments after first evaluation study (driving simulator experiment)

A driving simulator experiment was conducted to study influences of the conceptual design of the overtaking assistant on overtaking efficiency, safety and comfort in a controlled environment. 12 male and 12 female participants drove the simulator without and with the overtaking assistant, resulting in the following findings regarding the design of the assistant.

A first important evaluation element of the conceptual overtaking assistant design is the threshold setting, that is, the minimum advised gap in the oncoming traffic stream to perform an overtaking manoeuvre. The applied threshold setting in the driving simulator experiment was the same for all participants and was set to 8 s. In the conceptual design described above, as presented in Figure 4.7, the threshold setting was 10 s. However, a pilot study with the simulator showed that simulator drivers could easily perform overtaking manoeuvres when gaps of 8 s and larger were accepted. The main study showed that although the perception of the required overtaking gap differs, all participants used about the same time to perform an overtaking manoeuvre. The perception difference resulted from the questionnaire answers, where some participants indicated that the assistant was displaying a green sign, while there was an oncoming vehicle in view and others said that the assistant was displaying a red sign, while there was enough time to overtake the preceding vehicle, while the threshold gap for a green sign was similar for all participants. To adjust the design to better agreement between the system threshold setting and the perceived required overtaking time of drivers, the assistant could be designed such that drivers can set the threshold setting themselves. The minimum possible setting should be at least as large as the real required time for overtaking, which is about 8 s, plus a safety margin. This result of the driving simulator experiment has led to the choice to also test the effects of different threshold settings in the microscopic traffic simulation study described in Chapter 7.

A second result of the driving simulator experiment regarding possible design adjustments is that all participants but one preferred the assistant to be designed with a manual on/off switch. This feature will therefore remain in the proposed design. Note that during the experiment, the system could not be switched off, because overtaking with the assistant was studied.

With respect to the human machine interface, most participants preferred a visual assistant; 2 participants preferred acoustic information and 8 a combination of both. This resulted in the decision to keep a visual interface.
A final important result of the driving simulator experiment with regard to the overtaking assistant design, is the too short duration of the blinking green sign. The tested design assumes that drivers switch the overtaking assistant on at the moment they have an overtaking wish and that they will use the blinking red sign to perform all subtasks of overtaking prior to the move to the left lane (e.g. check mirror, change gear). When drivers start their overtaking manoeuvre halfway into the green sign phase, they possibly cannot complete the manoeuvre safely, because in the proposed design does not display how much green time is left. A possible design solution for this problem, is to extend the duration of the blinking green phase to the minimum duration of a complete overtaking manoeuvre that is about 8 s. The red sign should light up during the added safety margin, that is, 3 s before the next oncoming vehicle arrives. In that case, drivers can always start an overtaking manoeuvre when the assistant is displaying the green sign, because the following blinking green sign is as least as long as a complete overtaking manoeuvre. This design is comparable with the traffic lights used for pedestrian crossings where the blinking green phase is long enough to cross the whole road section. Another solution is the descriptive overtaking assistant design described above that gives only information on the time available for overtaking.

4.7.2 Design adjustments after second evaluation study (micro simulation study)

The proposed design adjustments of the overtaking assistant simulator study were implemented in the second evaluation study, a microscopic traffic simulation. The simulated assistant worked the same as the assistant tested in the simulator with the adjusted, extended blinking green phase. In terms of the tested overtaking assistant in the driving simulator experiment, the flashing green sign starts as soon as the remaining gap became smaller than the threshold gap. Green keeps blinking until 3 seconds before the next oncoming vehicle is at the same level as the overtaker. At this moment, the red sign of the assistant lights up.

The simulation study regarded two sets of simulations: one with varying assistant threshold settings and one with varying penetration rates. The simulated threshold settings were 8, 9.5, 11, 12.5 and 14 s, all with 100% penetration and compliance. The results of the threshold setting simulations showed that a threshold setting of 11 s approached the results of the unassisted drivers for all analysed indicators to measure traffic system efficiency, driver comfort and safety. As a positive deviation from unassisted drivers, the overtaking frequency was higher for assisted drivers. All simulated threshold settings resulted in more overtaking manoeuvres. For a threshold setting of 8 s, TTCs smaller than 3 s were found. With respect to the proposed design, 11 s will be proposed as a default threshold setting for the overtaking assistant. If the final design has an adjustable threshold setting, the 8 s can be included as a minimum threshold.

The simulated penetration rates were 0, 5, 10, 25, 50 and 100% all for a threshold setting of 8 s and 100% compliance was assumed. The results indicated that for low penetration rates, driving with overtaking assistance gains efficiency and comfort without losing safety. For higher penetration rates this advantage diminishes, however, neither the assisted nor the unassisted drivers are negatively affected on the three studied areas of traffic system efficiency, drivers' comfort and safety. The penetration rate simulation results have not led to design adjustments.
4.7.3 Adjusted of conceptual overtaking assistant to satisfy needs

The two evaluation studies resulted in an adjusted, conceptual overtaking assistant design. The resulting proposed prescriptive overtaking assistant has an on/off switch and displays a red sign when it is switched on. The system starts blinking 3 s before a gap larger than 11 s appears in the oncoming traffic stream, followed by a green sign. The green sign is on as long as the remaining gap is larger than 11 s. When the overtaking gap becomes critical, that is, smaller than 11 s, green starts blinking. This gives drivers the opportunity to safely complete readily started overtaking manoeuvres. When the oncoming vehicle is 3 s away from the overtaker, the red sign lights up. When the gap after the next oncoming vehicle is again sufficiently large to safely overtake a preceding vehicle, red will be blinking immediately after the blinking green phase.

The adjusted conceptual overtaking assistant design needs to be evaluated against the needs formulated in the analysis phase (Section 4.4). This subsection verifies how far the resulting, conceptual design satisfies the needs. Table 4.3 summarises which needs are satisfied and for which needs further evaluation is necessary to check whether the assistant can satisfy it.

### Table 4.3 The overtaking assistant needs and to what extent they are satisfied

<table>
<thead>
<tr>
<th>Needs. The system should:</th>
<th>Satisfied?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Be prescriptive informing</td>
<td>✓</td>
</tr>
<tr>
<td>2 Give visual information rather than auditory or haptic</td>
<td>✓</td>
</tr>
<tr>
<td>3 Have an on/off switch</td>
<td>✓</td>
</tr>
<tr>
<td>4 Select overtaking gaps as efficient as drivers do without assistance</td>
<td>✓</td>
</tr>
<tr>
<td>5 Announce an overtaking opportunity a few seconds before it is present</td>
<td>✓ / ?</td>
</tr>
<tr>
<td>6 Never advise a safe overtaking opportunity when it is not</td>
<td>✓ / ?</td>
</tr>
<tr>
<td>7 Be able to assist all driver (types)</td>
<td>✓</td>
</tr>
<tr>
<td>8 Not effect driver comfort negatively</td>
<td>✓</td>
</tr>
<tr>
<td>9 Not affect driver safety negatively</td>
<td>✓</td>
</tr>
<tr>
<td>10 Not affect network efficiency negatively</td>
<td>✓</td>
</tr>
<tr>
<td>11 Not affect the sale of vehicle equipped with it negatively</td>
<td>?</td>
</tr>
<tr>
<td>12 At least bring in what it costs</td>
<td>?</td>
</tr>
<tr>
<td>13 Not influence reputation negatively</td>
<td>?</td>
</tr>
<tr>
<td>14 Not put users and surrounding traffic at danger</td>
<td>?</td>
</tr>
</tbody>
</table>

Eight of the 14 needs are satisfied with the resulting design of the overtaking assistant after the design adjustments as a result of the simulator experiment and the simulation study. The assistant is prescriptive informing, has a visual interface and an on/off switch. Overtaking opportunities are announced 3 s before they are present and overtaking efficiency, comfort and safety are not negatively affected. The similar effectiveness in gap selection was proved with the simulator experiment, where rides without and with assistance, offering the same number of overtaking gaps, resulted in similar number of overtaking manoeuvres. To enable assistance for all driver types, adjustable threshold settings were proposed.

Needs 5 and 6 in Table 4.3 are satisfied in the simulator experiment. However, the functioning of the assistant in the real world will be different, because different devices are needed to calculate the available overtaking time. Although in the simulator experiment the
assistant never advised a safe overtaking opportunity while it was not safe, this does not guarantee anything in reality. Furthermore, the devices needed to announce overtaking gaps 3 s before they are present, for example vehicle-to-vehicle communication to detect oncoming vehicles on time, are not yet available. When these are available, new evaluation studies of the overtaking assistant for a real car, in the real world, are needed. Indeed, for safety assessment of driver assistance systems, field trials are always needed (Carsten and Nilsson, 2001).

For the needs 11, 12 and 13, being not affect sale of the equipped vehicles negatively, balanced costs and not influence the automotive industry’s reputation negatively, the automotive industry needs to investigate the market opinions with regard to overtaking assistance and production costs. One of the questionnaires of the driving simulator experiment (see Appendix A) included some questions that give indications: almost half of the participants indicated that they did not want the system in their vehicle, even when it was for free and of the remaining 13 participants, 7 wanted it only for free.

The final need that the assistant should not put users and surrounding traffic at danger is a logical need and a crucial need and difficult to test. Even well settled devices such as cruise control has put surrounding traffic at danger, as it caused an accident where a truck equipped with cruise control drove into the back of a queue on a Belgium motorway. As a consequence, no cruise control signs are installed at queue prone locations (Belgisch staatsblad, 2004). Better evaluation and pilot studies before systems are introduced to the market, could possible avoid such ‘ad-hoc’ solutions.

4.8 Summary and discussion of conceptual overtaking assistant design

To answer the third research question of this dissertation research: how should an overtaking assistant be designed? the basic design cycle (Roozenburg and Eekels, 2001) was applied. As a first step of this cycle, the global function description was that this system will assist drivers with the task to judge whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. Necessary assumptions were formulated that enabled a conceptual design of a prescriptive informing overtaking assistant. The design was evaluated against a set of needs, including desires and limitations of all stakeholders involved. For this evaluation, a driving simulator experiment and a simulation study were elaborated, resulting in a few design adjustments. The final conceptual overtaking assistant design is presented in Figure 4.9 and:

- Has an on/off switch;
- Displays, by default, a red sign, that is, it is not safe to overtake, when it is switched on;
- Displays a red blinking sign during the 3 s prior to an overtaking gap;
- Displays a green sign for a gap in the oncoming traffic stream larger than 11 s;
- Displays a blinking green sign as soon as the overtaking gap becomes 11 s or smaller;
- Displays a red sign after the blinking green sign, 3 s before the next oncoming vehicle is at the same level as the overtaker. When the gap after this one oncoming vehicle is again sufficiently large to safely perform an overtaking manoeuvre blinking green is followed by blinking red.
To optimise the performance of the overtaking assistant, especially to make it applicable to all circumstances, an alternative design was suggested. This descriptive informing overtaking assistant displays the available time left until the next oncoming vehicle arrives and is also presented in Figure 4.9.

Both the prescriptive and the descriptive design need to be tested in practice, before it can be introduced to the market. More importantly, available technologies anno 2007 are unable to collect all necessary data for calculation of oncoming traffic stream gaps. Both distance to and speed of oncoming vehicles cannot be measured yet. Vehicle-to-vehicle communication technology is the most promising development with respect to realisation of overtaking assistance systems. Several challenges of inter-vehicle communication are presented in Nagel (2007).

An advanced design possibility with regard to the on/off switch and the threshold setting of the assistant, is that the system learns from earlier overtaking decisions of drivers. The system could learn in which situations (car-following?) drivers have an overtaking wish and will give only information when drivers need it. With respect to threshold setting, the system could learn from earlier overtaking decisions from drivers, to make the threshold setting driver dependent. This will lead to an overtaking assistant approaching human overtaking behaviour as close as possible, which will increase acceptance of the system.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Description</th>
<th>Prescriptive assistant</th>
<th>Alternative descriptive assistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>No overtaking opportunity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>3 s prior opportunity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Overtaking opportunity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Less than 10 s left</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>No overtaking opportunity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.9 Original overtaking assistant design and alternative design
5 A Driving Simulator Experiment on Overtaking Assistance

An overtaking assistant that assists drivers with overtaking gap acceptance in the oncoming traffic stream on two-lane rural roads is tested in a driving simulator experiment. Analysis of the results presents that overtaking frequency does not vary between rides with or without assistance. The distance headway during the 5 s before the manoeuvre starts is also not affected by the assistant. The variation in lateral position becomes smaller with the overtaking assistant and this change is significant for male participants. It turns out that fewer gaps smaller than 8 s are accepted to perform an overtaking manoeuvre when driving with the assistant. Female participants spend shorter time in the left lane when driving with assistance compared to driving without assistance. The minimum time-to-collision with a first oncoming vehicle becomes smaller with the overtaking assistant, often below the safety threshold of 3 s. Indicator usage is not affected by the overtaking assistant. The workload and activation levels of the participants increase more when driving with an overtaking assistant, compared to the situation without assistance. Participant rating usefulness of the system higher than they rate its satisfaction. Based on the results, it is recommended to continue the development of an overtaking assistant, with a larger threshold for a green sign and with the possibility to adjust this threshold to drivers’ preferences.
5.1 Introduction

This chapter presents a driving simulator experiment testing an overtaking assistant that assists drivers’ overtaking gap acceptance in the oncoming traffic stream on two-lane rural roads. It aims to answer the fourth research question of this dissertation: what are the individual driver effects of an overtaking assistant on overtaking efficiency, safety and comfort?

A driving simulator experiment is applied to assess the conceptual overtaking assistant as proposed in Chapter 4. This method enables collection of many driver performance indicators in a controlled environment without putting (other) drivers at risk. The analysed indicators to measure overtaking efficiency, comfort and safety are overtaking frequency, distance headway during 5 s prior to overtaking, time headway at the start, lateral position, accepted overtaking gap, time spent in the left lane, time-to-collision (TTC), indicator usage, workload, activation levels, acceptance of the system, relationship between risky driving and overtaking frequency and participants’ opinion about the system. The results are used to decide whether there is potential for further development of an overtaking assistant.

Figure 5.1 presents the outline of this chapter. Section 5.2 continues with a pre-assessment of indicators to measure overtaking efficiency, safety and comfort. Next, all elements of the applied method are described, including the driving simulator, the overtaking assistant, the participants, the experimental design, the procedure, the simulator environment, the surrounding traffic and the data collection and analysis. The results are described in Section 5.4, followed by a separate section with the results of the overtaking assistant compared to overtaking in an overtaking lane. A ride on a road with an overtaking lane is included in the experiment to compare the assistant with another feasible solution to improve overtaking on two-lane rural roads. The final section of this chapter summarises and discusses the results.
5.2 Pre-assessment of overtaking performance indicators

The proposed integrated driver assistance systems assessment methodology by the European project ADVISORS states that the choice of assessment method (and the techniques and tools used) will depend on the previously defined indicators (ADVISORS, 2002). Indicators to measure efficiency, safety and comfort of overtaking should firstly be selected and the choice of the assessment method depends on the selected indicators. Hence, this subsection firstly describes the selected indicators and how they might change when driving with an overtaking assistant. The referred ADVISORS project suggested driving simulator experiments as one of the possible tools to assess a new driver assistance system. Since a driving simulator enables collection of all selected indicators, this method was chosen and advantages and disadvantages of it are discussed in the final subsection of this section.

Overtaking efficiency, safety and comfort are the dimensions in which the performance of overtaking is expressed in this dissertation. These dimensions are quantified using multiple observable performance indicators. Table 5.1 presents the selected indicators and which of the dimensions of overtaking, efficiency, safety and comfort they aim to express. The explanation of these indicators is split over two subsections, describing objective and subjective indicators respectively. This split is sometimes ambiguous, for example TTC is described as an objective indicator, while other studies might indicate it as a subjective indicator. The division should therefore not be interpreted as strict, but as a way to structure the indicators.

Table 5.1 Selected indicators to measure overtaking efficiency, safety and comfort

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Impacts overtaking assistant on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Efficiency</td>
</tr>
<tr>
<td>Overtaking frequency</td>
<td>X</td>
</tr>
<tr>
<td>Distance headway during 5 s prior to overtaking</td>
<td>X</td>
</tr>
<tr>
<td>Time headway at start</td>
<td>X</td>
</tr>
<tr>
<td>Lateral position</td>
<td>X</td>
</tr>
<tr>
<td>Accepted gap</td>
<td>X</td>
</tr>
<tr>
<td>Time spent in the left lane</td>
<td>X</td>
</tr>
<tr>
<td>TTC</td>
<td>X</td>
</tr>
<tr>
<td>Indicator usage</td>
<td>X</td>
</tr>
<tr>
<td>Workload</td>
<td>X</td>
</tr>
<tr>
<td>Activation</td>
<td>X</td>
</tr>
<tr>
<td>Acceptance</td>
<td>X</td>
</tr>
<tr>
<td>Sensation seeking</td>
<td>X</td>
</tr>
</tbody>
</table>

5.2.1 Pre-assessment of selected objective indicators of overtaking assistant effects

Overtaking is a complex driving task (McKnight and Adams, 1970), involving many performance related indicators. There does not seem to be much consensus on which indicators are best suited to evaluate driver assistance systems in general (Van Driel, 2007). This assessment of the overtaking assistant, as for many assessment studies of driver assistance systems, aims to identify any effects of the system. Hence, the most probably affected indicators are chosen.
Assisted Overtaking

Overtaking frequency

Overtaking frequency is defined by the number of overtaking manoeuvres per kilometre per hour. Proposals are made to include overtaking frequency as an indicator for the level of service of a road (Luttinen et al., 2006). This suggests that overtaking frequency is an important indicator for efficiency and comfort effects of an overtaking assistant.

Overtaking frequency can be seen as a multiplication of overtaking need and overtaking possibility. This makes it difficult to say whether higher overtaking frequency is good or bad for efficiency and comfort. What the net effect of the overtaking assistant on overtaking frequency will be is difficult to estimate. Cautious drivers will be stimulated to overtake slower vehicles when driving with the system, while more daring drivers could be stimulated not to overtake if the system indicates that it is not safe to overtake. However, the system is introduced as an assistance system and not as a system to prevent overtaking. The expectation regarding overtaking frequency is that overtaking frequency will be higher when driving with an overtaking assistant.

Distance headway during 5 s prior to overtaking

The distance headway during 5 s prior to overtaking is selected as an indicator, because it is expected to be influenced by the oncoming overtaking manoeuvre. The observation results described in Chapter 2 showed that drivers immediately use an available gap when this is available, which implies that drivers start to prepare for the overtaking manoeuvre before the gap is present. How long this preparation to the overtaking manoeuvre exactly takes is not known, but 5 s are expected to be long enough to observe possible effects of the oncoming overtaking manoeuvre on this distance headway.

The distance headway during 5 s prior to overtaking is presumed to be an indicator of overtaking safety and comfort. For safety because small headways generate potential dangerous situations (Vogel, 2003). The question is, what are dangerous distance headways when drivers are waiting for an opportunity to overtake. In these cases, drivers are alert and their reaction time will be short. Furthermore, if the distance headway with the preceding vehicle is small, the distance to be travelled in the left lane to pass the preceding vehicle will be less. Interviews with close-followers on the road revealed that hurry or wish to overtake the car ahead was a justification for close-following in the majority of cases (Rajalin et al., 1997). The reason why they are close-following was not clearly stated. Presumably, drivers are irritated with the lower speed of the preceding vehicles, try to hurry them up and think that they need less time to overtake the preceding vehicle when they are following closely. Another study found that when overtaking was prohibited, following distance increased (Summala, 1980). This suggests that comfort is also affected by the distance headway during 5 s prior to overtaking, because without overtaking desire, the chosen headway increases. The overtaking assistant aims to take over the search for available overtaking gaps, which is expected to increase the distance headway during 5 s prior to overtaking. The expectation is that the distance headway during 5 s prior to overtaking will increase when driving with an overtaking assistant.
Chapter 5 – A driving simulator experiment on overtaking assistance

**Time headway at the start of the overtaking manoeuvre**
The next safety indicator is the time headway at the start of the manoeuvre, at the moment the overtaker moves to the other lane. During the observations of overtaking manoeuvres described in Chapter 2, 25% of the observed headways were smaller than 0.5 s. For the observed speeds above 70 km/h this is expected to be unsafe. No literature was found giving a reason why headways at the start of overtaking manoeuvre are small. Possible reasons are that drivers want to use the gap in the oncoming traffic stream as soon as it is present and start to accelerate in the right lane, accepting the smaller headway with the preceding vehicle. They also might not know for sure whether the gap in the oncoming stream is large enough and try to reduce the required time for overtaking. When this is true, the overtaking assistant will increase the time headway at the start of the overtaking manoeuvre, because then the assistant will tell drivers that the gap is large enough to perform an overtaking manoeuvre. This results in the expectation that the headway at the start of the overtaking manoeuvre will increase, when driving with de overtaking assistant.

**Lateral position**
Lateral position of a vehicle is defined by either the distance between the centre line and the centre of the vehicle, or the deviation of the centre of the vehicle from the centre of the driving lane. A relationship between safety or accident risk and lateral position control has been established (O’Hanlon et al., 1982, Allen and Stein, 1987). There is, however, little evidence. Analysis of accidents demonstrated swipe accidents, where vehicles crash into the side of other vehicles, but it was hard to prove that overtaking or intention to overtake was the starting point for these accidents (Wang and Knipling, 1994). If drivers are looking for an opportunity to overtake, they probably move to the centre line in order to look past the preceding vehicle to see whether there is any oncoming traffic. A simulator experiment with surrogate in-vehicle information systems showed an increase in lateral position while driving with surrogate in-vehicle information systems (Santos et al., 2005). Less variation in lateral position will improve safety, for example the risk of lane excursions will be reduced. Since the proposed overtaking assistant assists drivers with the task to find an overtaking gap in the oncoming traffic stream, without having to look past the preceding vehicle to find a gap, it is expected that the variation in lateral position will be smaller when driving with an overtaking assistant.

**Accepted gap**
On two-lane rural roads with oncoming traffic, drivers have to accept gaps in the oncoming traffic stream to perform overtaking manoeuvres. This gap acceptance is one of the most difficult subtasks of the overtaking manoeuvre as described in Chapter 3. The overtaking assistant is designed to assist drivers with this task. The assistant aims to avoid that risk-taking drivers accept gaps that are too small for overtaking and to assist less daring drivers with acceptance of gaps that are large enough to overtake. So, with the assistant, it is expected that fewer gaps which are too small will be accepted, and larger gaps will be accepted more. The resulting expectation is that variation in size of accepted gaps will be less when driving with an overtaking assistant.
**Time spent in the left lane**
The time spent in the left lane is the time between the moment the centre of the vehicle crosses the centre line (move to the left) till the moment the centre of the vehicle crosses the centre line again (move to the right). From a safety point of view, the shorter the time spent in the left lane, the better, since in the left lane, overtakers are at risk to collide with oncoming vehicles. During the observations on the Flevoland road described in Chapter 2, the average time spent in the left lane was 7.8 s, with a standard deviation of 1.9 s. This did not vary significantly with the speed of the preceding vehicle. Another simulator experiment found that if preceding vehicle’s speed is not too far below the speed limit (max. 16 km/h), the time spent in the left lane is independent of the speed of the preceding vehicle (Jenkins, 2004).

What could affect the time spent in the left lane is the acceleration rate of the vehicle by the driver. Although the assistant does not intervene with acceleration, drivers might change their acceleration behaviour due to the overtaking assistant. Another aspect that could affect the time spent in the left lane is the headway prior to the overtaking manoeuvre. In line with the expectation that the headway at the start of the manoeuvre will increase due to the overtaking assistant, it is expected that the time spent in the left lane will increase when driving with an overtaking assistant.

**Time-To-Collision (TTC)**
TTC is the time left between two vehicles on a collision course if they continue at their present speed and on the same path (Hayward, 1972). For the overtaking case, TTC with oncoming traffic can become rather small, since vehicles drive with relative high speed in opposite direction. TTC is therefore included in this experiment as an indicator of overtaking safety. TTC is regarded as an important cue for detecting potentially dangerous situations in traffic (Van der Horst, 1990). The overtaking assistant could affect TTC, because the system aims to affect acceptance of gaps in the oncoming traffic stream. Encounters with a minimum TTC smaller than 1.5 s are considered critical (Van der Horst, 1990). Most collision avoidance systems already warn a driver of possible collisions if the TTC becomes smaller than 3 s (Lee et al., 2004). If a vehicle is equipped with both a collision avoidance system (CAS) and an overtaking assistant, advice should not conflict, meaning that it could occur that the overtaking assistant indicates that it is safe to overtake and during the manoeuvre, the CAS warns the driver of a collision. The design of the overtaking assistant should be such that these conflicts are prevented, which leads to the expectation that TTC will not become smaller than 3 s when driving with an overtaking assistant.

**Indicator usage**
According to Dutch traffic rules, overtakers should use their indicator when changing lanes, thus at the start and end of an overtaking manoeuvre. Observation of overtaking on a two-lane rural road described in Chapter 2, showed that drivers use their indicator twice as often at the start of the manoeuvre, to move to the left lane compared to at the end of the manoeuvre, to move back to the right lane. Some lane change assistance systems work only if the indicator is

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* The time spent in the left lane in the observation study was measured from the moment the left front wheel touches the centre line (move to left) until the moment the left back wheel has crossed the centre line again (move to right). It was not possible to extract these moments from the simulator data.
used (European Commission, 2002). This was, however, not recommended as a result of a comprehensive examination of lane changes in the USA, where many lane changes were performed without indicator usage (Lee et al., 2004). However, if vehicles are equipped with systems that assist with lane changes, drivers possibly have more time or pay more attention to indicator usage. Hence, the expectation is that indicator usage increases, both at the start and end of the manoeuvre, when driving with an overtaking assistant.

**Summary objective indicators expectations**

A summary of the expected effects of overtaking assistant on the chosen objective indicators is presented in Table 5.2. The table also presents the resulting consequences on the measures they indicate. The next subsection discusses the selected subjective indicators to measure efficiency, safety and comfort of overtaking.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Expected change:</th>
<th>Consequences on: (+ = positive, - = negative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking frequency</td>
<td>Higher</td>
<td>Efficiency + Safety + Comfort +</td>
</tr>
<tr>
<td>Distance headway during 5 s prior to overtaking</td>
<td>Larger</td>
<td>Efficiency + Safety +</td>
</tr>
<tr>
<td>Time headway at start</td>
<td>Larger</td>
<td>Efficiency +</td>
</tr>
<tr>
<td>Lateral position</td>
<td>Fewer deviations</td>
<td>Efficiency + Safety +</td>
</tr>
<tr>
<td>Accepted gap</td>
<td>Less variation</td>
<td>Efficiency + Safety + Comfort +</td>
</tr>
<tr>
<td>Time spent in the left lane</td>
<td>More</td>
<td>Efficiency + Safety -</td>
</tr>
<tr>
<td>TTC: percentage small headways (&lt; 3 s)</td>
<td>Lower</td>
<td>Efficiency + Safety +</td>
</tr>
<tr>
<td>Indicator usage</td>
<td>Higher</td>
<td>Efficiency + Safety +</td>
</tr>
</tbody>
</table>

**5.2.2 Pre-assessment of selected subjective indicators of overtaking assistant effects**

The above described indicators to measure efficiency, safety and comfort do not tell anything about the effects of the overtaking assistant on the drivers themselves. Additional subjective indicators enable to obtain information on workload, activation levels, drivers’ acceptance of the system and possible relation between overtaking and risky driving. This subsection explains how information on these indicators can be collected and what the expected effects of these indicators are on efficiency, safety and comfort when overtaking with assistance.

**Workload**

Workload is the information processing capacity that is used for task performance (De Waard, 1996). When workload is high, more mental effort is required to perform a task correctly. This shows the theoretical relation between workload and mental effort. These terms are used indifferently in practise. Workload is task-specific and person-specific. The experienced load is affected by individual capabilities, motivation to perform a task, applied task performance strategies, mood and operator state. Figure 5.2 displays that optimal performance levels are accompanied with a medium workload. The figure uses demand to indicate the task demands (e.g. longitudinal and lateral vehicle control) which is determined by the attained goal, which is external and independent of the individual. Demand is divided into regions D, A1, A2, A3, B and C. In region D (deactivation), the operator’s state is affected by, for example, a monotonous task. By ‘trying harder’ (i.e. investing effort), the primary-task performance level
is not yet affected. In region A2, performance is optimal. The operator can easily cope with the task requirements and reach a (self-set) adequate level of performance. In the regions A1 and A3, performance remains unaffected, but the operator has to exert effort to preserve an undisturbed performance level. In region B this is no longer possible and performance declines, while in region C performance is at a minimum level: the operator is overloaded. Figure 5.2 shows that no negative effects will be generated as long as the workload stays within the optimal performance level region A.

![Figure 5.2 Task performance and workload as a function of demand (adapted from De Waard, 1996)](image)

The required mental effort for a changing workload can be measured by means of physiological measures, for example heart rate, task performance measures, for example secondary tasks such as the peripheral detection task and self-report measures, for example the rating scale of mental effort (Zijlstra, 1993). The last is a one-dimensional scale, represented by a vertical line with several anchor points which relate to mental effort or workload levels, ranging from *no workload at all* to *highest workload possible* (See Appendix B). With regard to measurement of the most important characteristic of workload: sensitivity to workload, all three workload measures have their advantages and disadvantages. Hence, to measure workload, a combination of measures is recommended (De Waard, 1996). For this experiment, heart rate and the rating scale of mental effort are chosen.

The overtaking assistant aims to take over the most demanding part of the overtaking task that is the judgement of the gap with oncoming vehicles. This will probably decrease the task demand, which in turn will decrease workload. Moreover, the system is designed in such a way that it is on at drivers’ request to prevent increasing workload at moments that performance could suffer. The resulting expectation is that workload will be decreased and will stay within the optimal performance level, when driving with the overtaking assistant.

**Activation**

Activation is a second selected subjective indicator, to measure overtaking safety and comfort. Self-reported activation levels (Bartenwerfer, 1969) can measure the difficulty to drive with a driver assistance system such as the overtaking assistant. This is a one-
dimensional scale, represented by a vertical line with several anchor points which relate to activation states ranging from *deep sleep* to *frightened to death* (See Appendix B). Participants have to indicate their mental activation state before and after experience with and without a tested system. Differences in the growth of activation levels between driving without assistance system and with assistance system indicate a change in the difficulty of the driving task. For example, drivers find themselves to be less activated when driving with ACC (Hoedemaeker, 1999). Both a move to higher activation levels and a move to lower activation levels are undesirable. Lower activation could lead to lower attention levels resulting in higher risks (Summala and Näätänen, 1988). Higher activation levels imply an increase of the difficulty of the driving task, which is, especially during an overtaking manoeuvre, when activation levels are expected to be larger than during normal driving, undesirable as well. The overtaking assistant will probably decrease the activation level during an overtaking manoeuvre when activations are generally increased, which leads to the expectation that activation levels will be less increased during an overtaking manoeuvre, when driving with an overtaking assistant.

**Acceptance**

A prerequisite for the introduction of new driver assistance systems is acceptance by the public (Van der Laan et al., 1997). Analysis of questionnaires and methods to assess driver acceptance resulted in the development of a simple questionnaire for the assessment of acceptance of new in-vehicle technology (Van der Laan et al., 1997). By means of the Likert scale (five point scores on nine items), scores on usefulness and satisfaction are determined (See Appendix B). This questionnaire appears to be a useful first step in attempting to standardise the measurement of acceptance of driver assistance systems, which is selected in this study as an indicator for the comfort of overtaking.

In a user-needs survey in which participants were asked what assistance systems they need in their vehicle, 61% of the participants indicated a need for *warning of oncoming traffic* (Van Driel and Van Arem, 2005). This indicates that the acceptance of the overtaking assistant could be high. However, since participants of the simulator experiment will be confronted with the assistant, without knowing their opinion about such systems, it is expected that the acceptance of the overtaking assistant will be neutral (both average scores for usefulness and satisfaction will be around 0).

To get more information about drivers’ opinion about a system such as the overtaking assistant, additional questionnaire can be made with various questions about the overtaking assistant. The answers to these questions give an indication of the opportunities of such as system.

**Sensation seeking**

Sensation seeking (SS) is a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal and financial risks for the sake of such experiences (Zuckerman, 1994). Whether a driver is a sensation seeker can be studied by means of a standardised sensation seeking questionnaire (Jonah, 1997). This is a questionnaire with 68 questions on general sensation items. From this questionnaire, four subscales are distracted: boredom susceptibility (BS), thrill and adventure...
seeking (TAS), experience seeking (ES) and disinhibition (DIS). TAS is found to be most strongly related with risky driving, followed by DIS and ES (Jonah, 1997). Although the relationships between sensation seeking and risky driving are studied much, the validity of this measure is not proven yet. Nevertheless, sensation seeking scores are assumed to be indicators of overtaking efficiency and safety.

Overtaking is often ranged in the list of elements of driving that characterise risky driving. In a questionnaire study, Arnett (1997) found high school students scoring higher on Arnett’s SS scale, adapted from the referred Jonah-scale, were more likely to pass in no passing zones. Another study presented that violation of traffic rules and speeding (including overtake the car in front even when it keeps appropriate speed) is strongly related to reckless driving, drinking and driving and seat belt use, perhaps capturing a driver’s risk-taking behaviour (Iversen, 2004). In both studies, overtaking is considered in the light of traffic violations, while, in this experiment, overtaking is treated as a comfort improving manoeuvre. We argue that the performance of legal overtaking manoeuvres is not (always) related to risky driving and thus not related to sensation seeking. Moreover, with the overtaking assistant, we aim to assist the less daring drivers with overtaking performance. This results in the expectation that overtaking frequency with the overtaking assistant is not related to sensation seeking.

The sensation seeking variable goes a step further than the other presented variables. All discussed variables measure possible changes in driving performance when driving with the overtaking assistant. The sensation seeking variable is a descriptive variable that tries to explain differences between drivers.

**Summary of subjective indicators expectations**

The expected effects of the overtaking assistant on overtaking efficiency, safety and comfort, measured with the subjective indicators are summarised in Table 5.3. The consequences of the chosen subjective indicators are all expected to be positive. The positive consequence on safety of the sensation seeking expectations covers that with the assistant, also the not sensation seeking drivers will overtake more. These manoeuvres will then not be the reckless ones at unsafe locations, in stead, these will be the safe ones advised by the overtaking assistant.

**Table 5.3 Summary subjective indicators effects and their consequences**

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Expectations:</th>
<th>Consequences on: Efficiency</th>
<th>Safety</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workload</td>
<td>Decrease, but stay in optimal region</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Activation</td>
<td>Less increased during overtaking</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Acceptance</td>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensation seeking</td>
<td>Less relation with overtaking frequency</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

To collect all selected indicators to measure efficiency, safety and comfort effects of the overtaking assistant, a suitable assessment method was searched. A driving simulator
experiment is one of the few available methods to evaluate the overtaking assistant at this conceptual phase of development. The next subsection describes this assessment method.

5.2.3 The driving simulator assessment method

A driving simulator experiment enables collection of detailed data of a subject vehicle (the simulator) and the surrounding traffic in a controlled environment. Questionnaires completed by participants add information about participants’ perceptions. Together, this delivers useful data to study new driver assistance systems as the overtaking assistant. Since the necessary devices to produce the proposed overtaking assistant in reality are not yet available as described in Chapter 4, it is impossible to test the overtaking assistant in a real vehicle. Hence, it is not possible to test the overtaking assistant with alternative assessment methods apart from a driving simulator such as a test track, an instrumented vehicle or a pilot study. Despite the fact that a driving simulator experiment seems a viable assessment method at this conceptual phase of development of the overtaking assistant, it is necessary to discuss the validity of driving simulators.

An important advantage of driving simulators is that they allow driving conditions and environment conditions to be kept constant (Nilsson, 1993). They are well suited for comparative effect studies where one or a couple of factors are systematically varied, while all other factors are kept constant (Hoedemaeker, 1999). And, all relevant performance measures can be sampled and analysed afterwards. With respect to driver assistance systems, a driving simulator enables the test of these systems during the conceptual phase of the development (De Waard and Brookhuis, 1997).

On the other hand, driving simulators do have some limitations. Overtaking is a task that requires the use of visual information from large distances, which might be different in a simulator, as a result of relatively low screen resolution (Kaptein et al., 1996). This results in later recognition of objects or vehicles at larger distances. Despite this, results of driving simulator experiments where overtaking manoeuvres are studied and compared with real life manoeuvres, at least showed relative validity (Charlton, 2007). Another comparison between real world and driving simulator resulted in larger headways with the preceding vehicle in the simulator (23 s, vs. 7 s in the real world)) and longer average time spent in the left lane (simulator 20 s, real world 10.7 s) (Jenkins, 2005). A result possibly related to overtaking is that at high speed, lateral position in a driving simulator differs from driving in the real world: in a driving simulator, drivers drive closer to the centre line (Kaptein et al., 1996). These findings were confirmed in a study of driving performance in a simulator (Dorn and Barker, 2005). Another study found higher speeds and larger standard deviations of lateral position in a driving simulator experiment that studied the effects of preceding vehicle’s speed choice (Tenkink, 1991). However, the found experimental effect was in the same direction as found for driving in the real world.

There is an emerging consensus that relative validity of simulators (direction and size of change are similar) may be more relevant than absolute validity of simulators (real numbers are similar) (Godley et al., 2002). Validation of simulator results of overtaking on a rural road with oncoming traffic is the least to be done to see if the results reflect real life overtaking. For this experiment, the findings of the simulator experiment will be compared with the
observations of overtaking manoeuvres with the instrumented vehicle described in Chapter 2. Validation of driving simulator results is not attainable within the framework of this dissertation research, and is not necessary to fulfil the requirements for this experiment. The direction and relative size of change of relevant variables is most important and can be obtained with driving simulators (Kaptein et al., 1996, De Waard and Brookhuis, 1997).

In summary, giving the above findings of applicability and validity of driving simulators, a driving simulator is selected as the most suitable tool to test driver assistance systems such as the overtaking assistant in the conceptual development phase. It can study the interaction between drivers and assistance systems in an efficient and risk-free manner. In particular conclusions on relative effect size can be drawn.

5.3 Method: overtaking assistant assessment with a driving simulator

With a driving simulator, effects of an overtaking assistant on overtaking efficiency, safety and comfort on two-lane rural roads with oncoming traffic were studied. This subsection describes the overtaking assistant, the driving simulator, the participants, the design of the experiment, the procedure, the driving environment and the data collection and analysis.

5.3.1 Driving simulator

The TNO low-cost driving simulator was used because of its availability and its flexible driving environment (Kappé et al., 2002). The scenarios for this simulator can be developed and tested on a normal computer additionally equipped with a steering wheel and pedals, which are usually used for computer games. The ability to develop and test an experiment at your own desk instead of on the driving simulator itself saves a lot of time and money, which were important reasons to choose for this simulator. The fixed-base simulator is a mock-up of the front part of a Volkswagen Golf, including the bonnet and the two front seats. All features, including, steering wheel, gas pedal, brake, clutch, indicators, dashboard and lights are operated as in a normal car. The environment is projected on three screens that together cover 180 degrees of view. The two side mirrors and rear mirror are projected on this screen. The overtaking assistant was also projected on the front screen, to the right of the rear mirror. All sounds are produced by speakers.

5.3.2 Overtaking assistant

Chapter 4 discussed the design of the overtaking assistant. The resulting conceptual design assists drivers with overtaking gap acceptance in the oncoming traffic stream. If this gap is judged sufficiently large to safely perform an overtaking manoeuvre, a green sign is displayed to the driver. If it is not safe to overtake, a red sign is displayed. Three seconds blinking red and blinking green are displayed between a switch from red to green and from green to red respectively.

The threshold gap for a green sign (the minimum recommended gap to perform an overtaking manoeuvre) should be 10 s according to the design results of Chapter 4. However, a pilot
study in the simulator revealed that drivers were able to perform an overtaking manoeuvre much faster and became impatient with the assistant. This was also due to the programmed arrivals of oncoming vehicles, with increasing gaps between the oncoming vehicles as will be explained in 5.3.7, enabling the study of unassisted gap acceptance. The first gap between (groups of) oncoming vehicles was 4 s, the second 6 s, the third 8 s and so on. A design displaying a green sign for gaps larger than 10 s meant that drivers had to let pass five (groups of) oncoming vehicles before an overtaking opportunity. Most pilot study drivers disobeyed the system and used a gap smaller than 10 s. A gap of 8 s was mostly used and drivers did not have to rush when using this gap. Hence, 8 s was chosen to be the threshold value for the assistant to display the green sign.

The human-machine interface of the assistant is a traffic-light like picture projected at the front screen of the driving simulator, right next to the rear mirror. This position was recommended by Lee et al. (2004) for lane change assistance systems, since all drivers have at least one glance forward during the 3 s prior to a lane change.

5.3.3 Participants
Twenty-four experienced drivers, 12 male and 12 female, were recruited from the TNO driving simulator subject database. The average age of the participants was 45 years with a standard deviation of 9 years. On average, the subject sample had held a driving license for 26 years and drove around 17,000 km in the past 12 months. The participants received a monetary reward for their participation.

For a new system such as the overtaking assistant it is useful to study its effects on different driver groups such as male/female, young/elderly and leisure/commuter. The chosen participants made it possible to distinguish between male and female drivers. Differences for other groups should be studied at a later stage of the overtaking assistant development.

5.3.4 Experimental design
A so-called repeated measures design was adopted, where three scenarios (reference i.e. the current situation, the overtaking lane and the overtaking assistant) functioned as within-subject factors. This means that all participants drive these scenarios, to enable comparison of the scenarios within the subjects. To avoid learning effects, counterbalancing of the three scenarios is used, by means of the Latin Square design. This implies that one third of the participants (4 male and 4 female participants) were subjected to the scenarios in the order reference-lane-assistant, one third in the order lane-assistant-reference and one third in the order assistant-reference-lane. The circumstances for the three scenarios were kept as constant as possible. The selected indicators described in Section 5.2 are collected for all scenarios. Between the main rides, participants completed some questionnaires, listened to the next scenario explanation and did a test ride. This created enough time between the main rides to avoid carry-over effects meaning that the performance on the second scenario will be affected by the experience from the first scenario. The existence and speed of preceding vehicles is programmed in such a way that situations for all participants are comparable, but the structure is made as unobtrusive as possible by randomly varying colours and makes of the preceding vehicles and oncoming vehicles. The offered overtaking gaps between groups of oncoming vehicles are also regulated, which will be explained in more detail in Section 5.3.7.
5.3.5 Procedure
Within a time frame of about 3 hours, participants completed the whole experiment. They started with a short introduction to the experiment and some general questions about overtaking. Although all participants did have experience with the driving simulator, they were allowed to drive the simulator again to get used to it. The general instructions given to the participants were to drive as they would normally do and to imagine that they were in some kind of hurry. They were for example on their way to a wedding or an important meeting and left home a little too late. Explanation about the scenario to be driven was given followed by a 5 minute test ride. After the test ride for the overtaking lane scenario, participants were asked whether they had understood how to use the overtaking lanes and whether they could tell what special signs they had seen along the road meant. After the overtaking assistant test ride, the participants were asked to tell briefly what the assistant did. In case of error, participants were corrected, to make sure they would understand the assistant while they were driving the experimental ride. After this, the participants drove the experimental ride, which took about 15 minutes. Activation questionnaires (Bartenwerfer, 1969) and workload questionnaires (Zijlstra, 1993) were given before and after the experimental ride. An additional acceptance questionnaire and some general questions about the overtaking lane and the overtaking assistant were asked after the experimental rides of the lane scenario and the assistant scenario respectively. Heart-rate data was collected during the main rides of the three scenarios. At the end, participants completed the sensation seeking questionnaire. All questionnaires are presented in Appendix B.

5.3.6 Driving simulator environment
The simulated environment was based on the N305 Almere-Zeewolde described in Chapter 2 and referred to as Flevoland road. This road was originally selected because of its ideal overtaking circumstances with relatively long stretches flat road with perfect views. The total length of the simulated road was 20 km, including 3 stretches of about 5 km and 2 junctions, at which the driving directions are split.

The roads for the reference scenario (without assistance) and the assistant scenario were similar. For the overtaking lane scenario, an overtaking lane was added, alternating for both directions as shown in the two right pictures in Figure 5.3.

5.3.7 Surrounding simulated traffic
The simulated traffic in the driving simulator environment consisted of preceding vehicles and oncoming traffic. The subject vehicle (the simulator / the participant) encountered preceding vehicles, which were waiting for the subject vehicle to make sure the participant would encounter the preceding vehicles. They accelerated to their programmed speed in such a way that the participants would not see this waiting. Three different speed regimes were programmed: the first type preceding vehicles was driving at 75 km/h, the second type 85 km/h, and the third type changed its speed every 8 s between 76 and 91 km/h. Note that these speeds are the programmed speeds, speeds displayed at the participant’s speedometer are somewhat higher, because all regular cars’ speedometers have a bias to a higher speed (Openbaar-Ministerie, 2006). The driving simulator vehicle has this as well. If a participant encountered a preceding vehicle of the first type and overtook it, it would encounter the second type, the third type, the first type again and so on. When a participant did not overtake
a preceding vehicle within 2 minutes following, this vehicle would either park along the road, or turn right at a junction, whatever could happen first, to guarantee that participants met enough different preceding vehicles.

Oncoming vehicles were generated as soon as participants start following a preceding vehicle. The first offered gap between 2 groups of oncoming vehicles was 4 s, the second 6 s, the third 8 s, and so on. This enabled to study which gap size participants judged as large enough to perform an overtaking manoeuvre. During a pilot study, participants were asked if they recognized some kind of structure within the arrival of the oncoming vehicles, but they did not. The variance in group size of the oncoming vehicles well camouflaged the regulated increasing gaps between the groups. This group size varied between 1 and 6 and the gaps within a group of vehicles varied between 1 and 2 s. The speed of all oncoming traffic was 100 km/h, similar to the speed limit.

The regulated arrival of the oncoming vehicles implied that the overtaking assistant would display a green sign after the third group of oncoming vehicles had passed. The first overtaking possibility according to the overtaking assistant was therefore always 8 s, the second 10 s, the third 12 s and so on.

5.3.8 Data collection and analysis
The following data sets are collected during the experiment:
- Pre-defined data to collect;
- Dynamic performance data sampled at 10 Hz\(^{10}\);
- Questionnaires (mental effort, activation, acceptance, opinion, sensation seeking);
- Heart rate data.

**Table 5.4 Collected indicators with descriptions how they are obtained and computed**

<table>
<thead>
<tr>
<th>Indicator Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking frequency</td>
<td>Each cross of the centre of the simulator over the centre line (d(_{\text{latpos}}&gt;1.65)) longer than 1.5 s while an oncoming vehicle (TTC&lt;9999) was present was counted as an overtaking manoeuvre. The overtaking frequency was counted as the total number of overtaking manoeuvres performed by a participant per ride.</td>
</tr>
<tr>
<td>Distance headway during overtaking 5 s prior to overtaking</td>
<td>Distance between the front bumper of the simulator and the rear bumper of the preceding vehicle during the 5 s prior to overtaking.</td>
</tr>
<tr>
<td>Time headway at start</td>
<td>Time between the simulator’s front bumper and the preceding vehicle’s rear bumper at the moment the centre of the simulator was above the centre line (d(_{\text{latpos}}=1.65)).</td>
</tr>
<tr>
<td>Lateral position</td>
<td>Given as the distance of the centre of the simulator and the centre of the right most driving lane. Positive value meant that the simulator was to the left of the centre of the right lane, negative values meant that the simulator was to the right of the centre of the right lane. The lateral position was a summation of absolute values of left and right deviations from the centre of the lane during 5 s prior to overtaking.</td>
</tr>
<tr>
<td>Accepted gap</td>
<td>The chosen pre-programmed gap (4, 6, 8 and so on) in the oncoming traffic stream that was used by the participant to perform an overtaking manoeuvre. This variable is obtained from the pre-defined data set.</td>
</tr>
<tr>
<td>Time spent in the left lane</td>
<td>Time between the moment the centre of the simulator has passed the centre line (move to left) until the moment the centre of the vehicle has passed the centre line again (move back to right).</td>
</tr>
<tr>
<td>TTC(^{11})</td>
<td>The time left between the oncoming vehicle and the simulator if they continue at their present speed, measured at the moment the centre of the simulator is above the centre line at the end of an overtaking manoeuvre.</td>
</tr>
<tr>
<td>Indicator usage</td>
<td>The position of the indicator (0 = off, 1 = to right, 2 = to left) measured at the start and at the end of an overtaking manoeuvre.</td>
</tr>
<tr>
<td>Workload</td>
<td>Before and after each main ride, the rating scale of mental effort was completed.</td>
</tr>
<tr>
<td>Activation</td>
<td>Before and after each main ride, participants rated their activation level.</td>
</tr>
<tr>
<td>Acceptance</td>
<td>After the scenarios overtaking assistant and overtaking lane, participants gave scores to nine items on a five-point scale. These items scored on usefulness and satisfaction, representing the acceptance of the system.</td>
</tr>
<tr>
<td>Sensation seeking</td>
<td>At the end of the experiment, participants completed the sensation seeking questionnaire. Scores on the subscales of the questionnaires were compared with overtaking frequencies.</td>
</tr>
</tbody>
</table>

\(^{10}\) The software of the simulator includes an extensive list of variables to collect during simulator runs. See for an overview: Van Wolffelaar, P.C. & Van Winsum, W. (2005). Programming within the Dutch Driver Simulator Platform. Delft: TRAIL Research School. Of this list, the necessary variables to collect data for the indicators are selected, e.g. d\(_{\text{latpos}}\) and TTC.

\(^{11}\) As stated in Section 2.4.2, strictly speaking, the measured TTC is not a TTC but a Post-Encroachment-Time (PET), because the two vehicle are not on a collision course anymore. For the sake of consistency, we have chosen to use the term TTC.
Table 5.4 presents a description of how the indicators were obtained from the collected data sets. Heart rate data were collected to analyse workload. However, the collection frequency turned out to be too low to do the analysis and therefore workload is subjectively measured only with the rating scale of mental effort. Results on the emotions scores are reported elsewhere (Harms, 2006).

The data set ‘Pre-defined data to collect’ was programmed in such a way that for each time both front and back wheels of the simulator crossed the centre line, that is, an overtaking manoeuvre, several static, pre-defined variables were collected. Examples are the accepted gap with the oncoming vehicles and indicator usage.

The dynamic performance data was sampled at 10 Hz, which results in 10 data rows per driven second, collected during the three scenarios’ main rides. Data collected during an overtaking manoeuvre, was extracted from this data set, enabling analysis of overtaking manoeuvres. The software package Matlab 7.0 was used to extract these overtaking data by looking at the lateral position of the simulator. If the simulator had crossed the centre line (d_laplos > 1.625) longer than 1.5 s, it was assumed that an overtaking manoeuvre was performed. Since the overtaking manoeuvres were programmed in such a way that there was always oncoming traffic during overtaking demand situation, the TTC with the oncoming vehicle was used as an extra check, including that the TTC with oncoming vehicle should be smaller than 9999\(^1\).

Data sampled 5 s prior to overtaking were extracted from the dynamic performance data. These data were used for the analysis of indicators that need to be measured before the overtaking manoeuvre was performed that is distance headway, lateral position and indicator usage. The resulting 2 data files, one with data 5 s prior to overtaking and one with data during overtaking, were completed with participant number, scenario number, scenario order (e.g. lane-assistant-reference), gender and overtaking manoeuvre number.

Statistical tests and notification

Descriptive statistics were applied for all measures, calculating means, averages, minima and maxima. Analysis of variance (ANOVA) for repeated measurements was applied to analyse overtaking frequency, distance headway, time headway, time spent in the left lane, TTC and lateral position, using SPSS 12.0. This statistical test examines the equality of means and is appropriate when all subjects or cases of a sample are measured under a number of different conditions. These conditions are represented by the within-subjects factors being a set of variables measured for all participants. The between-subject factors divide the sample into groups. In this experiment, gender was included as a between-subjects factor and scenario (reference-assistant)\(^2\) and speed of the preceding vehicle (split in above 80 km/h and below 80 km/h) as within-subjects factors. To allow ANOVA for repeated measures analysis, the indicators should be normally distributed and variance should be homogeneous. Although for all overtaking manoeuvres together the indicators were not all normally distributed, per participant most were normally distributed.

\(^1\) 9999 is the default given value when there is no oncoming vehicle
\(^2\) The lane scenario was only included for the analysis of the overtaking lane, described in Section 5.5
The dependent t-test is applied to study whether means are significantly different. A dependent t-test is applied when two experimental conditions (in this case driving without and with the overtaking assistant) are completed by the same participants. The dependent t-test tests whether differences between means of two groups are statistically meaningful. The mean difference between the two groups is compared with the expected differences. The calculated t-statistic is the ratio of the systematic variation in the experiment to the unsystematic variation. The higher this statistic, the more likely that the compared two means are different.

A t-test and an ANOVA assume normal distribution of the tested variable. Kolmogorov-Smirnov (KS) tests were applied to test this. When a variable was not normally distributed, the non-parametric Friedman test was used instead of the t-test, also testing differences in means, but without the assumption that the tested variables are normally distributed. For all tests, an alpha of 0.05 is used to determine the significance of effects.

5.4 Results of overtaking assistant driving simulator experiment

All participants completed the experiment successfully.

Table 5.5. Descriptive statistics for the analysed variables of overtaking per scenario

<table>
<thead>
<tr>
<th>Variable</th>
<th>Scenario</th>
<th>min</th>
<th>Max</th>
<th>mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking frequency [#]</td>
<td>Reference</td>
<td>1</td>
<td>31</td>
<td>14.6</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>4</td>
<td>27</td>
<td>15.2</td>
<td>5.1</td>
<td>24</td>
</tr>
<tr>
<td>Average time headway during 5 s prior to overtaking [s]</td>
<td>Reference</td>
<td>0.18</td>
<td>2.9</td>
<td>0.9</td>
<td>0.6</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>0.17</td>
<td>2.8</td>
<td>0.8</td>
<td>0.5</td>
<td>365</td>
</tr>
<tr>
<td>Time headway at start [s]</td>
<td>Reference</td>
<td>0.03</td>
<td>1.5</td>
<td>0.4</td>
<td>0.3</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>0.03</td>
<td>1.3</td>
<td>0.4</td>
<td>0.2</td>
<td>365</td>
</tr>
<tr>
<td>Lateral position [sum of deviations from centre]</td>
<td>Reference</td>
<td>6.6</td>
<td>55.0</td>
<td>19.8</td>
<td>8.1</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>6.3</td>
<td>54.8</td>
<td>18.8</td>
<td>6.9</td>
<td>365</td>
</tr>
<tr>
<td>Accepted gap [4, 6, 8, 10, ... s]</td>
<td>Reference</td>
<td>4</td>
<td>24</td>
<td>Most frequent: 8.0 (35%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>4</td>
<td>24</td>
<td>Most frequent: 8.0 (41%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spent in the left lane [s]</td>
<td>Reference</td>
<td>1.5</td>
<td>6.9</td>
<td>3.6</td>
<td>1.1</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>1.6</td>
<td>6.6</td>
<td>3.6</td>
<td>1.0</td>
<td>365</td>
</tr>
<tr>
<td>Minimum TTC [s]</td>
<td>Reference</td>
<td>0.1</td>
<td>12.3</td>
<td>3.0</td>
<td>1.9</td>
<td>331</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>0.1</td>
<td>12.2</td>
<td>2.5</td>
<td>1.7</td>
<td>358</td>
</tr>
<tr>
<td>Indicator usage [% correct usage]</td>
<td>Reference</td>
<td>At start manoeuvre: 57%, at end: 38%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>At start manoeuvre: 64%, at end: 46%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workload [scale 0-100]</td>
<td>Reference</td>
<td>Before ride: 36, after ride: 46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>Before ride: 40, after ride: 58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activation [scale 0-20]</td>
<td>Reference</td>
<td>Before ride: 14, after ride: 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>Before ride: 15, after ride: 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptance assistant (assistant scenario only)</td>
<td>Usefulness</td>
<td>-1.8</td>
<td>+1.8</td>
<td>+0.06</td>
<td>0.46</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Satisfaction</td>
<td>-2.0</td>
<td>+2.0</td>
<td>-0.32</td>
<td>1.4</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 5.5 presents an overview of the general descriptive statistics results of the analysed indicators, including minimum, maximum, mean, standard deviation and number of cases N.

14 SD = standard deviation
15 The average time headway is presented instead of distance headway, to include vehicle speeds
Unfortunately, the collected heart rate data could not be used for the analysis, because the frequency at which these data were collected was too low to indicate changes in heart rate.

5.4.1 Overtaking frequency
The number of overtaking manoeuvres per ride is a first indicator to measure the effects of the overtaking assistant on overtaking efficiency. Figure 5.4 reveals that female participants overtook more with the assistant compared to the reference scenario and male participants less, which decreased the difference between gender from significant in the reference scenario ($t_{22}=2.323; p<.05$) to not significant in the assistant scenario.

![Figure 5.4 Overtaking frequency without and with an overtaking assistant by gender (plus and minus one standard deviation).](image)

In the reference scenario, the 12 male participants together made 211 overtaking manoeuvres and the 12 female participants 139. In the assistant scenario, these were 202 and 163 respectively. This involves that the mean overtaking frequency across all participants did not differ significantly between the 2 scenarios and for the 2 scenarios together, male participants had a significant higher overtaking frequency ($F_{1,22} = 4.418, p < .05$).

5.4.2 Distance headway during 5 s prior to overtaking
The next analysed indicator is the headway between the overtaker and the preceding vehicle during 5 s prior to overtaking. Figure 5.5 presents the distance headways of 2 participants during 5 s prior to overtaking, which are representative for all participants. The headways of the reference scenario are presented with a -, of the assistant scenario with a + and for completeness, the overtaking manoeuvres of the overtaking lane scenario are included as well, presented with an o.
In general, the headway between the overtaker and the preceding vehicle decreased when the time until the start of the manoeuvre becomes less. This indicates that overtakers start to
accelerate in the right lane before they move to the left lane. This was also observed during the overtaking observation study described in Chapter 2. During these observations, most headways varied between 10 and 40 m. Figure 5.5 presents that in the simulator, these headways varied between 5 and 50 m. For the driven speed these distance headways correspond with time headways between 0.4 and 2.0 s. The derivative of the displayed distance headways in the figure gives the relative speed between the preceding vehicle and the overtaker, which varies between 0 and 6 m/s (about 22 km/h). The headways of the two displayed participants in the assistant scenario are somewhat larger than in the reference scenario and are also more divided.

5.4.3 Time headway at start
A second analysed headway indicator is the time headway at the start of the manoeuvre. The time headway differed not significantly between the two scenarios (reference-assistant) and not between the two speeds of the preceding vehicles (below 80 km/h – above 80 km/h). Male participants had significantly smaller time headways at the start of the manoeuvre than female participants ($F_{1,20}= 4.003, p <.05$). The three-way interaction effect of scenario, preceding vehicle speed and gender was significant ($F_{1,20}=7.642, p<.05$). This means that for gender the time headway of the two scenarios differed with the speed of the preceding vehicle in a different manner.

5.4.4 Lateral position
Lateral position data are analysed as an indicator for both overtaking safety and overtaking comfort. The lateral position is a summation of deviations from the centre line during 5 s prior to overtaking, as described in Table 5.4. The lateral position in the assistant scenario was significantly smaller than in the reference scenario ($F_{1,20}=7.352, p<.05$). For both male and female participants the lateral position decreased when driving with the overtaking assistant. When preceding vehicles were driving above 80 km/h, the lateral position was significantly larger than when preceding vehicle drive below 80 km/h ($F_{1,20}=10.177, p<.005$). The interaction effect of scenario and gender was also significant. This indicates that the lateral position for the two scenarios differed between male and female participants.

5.4.5 Accepted gap
Acceptance of gaps in the oncoming traffic stream to perform an overtaking manoeuvre is one of the most important indicators to study possible effects of the overtaking assistant, since the overtaking assistant aims to assist with this gap acceptance task. Figure 5.6 shows a shift to larger accepted gaps when driving with the overtaking assistant.

The average duration of observed overtaking manoeuvres on a real road as described in Chapter 2, was 7.8 s. This suggests that accidents could occur when gaps of 4 or 6 s were accepted, but, in the simulator, participants were able to perform the manoeuvres within these short gaps. The then applied strategies often included lane sharing and cutting in (see Chapter 2 for a description). When a collision occurred, the participant was stopped and kindly asked to repeat the ride. This occurred only for 3 of the 72 rides.
5.4.6 Time spent in the left lane

The next analysed indicator is the time spent in the left lane. With the assistant, this indicator was smaller than in the reference scenario ($F_{1,20} = 4.789$, $p < .05$). Figure 5.7 presents the difference between the two scenarios per gender. The figure makes clear that the difference between the two scenarios was mainly caused by the female participants.

Comparing gender, female participants spent significantly more time in the left lane than male participants. This difference was not significant in the assistant scenario that can be read from the graph, presenting the measurements for male and female closer to each other. The resulting effect of the assistant is that the difference in time spent in the left lane between male and female becomes smaller.

The speed of the preceding vehicle did have a strong effect on the time spent in the left lane for both scenarios. For preceding vehicle speed below 80 km/h the time spent in the left lane in the reference scenario was 3.6 s and in the assistant scenario 3.5 s, where for preceding vehicle speed above 80 km/h these were 4.1 s and 3.9 s respectively.

5.4.7 Time-To-Collision (TTC)

For the safety of overtaking, TTC is an interesting indicator to analyse. The minimum TTC with the first oncoming vehicle after overtaking was over all participants significantly smaller in the assistant scenario as compared to the reference scenario ($F_{1,20} = 20.536$, $p < .001$). Figure 5.8 presents that both male participants and female participants contributed to this decrease in TTC.
Figure 5.7 Average time spent in the left lane while overtaking without and with overtaking assistant by gender.

For male and female participants, the TTC when driving with the assistant drops below 3 s, which is often seen as the minimum required safety margin between two vehicles on a collision course. This is an undesired effect of the overtaking assistant.

Figure 5.8 Minimum TTC till first oncoming vehicle without and with overtaking assistant, per gender

5.4.8 Indicator usage

In the Netherlands, indicator usage is obligatory for each lane change. In case of overtaking, drivers should use it twice: for the change to the left lane and for the change back to the right lane. Figure 5.9 shows that not all participants used their indicator correctly. At the end of the
Assisted Overtaking

manoeuvre, some even indicated a move to the left, while they were returning to the right lane. Probably, these participants have left the indicator on during the whole manoeuvre. Neither male participants nor female participants used their indicator differently in the reference scenario and in the assistant scenario. Also, no differences in indicator usage between male and females were found. For gender and scenario, the indicator was used correctly at the start of the manoeuvre for about ¾ of the overtaking manoeuvres.

<table>
<thead>
<tr>
<th>Reference scenario</th>
<th>Assistant scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the start of the manoeuvre</td>
<td></td>
</tr>
<tr>
<td>Off 43%</td>
<td>Off 30%</td>
</tr>
<tr>
<td>Left 57%</td>
<td>Left 64%</td>
</tr>
<tr>
<td>At the end of the manoeuvre</td>
<td></td>
</tr>
<tr>
<td>Left 7%</td>
<td>Right 8%</td>
</tr>
<tr>
<td>Off 55%</td>
<td>Off 40%</td>
</tr>
<tr>
<td>Right 38%</td>
<td>Right 46%</td>
</tr>
</tbody>
</table>

**Figure 5.9 Indicator usage before and after the overtaking manoeuvre for reference scenario and the assistant scenario**

**5.4.9 Subjective indicators**

In addition to objective data collections during the rides, participants were also asked to complete questionnaires before and after the rides. One of these included the workload questionnaire as explained in more detail in 5.2.2. The workload is measured just before and just after the rides, and for both scenarios, the scores after the ride were higher. When comparing the two scenarios, the workload score grew more during the assistant scenario, and were already higher before the ride. Apparently, after the explanation of how the assistant works, participants were already thinking about it, before the ride started, which increased their workload. Females’ workload before and after the assistant scenario is significantly higher than the males’ workload (Before: $t_{22}=-2.137, p<.001$, after: $t_{22}=-4.010= p<.001$).

Another questionnaire measured the activation level of all participants, also before and after a ride. The activation level of all drivers before driving the reference scenario and the assistant scenario was on average for both rated as similar to *I am solving a cross puzzle*. After 15 minutes driving with the overtaking assistant the average activation level was *I am watching an exciting movie* while for the reference scenario only the activation level *I am reading a newspaper* was reached. Female participants had significantly higher activation levels after the reference scenario and before and after the assistant scenario than male participants.
A third questionnaire completed after driving the assistant scenario is the acceptance questionnaire, resulting in usefulness and satisfaction scores, both indicators for the comfort of overtaking. With regard to acceptance, the average score on usefulness of the overtaking assistant was +0.6 (scale -2 - +2). The participants were less satisfied about the system, this item average rate was - 0.3 across all participants.

5.4.10 Additional questionnaires
After completion of the assistant ride, participants were asked to complete an additional questionnaire involving questions about opinions of the assistant. Figure 5.10 presents the results. These results were not directly used as indicators for overtaking efficiency, safety or comfort, but were useful for the set of needs for the design of the assistant, as explained in Chapter 4. These results were used in the evaluation phase of the assistant, to improve the first conceptual design.

Notable results are that 23 participants of the 24 preferred a system that can be switched on and off manually and half of the participants thought that overtaking with the assistant was more difficult than without.

![Figure 5.10. Results of the multiple choice questions about the overtaking assistant (the indicated duration of the lessons of the first question was half an hour)](image)

Additional remarks of participants about the assistant included two extremes. Some participants thought the assistant’s threshold for the green sign was too low: *the assistant displays a green sign while I see an oncoming vehicle!*, whereas other participants thought the assistant’s threshold was too high: *the assistant displays a red sign while I could easily overtake the preceding vehicle*. The threshold value for a green sign for the tested overtaking assistant was 8 s and similar for all participants. Thus, perception of required overtaking time differs, whereas the real required time is similar.
Finally, the relationship between risky driving and overtaking frequency was studied. If such a relationship exists and if an overtaking assistant affects overtaking frequency, than it could also affect risky driving. In the most positive case, an overtaking assistant could help reducing risky driving. To study the possible relationship between risky driving and overtaking frequency, all participants completed a sensation seeking questionnaire. The Bi-variate Pearson’s correlation test (a Shapiro-Wilks test demonstrated that overtaking frequency is normally distributed) showed a significant relation between the number of overtaking manoeuvres performed in the assistant scenario and the BS scale (explained in 5.2.2) ($r = .483, p < 0.02$) and not with the other subscales that are more strongly related to risky driving. This means that no relation could be proven between risky driving and overtaking frequency.

The relationship with risky driving is the last analysed indicator of the effects of an overtaking assistant on overtaking. The next section is spent on the result of the overtaking assistant compared to the results of the overtaking lane, included in the driving simulator experiment as an alternative solution to improve overtaking on two lane rural roads.

### 5.5 Results of the assistant compared to the overtaking lane

The simulator experiment included three scenarios: a reference scenario, a lane scenario and an assistant scenario. The lane scenario included an overtaking lane as a solution to improve overtaking. Including an assistant scenario as well as a lane scenario in one simulator experiment enables comparison of their effects on efficiency, safety and comfort of overtaking. The results of the overtaking lane are thoroughly discussed elsewhere (Harms, 2006). Here, an overview is given of the most interesting results compared to the assistant scenario results. Table 5.6 presents the mean and standard deviation of the compared indicators, split to gender. Note that not all indicators could be calculated for the lane scenario since oncoming vehicles did not drive on the adjacent lane.

#### Table 5.6 Mean and standard deviation per gender for the analysed variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Scenario</th>
<th>Mean male / female</th>
<th>Standard deviation male / female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking frequency [#]</td>
<td>Reference</td>
<td>17.7 / 11.6</td>
<td>7.2 / 5.6</td>
</tr>
<tr>
<td></td>
<td>Lane</td>
<td>16.4 / 11.1</td>
<td>6.9 / 5.7</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>16.8 / 13.6</td>
<td>5.1 / 4.9</td>
</tr>
<tr>
<td>Time headway at start [s]</td>
<td>Reference</td>
<td>0.3 / 0.4</td>
<td>0.1 / 0.2</td>
</tr>
<tr>
<td></td>
<td>Lane</td>
<td>0.7 / 1.0</td>
<td>0.5 / 0.7</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>0.3 / 0.4</td>
<td>0.1 / 0.2</td>
</tr>
<tr>
<td>Time spent in the left lane [s] / Time in overtaking lane [s]</td>
<td>Reference</td>
<td>3.6 / 4.3</td>
<td>0.9 / 0.7</td>
</tr>
<tr>
<td></td>
<td>Lane</td>
<td>5.0 / 6.2</td>
<td>2.1 / 1.5</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>3.6 / 3.9</td>
<td>0.7 / 0.6</td>
</tr>
<tr>
<td>Lateral position [m]$^{16}$</td>
<td>Reference</td>
<td>20.6 / 18.6</td>
<td>8.9 / 6.6</td>
</tr>
<tr>
<td></td>
<td>Lane</td>
<td>20.5 / 20.2</td>
<td>8.4 / 7.2</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>18.2 / 18.8</td>
<td>7.1 / 6.6</td>
</tr>
</tbody>
</table>

$^{16}$ The shown values of lateral position are summations of deviations from the centre of the lane during 5 s prior to an overtaking manoeuvre, measured 10 times per s.
Table 5.6 presents that the overtaking frequency for the lane scenario was somewhat lower compared to the reference and the assistant scenario, caused by the overtaking prohibition when the overtaking lane was dedicated for the opposing driving direction. For the parts of the road with an overtaking lane, the overtaking frequency of the lane scenario was significantly higher than the reference scenario \(Z=-2.968, p<.003\). The time headway at the start of the overtaking manoeuvre and time spent in the left lane were longer for the lane scenario and lateral position varied more, especially for the female participants.

Analysis of variance (ANOVA) for repeated measurements (described in 5.3.8) are again applied, with scenario as a three level within-subjects factor (reference, lane, assistant), preceding vehicle speed as a two level within-subject factor (below 80 km/h and above 80 km/h) and gender as a between-subjects factor. All results with a confidence of 95% or higher are discussed.

Significant differences between gender is found for the indicators time headway at the start \(F_{1,20}=14.732, p<.001\) and time spent in the left lane / in the overtaking lane \(F_{1,120}=27.081, p<.001\)^17. The larger headways at the start for female participants also yield longer time spent in the left lane / in the overtaking lane.

Lateral position differed significantly between the scenarios \(F_{2,20}=3.864, p<.05\). This difference is illustrated in Figure 5.11. It reveals that male participants swerved more in the reference scenario, possibly caused by the intention to steer to the left when looking for an overtaking manoeuvre, while female participants swerved more in the lane scenario, possibly caused by the lack of a feeling of danger to collide with oncoming vehicles, since there are no oncoming vehicle on the adjacent lane.

![Figure 5.11 Lateral position per scenario separated per gender](image-url)

Mauchly’s Test of Sphericity was significant for the time spent in the left lane, which asks to apply Greenhouse-Geisser correction, which reduces the degrees of freedom.
Pairwise comparisons were performed to find out whether differences between the scenarios were equally split between the scenarios or whether one scenario was different from the other two. Pairwise comparison demonstrated that the difference in time headway at the start of the manoeuvre was caused by the difference between the lane scenario and the other two scenarios. For the time spent in the left lane, the difference between the reference and assistant scenario was only a trend ($p < .1$), while the lane scenario was significantly different from the other two. Lateral position differed significantly between the scenarios and this difference was completely caused by the difference between the lane scenario and the assistant scenario.

In addition to objective indicators to measure efficiency, safety and comfort of overtaking, subjective indicators were analysed for the lane scenario as well. The mental workload of participants after a ride with the overtaking assistant was significantly higher than after a ride with an overtaking lane ($F_{1,63,31,96} = 6.224, p < .01$). For the workload scores an interaction effect between scenario and gender was also found: female participant’s workload after all three scenarios is significantly higher than male participants’ levels ($F_{1,63,31,96} = 4.349, p < .05$).

Activation levels before and after the rides were also significantly larger when driving with the overtaking assistant compared to the scenario with the overtaking lane (before: $F_{1,63} = 3.336, p < .05$, after: $F_{1,63} = 5.181, p < .01$). The participants were more activated before and after the rides and the growth in activation was also larger.

With respect to acceptance of the overtaking lane or the overtaking assistant, the lane scored significantly higher on both usefulness ($F_{1,22} = 26.441, p < .001$) and satisfaction ($F_{1,22} = 46.600, p < .001$). In other words, the participants prefer to overtake on an overtaking lane than to overtake with an overtaking assistant.

### 5.6 Summary and discussion of overtaking assistant effects

To answer the fourth research question of this dissertation research: what are the individual driver effects of an overtaking assistant on overtaking efficiency, safety and comfort? a driving simulator experiment was performed. This experiment is the first evaluation study as part of the design cycle of the overtaking assistant.

Several indicators were selected to measure these effects on overtaking efficiency, safety and comfort. Table 5.7 summarises the changes of these indicators when driving with an overtaking assistant together with the beforehand expected changes. The expected consequences on efficiency, safety and comfort are displayed in brackets with the found consequences behind them.

Positive results of evaluated overtaking assistant were a decrease in variation of lateral position, a decrease of the accepted gaps smaller than 8 s, a decrease in time spent in the left lane and a moderate positive score on usefulness.
Possible negative results were smaller time headways at the start of the overtaking manoeuvre, smaller minimum TTC with the first oncoming vehicle, an increase in workload and activation and low scores on satisfaction.

Section 5.6.2 discusses these findings regarding the in Section 5.2 formulated expectations, other research findings and compared to the results overtaking observation study described in Chapter 2. The next section discusses the use of a driving simulator for driver assistance systems evaluations.

Table 5.7 Expected and found changes in indicators to measure efficiency, safety and comfort effects of the overtaking assistant on overtaking.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Expected change:</th>
<th>Found change:</th>
<th>Efficiency</th>
<th>Safety</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking frequency</td>
<td>Higher</td>
<td>No significant difference</td>
<td>(+) 0</td>
<td>(+) 0</td>
<td></td>
</tr>
<tr>
<td>Distance headway during 5 s prior to overtaking</td>
<td>Larger</td>
<td>No significant difference</td>
<td>(+) 0</td>
<td>(+) 0</td>
<td></td>
</tr>
<tr>
<td>Time headway at start</td>
<td>Larger</td>
<td>No significant difference</td>
<td>(+) 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral position</td>
<td>Fewer deviations</td>
<td>Fewer deviations</td>
<td>(+) + (+) +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accepted gap</td>
<td>Less variation</td>
<td>No significant difference</td>
<td>(+) 0</td>
<td>(+) 0</td>
<td></td>
</tr>
<tr>
<td>Time spent in the left lane</td>
<td>Larger</td>
<td>Smaller</td>
<td>(-) + (+) +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTC</td>
<td>Not smaller than 3 s</td>
<td>Smaller, also than 3 s</td>
<td>(+) - (+) -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indicator usage</td>
<td>Higher</td>
<td>No significant difference</td>
<td>(+) 0</td>
<td>(+) 0</td>
<td></td>
</tr>
<tr>
<td>Workload</td>
<td>Decrease, but stay in optimal region</td>
<td>Slight increase</td>
<td>(+) 0</td>
<td>(+) 0</td>
<td></td>
</tr>
<tr>
<td>Activation</td>
<td>Less increased during overtaking</td>
<td>No significant difference</td>
<td>(+) 0</td>
<td>(+) 0</td>
<td></td>
</tr>
<tr>
<td>Acceptance</td>
<td>Moderate (± 0)</td>
<td>+0.6 and -0.3</td>
<td>(0) 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensation seeking</td>
<td>No relation with overtaking frequency</td>
<td>No relation with overtaking frequency</td>
<td>(+) + (+) +</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 The consequences in brackets were the expected consequences

5.6.1 Using a simulator to assess user-acceptance of an overtaking assistant

The use of a simulator to assess a driver assistance system such as the overtaking assistant has obvious design advantages and safety advantages. Three collisions occurred during the experiment, which is rather much. An explanation for these collisions is that in a driving simulator there are no real consequences for driving unsafely. It has been shown that drivers are more risk taking and drive at higher speeds as compared to when they are actually driving (Kemeny and Panerai, 2003). In addition, although the simulator environment and circumstances have been made as real as possible, there remained difference with reality. The next section discusses the possible consequences of these differences.
To verify the validity of this driving simulator experiment, the results are compared with the instrumented vehicle observations of overtaking manoeuvres described in Chapter 2. One of the compared indicators is the time spent in the left lane, which was in the simulator more than twice as short as observed with the instrumented vehicle, 3.4 s versus 7.8 s. Although the used definition was different (in the simulator the centre of the vehicle was used as a reference and during observations the left and right wheel), the difference remains fairly large. In another study where real world and simulator overtaking manoeuvres were compared, the average time spent in the left lane was larger in the simulator (simulator 20 s, real world 10.7 s) (Jenkins, 2005). And, another simulator experiment found average overtaking durations of 10 s (Benedetto et al., 2004), which is also larger than the time spent in the left lane measured in this experiment. A possible explanation for the found shorter time spent in the left lane is the presence of oncoming vehicles, which will force drivers to perform the overtaking manoeuvre quickly. For most of the observed overtaking manoeuvres described in Chapter 2, no oncoming vehicle was present within 10 s after completion of the manoeuvre. Another reason for the short time spent in the left lane in the simulator experiment is the instruction to participants to imagine to be in a hurry, which forced them to accepted small gaps and to complete the manoeuvre quickly.

An aspect causing differences between real world driving and simulator driving is the difference in surrounding traffic. To obtain as much overtaking manoeuvres as possible, the participants encountered many slower preceding vehicles. On a real road, a driver could be driving for some time before it meets a slower preceding vehicle. This might influence the duration of the overtaking manoeuvre. Gray and Regan (2000) found that drivers initiated overtaking up to 0.5 s later after following driving on a straight empty road for 5 minutes, than comparable manoeuvres made after viewing a static scene or after 5 minutes of curve driving. This could mean that overtaking in the real world will take longer than the manoeuvres performed in this driving simulator experiment. An implication for the design of an overtaking assistant is that its threshold for the green sign needs to be larger. This finding stresses the importance that a driving simulator assessment of a driver assistance system always needs to be followed by a real world pilot study (Carsten and Nilsson, 2001).

5.6.2 Discussion of objective indicators results
The expectation that overtaking frequency will be higher when driving with an overtaking assistant was not confirmed: no difference was found in overtaking frequency between the reference scenario and the assistant scenario. A possible cause for this similarity is the chosen design of the experiment, where participants were confronted with many slow preceding vehicles. In real life, the number of encounters with slower preceding vehicles will be lower, which may affect the overtaking frequency.

Another result to discuss is the smaller difference between overtaking frequency of male participants and female participants in the assistant scenario compared with the reference scenario. This enables a standardised design of an overtaking assistant, suitable for both male and female drivers. However, other driver groups, for example young and elderly drivers or commuters and leisure traffic could react differently when driving with the overtaking assistant. It is necessary to study these possible differences before the overtaking assistant will be introduced to the market. Remaining different assistance demand can be captured by
means of a design that gives the driver the choice to switch the system on and off. And 23 of the 24 participants preferred such a design.

The expectation that distance headway during 5 s prior to overtaking and time headway at the start will increase was not supported: no significant differences were found for both analysed headway indicators. Although female participants did have significant longer time headways at the start of the manoeuvre than male participants in the assistant scenario, for both the headway was far below the recommended safe headway of 2 s. The question is whether 2 seconds headway should be kept during overtaking situations, since this will increase the time necessary to perform the overtaking manoeuvre. Furthermore, when preparing an overtaking manoeuvre, drivers’ reaction time will be short, since their attention level is high, also suggesting allowing a shorter headway at the start of overtaking manoeuvres. Figure 5.5 showed that the time headway decreased during the 5 s before the overtaking manoeuvres started. Jenkins (2005) also found that participants of a driving simulator experiment started to accelerate in the right lane for 46 out of 96 performed overtaking manoeuvres.

The expectation that the variation in lateral position will be less when driving with the overtaking assistant is confirmed: for both male participants and female participants the variation in lateral position decreases with the overtaking assistant. The need to look past the preceding vehicle decreases with the assistant, because the assistant will search for an appropriate gap. Less variation in lateral position could positively affect the number of slide swipe accidents, however, it is hard to prove that overtaking is currently a cause for these accidents. Nevertheless, less variation in lateral position during the 5 s prior to overtaking starts is assumed to affect safety positively.

The expectation that the variation of accepted gaps will be less when driving with an overtaking assistant is confirmed: a decrease in accepted gaps smaller than 8 s was found. As described in Section 5.3, gaps between the (groups of) oncoming vehicles when a preceding vehicle was present gradually grew from 4, to 6, to 8 s and so on and the threshold gap for the assistant to display a green sign was set to 8 s. Due to this setting, a large peak of accepted gaps of 8 s when driving with the assistant was expected, but this did not occur. Although fewer gaps smaller than 8 s were accepted when driving with the assistant, the difference with the reference scenario was not significant. Interesting would be to see the change in accepted gaps if the assistant displays the green sign for a different gap, for example 10 s. This is studied in a follow-up driving simulator experiment of this experiment and results of this experiment are awaited. Existence of accepted gaps larger than 20 s in the assistant scenario means that participants ignored at least 7 times an advice of the overtaking assistant that it is safe to overtake. This ignorance could be caused by the fact that participants did not trust the overtaking assistant or that the preceding vehicle was driving fast enough to participant’s opinion, which means that they did not have an overtaking wish. Further analysis of the relation between accepted gaps and speed of preceding vehicles is necessary to answer this question.

The expectation that the time spent in the left lane will increase when driving with an overtaking assistant is not supported, this indicator became significantly shorter when driving with an overtaking assistant. This decrease was completely caused by the female participants,
male participants’ time spent in the left lane slightly increased in the assistant scenario. Males and females did have similar time spent in the left lane when overtaking with the overtaking assistant, which enables a standardised design of the overtaking assistant. Moreover, from a safety point of view, shorter time spent in the left lane is a positive development, since overtakers and oncoming vehicles are shorter on a collision course. Interesting are the combined results of the time spent in the left lane and overtaking frequency: male participants overtake less with assistance and their time spent in the left lane increases, female participants overtake more with assistance and their time spent in the left lane decreases. This means that for the two distinguished driver types (male/female) the differences in overtaking performance decrease if the assistant is used, which is again a positive result with respect to the opportunity of a standardised overtaking assistant.

The expectation that TTC will not become smaller than 3 s when driving with an overtaking assistant is not supported: the average TTC in the assistant scenario became 2.6 s, while in the reference scenario the TTC was 3.2 s. To prevent conflicting advice of other assistance systems, that is, the overtaking assistant indicates a safe opportunity to overtake, while during the overtaking manoeuvre a collision avoidance system (CAS) gives a warning of a TTC smaller than 3 s, the TTC should not become smaller than 3 s during an overtaking manoeuvre. These 3 s safety margin should therefore be added to the average duration of overtaking manoeuvres to determine the threshold for a green sign of the overtaking assistant. However, overtaking manoeuvres are perhaps special cases for which lower TTC are acceptable. A study of passing sight distance reported that an overtaking manoeuvre exhibits no risk when it is completed with more than 2 s clearance time (El Khoury and Hobeika, 2007). Clearance time was defined as the time gap between the passing vehicle and the oncoming vehicle at the end of the overtaking manoeuvre\(^\text{18}\) which is equal to the here defined TTC. This would suggest adjustments of CAS to overtaking situations, to avoid collision warnings when drivers safely perform overtaking manoeuvres.

The expectation that the indicator will be used more often when driving with the assistant is confirmed: the indicator is used more often at the start and at the end of the manoeuvre when driving with an overtaking assistant, however, this was not a significant change. It is likely that when drivers are more used to the overtaking assistant, indicator usage will increase, because the overtaking task will demand less effort.

It was expected that both workload and activation would decrease when driving with an overtaking assistant, instead, both increased. Increases in workload and activation are found more often when new assistance systems are tested in driving simulator studies (e.g. Brookhuis and De Waard, 1999, e.g. Van Driel and Van Arem, 2006). In general, the amount of effort subjects put into driving in a simulator is higher compared with driving in a real car (De Waard and Brookhuis, 1997). It is expected that as soon as drivers are used to the overtaking assistant, workload and activation will decrease, since the system aims to take over certain tasks. Moreover, a manual on/off switch will avoid increases of workload and activation at moments that performance levels could suffer from higher workload.

\(^{18}\) The paper distinguished aborted overtaking manoeuvres and completed manoeuvres. The given definition of clearance time accounts for both
The expectation that acceptance would be moderate, is supported regarding usefulness, since this score was 0.6 (scale -2, +2). Satisfaction, however, scored rather low: -0.3. A possible explanation for this can be found in drivers’ remarks about the system. Some thought the system’s threshold gap for the green sign was too low, whereas others thought it was too high. This implies that the threshold is dependent on the driver’s perception of an overtaking gap. However, the time required to perform the manoeuvre, both in the simulator and as observed with the instrumented vehicle, did not differ much between drivers. Moreover, with the assistant, the difference between male and female’s time spent in the left lane became smaller for the assistant scenario. The perceptual difference of an overtaking opportunity may become smaller after some practice with the overtaking assistant. The self reported required practice ranged from less than 5 lessons of half an hour to more than 20 lessons of half an hour.

Finally, the expectation that overtaking frequency is not related to sensation seeking was supported, since no relationship between sensation seeking rates related to risky driving, and overtaking frequency was found. This indicates that overtaking with hurry as the incentive is not related to risky driving. Shinar and Compton (2004) did find a relationship between passing (overtaking) and aggressive driving, however, they studied wrongly executed overtaking manoeuvres, for example including cutting in or passing on the shoulder.

The results of this overtaking assistant simulator experiment have led to the decision to continue the development of the overtaking assistant. The results are used to improve the conceptual design of the overtaking assistant described in Chapter 4. This improved design is subsequently tested in a traffic simulation study, described in Chapter 7.
6 Empirical Overtaking Frequency Data Collection on Two-lane Rural Roads

Overtaking frequencies on two-lane rural roads in the Netherlands are measured by applying an extended license plate recognition method. One of the two observed roads is selected because of its ideal overtaking circumstances, and overtaking frequencies above 60 per kilometre per hour per lane are measured. The frequency is found to be highly dependent on the distribution of traffic in both driving directions: the more vehicles in analysis direction and the fewer oncoming vehicles, the higher the overtaking frequency. Average speeds of active drivers, who performed an overtaking manoeuvre, are higher than those of other drivers and the gained travel time is on average 15 s on a road segment of 5 km. Among the active drivers, motorbikes are overrepresented, while trucks were overrepresented among the overtaken vehicles. Between 5 and 25% violations are measured on the observed segments with an overtaking prohibition, calculated as a percentage of the overtaking frequency on the simultaneously observed similar road segment without prohibition.
6.1 Introduction

This chapter describes empirical overtaking frequency data of Dutch two-lane rural roads, which serves three goals. Firstly, the data are used to find the functional relationship between overtaking frequency and its explanatory variables. Secondly, the collected data determine the reference situation for the subsequent chapter, analysing the effects of the overtaking assistant on traffic system efficiency, drivers’ comfort and safety. And thirdly, the frequency data give a total view, together with Chapter 2 on overtaking behaviour, of current, unassisted overtaking performance on two-lane rural roads.

Overtaking frequency is the number of overtaking manoeuvres performed per kilometre per hour. To obtain overtaking frequencies on two-lane rural roads the license plate recognition methodology is applied. This method enables collection of the indicators: flows, distribution of traffic in the two directions, speeds, overtaking frequencies, number of active drivers (who performed overtaking manoeuvres), number of passive drivers (who are overtaken) and vehicle types. These indicators are selected to accurately describe the current overtaking situation to enable comparison with possible future situations when different percentages drivers are equipped with an overtaking assistant.

Figure 6.1 presents the outline of this chapter. The next section reviews empirical overtaking frequency studies to find the gaps in current overtaking frequency knowledge. Section 6.3 continues with a description of the applied method to measure overtaking frequencies. It explains the observation methodology, the used instruments, the observed road segments and the data collection and analysis. Section 6.4 presents the observation results. The results of a simultaneously observed road segment with an overtaking prohibition are presented separately in Section 6.5. The effects of an overtaking prohibition were studied to enable comparison of the overtaking assistant with other solutions to omit overtaking as a traffic safety problem. The results of the overtaking frequency measurements are used to find the relationship between overtaking frequencies and its explanatory variables, described in Section 6.6. The final section summarises and discusses the findings.
6.2 Reviewing results of empirical overtaking frequency studies

Overtaking frequency is the number of overtaking manoeuvres performed per unit of road per unit of time. On two-lane rural roads, the frequency can be given by driving direction or for both directions together. In this dissertation, overtaking frequency is given by driving direction as number of overtaking manoeuvres per kilometre per hour. Flow is used to indicate the flow in the direction for which the overtaking frequency is measured, oncoming flow is the flow in the opposing direction and total flow is the flow and the oncoming flow together.

The overtaking frequency of roads with traffic in two directions depends on the flow and on the oncoming flow, since overtakers have to use the oncoming traffic lane to perform the overtaking manoeuvre. However, the exact relation of overtaking frequency, flow and oncoming flow is difficult to establish, because of a counteracting phenomenon: higher flows increase the likelihood that drivers with higher desired speeds encounter drivers with lower desired speeds, which increases overtaking demand. However, higher oncoming flows decrease the number of overtaking opportunities. In addition to oncoming traffic, other driver behaviour factors will lower overtaking frequencies as well. Examples are acceptance of speeds of preceding vehicles when these differ only marginally with the desired speed of the potential overtaker, the destination is almost reached and overtaking is not preferred anymore, or because drivers do not dare to take the risk of an overtaking manoeuvre.

To capture all different influences on overtaking frequency, many studies have been performed. This overtaking frequency studies review presents to what extent it has been successful to find the relationship between overtaking frequency and all possible parameters influencing it. This review does not include studies of infrastructural or environmental elements that limit the sight distance to perform overtaking manoeuvres. Most referred studies, as this study, assume perfect views, to enable to establish the pure effect of other traffic and drivers on overtaking frequencies.

The first studies of overtaking frequencies date from the forties. Norman (1942) estimated the ratio between observed and desired overtakings. Wardrop (1952) developed a formula for overtaking rates. He considered a homogenous segment of a highway (two-lane rural road) having traffic in one direction only and no overtaking-sight limitations. Then, overtaking supply, that is, the availability of overtaking opportunities, is continuous and vehicles can maintain their desired speed. For this ideal situation, Wardrop calculated a so-called (overtaking) density, \( \rho_o \), with the so-called catch-up formula:

\[
\rho_o = \frac{k^2 \gamma(u)}{2} \cdot \frac{k^2 \sigma_x(u)}{\sqrt{\pi}} = 0.564 \frac{q^2 \sigma_x(u)}{\pi},
\]  

(6.1)

With

\( \rho_o \) Overtaking density [PCU²/km-h]

Wardrop used the term passing instead of overtaking. In this dissertation, passing was used for the real pass of the preceding vehicle, a small part of the whole overtaking manoeuvre.
This formula allows several overtaking manoeuvres at the same moment, which means that any speed difference will yield an overtaking manoeuvre and a vehicle that is overtaking another vehicle can be overtaken at the same moment. Comparison of this theoretical overtaking demand with observed overtaking frequencies resulted in lower observed frequencies for higher flows (Enberg and Pursula, 1991). More than fifty years after the making of this formula, the Wardrop catch-up formula is still applied, for example by Ojala and Enberg (2004).

The theoretical passing density calculated with Wardrop’s formula is assumed to be an upper bound of overtaking frequency in practice, where overtaking frequencies on two-lane rural roads will be limited by many factors of which oncoming traffic is the most important. Daganzo (1975) took the influence of oncoming traffic into account and assumed a passing rate (overtaking frequency) \( \mu \) given by:

\[
\mu = 637 \exp\left(\frac{q}{153}\right)
\]  

(6.2)

With

- \( \mu \) Overtaking rate [#/h]
- \( q \) Total flow [veh/h]

For equation (6.2) it was assumed that the traffic in the other direction was approximately equal to the traffic in the analysed direction. This calculated passing rate is dependent on only the oncoming flow, and diminishes from more than 300 /h for oncoming flows smaller than 100 veh/h to less than 10 /h for oncoming flows larger than 700 veh/h.

Overtaking frequency research intensified in the eighties resulting in the book ‘Two-lane highway traffic operations’, with a review of most previous performed overtaking frequency studies (McLean, 1989). This book proposed a new formula for overtaking opportunities, being:

\[
P(\alpha.t.) = P(g > 30) \ast P(\text{road})
\]

\[
P(g > 30) = q(1 - r)(\frac{1}{16}q - 4)\exp\left(-\frac{26}{16q - 4}\right)
\]

\[
P(\text{road}) = \frac{15 + \gamma^{*} f_{v}}{3600}
\]  

(6.3)

When the space distribution of the speed \( v \) and standard deviation \( \sigma(s) \), the mean difference of speed is \( \gamma(v) = 2.5 \times 10^{-2} \). (Stuart, A., & Ord, J.K. (1987). Kendall's Advanced Theory of Statistics. Volume 1: Distribution Theory (Fifth ed.). London: Charles Griffin & Company Ltd.)
Chapter 6 – Empirical overtaking frequency data collection on two lane rural roads

With

- $P(o.t.)$ Probability of an overtaking opportunity [-]
- $P(g>30)$ Proportion of time that there is an overtaking possibility, with 30 s as the critical gap, larger gaps in oncoming traffic stream are overtaking opportunities [-]
- $g$ Gap to the next oncoming vehicle [s]
- $r$ Proportion of following vehicles at distance $x$ [-]
- $\bar{h}$ Mean free headway [s]
- $q$ Total flow [veh/s]
- $P(road)$ Proportion of road length suitable for overtaking [-]
- $P_f$ Proportion of road length without barrier lines (overtaking prohibitions) [-]
- $V$ Stream speed [km/h]
- $f_b$ Frequency of barrier zone lines [zones/km]

This formula takes sight distance limitations into account, assuming that these are always indicated with overtaking prohibitions. Furthermore, oncoming traffic is taken into account by calculating the proportion of time that there is an overtaking possibility. Their assumed critical overtaking gap is 30 s, which is in this study, the time headway between two successive oncoming vehicles. The difference between this time headway and the observed duration of 7.8 s described in Chapter 2, is rather large, even though the overtaking duration covers only a part of this time headway.

The practical usability of McLean’s formula is limited, because it needs many empirical data, of which some (e.g. $g$) are difficult to obtain. To enlarge the usability of overtaking frequency estimations, developments moved to equations including more easy to measure variables as flow, directional split and truck percentage (Morrall and Werner, 1988, McLean, 1989, Botma and Fi, 1991, Enberg and Pursula, 1991, Lovell and May, 1994, Washburn and Morriss, 2006). All these attempts suffered from the lack of empirical data on overtaking frequencies.

In the eighties, more effort was made into empirical overtaking data collection on two-lane rural roads. Among others, observations were performed in the American state Texas (Messer, 1983), in Australia (Werner and Morrall, 1984), Finland (Kallberg, 1980) and in the Netherlands (Dommerholt and Botma, 1988). An interesting result came from Finnish overtaking frequency observations. Kallberg (1980) concluded that resulting number of actual overtaking manoeuvres and vehicles in a platoon is dependent on the ratio between the total overtaking possibility and the total overtaking demand. This implies that especially accurate estimation of overtaking opportunities and overtaking demand are necessary. An attempt to capture both in formulas was done by Dommerholt and Botma (1988). They developed an expected number of overtaking manoeuvres formula:

$$N_{\text{exp}} = N_{\text{red}} * PPI$$

With

- $N_{\text{exp}}$ Expected overtaking manoeuvres carried out within 1 km during 1 h [#/km-h]
- $N_{\text{red}}$ Reduced number of overtaking manoeuvres [#/km-h]
- $PPI$ Probability of overtaking within 1 km [-]
In their formulation, the subscripted 1 indicates the driving direction, 2 is used for the opposing direction and when no subscripted number is used, both directions are meant. Equation (6.4) includes the reduced number of overtaking and the probability of an overtaking manoeuvre within 1 km. The first was calculated with the formula:

\[ N_{1,\text{red}} = N_{1, \text{the}} \cdot \left( \frac{PP1 \text{ at } Q_1}{PP1 \text{ at } Q_C} \right) \]  \hspace{1cm} (6.5)

With

- \( N_{1,\text{red}} \) Reduced number of overtaking manoeuvres [#/km-h]
- \( N_{1,\text{the}} \) Theoretical overtaking rate [#/km-h]
- \( PP1 \text{ at } Q_1 \) Probability that overtaking is possible over 1 km [-]
- \( PP1 \text{ at } Q_C \) Probability that overtaking is possible over 1 km for the critical flow [-]

In this formula, the theoretical overtaking rate equals:

\[ N_{1,\text{the}} = \frac{1}{\sqrt{\pi}} \cdot \sigma_{s,1} \cdot k_1^2 \]  \hspace{1cm} (6.6)

With

- \( \sigma_{s,1} \) Standard deviation of the speed \( \bar{u} \) [kph]
- \( k_1 \) Density [PCU/km]

The probability that overtaking is possible over 1 km was calculated with:

\[ PP1 = 1 - (1 - P_1)^{3600} \]  \hspace{1cm} (6.7)

With

- \( P_1 \) Probability of an accepted gap [-]
- \( Q_2 \) Flow in the opposing direction [veh/h]
- \( u \) Speed in both directions [km/h]

Finally, the probability of an accepted gap is calculated with:

\[ P_1 = \exp[-HC_1 \cdot \frac{Q_2}{3600}] \]  \hspace{1cm} (6.8)

With

- \( P_1 \) Probability of an accepted gap [-]
- \( HC_1 \) Critical headway value to accept as overtaking possibility [s]
- \( Q_2 \) Flow in the opposing direction [veh/h]

Although this set of equations looks complex, it did enable calculation of the expected number of overtaking per kilometre per hour with relative easy to measure variables as flows and speeds. However, the critical headway to accept as an overtaking possibility was more
difficult to obtain. To verify how well equation (6.4) calculates the real overtaking frequencies, observations were performed on six roads (Dommerholt and Botma, 1988). The observed frequencies were lower than the theoretical density and also lower than the calculated reduced number of overtaking manoeuvres. They improved the model by including two factors that reduces the theoretical overtaking demand. Their new model took into account that drivers do not want to overtake if their desired speed is less than the speed of the vehicle in front plus a threshold value and for flows above 400 veh/h the overtaking demand is further reduced with a factor that decreases linearly with increasing mean platoon length. Both modifications resulted in an adjusted reduced number of wished overtaking formula:

$$N_{red} = \left( \frac{1}{\sqrt{\sigma_{v1}}} \cdot \sigma_{v1} \cdot k_1 \right)^{0.25 \cdot \frac{TH}{V}}$$  \hspace{1cm} (6.9)

With

- $N_{red}$: Reduced number of overtaking manoeuvres [#/km-h]
- $\sigma_{v1}$: Standard deviation of the speed $\bar{v}$ [km/h]
- $k_1$: Density [PCU/km]
- $TH$: Threshold value for necessary speed difference to have an overtaking wish [km/h]

Application of equation (6.9) instead of equation (6.5) resulted in fewer overtaking opportunities for low flows and more for higher flows and the reduced number of overtaking manoeuvres and expected number of overtaking have a lower maximum at higher flows.

Although the results of Dommerholt and Botma were promising, further research was necessary, especially into the effect of the distribution of traffic in the two driving directions. Since the observed directional distribution of Dommerholt and Botma did not exceed 60/40, they assumed an equal distribution on the two-lanes. In our view, especially the distribution of traffic in both driving directions is an important explanatory variable for overtaking frequency.

More recent overtaking frequency studies focussed mainly on empirical data collection. In Finland, a large-scale study of two-lane rural roads included observation of overtaking frequency too (Tapio, 2003). They used a helicopter to observe overtaking frequencies and their data set will include valuable knowledge on traffic performance on two-lane rural roads in general and on overtaking frequencies specifically. However, this data set was not available at the start of this dissertation, and, till 2007, only available in Finnish.

Tuovinen and Enberg (2006) made estimations of overtaking rates as a function of the square of one-way traffic flows, as part of a study of the effects of rumble strips. Regression analysis resulted in separate equations for each observed road segment, which all did not differ significantly. An example equation was:

$$OV_{North, one-year-after} = 4.53 + 0.00087Q^2 \hspace{1cm} R^2 = 0.42$$  \hspace{1cm} (6.10)

With
Another step to get more insight into overtaking frequencies on two-lane rural roads is the development of two-lane rural road overtaking simulation models. Examples are TWOPASS (McLean, 1989), TRARR (May, 1991), and RuTSim (Tapani, 2005a). The last takes oncoming traffic, sight distance and differences between drivers explicitly into account. The performance of such models strongly depends on accurate observation data of current traffic situation. For the calibration and validation of the model, observations over general traffic variables as directional flows, speeds, densities, truck percentages are necessary. Also, overtaking frequencies should be observed to verify whether the model is able to produce the right overtaking frequencies. This is the aim of this study: to collect overtaking frequency data for the calibration of microscopic traffic simulation model applied in Chapter 7.

In summary, overtaking on two-lane rural roads has been studied for more than fifty years. The aims of these studies moved from theoretical establishment of overtaking rates, via development of formulas taking factors that reduce the overtaking frequency into account, and empirical overtaking data collection, to developments of microscopic traffic simulation models explicitly modelling overtaking. Detailed empirical overtaking data are necessary to calibrate, validate and further develop contemporary microscopic traffic simulation models and give the opportunity to do another attempt to accurately describe the relationship between overtaking frequency and its explanatory variables.

This overview is made to summarise the development of overtaking frequency research in the past years and to give ground for another overtaking frequency study. The overview reveals the need for more empirical overtaking frequency data, to enable calibration and validation of microscopic traffic simulation models modelling overtaking on two-lane rural roads. Furthermore, the referred formulas to estimate overtaking frequency give the opportunity to compare the formula we will develop to estimate overtaking frequency with these earlier findings.

The next section describes the applied method to obtain empirical overtaking frequency data, collected to create the reference situation of the simulation study of the effects of the overtaking assistant (Chapter 7) and to find the dependent variables of overtaking frequency. Overtaking frequency data on road segments where overtaking is not permitted were collected simultaneously, to verify the effects of an overtaking prohibition, as an alternative solution to improve the safety of overtaking.

6.3 Method: observations with the license plate recognition methodology

This section describes the method to collect overtaking frequency data. The first subsection starts with an explanation of the applied license plate recognition methodology, followed by a description of the observed road segments. Subsection 6.3.4 explains the data collection and 6.3.5 describes the applied analysis. This section ends with a subsection on expected observation results.
6.3.1 The license plate recognition methodology

Overtaking frequencies were obtained by means of the license plate recognition methodology (e.g., applied in Enberg and Pursula (1991), Cielecky and Pursula (1994) and Tuovinen and Enberg (2006)). This method recognizes vehicles by means of their license plate observed at the start and end cross-sections of road segments. Comparison of the order of vehicles at both cross-sections enables extraction of overtaking frequencies. Figure 6.2 visualizes the method, where four vehicles enter a road segment in the order A, B, C, D and leave the segment in the order C, A, B, D. In this case it was assumed vehicle C has overtaken vehicles A and B. More details about the application of the license plate recognition methodology can be found in Appendix C.

Figure 6.2 The applied license plate recognition method: compare observed order at road segment 1 with order at road segment 2. Vehicle C has overtaken vehicles A and B

The license plate recognition methodology was chosen above other methods to gather overtaking data, including observation from the air by means of cameras on high buildings or under helicopters (explained in Karimi et al., 2006) and observation of a road segment in the reach of an observer’s view or camera view and count the observed number of overtaking manoeuvres (applied in e.g., Harris et al., 1986, Van de Pol and Janssen, 1998, Commandeur et al., 2003)). Although this last method enables real observation of the performed overtaking manoeuvre, the observed road site is restricted to the observers’ distance view or camera’s reach which makes this method rather limited. The application of observation of traffic from the air has become more and more popular. The well known MGSim data set (e.g., Toledo and Zohar (2007)) was collected by means of cameras on high buildings. However, in the Netherlands, high buildings along two-lane rural roads are rare. Another problem with air observations accounting for both cameras on high buildings and cameras under helicopters is the limited reach of the cameras. Ossen and Hoogendoorn (2005) for example, were able to analyse car-following behaviour over a maximum observed distance of 400 to 500 m. Since overtaking manoeuvres often take more than 200 m and can start and end at any point on a road segment, it is difficult to precisely observe a complete manoeuvre within the reach of the camera. Tapio (2003) was able to apply helicopter observations on two-lane rural roads to observe overtaking manoeuvres. However, the results of this study were, when writing this dissertation, available only in Finnish. Other methods to obtain overtaking frequency on two-lane rural roads were not found in literature and thus the license plate recognition methodology was assumed to be the most suitable, available method.

With the license plate recognition method, five observations are performed on two different roads observing two successive road segments. The next subsection gives a detailed description of the observed road segments.
6.3.2 Observed road segments
The Flevoland road and the N255 Oost-Westweg, province of Zeeland, both in the Netherlands, were selected for the overtaking frequency observations. Both roads are flow roads, comparable with the English two-lane rural roads and the American Class I two-lane highways. The speed limit is 100 km/h while trucks, buses and vehicles with trailers have a limit of 80 km/h. Slow traffic, for example tractors and bicycles, is prohibited. Figure 6.3 displays the Flevoland road, which was selected because of its expected ideal overtaking circumstances: relatively long flat road stretches without intersections or sight limitations. This road was also used for the overtaking observation study described in Chapter 2, in the simulator study described in Chapter 5 and will be used in the simulation study described in Chapter 7.

The main observed road segment has a length of 5.125 km. There are no intersections on this segment and one parking bay at each side of the road, somewhere in the middle of the segment. A simultaneously observed road segment with overtaking prohibition has a length of 4.200 km and lies in the direction of Zeewolde. The reason for the overtaking prohibition is because of the unsafety of the overtaking manoeuvre itself. There are no sight limitations. The Dutch Sustainable Safety Program described in Chapter 1 recommends road authorities to design all Dutch two-lane flow-roads with an overtaking prohibition. Since not all road segments can be changed at once, The Province of Flevoland decided to implement only the recommended design when other road works are necessary as well. This was the case for the observed road segment and hence, the Sustainable Safety design with an overtaking prohibition (double continuous line) was implemented at this segment.

Figure 6.4 displays the second selected road, the N255 in the province Zeeland. This so-called Zeeland road is, according to the infrastructure, a general Dutch road with short distances between intersections and more disturbing elements along the road than the Flevoland road such as trees, fly-overs and buildings. The Zeeland road has many tourist drivers, who often drive below the speed limit or drive with a caravan, probably affecting overtaking frequencies.

21 Passenger vehicles with trailers including caravans have a maximum speed limit of 80 km/h on Dutch roads
The Zeeland road is included in this study, because of a request of the Province of Zeeland to study the effects of overtaking prohibitions by means of double continuous centre lines, of which the results are presented elsewhere (Hegeman, 2004b). Again, two comparable road segments were selected for the observations, one where overtaking is permitted and one with prohibition. The first has a length of 2.7 km, the second was 2.05 km, which were the longest possible lengths to observe without disturbing road entries, exits or intersections. Again, as on the Flevoland road, the only reason for the overtaking prohibition was because of the recommended design of the Dutch Sustainable Safety Program. The sight distance of both road segments are similar.

### 6.3.3 Overtaking frequency related measures to observe

The following characteristics are chosen to observe:

- Flow;
- Speed;
- Density;
- Overtaking frequency;
- Active drivers (overtakers);
- Passive drivers (overtaken drivers);
- Neutral drivers (not involved in overtaking);
- Vehicle type

The distinguished vehicle types include passenger cars, trucks, motorbikes and foreign vehicles. Observation of the listed characteristics enables accurate description of the current traffic situation on two-lane rural roads. Furthermore, they give the necessary information to attempt to find the relationship between overtaking frequency and its explanatory variables. And, these characteristics enable comparison of road segments without and with overtaking prohibition. These are the three aims of the chapter as presented in the introduction.

Possible infrastructural limitations for overtaking opportunities, such as curvature and hilliness are not included in this overtaking frequency study. Instead, road segments were especially selected in order to exclude infrastructural overtaking limitations. Overtaking frequencies observed under the selected infrastructural circumstances will be maximal regarding infrastructure, only existence of other traffic will limit drivers’ overtaking opportunities. This enables to study the pure effects of other traffic on overtaking frequency.

---

22 With the chosen observation method – to measure the arrival time and order of vehicles at the start- and end-cross-section of the road segment – it was not possible to measure platooning. Additionally to one observation, pneumatic tubes were installed halfway the road section, to observe platooning. Unfortunately, these data are not analysed yet and are aimed to be published in a paper.
6.3.4 Overtaking frequency data collection

Eight observations were carried out on Flevoland road and four on the Zeeland road, all elaborated in Table 6.1. The abbreviations of the measurements as presented in the first column of Table 6.1 are used in the remainder of this chapter.

The F0 observation aimed to test the observation method, to find the right positions for the cameras and observers and to measure the data processing speed of the observers (see Appendix C). The F2 observations will yield average overtaking frequencies. On this observation day, the road segments without and with an overtaking prohibition were observed simultaneously.

To study the influence of bad weather, such as rain, fog and slippery roads, a bad weather observation was planned, observing only the road segment where overtaking was permitted. However, despite the fairly bad weather forecast, it rained only for 10 minutes and data of this observation day, F1 in Table 6.1, are considered to be similar to F0 and F2 data for this road segment. Overtaking frequencies were observed for both driving directions during all observations of the Flevoland road.

### Table 6.1 Details of the twelve overtaking frequency observations

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0-dir1</td>
<td>Flevoland N305, direction 1 (Almere → Zeewolde), test observation Wednesday 17th September 2003, 15.30-18.30 h</td>
</tr>
<tr>
<td>F0-dir2</td>
<td>Flevoland N305, direction 2 (Zeewolde → Almere), test observation Wednesday 17th September 2003, 15.30 - 18.30 h</td>
</tr>
<tr>
<td>F1-dir1</td>
<td>Flevoland N305, direction 1, 1st observation Monday 22nd March 2004, 12.00 – 20.00 h</td>
</tr>
<tr>
<td>F1-dir2</td>
<td>Flevoland N305, direction 2, 1st observation Monday 22nd March 2004, 12.00 – 20.00 h</td>
</tr>
<tr>
<td>F2-dir1</td>
<td>Flevoland N305, direction 1, 2nd observation Monday 19th April 2004, 12.00 – 20.00 h</td>
</tr>
<tr>
<td>F2-dir1-P</td>
<td>Flevoland N305, direction 1, 2nd observation on a segment with overtaking Prohibition Monday 19th April 2004, 12.00 – 20.00 h</td>
</tr>
<tr>
<td>F2-dir2</td>
<td>Flevoland N305, direction 2, 2nd observation Monday 19th April 2004, 12.00 – 20.00 h</td>
</tr>
<tr>
<td>F2-dir2-P</td>
<td>Flevoland N305, direction 2, 2nd observation on a segment with overtaking Prohibition Monday 19th April 2004, 13.00 – 20.00 h</td>
</tr>
<tr>
<td>ZW</td>
<td>Zeeland N255, busiest direction is observed only (East → West), Working day Tuesday 11th May 2004, 12.30 – 18.30 h</td>
</tr>
<tr>
<td>ZW-P</td>
<td>Zeeland N255, Working day on segment with Prohibition Tuesday 11th May 2004, 12.30 – 18.30 h</td>
</tr>
<tr>
<td>ZH</td>
<td>Zeeland N255, Holiday (Ascension Day) Sunday 20th May 2004, 12.30 – 18.30 h</td>
</tr>
<tr>
<td>ZH-P</td>
<td>Zeeland N255, Holiday (Ascension Day) on segment with Prohibition Sunday 20th May 2004, 12.30 – 18.30 h</td>
</tr>
</tbody>
</table>
On the Zeeland road, overtaking frequencies were observed only for the busiest direction, simultaneously on the road segments where overtaking is permitted and with prohibition. In the opposing direction only the flows were measured. Both a normal workday, ZW, and a holiday (Ascension Day), ZH, were observed. The reason to observe a workday and a holiday was that Zeeland has much leisure traffic, with probably different influence on overtaking frequencies on a workday and a holiday. The weather on both observation days was cloudy, but no rain.

### 6.3.5 Overtaking frequency data analysis

The observed and analysed characteristics are flow, speed, density, traffic distribution in the two directions, overtaking frequency, active drivers, passive drivers, neutral drivers, speed distributions of these driver types and vehicle types. This subsection explains how these characteristics are obtained from the observations.

#### Flow, speed, density

To define flow, speed and density for a time-space region, the formulas of Edie are used (Edie, 1965). For flow, this formula is:

\[
q = \frac{\sum d_i}{X T}
\]  

(6.11)

With

- \( q \) Flow [m/s]
- \( \sum d_i \) Summation of distances over which a vehicle is present [veh-m]
- \( X \) Total length of the road segment [m]
- \( T \) Total time period for which the flow is calculated [s]

And for the space mean speed:

\[
u = \frac{\sum d_i}{\sum r_i}
\]  

(6.12)

With

- \( u \) Space mean speed [m/s]
- \( \sum d_i \) Summation of distances over which a vehicle is present [veh-m]
- \( \sum r_i \) Summation of time a vehicle is present [veh-s]

And for the density:

\[
k = \frac{\sum r_i}{X T}
\]  

(6.13)

---

\[23\] Edie used the term intensity instead of flow
With
\[
\sum_{i} T_i \quad \text{Summation of time a vehicle is present [veh-s]}
\]
\[X \quad \text{Length of the road segment [m]}
\]
\[T \quad \text{Time period for which the flow is calculated [s]}
\]

To estimate the relationship between speed and density, the following equation is applied:

\[
u(k) = u_0 - c_1k
\]

With
\[u(k) \quad \text{Speed \( u \) for density \( k \) [km/h]}
\]
\[u_0 \quad \text{Initial speed [km/h]}
\]
\[c_1 \quad \text{Parameter to estimate [km}^2\text{/veh.h]}
\]
\[k \quad \text{Density [veh/km]}
\]

**Overtaking frequency, active drivers, passive drivers and their speeds**

For the analysis of overtaking frequency, active drivers, neutral drivers and passive drivers are distinguished and explained with Figure 6.2. In this figure, vehicle C has overtaken vehicles A and B. Then, overtaking frequency is 2. C is counted as 1 active driver, vehicle A as 1 passive driver, vehicle B also as 1 passive driver and vehicle D as 1 neutral driver. These measures were normalised to space and time, that is, the units are per kilometre per hour. Speeds of active, neutral and passive drivers are presented by means of a distribution for which the speeds per driver type were put in ascending order and divided into speed bins of four km/h wide.

**Vehicle types**

Different vehicle types, such as trucks, motorbikes and foreign cars were extracted from the data set by means of their license plates in the following manner. All Dutch truck license plates at the front of vehicles start with a \( B \) and at the back of vehicles, truck license plates start with an \( O \). By adding all observed license plates with either a \( B \) or an \( O \), truck percentages are obtained. Motorbike percentages are obtained in a similar way, adding all license plates starting with a \( M \). Foreign cars were manually extracted from the camera data, counting the non-yellow license plates\(^{24}\). These are obtained only on the Zeeland road, hardly any foreign cars are expected on the Flevoland road.

**Analysis tools and methods**

For the analysis, the software packages Microsoft Excel 2007, Matlab2007 and SPSS version 13 were used.

**6.3.6 Expected results of overtaking frequency observations**

Before the results of the overtaking frequency observations are presented, this subsection presents the expected results. For the Flevoland road, flows are expected to be high, at peak hours close to capacity. Speeds are expected to be high as well. These expectations are based

\(^{24}\) The standard colour of Dutch license plates is yellow
on the known high average annual daily traffic volume that the observed traffic will be mainly commuter traffic, often in a hurry on their way home or to work. For the same reason, overtaking frequencies are expected to be high. Another reason for the expected high overtaking frequency is the infrastructural ideal overtaking situations. However, the travel time gain due to the overtaking manoeuvres is expected to be low. The travel distance is too short to gain much travel time. Finally, truck percentages on the Flevoland road are expected to be similar to other Dutch roads, around 13.5% (Huijbregts and Rozemeijer, 2005).

For the Zeeland road, flows and average speeds are expected to be lower than on the Flevoland road. Also, overtaking frequencies are expected to be lower, because less commuter traffic is expected, resulting in fewer drivers in a hurry. Truck percentages on the Zeeland road are expected to be lower than on the Flevoland road, because of the local function of the road, without many business areas in the neighbourhood.

With respect to the relationship between overtaking frequency and its explanatory variables, the expectancy is as follows. Overtaking frequency is expected to be highly dependent on the distribution of traffic in the two driving directions and less on the total flow. Growing flows in one direction will increase the overtaking demand in this direction. When the flow in the opposing direction also grows, the number of overtaking opportunities will decrease. This could cause that situations with different total flows but similar distribution of traffic in the two directions will have the same overtaking frequency: for low total flows situations, the overtaking demand will be small in combination with many opportunities to overtake and for the high total flows, the overtaking demand will be large in combination with few opportunities.

The overtaking frequency regarding speed is expected to be larger when differences in desired speeds are larger as well. But, due to the speed limit, effects of speeds are expected to be small, because most drivers are expected to stick to the speed limit. Finally, higher truck percentages and more vehicles with trailers are expected to increase the overtaking frequency, since trucks have a lower speed limit than passenger cars.

6.4 Results of overtaking frequency observations

Observations of overtaking frequencies are carried out on two different two-lane rural roads in the Netherlands. This section presents the observed flows, speeds, densities, overtaking frequencies, vehicle type distributions, active, passive and neutral drivers and their speed distributions for all observed road segments of both roads where overtaking is permitted. The results of the observed segments with an overtaking prohibition are presented separately in Section 6.5

6.4.1 Flow, speed and density
Table 6.2 presents observed flows, speeds and densities for each observed road segment where overtaking is permitted, averaged over the whole observation period.
Table 6.2 General observation results including average flow, speed and density

<table>
<thead>
<tr>
<th></th>
<th>F0-dir1</th>
<th>F0-dir2</th>
<th>F1-dir1</th>
<th>F1-dir2</th>
<th>F2-dir1</th>
<th>F2-dir2</th>
<th>ZW</th>
<th>ZH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation duration [h]</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Average flow [veh/h]</td>
<td>1023</td>
<td>456</td>
<td>429</td>
<td>692</td>
<td>536</td>
<td>334</td>
<td>258</td>
<td>438</td>
</tr>
<tr>
<td>Average opposing flow [veh/h]</td>
<td>456</td>
<td>1023</td>
<td>692</td>
<td>429</td>
<td>334</td>
<td>536</td>
<td>231</td>
<td>328</td>
</tr>
<tr>
<td>Average total flow [veh/h]</td>
<td>1479</td>
<td>1479</td>
<td>1121</td>
<td>1121</td>
<td>870</td>
<td>870</td>
<td>489</td>
<td>766</td>
</tr>
<tr>
<td>Average speed [km/h]</td>
<td>85.9</td>
<td>91.8</td>
<td>91.7</td>
<td>87.8</td>
<td>89.0</td>
<td>89.3</td>
<td>89.3</td>
<td>86.6</td>
</tr>
<tr>
<td>Average density [veh/km]</td>
<td>11.9</td>
<td>5.0</td>
<td>7.6</td>
<td>4.9</td>
<td>6.0</td>
<td>3.7</td>
<td>2.9</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Table 6.2 shows that the Flevoland road is busier than the Zeeland road. On the Flevoland road, direction 1 is busier than direction 2 and the distribution of traffic in the two directions on the Zeeland road is more equal. The observed average speed range between 85 and 92 km/h. During observations F0, higher average speeds were reached in the less busy direction than in the busy direction. The speed difference between the two driving directions was less during the other two observation on the Flevoland road, when differences in flows were also smaller. More equal flows for F1 and F2 compared to F0 are probably caused by the shorter observation period of F0, when fewer off-peak hours were observed. The observed speeds on workday on the Zeeland road were comparable with the speeds during the second observation on the Flevoland road, while the flows on the Flevoland road were almost 70% higher in the analysed direction and almost 40% in the opposing direction. Lowest average speeds were observed during observation ZH, with higher flows than ZW, but less than for example F2-dir1, with higher average speeds as well. The presented average densities in Table 6.2 were calculated with the general traffic formula flow equals density times space mean speed (q = ku). The highest observed density approached 15 veh/km (F0-dir1), which is far below estimated capacity densities of two-lane rural roads of 20 veh/km (cited in Luttinen, 2001).

To present the observations independent of observation duration, each observation was split in 15-minute periods over which average flows, speeds and densities per driving direction are calculated, using equations (6.11), (6.12) and (6.13). Figure 6.1 presents the resulting fundamental diagrams.

The speed-flow graph at the right-bottom corner of Figure 6.5 shows a cloud of average 15 minutes speeds between 80 and 100 km/h, which are the speed limits of trucks and passenger cars respectively. Although the average speeds decrease somewhat for flows above 1000 veh/h, one cannot speak of a breakdown or traffic jam. There are three data points which lie somewhat below the points cloud. A closer look at the data for those points demonstrated higher truck percentages for these periods and a group of rather slow driving passenger cars. A possible reason could be that there has been some special transport on the road that could not be passed by other vehicles.
Figure 6.5 Flow-density, speed-density and speed-flow diagrams, presenting the average data for 15 minutes observations of one driving lane of all observed road segments. Regression lines are estimated for the Flevoland road data and Zeeland road data separately.

The flow-density graph at the upper-left corner of Figure 6.5 shows the free flow branch of the general flow-density graphs (Transportation Research Board, 2000). The maximum observed one way flow was almost 1200 veh/h, which was too low to cause congestion, by which the congestion part of the speed-flow curve is not observed. This graph includes the same three outliers as the speed-flow graph demonstrated.

The third graph in Figure 6.5 at the left-bottom corner is the speed-density graph and shows a maximum observed density of almost 15 veh/km. This graph includes the same three outlying data points as the other two graphs.

For all three graphs linear regression lines are added, separated for the Flevoland data and Zeeland data. The three outliers of the Flevoland data were excluded. The estimation of the \( u(k) \) relationship resulted in a very poor fit with \( R^2 \) below 0.3. This means that the observed variance in speeds cannot be explained (only) by the observed densities. There are possible other explanatory factors for the observed speeds, for example overtaking abilities, driver differences and natural noise.

The speed, flow and density results have given a general view of the observed road segments. The next subsection continues with the more specific overtaking frequency results.
6.4.2 Overtaking frequency

Table 6.3 gives an overview of overtaking frequency results, averaged over the whole observation duration, together with relevant flow characteristics. Table 6.3 shows minimum average observed overtaking frequencies of 3.7 /km-h to maximum average observed frequencies of 51.4/km-h. The largest frequencies are observed for the largest flows in analysis direction with the lowest oncoming flows. In other words, when the directional distribution of the traffic on the two driving directions becomes less equal, the overtaking frequency of the busy direction grows and of the less busy direction reduces.

The number of passive drivers is larger than the number of active drivers, for all observation sessions. This implies that more drivers are overtaken by (fewer) overtakers. In other words, it occurs more often that one driver overtakes several other drivers than that one driver is overtaken by several other drivers.

Table 6.3 gives the impression that the overtaking frequency is dependent on the flow in driving direction, the oncoming flow and the total flow. To show this more clearly, the observation sessions are divided into 15 minutes periods. The observed total flows for each 15 minute period are divided into four groups including flows lower than 500 veh/h, between 500 and 1000 veh/h, between 1000 and 1500 veh/h and more than 1500 veh/h. Next, the overtaking frequencies per 15 minute period are calculated and also the share of flow in the direction for which the overtaking frequency is calculated. The resulting Figure 6.6 presents a subplot for each total flow group, presenting the overtaking frequency against the share of flow in the same driving direction. The figure includes all observation sessions, each displayed with a different symbol.

<table>
<thead>
<tr>
<th></th>
<th>F0-dir1</th>
<th>F0-dir2</th>
<th>F1-dir1</th>
<th>F1-dir2</th>
<th>F2-dir1</th>
<th>F2-dir2</th>
<th>ZW</th>
<th>ZH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation duration [h]</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Flow [veh/h]</td>
<td>1023</td>
<td>456</td>
<td>692</td>
<td>429</td>
<td>536</td>
<td>334</td>
<td>258</td>
<td>438</td>
</tr>
<tr>
<td>Opposing flow [veh/h]</td>
<td>456</td>
<td>1023</td>
<td>429</td>
<td>692</td>
<td>334</td>
<td>536</td>
<td>231</td>
<td>328</td>
</tr>
<tr>
<td>Total flow [veh/h]</td>
<td>1479</td>
<td>1479</td>
<td>1121</td>
<td>1121</td>
<td>870</td>
<td>870</td>
<td>489</td>
<td>766</td>
</tr>
<tr>
<td>Split [dir/tot]</td>
<td>0.69</td>
<td>0.31</td>
<td>0.62</td>
<td>0.38</td>
<td>0.62</td>
<td>0.38</td>
<td>0.53</td>
<td>0.57</td>
</tr>
<tr>
<td>Overtaking frequency [#/km-h]</td>
<td>51.4</td>
<td>3.7</td>
<td>25.4</td>
<td>6.6</td>
<td>22.6</td>
<td>6.8</td>
<td>6.7</td>
<td>16.4</td>
</tr>
<tr>
<td>Active drivers [#/km-h]</td>
<td>21.7</td>
<td>2.6</td>
<td>13.1</td>
<td>4.3</td>
<td>10.6</td>
<td>4.5</td>
<td>5.7</td>
<td>10.2</td>
</tr>
<tr>
<td>Passive drivers [#/km-h]</td>
<td>35.3</td>
<td>3.1</td>
<td>16.9</td>
<td>4.8</td>
<td>16.5</td>
<td>4.7</td>
<td>5.7</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Figure 6.6 firstly reveals that most observed total flows on the Flevoland road were between 500 and 1500 veh/h, because observations are found in the right-top and left-bottom subplots.
For the flows lower than 500 veh/h, the overtaking frequency is fairly low and the effect of less equal distribution of traffic results in more overtaking manoeuvres in the busy direction and less in the less busy direction is visible. The same influence of traffic distribution is visible in the right bottom subplot of Figure 6.6, including those observations with flows above 1500 veh/h. Even for these relative high total flows, overtaking frequencies of 61/km-h were observed. Comparing this subplot with the subplot for the flows below 500 veh/h reveals that for similar distribution, for example 0.38 / 0.62, the overtaking frequency was fairly similar, around 32 /km-h. In other words, total flow difference of 1000 vehicles did not affect overtaking frequency as long as the distribution of traffic in both directions remains similar.

Most observation results have flows between 500 and 1500 veh/h, presented in the right-top and left-bottom subplot of Figure 6.6. The influence of the distribution of traffic is also visible in these graphs, because when the flows in the two driving directions differs more, the overtaking frequency in the busy direction becomes higher and in the less busy direction lower. The best example of this effect is displayed with the + clustered around an overtaking frequency of 50 /km-h, while the overtaking frequency of the complementing less busy direction o stayed below 10 /km-h.

Each graph in Figure 6.6 includes a line fitted to the data points. This line has a similar shape for all four graphs, indicating that overtaking frequency is independent of total flow, at least for the observed flows.
Two observed extreme overtaking frequencies, 124/km-h and 87/km-h are not included in Figure 6.6. These extremes were averages over 15 minute observations during ZH observation, with 741 veh/h in the analysed direction and 206 veh/h in the opposing direction and during the F0 observation, with 933 veh/h in the analysis direction and 323 veh/h in the opposing direction, respectively. Both observations were assumed to be outliers. Nevertheless, these extremes did occur on the road, showing that the overtaking frequency can vary a lot.

### 6.4.3 Overtaking and speed

Section 6.4.1 described the general average speed results and its relation with flow and density. This subsection analyses the driven speeds further to get a better view of the relationship between speed and overtaking. Speeds of active drivers, neutral drivers and passive drivers are distinguished. Figure 6.7 presents the active, passive and neutral drivers’ speed distributions for F2-dir1. This graph is representative for the speed distribution results of all other observations.

Figure 6.7 is a histogram presenting the frequencies of all speeds. For clarity, the Normal distribution lines are fitted. Although the active, passive and neutral drivers’ speeds were not Normal distributed\textsuperscript{25}, the lines give an impression of the differences between the three distributions. The neutral drivers’ speeds, representing the larger part of all observed drivers, were between the active drivers’ speed and passive drivers’ speeds.

![Figure 6.7 Speed distributions of the F1-dir1 observation session, split to active drivers, neutral drivers and passive drivers](image)

\textsuperscript{25} Tested with Kolmogorov-Smirnov tests of normality. These showed that all speed distributions were significantly different from the normal distribution at 95\% confidence level. Active drivers’ speed $D(474)=0.063$, $p<.05$, neutral drivers’ speed $D(2459)=0.056$, $p<.05$, passive drivers’ speed $D(614)=0.072$, $p<.05$
Passive drivers’ speeds are mainly found to the left of the neutral drivers’ distribution, meaning that their average speeds are lower than the other drivers’ speeds. Contrary, active drivers’ speeds were mainly found on the right site, indicating that the performed overtaking manoeuvres did yield higher average speeds. To calculate the gained travel time gain, the inverses of average speeds of the active drivers (98.9 km/h) and neutral drivers (91.3 km/h) are multiplied with the distance travelled (5.125 km). The travel times of the average active driver was 15.2 s shorter than that of the average neutral driver.

6.4.4 Overtaking and vehicle type
The final presented results of the overtaking frequency observations are the shares of each vehicle type. To study the possible effects of vehicle types on overtaking frequencies, the share of different vehicle types were extracted from the observed data. Figure 6.8 presents these shares for each observation session, averaged over the whole observation periods.

The freight percentage on the Flevoland road varies between 5 and just above 10%. The observed percentages were somewhat lower during the test observation session F0, probably due to the shorter observation duration, for which the evening-peak accounts for a larger share of the whole observation session, during which truck percentages are generally lower. The truck percentages on the Zeeland road were lower, especially on the holiday. The percentage motorbikes did not exceed the 2% for all observation sessions. The share of foreign cars on the Zeeland road was above 10% on a normal weekday and above 13% on the holiday.

![Figure 6.8 Share of vehicle types](image)

Some extra analyses were performed with the F0 data set, to study the relation between overtaking and vehicle type. Table 6.4 presents percentages active and passive drivers per vehicle type. Trucks were overrepresented in the passive drivers group. For the busy driving direction, 46.8% of the overtaken vehicles were trucks, while they represented 7.2% of the total flow. Motorbikes are overrepresented in the active drivers group. Of all motorbikes in the busy direction, 61.5% performed at least one overtaking manoeuvre. For the direction

26 Foreign vehicles were not distinguished on the Flevoland road, their percentages are expected to be negligible
with much oncoming traffic the 1% motorbikes in the total flow represented 12.5% of the active drivers. This last result reveals that when situations become more critical or difficult, especially motorbikes are (still) able to perform overtaking manoeuvres.

Table 6.4 Share of vehicle types amongst active and passive drivers for the F0 observations

<table>
<thead>
<tr>
<th>Vehicle type:</th>
<th>Other</th>
<th>Trucks</th>
<th>Motorbike</th>
<th>Other</th>
<th>Trucks</th>
<th>Motorbike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total share</td>
<td>91.9</td>
<td>7.2</td>
<td>0.8</td>
<td>93.8</td>
<td>5.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Percentage active drivers in comparison with own %</td>
<td>11.3</td>
<td>0.9</td>
<td>61.5</td>
<td>2.6</td>
<td>1.4</td>
<td>35.7</td>
</tr>
<tr>
<td>Percentage active drivers in comparison with percentage active drivers</td>
<td>94.7</td>
<td>0.6</td>
<td>4.7</td>
<td>85.0</td>
<td>2.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Percentage passive drivers in comparison with own percentage</td>
<td>80.5</td>
<td>19.3</td>
<td>3.8</td>
<td>91.7</td>
<td>8.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Percentage passive drivers in comparison with total percentage passive drivers</td>
<td>15.3</td>
<td>46.8</td>
<td>3.8</td>
<td>3.3</td>
<td>5.5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

With the vehicle type results, all observed characteristics on the road segments where overtaking was permitted, are presented. The next section continues with the observation results of the road segments with overtaking prohibition.

6.5 Observation results when overtaking is prohibited

Chapter 1 presented overtaking prohibitions as an alternative solution, next to overtaking lanes and the overtaking assistant, to reduce the number of overtaking accidents. This dissertation focuses on the overtaking assistant as a solution to improve overtaking efficiency, safety and comfort. To enable comparison of the overtaking assistant with alternative solutions, the effects of an overtaking prohibition and overtaking lanes are included in this dissertation as well. The effects of an overtaking lane were included in Chapter 5, this section describes the observation results of the effects of an overtaking prohibition.

Table 6.5 presents the total overtaking manoeuvres and total active drivers for simultaneously observed road segments where overtaking is permitted and with overtaking prohibitions. As 6.3.2 described, the observed road segments were successive road segments with one intersection in between them and had similar road characteristics, only the lengths differed slightly. The reason for the overtaking prohibition was that these road segments were already designed conform the new recommendations of the Dutch Sustainable Safety Program. The sight distance was similar to the other road section.

Table 6.5 shows that overtaking frequency and number of active drivers decreased a lot when overtaking was prohibited. However, not all overtaking manoeuvres were prevented. Violations of the overtaking prohibitions vary from 4.5 to 27.7%. The number of drivers that violate prohibitions varies between 6.6 and 25.4%. Remarkable are the differences between the two observed driving directions on the Flevoland road. On the less busy direction with a
lot oncoming traffic (F2-dir2) the prohibition is violated 3 times as much as in the opposing direction.

**Table 6.5 Overview overtaking prohibition violation results**

<table>
<thead>
<tr>
<th></th>
<th>F2-dir1</th>
<th>F2-dir2</th>
<th>ZW</th>
<th>ZH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation duration [h]</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Average flow on segment with prohibition [veh/h]</td>
<td>413</td>
<td>291</td>
<td>232</td>
<td>231</td>
</tr>
<tr>
<td>Total overtaking prohibition violations [-]</td>
<td>41</td>
<td>39</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>Total overtaking manoeuvres on similar segment where overtaking is permitted [-]</td>
<td>839</td>
<td>249</td>
<td>83</td>
<td>207</td>
</tr>
<tr>
<td>Percentage violations [%]</td>
<td>27</td>
<td>4.9</td>
<td>15.7</td>
<td>27.7</td>
</tr>
<tr>
<td>Total drivers that violate overtaking prohibition [%]</td>
<td>26</td>
<td>33</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Total active drivers on road segment where overtaking is permitted [-]</td>
<td>392</td>
<td>165</td>
<td>71</td>
<td>129</td>
</tr>
<tr>
<td>Percentage violators [%]</td>
<td>6.6</td>
<td>20.0</td>
<td>25.4</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Another interesting characteristic to study the effects of overtaking prohibition on, is speed. Table 6.6 presents the averages flows and average speeds for the observed road segments where overtaking is permitted and with prohibition.

**Table 6.6 Average speeds on the road segments where overtaking is permitted and with overtaking prohibition**

<table>
<thead>
<tr>
<th>Overtaking permitted</th>
<th>With prohibition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow [veh/h]</td>
<td>Flow [veh/h]</td>
</tr>
<tr>
<td>Speed [km/h]</td>
<td>Speed [km/h]</td>
</tr>
<tr>
<td>F2-dir1 536</td>
<td>413</td>
</tr>
<tr>
<td>89.0</td>
<td>84.4</td>
</tr>
<tr>
<td>F2-dir2 334</td>
<td>291</td>
</tr>
<tr>
<td>89.3</td>
<td>88.2</td>
</tr>
<tr>
<td>ZW 258</td>
<td>271</td>
</tr>
<tr>
<td>89.3</td>
<td>86.2</td>
</tr>
<tr>
<td>ZH 438</td>
<td>470</td>
</tr>
<tr>
<td>86.6</td>
<td>83.4</td>
</tr>
</tbody>
</table>

For all observations, the average speeds on the segment with prohibitions were lower than on the segments where overtaking is permitted. These speed reductions on the Flevoland road were not caused by higher flows, since flows on the segments with prohibitions were lower. The overtaking prohibition is a more presumable cause of the lower average speeds. This suggestion is strengthened by less reduction in average speed on F2-dir1, where overtaking prohibition violation was high. For the Zeeland road, it is also unlikely that the slightly higher flows are the cause of the lower average speeds. It is more likely that the reduction in overtaking frequency and thus the overtaking prohibition, was the cause of the reduction in average speeds.

In summary, overtaking prohibitions do reduce the number of overtaking manoeuvres, but cannot prevent overtaking totally. Another Dutch overtaking observations study also observed

---

27 The percentage violations is calculated by dividing the observed overtaking manoeuvres on the segments with prohibition by the observed overtaking manoeuvre on the similar segment where overtaking is permitted.

28 The percentage violators is calculated by dividing the observed active drivers on the segments with prohibition by the observed active drivers on the similar segment where overtaking is permitted.
overtaking manoeuvres when it was prohibited (Overkamp and Schermers, 2002). Moreover, when overtaking is prohibited, other drivers do not expect overtaking manoeuvres, which might make the ones performed anyway, more dangerous (Houtenbos et al., 2005b). Roads in general are safer when expected behaviour corresponds with real behaviour (Davidse et al., 2002). This implies that overtaking where it is prohibited is more unsafe than overtaking at locations where it is permitted.

The effects of an overtaking prohibition presented in this section and the results of the overtaking lane described in Section 5.5 are compared with the overtaking assistant results, to verify which solution is most effective in improving overtaking efficiency, safety and comfort. This comparison is described in Chapter 8. This chapter now continues with a section on the relationship between overtaking frequency and its explanatory variables.

6.6 A new overtaking frequency estimation formula

One of the aims of this chapter was to find the relationship between overtaking frequency and its explanatory variables. The results presented in Section 6.4, especially Figure 6.6 showing the observed overtaking frequencies for the observed flows, give the indication that overtaking frequency is at least dependent on the flow and the oncoming flow. Truck percentage and differences in (desired) speed might also influence overtaking frequency. These are, however, not (yet) taken into account. As a first attempt, this section estimates the dependency of overtaking frequency on the independent variables flow in the direction for which the overtaking frequency is estimated and oncoming flow.

Overtaking frequency is expected to grow with the flow. The larger the flow, the more overtaking manoeuvres and if the flow is zero, there will be no overtaking manoeuvres. If the oncoming flow is zero, the overtaking frequency is maximal. The bigger the oncoming flow, the smaller the overtaking frequency, till a certain maximum oncoming flow for which overtaking becomes impossible. This maximum oncoming flow is smaller than the capacity of one lane. This results in a proposed functional form of overtaking frequency, being:

\[ OF = q_o^* (q_a - q_o)^\gamma \epsilon^\epsilon \]  

(6.15)

With

- \( OF \) Overtaking frequency \([#/km-h]\)
- \( q_a \) Flow in analysis direction (Shortly called flow throughout the chapter) \([veh/h]\)
- \( q_o \) Oncoming flow \([veh/h]\)
- \( q_c \) One directional flow at capacity \([veh/h]\)
- \( \alpha, \beta, \gamma \) Parameters to estimate \([-], [-], [#/h/km-veh^2]\)
- \( \epsilon \) Error term, assumed to be log-normally distributed

To use linear regression to estimate the parameters, the function should be linear. The linear equivalent of equation (6.15) is:

\[ \ln OF = \alpha \ln q_a + \beta \ln (q_a - q_o) + \gamma + \ln \epsilon \]  

(6.16)
With a normally distributed error term ln \( e \).

Multivariate Linear Regression was applied, minimising the sum of square of deviations between the estimated value and the real observations. For a flow at capacity of 1700 veh/h, in agreement with the capacity of one lane according to the *Highway Capacity Manual* (Highway Research Board, 2003), the estimated function becomes:

\[
OF = 1.6 \times 10^{-11} \cdot q_a^{1.5} \cdot (1700 - q_o)^{2.5} \quad R^2 = 0.67
\]  

(6.17)

An \( R^2 \) of 0.67 indicates that flow and the oncoming flow are good predictors of overtaking frequency. Figure 6.9 presents the estimated overtaking frequencies for combinations of flows and oncoming flows, together with the observed data points.

Figure 6.9 shows that overtaking frequency grows with flow in analysis direction and decreases with the oncoming flow. The maximum overtaking frequency is 196 and reached when the flow in analysis direction equals capacity. This maximum will never be reached in practice, because there will be no gaps available in front of the overtaken vehicle for the overtaker to move back into. The included observed combination of flows and frequencies show the fairly good fit with the estimated ones.

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*Figure 6.9* Estimated overtaking frequency as a function of flow in analysis direction and flow in opposing direction. The vertical lines show the observation results.
To get a better view of the reached overtaking frequencies for combinations of flow in analysis direction and oncoming flow, a contour graph is made, which is presented in Figure 6.10.

Figure 6.10 Contours of overtaking frequencies for flow in analysis direction and oncoming flow combinations

The first black line is the contour for 10 overtaking manoeuvres. Roughly, 10 overtaking manoeuvres are made when the flow is around 200 vehicles, and can still be reached when the oncoming flow grows to 1200 veh/h. Flows above 1600 veh/h can reach an overtaking frequency of 180 /km-h, as long as the oncoming flow remains below 100 veh/h.

To validate the found relationship for overtaking frequency with the flow and the oncoming flow the formula is compared to other overtaking frequency estimation formulas presented in Section 6.2. Table 6.7 presents the results. Wardrop is added to this table to compare with theoretical overtaking demand, when overtaking is possible at all times and all vehicles driver with their desired speed. Our model approaches our observations best. Note that our model is calibrated for the observation data and the other models are not calibrated for these data.

Table 6.7 Observed overtaking frequencies for some chosen observed flows

<table>
<thead>
<tr>
<th>Flows</th>
<th>Wardrop</th>
<th>Observed</th>
<th>Hegeman</th>
<th>Tuovinen</th>
<th>Botma(^{29})</th>
<th>Daganzo</th>
</tr>
</thead>
<tbody>
<tr>
<td>145 - 166</td>
<td>29.4</td>
<td>2</td>
<td>3.6</td>
<td>13.0</td>
<td>4.2</td>
<td>83.1</td>
</tr>
<tr>
<td>212 - 228</td>
<td>58.6</td>
<td>6</td>
<td>5.8</td>
<td>21.4</td>
<td>9.5</td>
<td>35.8</td>
</tr>
<tr>
<td>348 - 335</td>
<td>141.2</td>
<td>17</td>
<td>10.2</td>
<td>45.1</td>
<td>24.8</td>
<td>7.3</td>
</tr>
<tr>
<td>494 - 192</td>
<td>142.7</td>
<td>39</td>
<td>22.3</td>
<td>45.6</td>
<td>38.8</td>
<td>7.2</td>
</tr>
<tr>
<td>594 - 824</td>
<td>608.5</td>
<td>6</td>
<td>7.4</td>
<td>179.5</td>
<td>34.5</td>
<td>0.1</td>
</tr>
<tr>
<td>616 - 262</td>
<td>233.4</td>
<td>34</td>
<td>27.6</td>
<td>71.7</td>
<td>85.7</td>
<td>2.0</td>
</tr>
<tr>
<td>844 - 345</td>
<td>427.0</td>
<td>30</td>
<td>38.3</td>
<td>127.3</td>
<td>138.6</td>
<td>0.3</td>
</tr>
<tr>
<td>998 - 469</td>
<td>650.7</td>
<td>42</td>
<td>38.6</td>
<td>191.7</td>
<td>175.9</td>
<td>0.0</td>
</tr>
<tr>
<td>1149 - 577</td>
<td>901.6</td>
<td>32</td>
<td>37.9</td>
<td>263.8</td>
<td>231.9</td>
<td>0.0</td>
</tr>
</tbody>
</table>

\(^{29}\) To calculate the expected reduced number of overtaking manoeuvres with the formula’s of Botma, a critical headway value to accept as overtaking possibility was 20 and the threshold value for necessary speed difference to have an overtaking wish 5 km/h
Table 6.7 shows that most models overestimate the overtaking frequency, especially when the oncoming flow is higher than the flow in analysis direction. This is caused by the fact that these models either take the total flow into account, or only the flow in analysis direction.

Now the results of the empirical overtaking data collection on two-lane rural roads are presented and the relationship between overtaking frequency and flow and oncoming flow is estimated, this chapter finalises with the summary and discussion section.

6.7 Summary and discussion of overtaking frequency observations

Empirical overtaking frequency data were collected in order to accurately describe the current traffic situation on two-lane rural roads, necessary for the subsequent chapter, to study the effects of different penetration rates of drivers equipped with an overtaking assistant on traffic system efficiency, drivers’ comfort and safety. The data were secondly collected to find the relationship between overtaking frequency and its explanatory variables. Thirdly, road segments with overtaking prohibition are observed simultaneously to study the effects of a prohibition to put the overtaking assistant results in perspective.

The license plate recognition methodology was an adequate method to obtain flows, speeds, densities, overtaking frequencies, active drivers, passive drivers and vehicle types of an observed road segment. In total 12 data sets were obtained including 80 hours observation of two different roads. On both roads, the Flevoland road and the Zeeland road, similar road segments without and with overtaking prohibitions separated by one intersection were observed.

The general flow, speed and density results of both roads were as expected for two-lane rural roads. Flows on the Flevoland road varied between 330 veh/h in the less busy direction to over 1000 veh/h in the busier direction. Flows on the Zeeland road were lower, especially on the observed workday.

The average observed overtaking frequencies varied between 4/km-h and 51/km-h. When the observation period was split in 15-minute periods the maximum observed overtaking frequency was 124/km-h. The observed frequencies on the Flevoland road were higher than on the Zeeland road.

The overtaking frequency turned out to be less dependent on the total flow of the road and more on the distribution of the vehicles in the two driving directions.

Average speeds of active drivers, who performed overtaking manoeuvres were higher than the average speeds of neutral drivers, which were, in turn, higher than the speed of the passive drivers. The higher speeds of the active drivers resulted in an average travel time gain of 15 s for a road segment of 5 km.
Observed truck percentages varied between 5 and 10% on the Flevoland road and between 3 and 5% on the Zeeland road. Motorbikes represented less than 1% of the total traffic, but represented much higher percentages of the active drivers, up to 12.5%. Trucks on the other hand, were overrepresented among the passive drivers: 7% trucks represented 47% of the passive drivers.

The results of the segments with overtaking prohibition revealed between 5 and 28% violations and between 7 and 25% violators. While the observed flows on these segments were slightly lower in most segments than on the simultaneously observed segments where overtaking was permitted, average speeds were lower in all segments with prohibition. The smallest speed reduction was observed on the segment with the most violators.

A relationship between overtaking frequency and its explanatory variables was estimated. This resulted in the following relationship between overtaking frequency (OF), flow (qa) and oncoming flow (q_o):

\[
OF = 1.6 \times 10^{-11} \times q_a^{1.5} \times (1700 - q_o)^{3.5}
\] (6.18)

With \( R^2 \) of 0.67. In other words, with flow and oncoming flow only, 67% of variation in overtaking frequency can be explained. Comparison with existing models of Tuovinen and Enberg (Tuovinen and Enberg, 2006), Botma and Dommerholt (Dommerholt and Botma, 1988) and Daganzo (Daganzo, 1975), equation (6.18) fitted best and has the smallest number of input variables.

6.7.1 Discussion of overtaking frequency observations

Section 6.3.6 included some expected results of the overtaking frequency observations. This subsection discusses whether the results agree with expectations.

All results of the Flevoland road agree with expectations. Flows are high, but still free flowing and average speeds are fairly high as well. Overtaking frequencies ranged between 5 and 65 /km-h, which is about 10% of the theoretical overtaking rate calculated with the catch-up formula for the observed flows, speeds and standard deviation of speeds. A cause for the much lower overtaking frequencies in practice could be that drivers understand that overtaking does not reduce travel time much. The average travel time gain over 5 km was 15 s. Other possible explanation for the difference in theoretical overtaking demand and overtaking frequency in practice is that drivers postpone their overtaking manoeuvres to nearby road segments with two driving lanes in each direction or to flared approaches at intersection (Dommerholt and Botma, 1988).

The lower average speed measured during F2 compared to the F0 observations was surprising, since the F0 included fewer off-peak observation hours. Analysis of the results per 15 minutes observation showed that during the F2 session, three 15-minute periods had fairly low average speeds. A possible cause for these lower speeds could be that there was some kind of special transport on the road, which was difficult to pass. These three data point were removed from the data set for the estimations of relationship between overtaking frequency and its explanatory variables.
The results of the Zeeland road also confirmed to expectations. Overtaking frequencies on this road were lower than on the Flevoland road, probably due to the different driver types on the road. The Flevoland road has much commuter traffic, while the Zeeland road has more leisure traffic. A proof for this are the many foreign cars observed on the Zeeland road, especially on the holiday when they constituted almost 13% of all traffic.

The expectations regarding the relationship between overtaking frequency and its explanatory variables were in the right direction. It was indeed found that overtaking frequency is highly dependent on the distribution of vehicles in the two driving directions. In addition, different total flows with similar distributions in the two directions resulted in similar overtaking frequencies.

The truck percentages on the Flevoland road were around the Dutch average of 13.5% (Huijbregts and Rozemeijer, 2005), as expected. The truck percentages on the Zeeland road were lower, as expected, because of the more local function of this road, without much business areas. The observed high percentages of foreign cars on the Zeeland road were expected: the road was selected because of possible different (overtaking) behaviour caused by leisure traffic. Foreign cars were assumed to be leisure traffic.

### 6.7.2 International applicability of Dutch overtaking frequency results

All presented empirical data were collected on Dutch two-lane rural roads. To verify the international applicability of the overtaking frequency results, possible differences between the Netherlands and other countries need to be addressed. Firstly, the Netherlands is a flat country, without any hills. Hills will reduce overtaking frequency, because sight distance is limited. Secondly, the roads in the Netherlands are relatively narrow. The road widths of the observed roads were 8 m, including two driving lanes and no shoulder lane, which is narrower than in most other countries. In general, wider lanes will increase overtaking frequency (Tapani, 2005a). However, since Dutch drivers are used to the narrow lanes, their overtaking frequency might not suffer from the narrow lanes. Thirdly, the Dutch two-lane roads have fairly high flows.

The international applicability of Dutch overtaking frequency results is of special interest when microscopic traffic simulation model developed in another country will be applied to study the effects of the overtaking assistant on network efficiency, drivers’ safety and comfort. When such models are developed with different empirical overtaking data, estimations might not fit the Dutch situation. This is explicitly taken into account in the subsequent chapter, where RuTSim (Tapani, 2005a), developed in Sweden, is applied to model the Flevoland road.

The Flevoland road was selected to use for the microscopic traffic simulation study described in the next chapter. $F1$ data sets are used to calibrate the model and $F2$ data to validate it. These data enable accurate description of current traffic situation, including overtaking frequencies for unassisted drivers. This situation is used as a reference to test effects of different penetration rates and different threshold settings of the overtaking assistant.
7 A Microscopic Traffic Simulation Study on Overtaking Assistance

Microscopic traffic simulation, a recommended method for driver assistance systems assessment (ADVISORS, 2002), is the most convenient method to study the effect on collective flow characteristics of new technologies such as the overtaking assistant. The Swedish model RuTSim turns out to be the most suitable available model that is especially developed to study effects of new technologies on two-lane rural roads. Calibration and validation of RuTSim for a Dutch two-lane rural road reveals that an exact representation of the Dutch peak-hour situation without major model adjustments is difficult. The off-peak hour simulations reflect the empirical measurements well and are used for the simulations. An overtaking assistant threshold setting of 8 s, being the minimum recommended overtaking gap, increases drivers’ comfort and affects traffic system efficiency and drivers’ safety only marginally. An 11 s threshold corresponds with normal overtaking behaviour of the simulated drivers. When 5 or 10% of the drivers are equipped with the system, they gain travel time, have higher overtaking frequencies and spend less time following. For higher penetration rates, traffic system efficiency remains similar to the situation without assistance and neither the assisted drivers nor the non-assisted drivers’ comfort and safety are affected much.
7.1 Introduction

This chapter presents a driving simulation study looking at traffic system effects of an overtaking assistant when different percentages of drivers are equipped with it. Different threshold settings for the critical overtaking opportunity gap are studied as well. This chapter aims to answer the fifth research question of this dissertation research: What are the effects of the overtaking assistant on collective flow characteristics in terms of traffic system efficiency, drivers’ comfort and safety?

A microscopic traffic simulation study is applied enabling to study effects of different penetration rates of the proposed overtaking assistant. Microscopic traffic simulation enables collection of many indicators to measure traffic system efficiency, drivers’ comfort and safety for scenarios which do not (yet) exist in reality. The chosen indicators to measure traffic system efficiency are speeds and delays, to measure drivers’ comfort are time spent following and overtaking frequency and to measure drivers’ safety are time-to-collision (TTC), time integrated TTC and time exposed TTC. The results of this chapter together with the results of Chapter 5 are part of the evaluation phase of the design of the overtaking assistant described in Chapter 4. The next chapter summarises all results and recommends on the future of the overtaking assistant.

Figure 7.1 presents the outline of this chapter. The next section starts with a review of how overtaking manoeuvres on two-lane rural roads are modelled in current available microscopic traffic simulation models. Based on this review, the RuTSim model is chosen to use and Section 7.3 describes how overtaking is modelled in RuTSim. Section 7.4 explains the experimental set-up, including a description of all modelled scenarios. Before the results are presented in Section 7.6, the model needs to be calibrated and validated, which is done in Section 7.5. A summary and discussion section finalises this chapter.
7.2 Review of microscopic traffic simulation models modelling overtaking

Impact pre-assessment of driver assistance systems is necessary to secure real system benefits and to allow resources to be spent on the most promising alternatives. The European project ADVISORS recommends microscopic traffic simulation for further evaluations of driver assistance systems, after simulator studies, test track studies and before pilot studies are performed (ADVISORS, 2002). Microscopic traffic simulation is one of the few ways to predict possible impacts of driver assistance systems on the traffic system as a whole, before the system is introduced to the market. It allows inclusion of driver assistance systems functionalities together with induced driver behaviours in the sub-models that control vehicle movements. In addition to the request to enable modelling driver assistance systems, this study of the effects of an overtaking assistant also needs a microscopic traffic simulation model enabling modelling of overtaking on two-lane rural roads.

7.2.1 Overtaking modelling in well-known microscopic traffic simulation models

Amongst the most well-known and frequently applied microscopic traffic simulation models are Paramics (Quadstone-Limited, 2003), VISSIM (VISSIM, 2007) and AimsunNG (Aimsun, 1998). To our knowledge, so far, none of these models is applied to model overtaking on two-lane rural roads. Paramics is the worldwide most applied microscopic traffic simulation tool modelling both urban and freeways (Grontmij, 2007) and the developers claim that Paramics is capable of modelling overtaking on two-lane rural roads. Dutch users of Paramics, VISSIM and AimsunNG were asked whether they ever simulated overtaking on two-lane rural roads and they did not. Moreover, the Dutch dealer of AimsunNG for the BENELUX used an other microscopic traffic simulation model (DRACULA, described below) to model overtaking on two-lane rural roads (Overkamp and Schermers, 2002). This is an indication that for overtaking modelling, another microscopic traffic simulation models are required.

7.2.2 Overtaking modelling in less well-known microscopic traffic simulation models

Some less well-known microscopic traffic simulation models that enable overtaking modelling, include DRACULA (Liu et al., 1995), HUTSIM (Helsinki University of Technology, 2007) and SiMoNe (Minderhoud, 1999).

DRACULA was applied to study the effects of intelligent speed adaptation on rural roads (Carsten and Fowkes, 2000, Liu and Tate, 2000) and to study the effects of an overtaking prohibition (Overkamp and Schermers, 2002). The DRACULA overtaking model was updated in the 2005 version of the model, in which a wish for overtaking is triggered when a vehicle falls within a defined catching up region and its speed is severely constrained by the preceding vehicle. If there is enough space in front of the preceding vehicle for merging back after the overtaking, and the gap with oncoming traffic is sufficiently large, and it is within a visibility range, drivers will begin the overtaking manoeuvre with their normal speed and acceleration multiplied by a factor larger than one, in order to complete the manoeuvre quickly (Liu, 2005). To our knowledge the overtaking facility of DRACULA has not yet been validated with empirical data.
A different approach of overtaking modelling was applied in the HUTSIM model, where drivers decide to overtake when their speed loss due to slower driving preceding vehicles is higher than a certain threshold. As in DRACULA, desired speeds during overtaking are increased in the HUTSIM model in order to quickly perform the manoeuvre (Wietholt, 2006). On top of this a pressure parameter is added which increases the pressure to return back to the right lane when the gap with the first oncoming vehicle becomes smaller. An attempt to validate HUTSIM is made, using empirical Finnish and German data. Compared with these data, HUTSIM simulated too high overtaking frequencies. This was caused by ‘fluttering vehicles’ which did start an overtaking manoeuvre, but did not finish them (Wietholt, 2006). HUTSIM has not yet been applied to model driver assistance systems.

The Dutch model SiMoNe was originally developed as a motorway simulation model enabling modelling of next generation vehicles, that is, vehicles equipped with driver assistance systems. The model was extended to model two-lane rural roads with oncoming traffic (Minderhoud, 2004). The modelled overtaking wish is dependent on the following distance and speed difference, which differs between drivers. The time needed for overtaking is a summation of time headway, passage time, lane change time and a safety margin. When this time needed for overtaking is smaller than the estimated available gap until the next oncoming vehicle arrives, an overtaking manoeuvre is performed. Empirical data of the Flevoland road described in Chapter 6 was used to calibrate the model and the Zeeland road data was used for the validation. The conclusion of this validation was that overtaking frequencies vary a lot, often caused by factors not included in microscopic traffic simulation models, such as differences in driver types (commuters or leisure traffic).

In conclusion, of these three models, SiMoNe has the highest suitability to apply to this study, since it is able to model driver assistance systems and has been validated best. Since the three models have a specific way of overtaking modelling, a comparison study of these three models with the same overtaking data would be interesting to get more insight into which method gives the best representation of real overtaking behaviour. Before a definite choice of which simulation model will be used for this study is made, three special two-lane road models are discussed in the next section.

7.2.3 Special two-lane rural road microscopic traffic simulation models

In addition to the general microscopic traffic simulation models discussed in the subsection above, there are also some microscopic traffic simulation models especially developed to model overtaking on two-lane rural roads. The most well-known are the Traffic on Rural Roads (TRARR) model (Hoban et al., 1991), the Two-Lane Passing (TWOPAS) model (Leiman et al., 1998), and the Rural Road Traffic Simulator (RuTSim) model, a follow-up of the VTISim model (Brodin and Carlsson, 1986b).

The main development aim of the Australian TRARR model was to prepare guidelines for the design of passing lanes in level terrain and on grades (Hoban et al., 1991, Lovell and May, 1994). The overtaking model of TRARR is deterministic, which means that a vehicle will always start an overtaking manoeuvre if the time available for the manoeuvre is at least the estimated overtaking time times a safety factor. The desired speed and available power of the overtaking vehicle are increased during overtaking manoeuvres. Overtaking of more vehicles
at once is possible and vehicles being overtaken cannot start an overtaking manoeuvre. An interesting extra feature of the TRARR model is a so-called aggression index. Each vehicle is assigned an aggression level. Drivers will not overtake if either the vehicle in front or behind has a higher aggression level. A major drawback of the TRARR model for our aim is that it is not suitable to study the effects of driver assistance systems such as the overtaking assistant. Moreover, rough application of the model to Dutch data gave far too high overtaking frequencies. Many input data were required which are not easily obtained and calibration of the model was not easy. Another problem with the TRARR model was that it cannot be easily adjusted by users who are not involved in the development of the model. Finally, the development of the TRARR model stagnated in the nineties, since then, no new developments were published.

The American model TWOPAS (Leiman et al., 1998), was applied to generate data for the US Highway Capacity Manual procedures for capacity and level-of-service of two-lane highways (rural roads) (Harwood et al., 1999). TWOPAS is a time-based simulation model that includes an empirically based overtaking model. This model is stochastic and includes overtaking gap-acceptance functions that determine the overtaking probability given the speed of the preceding vehicle and the distance available for overtaking (McLean, 1989). The available overtaking distance is given by the clear sight distance or the distance to the closest oncoming vehicle. As the TRARR model, TWOPAS is not developed to model driver assistance systems. Moreover, the included overtaking model is based empirically only on overtaking data. And, the latest published development of the TWOPASS model were during the nineties (Leiman et al., 1998). A practical disadvantage of the TWOPASS model is that it is not freely available.

The European RuTSim model (Tapani, 2005a) was developed in 2005 as a follow-up of the VTISim model (Brodin and Carlsson, 1986a), which was, according to McLean (1989), the most proven of the rural road simulation tools available in 1989. RuTSim models vehicles’ speed adaptations with respect to preceding and following vehicles and also regarding oncoming vehicles and regarding road geometry. RuTSim distinguishes between flying overtaking and accelerative overtaking defined in Chapter 2. When a vehicle catches-up with a slower vehicle, it receives an opportunity for flying overtaking at the overtaking decision point. When flying overtaking is not possible due to limited sight distance or due to oncoming traffic, opportunities for accelerative overtaking manoeuvres will be given. Accelerative overtaking is possible only when sight distance is maximal and no oncoming vehicles are within sight. Overtaking of more vehicles at once is possible and treated as flying overtaking manoeuvres. The overtaking decision process is governed by drivers’ ability to overtake, the possibility to overtake considering surrounding traffic, possible overtaking restrictions and drivers’ willingness to overtake. RuTSim was especially developed to study the effects of driver assistance systems (Lundgren and Tapani, 2006) and it was calibrated and validated against Swedish empirical data (Tapani, 2005b).

From the found literature about the three discussed special two-lane rural road models, it is difficult to judge which includes the best method to model overtaking. RuTSim was chosen to apply to this study of the effects of an overtaking assistant and this choice is based on three facts. Firstly, the model is still being developed, using the most up-to-date knowledge on for
example car-following (e.g. the intelligent driver model of Treiber (2000) is implemented). Secondly, the model is explicitly developed to be flexible with respect to modelling of driver assistance systems. And thirdly, because the developers of RuTSim were willing to cooperate, also to enable validation of this Swedish model with Dutch overtaking data to enlarge its application possibilities.

RuTSim was chosen above SiMoNe due to collaboration advantages. It would be interesting to also apply SiMoNe for the overtaking assistant assessment and to compare the results of RuTSim and SiMoNe.

7.3 Method: simulation of the overtaking assistant in RuTSim

The Swedish rural road microscopic traffic simulation model RuTSim (Tapani, 2005a), is applied to study effects on collective flow characteristics of the overtaking assistant. Figure 7.2 presents a flow chart of all main elements of the model.

RuTSim simulates one road, including traffic entering and leaving at intersections or roundabouts. RuTSim is time-based, handling dynamic origin destination matrices with varying flows for the simulated time period, including information on percentage of each vehicle type (passenger cars, van or small trucks, trucks and trucks with trailer).

![Figure 7.2 Flow chart of the RuTSim model](image)

The applied car-following model is the intelligent driver model of Treiber (2000). A graphical user interface visualizes the simulation, enabling to check the geometry and adjust parameter settings. The output facilities of RuTSim enable aggregation of chosen output parameters over ex-post defined road sections or cross sections. Tapani (2005a) includes a complete...
7.1 Overtaking model of RuTSim

The general overtaking decision process in RuTSim is split in two stages. Potential overtakers are in the first stage when the interaction part of the applied intelligent driver model starts to dominate, that is, free driving changes into car-following. For clarity, the intelligent driver model is given (copied from Treiber (2000)):

\[
\hat{v}_u = a_0^{(a)} \left[ 1 - \left( \frac{v_a}{v_u^{(a)}} \right)^2 \right] - \left( \frac{s^* (v_a - \Delta v_u)}{s_u} \right)^2
\]  

(7.1)

With

- \( \hat{v}_u \): Assumed acceleration [m/s²]
- \( a_0 \): Maximum acceleration [m/s²]
- \( v_u \): Velocity [m/s]
- \( v_u^{(a)} \): Desired velocity [m/s]
- \( \Delta v_u \): Velocity difference [m/s]
- \( s^* \): Desired minimum gap [m]
- \( s_u \): Gap [m]

When drivers are in the first stage of the overtaking process, three conditions are checked:

1. Ability of vehicles to overtake
2. Possibility to overtake considering surrounding traffic
3. Possible overtaking restrictions

The ability to overtake depends on the traffic conditions at the overtaking decision point \( O_v \). At this point, the acceleration rate of the intelligent driver model equals the RuTSim acceleration parameter \( a_0 \). In formula:

\[
\left( \frac{s^* (v_a - \Delta v_u)}{s_u} \right)^2 = a_0
\]  

(7.2)

RuTSim distinguishes flying overtaking and accelerative overtaking, each with a different ability to overtake. For both, the estimated overtaking distance must be shorter than the maximum available overtaking length. For flying overtaking, this estimated overtaking distance is given by:

\[
l_{ovtk} = l_{rel} + \frac{l_{ov} v_{a-1}}{v_a - v_{a-1}} \quad \text{with} \quad l_{rel} = x_u - x_{a-1} + l_u + T_v v_a
\]  

(7.3)
With

\[ l_{ovtk} \] Estimated overtaking distance [m]
\[ l_{rel} \] Distance which the overtaker must travel relative to the distance the preceding vehicle will travel [m]
\[ v_n \] Speed of vehicle n [m/s]
\[ v_{n-1} \] Speed of the preceding vehicle [m/s]
\[ x_n \] Position vehicle n [m]
\[ x_{n-1} \] Position preceding vehicle [m]
\[ l_n \] Length of vehicle n [m]
\[ T_n \] Desired following time gap of vehicle n [s]

For accelerative overtaking, the estimated overtaking distance is given by:

\[ l_{ovtk} = v_n \left( \frac{2v_{n-1}}{a_{max}} \right) + l_{rel} \] (7.4)

With

\[ a_{max} \] Maximum acceleration of vehicle n (overtaker) given its current position and speed [m/s²]

When flying overtaking is not immediately possible, the overtaker will tail the preceding vehicle. Possibilities for accelerative overtaking manoeuvres depend on sight distance and distance with oncoming vehicles. When sight distance is not maximal or there is an oncoming vehicle within sight, the overtaker has to wait for a new overtaking opportunity, either when the oncoming vehicle has passed or when the sight distance is maximal again. Overtaking multiple vehicles at once is considered when the overtaker is side-by-side with the first overtaken vehicle, and is treated as flying overtaking manoeuvres. For a vehicle’s ability to overtake for accelerative overtaking the difference in desired speed of the overtaker and the preceding vehicle must be above the minimum allowed desired speed difference.

When the first condition, a vehicle’s ability to overtake, is satisfied, the possibility to overtake considering the surrounding traffic is taken care of. It is checked whether other vehicles occupy the lane required for the overtaking manoeuvre. No other vehicle should be overtaking the preceding vehicle or the subject vehicle (the potential overtaker). The overtaking track must also be free at least the overtaker’s desired following time headway \( T_n \). Overtaking manoeuvres are not allowed if any vehicle in the platoon ahead is preparing to make a left turn at an upcoming intersection.

The third condition, possible overtaking restrictions, takes overtaking prohibitions into account. Overtaking manoeuvres will not start if overtaking is not permissible, nor if there is any overtaking restriction within the minimum distance to the overtaking restriction.

As long as the three explained conditions are positive regarding overtaking, the preceding vehicle will be neglected until the overtaking decision point \( O_p \), as given in equation (7.2). At this point, the second stage of the overtaking decision process is reached, where the same
three conditions are verified again together with a fourth condition, the drivers’ willingness to overtake.

A driver’s willingness to overtake is included in RuTSim by means of Gompertz functions (Gompertz, 1825) to describe drivers’ willingness to overtake slower traffic. The functions are of the form:

\[
P(s) = \begin{cases} 
\exp(-A\exp(-ks)), & s > s_{\text{min}}^{\text{fly}} \\
0, & s \leq s_{\text{min}}^{\text{fly}}
\end{cases}
\]  

(7.5)

With

- \( P[s] \) Overtaking probability given a clear sight distance \( s \) [-]
- \( A \) An estimation parameter [s]
- \( k \) An estimation parameter [s]
- \( s \) Clear sight distance [m]
- \( s_{\text{min}}^{\text{fly}} \) Minimum clear sight distance for flying or accelerative overtaking [s]

The probability functions of the above equation are fitted to empirical (Swedish) data (Tapani, 2005a). Distinct functions are estimated for different types of overtaking (accelerative or flying), different overtaken vehicles (passenger car slower and faster than 90 km/h, trucks, and trucks with trailer), different sight limiting factors (natural obstacles or oncoming vehicles) and different road widths (wider than 11 m, smaller than 11 m). Carlson (1990) includes a complete description of the overtaking probability functions.

Figure 7.3 presents the cumulative probability functions for cars on roads with a width smaller than 11 m, for different speeds, different sight distances and different overtaking types. The included cumulative probability function for assisted drivers will be explained in 7.3.2.

In addition to the four discussed conditions, there are some other factors of the RuTSim overtaking model that are of importance for this study:

- When vehicles drive in a platoon, only the second vehicle is allowed to perform an accelerative overtaking manoeuvre. When this vehicle rejects an overtaking opportunity, no other vehicle in the platoon will receive an opportunity;
- During overtaking, the overtaker’s desired speed \( v_{\text{des}}^{\text{ovtk}} \) is incremented by a factor \( v_{\text{des}}^{\text{ovtk}} \). This results in higher desired speeds during overtaking. At the same time, the power to mass ratio is incremented to encourage drivers to use extra power during overtaking;
- During overtaking, the overtaken vehicle continues without changing its behaviour. As soon as the overtaker has passed the overtaken vehicle, this vehicle recognises the overtaker as a leading vehicle and facilitates the lane change of the overtaker. In turn, when the overtaker has to merge within a platoon, it recognises a new preceding vehicle as the vehicle to follow and adjust its speed to it.
Assisted Overtaking

Figure 7.3 Cumulative probability functions of drivers’ willingness to overtake slower vehicles, including the function when drivers are equipped with the overtaking assistant.

7.3.2 The overtaking assistant in RuTSim

The overtaking assistant has been modelled in RuTSim under the assumption that the assistant only influences drivers’ willingness to overtake. This is the fourth condition, which is checked in the second stage of the overtaking manoeuvre, when drivers have reached overtaking decision point $O_p$. The first three conditions were checked in the first stage as explained in Section 7.2.1. For equipped vehicles in the simulation, the stochastic overtaking probability functions, equation (7.5), have been replaced by a deterministic procedure. Assisted vehicles will accept an overtaking opportunity if the time to the next oncoming vehicle is longer than the overtaking assistant threshold. Equation (7.5) is replaced by:

$$P[s] = \begin{cases} 1, & T_{opp} > t^* \text{ and } s > s_{min}^{opp} \\ 0, & \text{otherwise} \end{cases}$$

(7.6)

With

- $P[s]$ Probability to overtake (1) or not (0) [-]
- $T_{opp}$ Time until the first oncoming vehicle arrives [s]
- $t^*$ Threshold setting of the assistant [s]
- $s_{min}^{opp}$ Minimum clear sight distance for flying or accelerative overtaking [s]

This model assumes full driver compliance with the overtaking assistant. Figure 7.3 includes the resulting probabilities of equation (7.6) when drivers are equipped with an overtaking assistant.

An aspect of the assistant that is not included in the RuTSim, is the feature to inform drivers about an overtaking gap some seconds before it is actual present. In the driving simulator...
experiment described in Chapter 5, the assistant’s red sign started flashing 3 s before the actual overtaking gap was available. This gave drivers the possibility to prepare for the overtaking manoeuvre, that is, to perform all the subtasks of phase two, prepare to overtake, of the overtaking manoeuvre described in Chapter 3. Since this feature is not included in RuTSim, drivers start the overtaking manoeuvre in the model later than in reality, which will increase the required gap size in the oncoming traffic stream, because the first seconds of the available gap are used to prepare the manoeuvre and not to move to the left lane used. This will decrease the number of overtaking opportunities.

7.4 Experimental set-up of simulation study of the overtaking assistant

The previous two sections explained the choice for RuTSim to assess the effects on collective flow characteristics of an overtaking assistant and how overtaking on two-lane rural roads and the overtaking assistant are modelled with RuTSim. This section continues with the experimental set-up, including the description of the simulated network, the origin and destination matrix, the scenarios, the required number of simulations for satisfying accuracy and the performance indicators to measure traffic system efficiency, drivers’ comfort and safety.

7.4.1 Simulated network and origin destination matrix

![Figure 7.4 The Flevoland road. Below: a schematic presentation of how the road is modelled in RuTSim](image)

The simulated network is a 20 km long part of the N305 Almere-Zeewolde, a rural two-lane road in the middle of the Netherlands, with a speed limit of 100 km/h for passenger cars and
80 km/h for trucks and cars with trailers. This, in this dissertation called Flevoland road, was used for the driving behaviour study described in Chapter 2, the driving simulator experiment described in Chapter 5 and the overtaking frequency study described in Chapter 6.

Figure 7.4 displays a map with the Flevoland road and a schematic overview of the simulated road. Road sections A and B are the observed road sections of the overtaking frequency study described in Chapter 6 respectively without and with an overtaking prohibition. Starting at the Almere site (left), the simulated network includes a T-junction, followed by two four-arm intersections with divided driving directions for the main road (Flevoland road) and another T-junction.

The used origin and destination matrix (OD-matrix) is presented in Table 7.1 and is based on the off-peak observation from 13.00 till 16.00 hours of the F2 data set described in Table 6.1. No data was available of the minor roads crossing the main road and turning rates were chosen such that the flows on the main road agreed with the observed flows. Flows on the minor road might not agree with reality, but no analyses were performed for these roads.

<table>
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<th>4</th>
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<td>10</td>
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</tbody>
</table>

7.4.2 Simulated threshold settings and penetration rate scenarios

The reference scenario is the Flevoland road as observed on 19th April 2004 between 13.00 and 16.00 hours. Against this reference situation, two scenario groups are modelled. One group includes scenarios with varying threshold settings of the assistant, that is, the minimum gap that is recommended as an overtaking opportunity and the other group includes scenarios with varying penetration rates, which is the percentage assisted drivers. Table 7.2 presents an overview of all scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Threshold [s]</th>
<th>Penetration rate [%]</th>
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</tr>
<tr>
<td>Threshold scenarios</td>
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<tr>
<td>Penetration scenarios</td>
<td>8</td>
<td>5, 10, 25, 50</td>
</tr>
</tbody>
</table>
Table 7.2 includes five threshold scenarios. Modelling these scenarios, the distribution of overtaking gaps to accept in RuTSim is overruled by the assistant when the offered gap is larger than the threshold setting. When this is the case, the driver/vehicle will always overtake. The chosen threshold settings to simulate are 8, 9.5, 11, 12.5 and 14 s. Eight seconds is chosen because it was the used threshold setting in the overtaking assistant driving simulator experiment described in Chapter 5 which was, in turn, based on the observed overtaking manoeuvres with the instrumented vehicle described in Chapter 2 with an average duration of 7.8 s. This was the time the overtaker spent in the left lane. Since the overtaker should return back to the right lane well before the next oncoming vehicle arrives, extra seconds should be added to the threshold setting for safe overtaking manoeuvres. However, in the pilot study for the driving simulator experiment, 8 s turned out to be the (minimum) convenient threshold setting. Next to the 8 s threshold setting, 11 s is simulated because this is expected to be the most sensible threshold setting of the assistant. These 11 s are a summation of the average duration of overtaking manoeuvres, about 8 s, plus 3 s safety margin. TTCs below 3 s are experienced by drivers as uncomfortable and they have to react adequately to avoid accidents (Hoogendoorn, 2000). The threshold setting of 14 s is added to study how this rather large threshold setting will affect the total number of overtaking opportunities. The threshold setting 9.5 s and 12.5 s were added to study possible (linear) relations between the simulated threshold settings. For all threshold setting scenarios 100% penetration was used, which means that all passenger cars are equipped with the overtaking assistant. The simulated 15% trucks do not have an overtaking assistant.

For all simulations 100% compliance is assumed. This involves that if drivers have the overtaking assistant available, they will always use it when an overtaking situation occurs. The reasons for this assumption came from the driving simulator experiment results. During that experiment, after some time driving with the overtaking assistant, participants tend to accept the first gap recommended by the assistant as a safe overtaking opportunity. Also, the results from the included questionnaire indicated that when drivers switch the system on, they will use it. With 100% compliance assumption in RuTSim, drivers still decide when to switch the system on, and thus the overtaking wish is not affected, but when drivers have an overtaking wish, they will obey to the system. These findings and expectations have lead to the decision to assume 100% compliance. However, further research on compliance and when manual controlled systems are switched on, is desired.

With respect to penetration rates, the reference scenario can be regarded as 0% penetration rate and the threshold setting scenarios as the 100% penetration rate. In addition to these extremes, 5, 10, 25 and 50% are simulated. Low penetration rates are of interest because these will occur first on the road when the system becomes available. Simulations with 1 and 2% were also tried, but because the chance of nil overtaking manoeuvres for the assisted drivers then becomes too large, it is not sensible to give any statistical results. Hence, 5% was chosen as the minimum sensible penetration rate to simulate. The higher percentages clarify what can be attained or what the maximum effects are, when more vehicles are equipped with an overtaking assistant. The penetration rate simulations were performed with a threshold setting of 8 s. The 8 s threshold was chosen because of the consistency with the simulator study. More importantly, 8 s is chosen to test the minimum possible threshold setting and to find the boundaries of possible effects. All other threshold settings are larger and have a smaller
possibility to effect safety negatively. With the choice for the threshold setting of 8 s not the most probably design of the overtaking assistant is chosen, rather the most risky.

In summary, ten different simulations are performed including the reference scenario, five threshold settings scenarios and four penetration rates scenarios. Each scenario has to be simulated more than one time, to take natural fluctuations in driving behaviour into account. The next subsection calculates the required sample size to reach satisfying confidence levels.

7.4.3 Number of simulation replications
The RuTSim model includes several stochastic variables such as desired speed, desired headway, acceleration levels and wish to overtake. The random seed assigns a value of these stochastic variables from their distribution for each driver/vehicle. This makes the model output different for each random seed reflecting day-to-day fluctuations. To take these output differences into account, the simulations should be run several times with different random seed to give a prediction of the average real life situation. How many runs are necessary depends on the confidence level one wants to reach with respect to a chosen output variable. Since this study is about overtaking, the overtaking frequency is chosen as the variable to base the sample size (number required runs) on. The formula to calculate the sample size \( n \) is given by (Buijs, 2003):

\[
    n = \frac{Z^2 \sigma^2}{a^2} \tag{7.7}
\]

With
- \( Z \) The \( Z \)-return value of the student-T-distribution of the chosen confidence level
- \( \sigma \) Standard deviation of the chosen variable (overtaking frequency)
- \( a \) Accepted difference of the found average of the chosen variable

For a 90% confidence interval, the \( Z \)-value is 1.65 (two-tail). The accepted difference in the found average of the overtaking frequency is subjectively chosen to be 6 and the standard deviation of 10. This gives a sample size of 7.6. This means that 8 runs are required to reach a 90% confidence level for an overtaking frequency average varying plus or minus 6 and a standard deviation of 10. In other words, the number of 8 replications is based on the widths of the resulting confidence intervals for the selected performance indicator 'overtaking frequency'. The resulting interval widths are different for different performance indicators. Intervals for overtaking frequencies, which are heavily dependent on properties and the order of individual vehicles on the road, will for example be wider than intervals in high penetration scenarios. Eight model replications were considered to be sufficient in order to be able to secure reasonably small differences for the selected performance indicators. Hence, 8 replications are used for the calibration, the validation and simulated scenarios.

7.4.4 Indicators of traffic system efficiency, drivers' comfort and safety
Before the simulations are performed, thoughts were given on which output measures should be used. Improvements in traffic safety often cause negative effects for traffic system
efficiency and vice versa. Take the simple example of traffic speed: the collision consequences of vehicles with low speeds is a lot less than vehicles with high speeds, but travel time will increase when vehicles drive at lower speeds. Because of these controversial effect possibilities, the effects of driver assistance systems aiming to improve safety should be assessed not only for traffic safety, but also for traffic system efficiency and drivers’ comfort. This testing has to be done before the new driver assistance systems is introduced to the market. To measure whether, and to what extent, measures are affected, indicators of these measures need to be identified (ADVISORS, 2002). The indicator choice depends on what the microscopic traffic simulation model can produce. This subsection describes the used RuTSim outputs to indicate changes in traffic system efficiency, drivers’ comfort and safety. All indicators are measured for section A for the whole simulation period of 2 hours excluding the 20 minute warm-up and cool-down period.

Traffic system efficiency: speed and delay
Most commonly used and well accepted traffic system efficiency measures are average travel speed (ATS), and delays. ATS of all drivers are summed and divided by the total number of drivers to get ATS of one simulation. Delays represent the difference in travel time when drivers were able to drive with their desired speed and the speeds achieved in the simulation. Both speeds and delays are assumed to be valid measures of traffic efficiency, since efficiency by definition increases when the profits increase more than the costs. Profit in traffic terms can be seen as speed and costs as delays.

Drivers’ comfort: percent time spent following and overtaking frequency
To measure drivers’ comfort, percent time spent following (PTSF) and overtaking frequency (OF) are used. PTSF in combination with ATS are often used to calculate the level of service (LOS) of a two-lane highway (rural road) (Transportation Research Board, 2000). PTSF is calculated by summing the time drivers maintain headways smaller than a certain threshold headway defining whether a vehicle is influenced by a vehicle in front. The threshold headway used in the RuTSim model is 5 s, which means that the PTSF is the percentage of time drivers travel with headways smaller than 5 s. PTSF is a well-known and frequently used measure and therefore assumed to be a valid indicator of drivers’ comfort (Transportation Research Board, 2000).

The second drivers’ comfort measure is overtaking frequency, which is, in a study to test the effects of an overtaking assistant, of high importance. Overtaking frequency is calculated by counting the number of overtaking manoeuvres performed on a road section without intersections (section A). To unify the overtaking frequency, it is calculated per kilometre per hour. To compare assisted and non-assisted drivers for different overtaking assistant penetration rates, the overtaking frequency is presented per 1000 vehicles. Each overtaken vehicle is counted as 1 overtaking manoeuvre, so two overtaken vehicles in one manoeuvre increases the overtaking frequency with two.

The validity of overtaking frequency as a drivers’ comfort indicator has not yet been approved. However, it is included in the calibration and validation of the RuTSim model, which will test its validity for this study.
**Safety: TTC, Time Exposed TTC and Time integrated TTC**

To measure safety effects of different threshold settings and penetration rates of the overtaking assistant, TTC and two derived TTC measures, time exposed TTC and time integrated TTC (Minderhoud and Bovy, 2001) are used. The definition and use of TTC are given in Section 5.2.1. Time exposed TTC is a summation of the total time spent in a safety critical situation, where the TTC is below a certain threshold. The severity of the critical situation is measured by the time integrated TTC, integrating the total time spent below the threshold TTC. The applied TTC threshold in RuTSim is 3 s (Tapani, 2005a) and is also used in this study. TTCs below 3 s are experienced by drivers as uncomfortable and they have to react adequately to avoid accidents (Hoogendoorn, 2000). In the referred study, TTCs below 1.5 s were determined critical.

With respect to the validity of the TTC indicator to measure safety, the relationship between accidents and small TTCs is difficult to prove. TTC has been studied thoroughly (Van der Horst, 1990). TTC was found to be a good indicator of actual occurrences of dangerous situations (Vogel, 2003). For two vehicles travelling in opposing direction at the same lane, TTC is assumed to be a valid indicator of safety. Also, TTC together with time exposed TTC and time integrated TTC are included in the list of 'Surrogate Safety measures' (Gettman and Head, 2003), an indication that these are generally accepted safety indicators.

### 7.4.5 Expectations effects of threshold settings and penetration rates

Now the indicators to measure effects of different threshold settings and varying penetration rates are chosen, expectations regarding these effects are formulated. Table 7.3 presents the expected changes of all selected performance indicators when the threshold setting becomes larger and when the penetration rate becomes larger. The expected effects of the penetration rates are split for assisted and non-assisted drivers.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Assisted</th>
<th>Non-assisted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average travel speed (ATS)</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Delay</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Percent time spent following (PTSF)</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Overtaking Frequency</td>
<td>Lower</td>
<td>Lower and Higher</td>
</tr>
<tr>
<td>TTC</td>
<td>Higher</td>
<td>Not affected</td>
</tr>
<tr>
<td>Time Exposed TTC</td>
<td>Lower</td>
<td>Not affected</td>
</tr>
<tr>
<td>Time Integrated TTC</td>
<td>Lower</td>
<td>Not affected</td>
</tr>
</tbody>
</table>

In general, a larger threshold means that larger (minimum) gaps are recommended as a safe overtaking opportunity, which means that fewer gaps will be found to perform overtaking manoeuvres. This is expected to decrease ATS, increase delay, increase PTSF and decrease the overtaking frequency. With respect to safety, when the minimum recommended overtaking gap is larger, it is expected that the TTC with the first oncoming vehicle after the
manoeuvre is performed increases, which decreases time exposed TTC and time integrated TTC.

Larger penetration rates mean that more drivers are equipped with the overtaking assistant, involving that averages of the assisted drivers will be calculated over a larger group of drivers and the group of non-assisted drivers becomes smaller. For the assisted drivers, it is expected that larger penetration rates increase ATS and decrease delay. Since there are more drivers equipped, there are more drivers daring to overtake and thus fewer vehicles left to be overtaken. This is expected to decrease PTSF. The expectation regarding overtaking frequency per 1000 vehicles is difficult, since more drivers perform overtaking manoeuvres, but fewer vehicles are left to be overtaken. So the number of vehicles performing overtaking manoeuvres is expected to grow and the number of overtaking manoeuvres per driver is expected to decrease. What the net effect of this will be is difficult to estimate. The last column of Table 7.3 shows all performance indicators for non-assisted drivers are expected not to be affected.

7.5 Calibration and validation of RuTSim for the Flevoland road

When a microscopic traffic simulation model is applied to a network, calibration is required to adjust the model to reflect the traffic conditions for the simulated network. The challenge of this study was not to analyse the collected flow characteristics effects of the overtaking assistant only, but also to apply a Swedish road microscopic traffic simulation model to Dutch roads. A detailed description of the challenges of this application can be found in Tapani and Hegeman (2007). This section summarises the needed model adjustments and the results of the calibration and validation.

The data sets $F_1$ and $F_2$ described in Table 6.1 are used for the calibration and validation respectively. Both sets were split into a peak period and an off-peak period and only the off-peak data is used for this study, including observation data from 13.00 till 16.00 hours. The calibration data set $F_2$ included data of two sections ((Section A where overtaking is permitted and section B with overtaking prohibition). The validation data set $F_1$ included observations of section A only. Both data sets included flows, average speeds, standard deviation of speeds and overtaking frequencies for both driving directions.

The first step of the calibration process was to adjust the observed flows to the simulated ones. The observed flows at the start cross-sections of the two observed road sections are compared to the output flows at these same cross-sections. The input flows were adjusted such that the flows in the simulations were within 5% of the observed flows. This involved an adjustment of the input flows of maximal 12% (increase).

7.5.1 RuTSim parameter adjustments to enable Dutch rural road simulation

The model output average speed, standard deviation of speed and overtaking frequency were calibrated to observations of these measures by adjusting the 6 parameters included in Table 7.4.
The first adjusted parameter is the speed distribution of trucks. In Sweden, only trucks with trailers, represented in RuTSim as truck3, have a lower speed limit of 80 km/h on two-lane rural roads with a speed limit of 100 km/h for other traffic. In the Netherlands, all trucks have to comply with this lower speed limit and most trucks are equipped with a speed limiter, limiting the truck’s maximum speed at or a little above 80 km/h. Hence, speed distributions of vans or small trucks and trucks without trailers, represented in RuTSim as truck1 and truck2 respectively, are adjusted to the observed speed distributions on the Flevoland road for trucks. Table 7.4 shows the minimum, maximum, average and standard deviation of the old and new speed distributions for these vehicle types. Since RuTSim requires desired speeds, the observed speed distributions were adjusted using the product-limit method.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Old (default) values</th>
<th>New (Dutch) values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed distribution - truck1</td>
<td>19.23 33.83 26.53 2.92</td>
<td>20.42 26.39 24.33 0.95</td>
<td>m/s</td>
</tr>
<tr>
<td>Speed distribution - truck2</td>
<td>20.81 28.81 24.31 1.5</td>
<td>20.42 26.39 22.33 0.95</td>
<td>m/s</td>
</tr>
<tr>
<td>Threshold for overtaking</td>
<td>0.5</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Threshold for overtaking for vehicles in a platoon</td>
<td>0.8</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Additional speed to desired speed during overtaking</td>
<td>7.5</td>
<td>10.0</td>
<td>km/h</td>
</tr>
<tr>
<td>Gap search acceleration</td>
<td>0.75</td>
<td>2.0</td>
<td>m/s²</td>
</tr>
<tr>
<td>Gaps cars and trucks</td>
<td>2 and 1</td>
<td>1.5 and 1</td>
<td>S</td>
</tr>
</tbody>
</table>

After these speed distribution adjustments, overtaking frequencies of the model were lower than the observed ones. These were increased by reducing the threshold gap for overtaking and increasing the overtaking probability of platoon vehicles. The duration of an overtaking manoeuvre in the RuTSim model with default parameter settings was approximately 15 s. Observed overtaking manoeuvres on the Flevoland road had an average duration of 7.8 s described in Chapter 2. To reduce the duration of an overtaking manoeuvre in the model, the desired speed during overtaking, the overtaking completion gap and the gap-search acceleration parameters were adjusted. With realistic constraints on vehicle accelerations, these modifications resulted in an average overtaking duration in the simulation of approximately 12 s. This overtaking duration is still longer than the observed average duration, however, to reduce the overtaking duration of the simulation further, it is necessary to model the start of the overtaking manoeuvre and completion processes in greater detail. This goes a step further than calibration and involves major changes to the model, which is without the scope of this study.

### 7.5.2 Calibration results

With the new parameter settings as presented in Table 7.4, the Flevoland road was simulated 8 times with different random seeds. The resulting prediction intervals for flows, average speeds, standard deviation of speeds and overtaking frequencies are shown in Figure 7.5. Although flows are not a calibration output because these were adjusted to the observations, they are included in the figure for completeness.
When the observation falls within the prediction interval of the model, the model represents the real situation on the Flevoland road. One observation is similar to the result of one single repetition of the stochastic simulation. The calibration is sufficient if it is probable that such a simulation run results in the observed values, meaning that if the observations falls within the prediction intervals obtained from multiple simulation runs.

![Figure 7.5 RuTSim calibration results for traffic flow (i), overtaking frequency (ii), average speed (iii) and average speed standard deviation (iv), shown with 95% prediction intervals. The observation data is presented with (*). (a) represents the section where overtaking is permitted, (b) the section where overtaking is prohibited.](image)

Figure 7.5 reveals a good agreement between the simulation and the observation for the section on which overtaking is permitted. The speeds on the other section are too high and the observed standard deviation in the busier direction 1 falls below the prediction interval. However, there are indications that the observations on this section could be influenced by construction activity in the area during the observation day. The observed high standard

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Average speed in this case is the average space mean speed calculated by dividing the length of the cross-section by the difference between the start cross-section passage time and end cross-section passage time for each vehicle and averages these speeds over all drivers/vehicles.
deviation of speed strengthens this indication, by which the calibration was considered to be sufficient, also because the section with an overtaking prohibition will not be considered in the study of the overtaking assistant.

On the sections where overtaking is prohibited, a few overtaking manoeuvres were observed. Since the prohibition is installed by means of a double continuous centre line, non-compliance is fairly easy. Although this does occur in practice, RuTSim is not able to model this traffic rules disobedience. Again, since the analysis of overtaking assistant effects will not be performed for sections with prohibition, this will have a limited effect on the results.

7.5.3 Validation results

Validation of a simulated model tests whether the model represents the traffic situation of the simulated network not for the data set on which it is calibrated only, but also for other data sets of the same road. The observed flows in the validation data set were on average 532 in direction 1 and 430 in direction 2, which is 33% and 48% higher than the flows of the calibration data set. The input flows of the simulation model were increased correspondingly.

| Table 7.5 Validation results. Prediction intervals resulting from 8 simulations with RuTSim and the observations |
|-------------------------------------------------|-------------------------------------------------|-------------|
| Average speed [km/h]                           | Prediction intervals RuTSim | Observation |
| Direction 1                                    | 86.4 – 89.1                   | 91.1        |
| Direction 2                                    | 85.8 – 87.7                   | 88.1        |
| Standard deviation of speed [km/h]              | 6.7 – 8.0                     | 8.1         |
| Direction 1                                    | 6.3 – 8.7                     | 7.6         |
| Overtaking frequencies [#/km-h]                | 6 – 16                         | 34          |
| Direction 2                                    | 2 – 6                          | 11          |

Table 7.5 shows that the observed average speeds fall above the simulation prediction intervals. The observed speed of the validation data set were even higher than the observed speed in the calibration data set, where traffic flows were at least 33% lower. According to theoretical speed-flow relationships, speed will decrease with increasing flow. Hence, it is not surprising that the observations are not within the RuTSim prediction interval. Additional observations are needed to investigate this property of the traffic on the studied road.

The average overtaking frequency of RuTSim is about half the observed overtaking frequency for the validation data set. Despite the high flows, drivers were able to perform many more overtaking manoeuvres than the model predicted.

7.5.4 Conclusions of calibration and validation results

The objectives of the calibration and validation of the RuTSim model was to investigate the feasibility to use microscopic traffic simulation to study the impact of different overtaking assistant threshold settings and different overtaking assistant penetration rates. The calibration was, given this objective and the available data, deemed as satisfactory. The overtaking model
currently used in RuTSim has limitations in describing overtaking manoeuvres when traffic flows are high. More research on overtaking modelling is consequently needed to describe overtaking frequencies and resulting traffic conditions for two-lane rural roads with high traffic flows. Additional traffic observations from different days are also necessary to assess the absolute impact of the overtaking assistant on the Flevoland road. This will facilitate a more detailed calibration of the simulation model and better identification of model limitations. Finally, since overtaking frequency, overtaking duration and for some situations average speed and standard deviation of speed in the model do not fully comply with observations, no particular conclusions on relative effects can be drawn.

7.6 Results of simulations of the overtaking assistant

This subsection presents the results of the simulations of the overtaking assistant for different threshold settings and different penetration rates. The reference scenario uses the off-peak calibration data-set (F2 between 13.00 and 16.00 hours) including the network, the origin destination matrix and the parameter settings. Results are given only for section A as presented in Figure 7.4. For all results, the averages of the modelled road section are shown, with the 95% confidence interval (t (7) =2.365).

7.6.1 Threshold setting

The first analysed indicator to measure traffic system efficiency is ATS. Figure 7.6 reveals that for both directions ATS decreases with increasing threshold setting. The largest average speeds are measured for the 8 s threshold setting, which means that overtakers accept gaps of 8 s and larger to perform an overtaking manoeuvre. Speeds in the busier direction 1 are somewhat higher than in the less busy direction 2, possibly caused by the fewer overtaking opportunities in this direction. Effects of the threshold setting are less in the less busy direction 2. Apparently, the availability of overtaking gaps for this direction does not decrease much when the threshold for an overtaking gap is increased from 8 to 14 s. The larger effect of the threshold setting in the busier direction 1 is not explained by more accepted gaps only, but possibly also that one overtaking driver can overtake more vehicles during one gap, since the smaller threshold setting of the assistant accounts also for a second overtaking, performed within the same gap (2+ overtaking strategy). Finally, ATS of the reference scenario is similar to the results of the 11 s threshold settings, in both directions.

Average delays for both directions for all threshold settings are roughly between 12 and 15 s as presented in Figure 7.6. The length of the observed road section is about 5 km, so 15 s delay means that drivers who would have liked to drive 100 km/h, now have driven the whole section at about 92 km/h. Note that this calculation is meant only to give an idea of delays; the absolute results of the simulation might not correspond with reality, due to differences in the reference scenario with observations of the Flevoland road. Delays in the busier direction 1 are slightly lower and the difference between the threshold settings is slightly larger. As for ATS, delays for the simulation with no assisted drivers, is similar to the 11 s threshold setting simulation.
The first analysed indicator to measure drivers’ comfort is percent time spent following (PTSF). Figure 7.7 shows that in both directions, drivers spend more than half of the time following another vehicle. Smaller threshold settings result in a lower PTSF and this effect is again larger for the busier direction 1. Notable are the small confidence intervals for each threshold setting. Apparently the PTSF is less affected by the stochastic of the model. As for ATS and delays, the reference scenario with no assisted drivers results in similar PTSF as the 11 s threshold of the assistant.
The second, analysed indicator to measure drivers’ comfort is overtaking frequency, which is an important indicator when the effects of an overtaking assistant are studied. Figure 7.8 reveals that the overtaking frequency per kilometre per hour per 1000 vehicles decreases from just above 30 for a threshold setting of 8 s, to just above 20 for a threshold setting of 14 s. The relative result is that in the simulations, overtaking frequencies decrease by about one third when the threshold setting is increased from 8 to 14 s. The confidence intervals for overtaking frequencies are larger than the intervals of all other analysed indicators so far. This means that the variance of overtaking frequencies between the 8 runs with different random seeds for each threshold setting is large. This variance is smaller in the less busy direction 2. In this direction, for a threshold setting of 8 s, the overtaking frequency is about half the frequency of the busier direction 1, while for the 14 s threshold setting the frequency is much lower than half the frequency in direction 1. This implies that the absolute impact of the threshold setting is larger in the busier direction 1 and the relative impact is larger in the less busy direction 2.

Compared with the results with respect to ATS, delays and PTSF, overtaking frequency is the first indicator substantially affected by the choice of the threshold setting of the overtaking assistant. The overtaking frequency of the reference scenario with no assisted drivers is about half the frequency of the runs where all drivers have an assistant with a threshold setting of 8 s. Where the results of the 11 s threshold scenario for the other analysed indicators were similar to the reference scenario, the overtaking frequencies of all threshold settings scenarios are a lot higher than the reference scenario. A threshold setting of 8 s doubles the overtaking frequency compared with the reference scenario.
The final analysed measure is drivers’ safety, indicated by TTC, time exposed TTC and time integrated TTC. Figure 7.9 shows that the minimum TTC between the overtaker and the first oncoming vehicle is smallest for the lowest threshold setting and increases linearly for larger threshold settings. For the less busy direction 2, the minimum TTC for the threshold settings of 8 s and 9.5 s becomes smaller than 3 s, which is often used as the threshold for collision avoidance systems to warn drivers of a possible collision (Lee et al., 2004). However, the average TTC of non-assisted drivers in this direction is also lower than 3 s.

The total time spent in a safety critical situation, time exposed TTC and the severity of the critical situation, time integrated TTC, differ, as expected, in the opposite direction from the TTC for the different threshold settings: the larger the threshold, the smaller the time integrated TTC and the time exposed TTC. The latter approaches 0 s for the 14 s threshold setting. A positive result regarding the overtaking assistant is that for all assisted scenarios the time exposed TTC and the time integrated TTC are smaller than for the reference scenario with no assisted drivers.
Figure 7.9 Minimum TTC, Time Exposed TTC, and Time-Integrated TTC for different threshold settings, shown for the busier direction 1 (left) and opposing direction 2. The graphs include averages, 95% confidence intervals and linear trend lines. The results of the reference scenario (no assisted drivers) are displayed with the horizontal line.

7.6.2 Penetration rate

To study possible effects of growing penetration rates of drivers equipped with an overtaking assistant, 5, 10, 25 and 50% are simulated. Zero percent is equal to the reference scenario and the 100% scenario is equal to the 8 s threshold setting scenarios, since 8 s was the chosen threshold setting for the penetration rate scenarios described in 7.4.2. Again, 100% compliance with the overtaking assistant is assumed.
The penetration rate results of ATS are presented in Figure 7.10. For all penetration rates in the busier direction 1, the assisted vehicles have a higher ATS than the non-assisted. The confidence intervals for low rates of assisted drivers are larger for assisted vehicles, because of the relatively low number of vehicles on which the intervals are based. For the less busy direction 2, there is no trend recognisable between different penetration rates and between assisted and non-assisted drivers. All ATS in this direction fluctuate around 89 km/h. The ATS of non-assisted drivers in the less busy direction 2 is not affected by the penetration rates.

The second analysed indicator for traffic system efficiency is delay and this does not differ much between different penetration rates, also included in Figure 7.10. In the busier direction 1, low penetration rates tend to have fewer delays for the assisted drivers, this effect is, however, not recognisable in the less busy direction 2. Delays of the non-assisted drivers are

Figure 7.10 ATS and average delay with 95% confidence intervals for different penetration rates of vehicles equipped with an overtaking assistant (threshold 8 s) in direction 1 (left) and opposing direction 2. * are assisted vehicles, o are non-assisted vehicles.
not affected by the overtaking assistant penetration rates. This accounts for both driving directions.

Continuing with the results of the indicators to measure drivers’ comfort, the effects on PTSF are presented in Figure 7.11. These results are not unambiguous. In the busier direction 1, the averages for 5% and 50% assisted drivers are close to each other, while 10% and 25% penetration rates show higher PTSF. The non-assisted drivers in the busier direction 1 have higher PTSF, the differences are, however, small. In the less busy direction 2, the assisted drivers spent less time following other vehicles than the non-assisted drivers and this effect is larger for lower penetration rates.

![Figure 7.11: Average PTSF with 95% confidence intervals for different penetration rates of vehicles equipped with an overtaking assistant (threshold 8 s) in direction 1 (left) and the opposing direction 2. * are assisted vehicles, o are non-assisted vehicles](image)

Overtaking frequency as an indicator for drivers’ comfort, was not affected much by the different penetration rates. Increasing penetration rates do not cause a clear change in overtaking frequencies as presented in Figure 7.12. Only in the busier direction 1, the assisted drivers in the 5% scenario manage to perform significantly more overtaking manoeuvres than the non-assisted drivers. The counteracting effect of higher penetration rates increasing the number of drivers performing overtaking manoeuvres and decreasing the number of overtaking manoeuvres per driver, possibly causes the lack of a trend between the penetration rate simulations. The overtaking frequencies of non-assisted drivers are not affected by the penetration rate in both directions.
Finally, the penetration rate simulation results of the safety measures are presented, starting with TTC indicator. Figure 7.13 reveals that the minimum TTC for different penetration rates does not differ much between assisted and non-assisted drivers in both directions. As for the different threshold settings, the TTCs in the less busy direction 2 are smaller than in the busier direction 1, often close to or below the uncomfortable TTC threshold of 3 s.

The results of the second and third indicators of drivers’ safety, time exposed TTC and time integrated TTC are also included in Figure 7.13. In general, time exposed TTC and time integrated TTC for the busier direction 1 are smaller than the less busy direction 2, but this difference is smaller than for the minimum TTC. As for TTC, the differences between assisted and non-assisted drivers are small, for all simulated penetration rates. Drivers do not benefit or disbenefit from the fact that other drivers are equipped or not with an overtaking assistant.

The safety indicators result for the penetration rate simulations are the final presented results of this chapter. Section 7.7 summarises and discusses the results.
Chapter 7 – A microscopic traffic simulation study on overtaking assistance

Figure 7.13 Minimum TTC, Time Exposed TTC, and Time-Integrated TTC with 95% confidence intervals for different penetration rates of vehicles equipped with an overtaking assistant (threshold 8 s) in direction 1 (left) and the opposing direction 2. * are assisted vehicles, o are non-assisted vehicles

7.7 Summary and discussion of collective flow characteristics effects overtaking assistance

To answer the fifth research question of this dissertation research: What are the effects of the overtaking assistant on collective flow characteristics in terms of traffic system efficiency, drivers’ comfort and safety? a microscopic traffic simulation study is performed. This study is the second evaluation study as part of the design cycle of the overtaking assistant. The simulated reference scenario was the N305 Almere-Zeewolde, in the middle of the Netherlands, a fairly busy two-lane rural road with a speed limit of 100 km/h for passenger vehicles and 80 km/h for trucks and vehicles with trailers, and with infrastructural ideal
overtaking circumstances. The rural road model RuTSim was applied, which was originally developed in Sweden to model overtaking on two-lane rural roads and enabling impact modelling of driver assistance systems (Tapani, 2005b).

7.7.1 Discussion application of a Swedish model to simulate Dutch roads

The overtaking assistant was modelled in RuTSim by replacing the overtaking probability functions for different speeds, sight distances and overtaking types (flying or accelerative) by the overtaking probability function of the overtaking assistant. This function was 0 for gaps too small for overtaking and became 1 when gaps in the oncoming traffic stream were larger than the threshold setting of the assistant.

Calibration of the RuTSim model revealed that when flows and road geometry were adjusted to Dutch situations, it was not possible to perfectly model the observed average speeds, standard deviation of speeds and overtaking frequencies by adjusting parameter settings only. Although it was possible to tune the model in such a way that the observed flows, average speeds and standard deviation of speeds were within the prediction intervals of the simulation outcomes, the overtaking frequencies remain lower than the observed frequencies, especially for high flows. A possible explanation for this is that Dutch drivers are used to high flows and relatively narrow traffic lanes, by which the Dutch overtaking frequencies are higher than the Swedish, where the RuTSim model is based on. Also, the duration of the simulated overtaking manoeuvres were longer than the average of the observed overtaking manoeuvres described in Chapter 2. Again, familiarity with the high flows and the Dutch characteristic to be in a hurry, wanting to be at home or at work on time, might result in acceptance of smaller gaps to perform overtaking manoeuvres, forcing drivers to perform them as fast as possible. Major adjustments to the Swedish RuTSim model are required to model the possibly unique Dutch overtaking situations. A suggested starting point for this modification is the moment the overtaking manoeuvre starts. The overtaking observation study described in Chapter 2 showed that Dutch drivers start their overtaking manoeuvre immediately after the last oncoming vehicle has passed. Some overtakers even already entered the left lane while the oncoming vehicle did not completely pass yet. This indicates that drivers select the overtaking gap before it is actually present. This ‘looking ahead’ is currently not included in the RuTSim model. In the model, drivers start to check whether it is possible to overtake at the moment a possible overtaking gap is available, which reduces the remaining time to perform the overtaking manoeuvre. In the driving simulator experiment described in Chapter 5, this looking ahead was included in the overtaking assistant by the 3 s of flashing red before the green sign was displayed. However, it was not possible to include this feature of the assistant in the RuTSim model within the scope of this simulation study. Nevertheless, RuTSim was able to model Dutch off-peak period accurately. Hence, these were used for the assessment of the overtaking assistant.

Two aspects of the overtaking assistant were studied. Firstly, the threshold setting was varied, that is, the minimum gap recommended by the system as an overtaking opportunity. The threshold settings 8, 9.5, 11, 12.5 and 14 s were simulated all with 100% penetration and full compliance. Secondly, penetration rates were varied, that is, the number of drivers equipped with the system, simulating 5, 10, 25 and 50%. For these penetration simulations the threshold
setting of 8 s was used and again 100% compliance was assumed. To take variability into account, all scenarios were simulated 8 times with different random seeds and averages and confidence intervals were calculated.

### 7.7.2 Discussion overtaking assistant threshold setting and penetration rate results

Simulations were performed with different threshold settings, that is, the minimum gap recommended by the system as an overtaking opportunity, including 8, 9.5, 11, 12.5 and 14 s. The impacts of threshold setting were all as expected. The higher the threshold setting, the less efficient traffic was, the less comfort drivers obtained from the system and the safer the overtaking manoeuvres were performed. The threshold setting of 11 s gave similar results as non-assisted overtaking performance in RuTSim, apart from the overtaking frequencies. These were, for all simulated threshold setting scenarios, higher than the reference scenario. The 8 s threshold scenarios even doubled the overtaking frequency. All other analysed indicators for traffic system efficiency, drivers’ comfort and safety were not affected much. However, the lowest threshold setting of 8 s, close to the observed average overtaking duration of 7.8 s, resulted in TTCs below 3 s. TTCs below 3 s are experienced by drivers as uncomfortable and at which drivers have to react adequately to avoid accidents (Hoogendoorn, 2000). However, the time integrated TTC and time exposed TTC were both smaller for all simulated threshold settings compared with non-assisted drivers. This was a positive safety result of the overtaking assistant. These results give ground for the recommendation to include 8 s as a threshold setting possibility, when the overtaking assistant will be designed such that drivers could choose their own threshold setting for the minimum gap to be recommended as an overtaking opportunity.

Next, simulations were performed with different penetration rates, that is, the number of drivers equipped with the system, simulating 5, 10, 25 and 50 %. For these penetration simulations the threshold setting of 8 s was used and again 100% compliance was assumed. The effects of penetration rate were small. For lower rates, assisted drivers tended to gain some efficiency, represented by lower delays and higher ATS. For higher rates, delays increased and ATS decreased, but the differences were small. Non-assisted drivers were not affected when penetration rate increased, their delays and ATS were respectively higher and lower than the assisted drivers and similar to the simulation without assisted drivers. This meant that the traffic efficiency in general is not negatively affected for any penetration rate of overtaking assistance. The PTSF as an indicator of drivers’ comfort was not affected much by different penetration rates. However, the results were opposite to expectations. It was expected that larger penetration rates would result in less PTSF and the opposite was found, although in the busier direction, the 50% penetration had smaller PTSF than the 10 and 25% scenarios. The PTSF for the non-assisted drivers were not affected by the penetration rate, which was also expected. Overtaking frequencies were not affected much by different penetration rates and no trend was recognisable. Compared with the scenario with no overtaking assistance, overtaking frequencies of non-assisted drivers in this direction decreased slightly for all penetration rate scenarios. It was expected that larger penetration rates would, at the one hand, increase of number of drivers performing overtaking manoeuvres and, at the other hand, decrease the number of overtaking manoeuvres per driver. This counteracting effect possibly caused the lack of a trend between the penetration rate
simulations. Finally, the safety indicators were little affected by the penetration rates, both for assisted and non-assisted drivers. This was also expected.

In conclusion, the overtaking assistant will have a positive effect on drivers’ comfort, represented by higher overtaking frequencies. At the same time, traffic system efficiency and drivers’ safety are not negatively affected. Smallest threshold settings have the largest positive comfort effects. However, when TTC below 3 s with first oncoming vehicles are judged as unsafe, the smallest possible safe threshold setting lies around 11 s. The penetration rate does not have much effect on the traffic system as a whole, which does not obstruct the development of the system.
8 Discussion and Conclusions

At the start of the 21st century overtaking on two-lane rural roads is a major traffic safety problem. However, this dissertation research demonstrates that most drivers are perfectly able to safely perform these manoeuvres. Their time spent in the left lane is about 8 s. Preparing subtasks of the manoeuvre, such as checking surrounding vehicles’ behaviours, changing gear and starting accelerations are started in the right lane, to use an available overtaking gap in the oncoming traffic stream optimally. This anticipative behaviour is accounted for in the proposed overtaking assistant design, which informs the driver about overtaking gaps 3 s before they become available. This system is developed to assist less daring drivers with overtaking and to prevent risk-taking drivers to perform overtaking manoeuvres in unsafe situations. A driving simulator experiment demonstrated that this assistant does not much affect overtaking efficiency, drivers’ comfort or safety, as long as the threshold for a safe gap is chosen such that the safety margin with the first oncoming vehicle remains above 3 s. A microscopic traffic simulation study shows that when this threshold is 11 s, traffic system efficiency remains similar or increases slightly due to increased number of overtaking manoeuvres. Drivers’ safety during overtaking increases, because the time-to-collision with oncoming vehicles will not become smaller than 3 s. And, drivers’ comfort is improved in terms of higher overtaking frequencies and less time spent following.
8.1 Results overview

The general objective of the Assisted Overtaking dissertation research was to thoroughly analyse overtaking performance on two-lane rural roads and study the opportunities of an overtaking assistant with respect to traffic system efficiency, drivers’ comfort and safety. The analysis of overtaking performance on two-lane rural roads was done by means of an observation study with an instrumented vehicle. This vehicle was applied as a moving observer to measure the performance of drivers overtaking it. Additional information on overtaking frequencies was obtained by means of the license plate recognition method, which enabled collection of the number of overtaking manoeuvres performed on a 5 km stretch of road. An overtaking task analysis provided the insight that estimation of gaps in the oncoming traffic stream to determine whether these are large enough to perform an overtaking manoeuvre, is the most difficult subtask of overtaking. All gathered information was used to design an overtaking assistant to assist with oncoming gap acceptance.

For the first assessment study, the overtaking assistant was realised with a traffic-like interface, showing a green sign for overtaking gaps. The results of this experiment changed the design of the overtaking assistant slightly, where the new design displayed a green sign for gaps that are sufficiently large to safely perform an overtaking manoeuvre and a red sign for smaller gaps. The green sign is preceded by 3 s of flashing red, to give drivers the possibility to prepare for the overtaking manoeuvre. When a safe gap becomes critical, that is, equal or smaller to the threshold for a safe gap, the green sign starts flashing. Three seconds before the next oncoming vehicle arrives, the red light lights up again. When the next gap is also an overtaking opportunity, flashing green is followed by flashing red.

The second assessment study included a microscopic traffic simulation study comparing different penetration levels and different threshold settings of the proposed assistant with a reference situation. Traffic system efficiency and drivers’ safety were equal to the reference situation for an assistant threshold setting of 11 s. At the same time, drivers’ comfort increased, expressed in higher overtaking frequencies and less time spent following. For a threshold setting of 8 s, time-to-collisions (TTC) with the next oncoming vehicle become smaller than 3 s, an often used safety threshold. For all penetration rates, both assisted and non-assisted drivers did not experience any negative effects of the assistant in terms of traffic system efficiency, drivers’ comfort and safety, apart from TTCs smaller than 3 s (average 2.5 s).

8.1.1 Answers to research questions

The general aim was divided into five research questions described in Chapter 1. This subsection recaps the research questions and summarises the findings.

1. How are overtaking manoeuvres performed on two-lane rural roads?

Overtaking manoeuvres performed on undivided roads with one lane in each driving direction are subdivided into four strategies: accelerative, flying, piggy backing and 2+. For accelerative overtaking, drivers have to accelerate to overtake the preceding vehicle, which they often
have been following for a while. In case of flying overtaking, acceleration is not necessary; drivers can overtake a preceding vehicle on the fly, without following. Piggy backing means that a driver follows a lead vehicle that overtakes a preceding vehicle, and for 2 overtaking, drivers overtake several preceding vehicles at once.

On roads with a speed limit of 100 km/h, drivers overtake preceding vehicles driving at different speeds (70, 80 or 90 km/h) in a similar way. Their perception-reaction time, that is, the time between the passage of the last oncoming vehicle after which the overtaking manoeuvre commences and the moment the left front wheel touches the centre line, is fairly short, mostly below 0.5 s. This indicates that drivers prepare for the overtaking manoeuvre before the overtaking gap is present. The duration of the overtaking manoeuvre, that is, the time between the moment the left front wheel touches the centre line until the moment the right back wheel has crossed the centre line again, is, on average 7.8 s. This duration differs significantly neither with preceding vehicles’ speed nor with overtaking strategy.

The headway between the overtaker and the preceding vehicle at the start of an overtaking manoeuvre is nearly always smaller than the generally recommended safe headway of 2 s, often even smaller than 0.5 s. The headway between the overtaker and the overtaken vehicle at the end of the manoeuvre is larger, but also often below 2 s. The indicator is used more often at the start of the manoeuvre than at the end. For both manoeuvres few overtakers obey the obligatory traffic rule to use the indicator for any lane change.

Our findings based on observations on Dutch roads agree with findings in other countries, although comparison is often difficult due to different definitions of observed indicators. Compared with findings of the past, the duration of overtaking manoeuvres seems to have decreased slightly.

Overtaking frequency on two-lane rural roads with a speed limit of 100 km/h is generally between 10 and 50 /km-h for total flows between 400 and 1800 veh/h. Overtaking frequency turned out to be highly dependent on the distribution of traffic in both directions: roads with large differences in flows in both directions can reach overtaking frequencies above 100 /km-h. Roads with similar traffic distributions and total flow difference of more than 1000 vehicles can have similar overtaking frequencies.

2. What are the subtasks of the overtaking and what are their matching assistance needs?

The overtaking task exists of about twenty subtasks divided into five phases. In the first phase drivers decide whether they wish to overtake, check whether overtaking is permissible and determine whether the infrastructure is suitable for overtaking manoeuvres. When these three conditions are positive, the subtasks of the second phase are initiated. These include: judging whether the gap with a first oncoming vehicle is sufficiently large to perform an overtaking manoeuvre; checking any deviations from preceding vehicles and other surrounding traffic; maintaining a safe headway with the preceding vehicle; changing to a lower gear when necessary; and switching on the indicator. The last subtask brings drivers to the third phase, including the start of the physical manoeuvre, that is, moving to the other lane. This requires steering, accelerating and monitoring, and again deviations of other vehicles are checked. The
fourth phase is the passing of the preceding vehicle, in which drivers drive in the opposing traffic lane. The gap with oncoming vehicles needs to be monitored and gear changes might be necessary again. When possible and desired, additional preceding vehicles can be passed.

The fifth and final phase includes the move back to the right lane, starting with the subtask of switching the indicator on, followed by steering, accelerating or decelerating to the desired speed and switching the indicator off.

For the subtasks listed above, twelve possible assistance needs are distinguished, including for example assistance with headway keeping and monitoring behaviours of preceding vehicles. Existing assistance systems enable the assistance with most of the distinguished needs during overtaking. The only high ranked assistance need that cannot be performed by existing systems is determining whether a gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. This task is selected for the design of an overtaking assistant. It is important for accurate assistance with this task that the information about overtaking gaps be given some seconds before the gap is actually present, to give drivers the time to prepare the manoeuvre and use the available gap optimally.

Verification of differences in rules and performance of overtaking in seventeen countries around the world showed that the rules for overtaking are fairly similar everywhere. Execution and performance, however, differs significantly, and reveals many unsafe overtaking strategies in different countries, that is, three vehicles side by side on two traffic lanes (often in e.g. Italy, Finland, Spain and Norway); the preceding vehicle moves to the emergency lane due to misjudgement of the overtaking gap by the overtaker (often in e.g. Great Britain, Norway and Italy), and the oncoming vehicle brakes because of misjudgement by the overtaker (often in e.g. Poland, Australia, Brazil and Portugal). From this assessment, we concluded that an overtaking assistant is internationally applicable and desirable.

3. How should an overtaking assistant be designed?

An overtaking assistant is designed to assist drivers in judging whether the next gap in the oncoming traffic stream is sufficiently large to safely perform an overtaking manoeuvre. The design resulted in a proposal for a descriptive informing system. This system measures the distance until the next oncoming vehicle, the oncoming vehicle’s speed and the speed of the driver’s own vehicle, and calculates the available overtaking time. This is compared with the estimated, required time for overtaking plus a safety margin. When the first is larger than the latter, the gap is indicated as an overtaking possibility. The threshold setting of the assistant, that is, the boundary between safe and unsafe gaps, was recommended in the first conceptual stage to be 10 s, based on the observed overtaking durations. This threshold setting is subject of the assessment studies answering the following two research questions.

4. What are the individual driver effects of an overtaking assistant on overtaking efficiency, safety and comfort?

The first assessment study of the proposed overtaking assistant is a driving simulator experiment. The interface of the overtaking assistant is designed as a traffic light, projected at the front screen, to the right of the rear-view mirror. The interface displays a green sign for
gaps in the oncoming traffic stream larger than the threshold setting (8 seconds was found to be most convenient for the simulator as a result of a pilot study) with and a red sign for smaller gaps. Three seconds of blinking red pre-announces the green sign and 3 s of blinking green the red sign.

The overtaking assistant increases the overtaking frequency of female participants, decreases variations in lateral position of male participants, slightly increases the average accepted overtaking gaps, decreases the time spent in the left lane and decreases the average minimum TTC with oncoming vehicles. This last result requires attention, because TTCs drop below an often used safety threshold of 3 s. All other results are fairly positive.

The workload and activation level of the participants increase more when driving with the assistant compared to without assistance. Participants consider that the assistant is useful, but the satisfaction scores are somewhat lower. Participants prefer the system giving visual information, and some also liked additional auditory assistance. The possibility to switch the assistant on/off is preferred.

This first assessment study of the overtaking assistant resulted in an adjusted design, in which the blinking green phase of the assistant was extended from 3 s to the length of the threshold setting of the assistant 3 s (the safety margin). Three seconds before the first oncoming vehicle arrive after a safe overtaking opportunity, the red sign lights up. When the next gap is also an overtaking opportunity, flashing green is followed by flashing red. The extension of the flashing green phase guarantees drivers that when they start an overtaking manoeuvre during the solid green phase, they are able to finish it safely.

5. What are the effects of the overtaking assistant on collective flow characteristics in terms of traffic system efficiency, drivers' comfort and safety?

Simulation of drivers assisted with an overtaking assistant with a threshold setting of 8, 11 or 14 s all increased the overtaking frequency compared to the reference scenario, without assistance. For a threshold setting of 11 s, all other indicators of traffic efficiency, drivers’ comfort and safety remain similar to the reference situation.

No percentages of drivers equipped with the overtaking assistant causes negative effects in terms of efficiency, comfort and safety on either assisted drivers or non-assisted drivers. For low percentages, the equipped drivers’ efficiency and comfort increased, in terms of higher average speeds, lower travel times, greater overtaking frequency and less time spent following.

8.2 Overtaking prohibition, overtaking lane, overtaking assistant

The performance of the overtaking assistant is compared with two other solutions to improve the safety of overtaking: overtaking prohibitions and overtaking lanes. Overtaking frequency observations on road segments with an overtaking prohibition (designed as a double continuous centre line) revealed that this prohibition is violated: up to 27% of the overtaking frequency on the simultaneous observed segment where overtaking is permitted, was reached.
The number of violators involved 25% of the number of overtakers on the other road segment. Moreover, the risk of overtaking violations is expected to be larger than of regular overtaking manoeuvres, since other drivers do not expect overtaking manoeuvres when they are prohibited. Lower expectancy also decreases compensative behaviour possibilities of other drivers (Houtenbos, 2007). Beside this limited safety effect of overtaking prohibitions, traffic system efficiency suffers from these prohibitions, since delays on these road sections were larger and average travel speeds lower. The observed segments with prohibitions did have lower average travel speeds for similar flows than the simultaneous observed segments where overtaking is permitted.

Overtaking lanes temporarily give drivers on two-lane rural roads the possibility to safely overtake on this extra lane. These lanes alternate for both directions, involving overtaking prohibitions for the direction without the overtaking lane. The simulator experiment showed that the overtaking frequency is lower in the overtaking lane scenario compared to the reference scenario (normal two-lane rural road) and the assistant scenario. Moreover, lateral position of female participants varies significantly more when driving on a road with the overtaking lane. However, participants rate the usefulness and satisfaction of the overtaking assistant. In a small country like the Netherlands with limited available space, overtaking lanes are not recommended as a solution for overtaking, mainly because overtaking frequencies will not increase, which limits the possible capacity gain.

8.3 Implications from partner BAMADAS projects

This dissertation research is part of the Dutch research programme: Behavioural Analysis and Modelling for the Design and Implementation of Advanced Driver Assistance Systems (BAMADAS). Three other dissertation researches, one post-doc research and one added research together intend to reach the BAMADAS aim to improve the knowledge regarding road vehicle driver behaviour in interaction with advance driver assistance systems. The implications from these studies for this dissertation and vice versa are discussed.

The partner research: Expecting the unexpected; a study of interactive driving behaviours at intersections (Houtenbos, 2007) concluded that road users can compensate for deviating behaviour of their interaction partners, indicating that unexpected behaviour does not necessarily yield a critically unsafe interaction situation. With respect to overtaking, this implies that overtaking errors do not need to result in an accident. This is confirmed by the finding of this research that surrounding traffic compensates overtaking errors by evasive actions, including a move to the emergency lane, braking or accelerating (Chapter 3). This partner research furthermore concluded that drivers felt that information about approaching road users was useful and led to a lower level of mental workload. This implies a potential for an extended overtaking assistant that also informs preceding vehicles and oncoming traffic about overtaking manoeuvres on hand. Such extended features of the assistant are fairly easy to add when the information necessary for the functioning of the proposed overtaking assistant is gathered by means of vehicle-to-vehicle communication. This is, in our view, the most fruitful development enabling the functioning of the proposed assistant.
A joint study of the researches *Expecting the unexpected* (Houtenbos, 2007); *Driving support in congestion* (Van Driel et al., 2007) and this research focussed on the assistance needs for interaction behaviour during overtaking. In this study, three driver assistance systems functionalities indicated by participants of a survey as being useful, were selected to be useful during overtaking: blind spot warning, indication of safe overtaking opportunities and warning in case of an imminent crash. This study contributed to the choice to base the overtaking assistant on the second suggested functionality.

The partner research *Advanced safety criteria specification by traffic interactions modelling* focuses on unintended behavioural adaptations due to driver assistance systems. This research includes a follow-up driving simulator experiment to the driving simulator experiment presented here. The same participants will be used and their rides are compared with novice participants, to study possible behavioural adaptations regarding the overtaking assistant. Furthermore, threshold settings of the assistant are adjusted to overtaking performance in unassisted rides. The results of this study are expected in 2008 (Dragutinovic, in prep.).

Finally, the implications of the partner research *Modelling and evaluation of the effects of traffic safety measures; comparative analysis of driver assistance systems and road infrastructure* (Lu, 2007) indicate that overtaking on two-lane rural roads is one of the few accident causes for which infrastructural solutions are inadequate. Driver assistance systems have been identified in this partner research as necessary additions to infrastructure solutions to improve traffic safety.

### 8.4 Scientific and technical implications

A new formula to predict overtaking frequency is proposed, including flow in analysis direction and flow in opposing direction as the independent variables, with a $R^2$ of 0.67. The strength of this formula is that it gives fairly accurate predications of overtaking frequencies both for high flows and low flows. Also, the dependency on only two, fairly easily measured variables is an improvement compared to existing overtaking frequency estimation methods.

The knowledge of overtaking on two-lane rural roads is extended. The thorough analysis of this manoeuvre has resulted in a rich source of data of traffic on two-lane rural roads in general and of overtaking specifically. The new insights in overtaking behaviour, for example the short time drivers need to start a planned manoeuvre after it becomes possible to make this manoeuvre, is valuable for the design of driver assistance systems in general. The research revealed that there are opportunities for an overtaking assistant to improve drivers’ comfort and to avoid TTCs smaller than 3 s with the next oncoming vehicle. This can also be seen as an improvement of drivers’ safety. To a small extend, traffic efficiency also gains from the higher overtaking frequency.

Empirical data collection of overtaking frequencies and overtaking behaviour have resulted in a rich source of traffic data, that can be used for many more applications.

In order to apply a Swedish microscopic traffic simulation model to model Dutch overtaking situations more insight had to be gained in regional driving differences. This is an important
issue for the application of microscopic traffic simulation models, confirming that calibration only might not be enough to accurately model micro behaviour such as overtaking. Thorough analysis of behaviour differences between the regions for which the model is developed and for which the modelled is applied, will probably result in major model adjustments to reach satisfying modelling results.

Both the instrumented vehicle methodology and license plate recognition methodology are proven to give natural, empirical overtaking data, which is crucial for the development of driver assistance systems such as the overtaking assistant and also valuable for the development of truthful microscopic traffic simulation models.

The combined application of an instrumented vehicle, the license plate recognition method, a driving simulator and a microscopic traffic simulation has proven to be fruitful and give synergy results. When these methods are applied to serve one general goal, design adjustments are functional and avoid unnecessary digressing. The dependability of the combined studies results in production of useful results.

8.5 Societal implications

The overtaking assistant is proven to be a useful solution increasing drivers’ comfort without reducing traffic system efficiency and drivers’ safety. Safety can even improve, when drivers obey the system and do not accept gaps that are not recommended by the system as a safe overtaking possibility. When drivers obey to the system, the frequency of overtaking accidents caused by inappropriate gap acceptance will decrease. The driving simulator experiment demonstrated that the number of accepted gaps smaller than the threshold setting of the assistant decreased when driving with the assistant. Also, the alternative design informs drivers how much time or distance remains until the next oncoming vehicle arrives. With this system, drivers learn how much time or distance they need to perform a manoeuvre, which will positively contribute to safety as well.

It is recommended that local authorities keep track of developments regarding overtaking assistance. These systems can help them with the rural road safety problems. To give the sales of these systems a push, the authorities can launch stimulating campaigns to make drivers aware of the possible safety benefits of these systems. Local road authorities are advised to be reserved with regard to installation of overtaking prohibitions on roads with large differences in flows in both directions. Empirical overtaking data of road segments with prohibitions demonstrated that drivers who get fewer opportunities to overtake (high opposing flows), are more inclined to ignore an overtaking prohibition. These data also revealed that traffic system efficiency in terms of travel times and average speeds is negatively affected by these prohibitions.

The automotive industry is encouraged to take on the development of overtaking assistance systems. When they want to manifest themselves as market leader in traffic safety and drivers’ comfort, overtaking assistance should be in their program. Car manufacturers such as
BMW have proven that for example a dynamic pass prediction fits with their image (Loewenau et al., 2006).

To legislators and authorities that make rules for driver assistance systems, this dissertation research signals possible conflicting advices between different driver assistance systems. Although this dissertation research has not made an inventory of the likeliness of these conflicts (e.g. a route navigation systems advising to turn right, while an overtaking assistant gives an overtaking advice at the same time), prioritising of advice can be a solution for this. Also, European rules can prescribe what should be the legally adopted minimum overtaking gap with the oncoming vehicle and other safety standards. These are necessary to avoid the wild spread of different driver assistance systems.

8.6 Further research

The assessment of the proposed overtaking assistant with a driving simulator proved the positive effects of the assistant and also suggested an alternative design. This descriptive rather than prescriptive informing assistant displays drivers the time left until the next oncoming vehicle arrives. Such a system requires some practice for drivers, since drivers need to learn how long it takes to overtake a preceding vehicle. A comparison study of the two designs is recommended as a first step of the further development of the overtaking assistant.

The choice for either an overtaking assistant advising gaps larger than a certain threshold as overtaking opportunities, or an overtaking assistant informing drivers about the time left until the next oncoming vehicle arrives does not affect the necessity of a pilot study. The functioning of both designs needs to be tested in reality. During this pilot study, special attention needs to be paid to possible conflicts with other driver assistance systems. When the pilot study is successful, an evaluation program for driver assistance systems, such as the one proposed by Lundberg and Chirster (2002), is necessary to make sure all possible failure aspects are dealt with. Of special importance are the fail-safe aspects and legal aspects that need more attention.

This study focussed on accelerative overtaking. Chapter 2 defined four overtaking strategies. Further research is necessary to study the effect and possibilities of the overtaking assistant for flying overtaking, piggy backing and the 2+ overtaking strategy.

The devices for providing the information necessary to give any overtaking assistance are not yet available. Extensive research by much of the automotive industry of the opportunities of vehicle-to-vehicle communication is ongoing, but did not yet arrive at the required level for overtaking assistance. For this, vehicle recognition of all vehicles on the road is necessary, requiring cooperating vehicle-to-vehicle communication between all car brands. We recommend that the automotive industry contributes to the developments, for the safety and comfort of their customers.

To improve the explained variance in overtaking frequency of the proposed overtaking frequency equation, it is suggested to include factors such as truck percentage and driver types (e.g. leisure drivers, commuters). This could be translated as a driver aggressiveness index or
a dynamic relaxation time as proposed by Tampère (Tampère, 2004). Further research is necessary to study how these variables influence overtaking frequency. However, the question is whether this will increase the explained variance. Overtaking frequency will always be affected by inter-driver and intra-driver differences, which makes it a difficult variable to predict.

Finally, an inventory needs to be made of the possibility to extend the application area from two-lane rural roads to urban streets and motorways. On motorways, some related systems are being developed, such as blind spot warning and lane change assistance (Cody, 2005). Cooperation between these systems will lead to synergy effects. The ideal situation is that vehicles are equipped with one, integrated system, including all assistance systems of the vehicle. Such a system should prioritise messages given to drivers, to avoid conflicting advices and to avoid an overload of advices at the same time. Traffic situations on urban streets are far more complex, due to the high intersection density and existence of vulnerable road users. Further research is needed to study whether overtaking gap information could also contribute to urban traffic safety.

8.7 A vision of the future

In the final pages of this dissertation research, two visions of the future are presented, without giving preference to one of the two, because this dissertation research has contributed to the genesis of both.

The first scenario is a future without overtaking assistance. Car recognition technologies cannot become reliable enough to guarantee that each oncoming vehicle is recognised. The vehicle-to-vehicle communication currently available does not evaluate communication between vehicles of all brands. Also, alternative recognition technologies, for example by means of route navigations systems and mobile phones, do not enable reliable working of the overtaking assistant. Technology and acceptance are closely related. Drivers will accept new technologies only when they rely on their perfect functioning. When the assistance sometimes overlooks an oncoming vehicle and an overtaking possibility is given while the driver sees this oncoming vehicle, the reliability is irreparably damaged. Another reason why the overtaking assistant can fail is that the automotive industry does not pick up the concept. They do not see synergy effects in offering their customers the possibility to equip their cars with an overtaking assistant and will not put effort in the development. When the automotive industry does not put energy into the image of an assistance system such as the overtaking assistant, drivers will not become enthusiastic about the assistant. Also, the automotive industry can be afraid of liability issues, such as being held responsible when a driver with a vehicle equipped with an overtaking assistant causes an overtaking accident. Product liability risks may slow down developments or even outweigh the benefits of marketing such systems (Van Wees, 2004). Finally, European rules and standards need to be ready before a product such as the overtaking assistant enters the market. Otherwise, the systems that enter the market may not be designed safe enough and may damage the image of such systems.

A second scenario is one in which most cars are equipped with an overtaking assistance system within twenty years. A main assumption needed for premise for this scenario is that
technologies develop fast enough in the coming years to guarantee recognition of all oncoming vehicles over a large enough distance. For a prescriptive assistant advising drivers whether oncoming gaps are large enough to safely perform an overtaking manoeuvre, the system should never give a positive advice (safe to overtake) when it is not safe. An descriptive design displaying the remaining distance until the next oncoming vehicle arrives has also to detect all oncoming vehicles. However, for this design, drivers can still judge themselves whether a given distance is larger enough to safely perform the overtaking manoeuvre. The automotive industry embraces the idea of the overtaking assistant and puts effort in the image of the system. They recommend that their customers equip their cars with these systems. Some agreement in the automotive industry on threshold settings and interfaces of the assistant is necessary to guarantee safe designs of all available overtaking assistants from any make. Authorities also promote systems such as the overtaking assistant, for example with campaigns encouraging drivers to buy overtaking assistants, which will lower the occurrence of overtaking accidents on their roads.

These two visions of the future are the extreme possibilities. From the results of this dissertation research, we think that the development of an overtaking assistant will continue. The readily started developments of assistance when it is not safe to overtake will grow in the direction of the findings of this research. Twenty years from now is presumably too soon to guarantee recognition of all oncoming vehicles. However, when this is possible, the overtaking assistant will become an attractive device to reduce accidents with overtaking on two-lane rural roads.
References


References


Reference


References


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Appendix A

Overtaking rules and performance questionnaire
Overtaking on two lane rural roads

The answers below apply to the country:

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the highest speed limit on 2-lane rural roads with opposing traffic?</td>
<td></td>
</tr>
<tr>
<td>What is the speed limit for trucks on these roads?</td>
<td></td>
</tr>
<tr>
<td>At a road with a speed limit of 100 km/h (say 60 mph) my desired speed is:</td>
<td></td>
</tr>
<tr>
<td>I will overtake a driver that drives at most…</td>
<td></td>
</tr>
</tbody>
</table>

An overtaking prohibition is organised with…

<table>
<thead>
<tr>
<th>II. Prevention</th>
<th>Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Occasionally</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>A sign at the beginning of each road section</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One continuous line between the driving directions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double continuous line between the driving directions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different paint colour for (double) solid line</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A hard barrier between the two driving directions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What do you think are reasons for overtaking prohibitions?

<table>
<thead>
<tr>
<th>Reason</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Restricted view (e.g. curves, hill, slope)</td>
<td></td>
</tr>
<tr>
<td>Bad surface</td>
<td></td>
</tr>
<tr>
<td>Prohibition only when it is busy (e.g. rush hour)</td>
<td></td>
</tr>
<tr>
<td>Prohibition only when the weather is bad</td>
<td></td>
</tr>
<tr>
<td>Maneuver itself is not safe, that is, ideal overtaking situation (no curve or hill, perfect view), but nevertheless a prohibition</td>
<td></td>
</tr>
</tbody>
</table>

Punishment to disobedience

<table>
<thead>
<tr>
<th>Type</th>
<th>No punishment</th>
<th>Fine</th>
<th>Amount</th>
<th>Risk of losing license</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chance of getting caught: 5%
**Overtaking performance in practice. What do drivers generally do?**

<table>
<thead>
<tr>
<th></th>
<th>Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Occasionally</th>
<th>Never</th>
<th>Obliged?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use indicator for move to opposing lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use indicator when moving back to own lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keep indicator ON when on opposing lane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horn, only when it is dark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flick head lights</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flick head lights, only when it is dark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please indicate if it is obliged to use it according to traffic rules in your country on rural roads.

**How do drivers perform overtaking manoeuvres on rural roads?**

<table>
<thead>
<tr>
<th></th>
<th>Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Occasionally</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>As traffic regulations prescribe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The overtaker overtakes while an opposing vehicle is present (three cars side by side on two lanes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The preceding vehicle reduces its speed to 'help' the overtaker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The opposing vehicle reduces its speed to 'help' the overtaker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The preceding vehicle moves to the shoulder lane (if available)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overtakers make estimation errors through which the opposing vehicle or preceding vehicle has to take correcting actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The overtaker 'cut in' very close to (in front of) the overtaken vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If an overtaker is overtaken by another vehicle from behind, what will happen?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overtaker will wait until overtakers from behind have passed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overtakers from behind give way to overtakers in front who also want to overtake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Additional comments**

---

Gender: M / F         Age: ...... year         I have a driving license for ......... years

I would like to get the result of this questionnaire (the paper will be sent to you) e-mail address:
Appendix B

Questionnaires included in the driving simulator experiment
General questionnaire, given at the start of the experiment


1. Geslacht: man / vrouw
2. Geboortejaar: 19..
3. Hoogst genoten opleiding: Basisschool / vbo / mavo / havo / vwo / mbo / hbo / wo
4. Hoeveel jaar heeft u uw rijbewijs? ................. jaar
5. Hoeveel kilometer heeft u de afgelopen 12 maanden gereden? ................. km

Dit onderzoek is gericht op autowegen buiten de bebouwde kom. Dit zijn enkelbaans, tweestrookswegen met een maximumsnelheid van 100 kilometer per uur. Hieronder ziet u een tweetal voorbeelden van deze wegen, altijd aangeduid met het bord in het midden.

6. Hoe vaak rijdt u op autowegen?
   a. Iedere (werk) dag
   b. Een paar keer per week
   c. Een paar keer per maand
   d. Een paar keer per jaar
   e. Minder dan een paar keer per jaar

7. Wanneer u op een autoweg rijdt, raakt u dan geïrriteerd als een auto langzamer rijdt dan de maximaal toegestane snelheid?
   Ja, altijd / ja, vaak / ja, soms / nee, nooit

Indien u hier ‘nee, nooit’ heeft geantwoord, ga dan door naar vraag 9, anders naar vraag 7.
8. Wanneer ik achter een langzame voorligger rijd en ik weet dat ik deze over een aangegeven aantal kilometers kan inhalen dan raak ik minder / evenveel / meer geïrriteerd door deze langzame voorligger.

9. Waarom raakt u geïrriteerd door een langzame voorligger?
   (rangschik de antwoorden die voor u van toepassing zijn met cijfers, waarbij 1 het meest van toepassing is, daarna 2, daarna 3, enzovoort)

<table>
<thead>
<tr>
<th>Rangorde</th>
<th>Antwoord</th>
</tr>
</thead>
<tbody>
<tr>
<td>....</td>
<td>Ik denk dat de voorganger niet weet wat de maximaal toegestane snelheid is</td>
</tr>
<tr>
<td>....</td>
<td>Ik ga langer over de rit doen dan noodzakelijk</td>
</tr>
<tr>
<td>....</td>
<td>Ik heb haast</td>
</tr>
<tr>
<td>....</td>
<td>Ik kan niet zo hard rijden als ik graag wil</td>
</tr>
<tr>
<td>....</td>
<td>Ik houd niet van volgen</td>
</tr>
<tr>
<td>....</td>
<td>Iets anders, namelijk:</td>
</tr>
</tbody>
</table>

10. Hoe vaak heeft u gedurende een werkweek haast tijdens het autorijden?
    a. Iedere dag, meerdere keren per dag
    b. Drie tot vijf keer per week
    c. Vijf tot tien keer per maand
    d. Minder dan vijf keer per maand
    e. Nooit

11. Hoe hard rijdt u zelf op een autoweg als u haast heeft, bijvoorbeeld als u op weg bent naar een belangrijke afspraak en u al laat bent? .................kilometer per uur

12. Wanneer gaat u, als u haast heeft, proberen een voorligger in te halen? (meerdere antwoorden mogelijk)
    a. Ik haal bijna nooit in
    b. Als de voorligger meer dan ........... kilometer per uur langzamer dan de limiet rijdt
    c. Als er niet te veel tegemoetkomend verkeer is
    d. Als er maar één auto voor mij rijdt (en niet een hele groep)
    e. Anders, namelijk: ...........................................................

13. Jaarlijks overlijden er relatief veel verkeersdeelnemers op autowegen door inhalen. Heeft u een idee hoe inhalen op deze wegen veiliger kan?
    ......................................................................................................
Workload scale – given before and after each main ride (6 x)
Activation questionnaire – given before and after each main ride (6 x)

- Ik zit doodhang in een neergestort vliegtuig
- Ik ben betrokken bij een verkeersongeval, dat ik zelf veroorzaakt heb
- Ik heb veel pijn, maar laat niets merken
- Ik probeer een drukke straat over te steken
- Ik kijk naar een spannende film
- Ik lees een misdaadverhaal
- Ik lees de krant
- Ik los een kruiswoordraadsel op
- Ik lig op de bank, en blader in een tijdschrift
- Ik lig op een bed met open ogen te dromen
Acceptance questionnaire, given after the ride with the overtaking lane

---

Proefpersoonnummer:  

---

Zojuist heeft u op een autoweg met inhaalstroken gereden. Wilt u hieronder aangeven wat u van deze stroken vond tijdens het rijden?

Er zijn telkens 5 antwoordmogelijkheden. Als u een term perfect van toepassing vindt, zet dan een kruisje in het vakje dat het dichtst bij die term staat. Als u een term in zekere 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 inhaalstrook tijdens het rijden:

<table>
<thead>
<tr>
<th>Term</th>
<th>Score</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>nuttig</td>
<td></td>
<td>zinloos</td>
</tr>
<tr>
<td>plezierig</td>
<td></td>
<td>onplezierig</td>
</tr>
<tr>
<td>slecht</td>
<td></td>
<td>goed</td>
</tr>
<tr>
<td>leuk</td>
<td></td>
<td>vervelend</td>
</tr>
<tr>
<td>effectief</td>
<td></td>
<td>niet effectief</td>
</tr>
<tr>
<td>irritant</td>
<td></td>
<td>aangenaam</td>
</tr>
<tr>
<td>behulpzaam</td>
<td></td>
<td>waardeloos</td>
</tr>
<tr>
<td>ongewenst</td>
<td></td>
<td>gewenst</td>
</tr>
<tr>
<td>waakzaamheidverhogend</td>
<td></td>
<td>slaapverwekkend</td>
</tr>
</tbody>
</table>
Acceptance questionnaire, given after the ride with the overtaking assistant

Proefpersoonnummer:

Zojuist heeft u gereden met een inhaalassistent. Wilt u hieronder aangeven wat u van het systeem vond tijdens het rijden?

Er zijn telkens 5 antwoordmogelijkheden. Als u een term perfect van toepassing vindt, zet dan een kruisje in het vakje dat het dichtst bij die term staat. Als u een term in zekere 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 inhaalassistent tijdens het rijden:

<table>
<thead>
<tr>
<th>Term</th>
<th>Zinloos</th>
<th>Onplezierig</th>
<th>Plezierig</th>
<th>Netteffectief</th>
<th>Aangenaam</th>
<th>Gewenst</th>
<th>Waardeloos</th>
<th>Gewenst</th>
<th>Vervelend</th>
<th>Nieteffectief</th>
<th>Waakzaamheidverhogend</th>
<th>Slaapverwekkend</th>
</tr>
</thead>
</table>
Additional questions about the overtaking assistant, given after the assistant ride

Niet invullen a. u. b.

Proefpersoonnummer:

U heeft zojuist ongeveer 15 minuten met een inhaalassistent op een autoweg gereden. Wilt u in deze enquête de juiste antwoorden omcirkelen?

1. Heeft u het gevoel gehad haast te hebben tijdens de voorafgaande rit?
   Ja / Een beetje / Nee

2. Heeft u …… ingehaald dan wanneer u in het echt met haast op een autoweg rijdt?
   a. vaker, omdat ……………………………………………………………………………………………
   …
   b. even veel
   c. minder vaak, omdat …………………………………………………………………………………

3. Werkte de inhaalassistent zoals van te voren was uitgelegd?
   a. Ja
   b. Nee, want ………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………

4. Inhalen met inhaalassistent is…… dan normaal inhalen
   a. makkelijker
   b. even moeilijk / makkelijk
   c. moeilijker

5. Inhalen met inhaalassistent kost …… dan normaal inhalen
   a. meer inspanning
   b. evenveel inspanning
   c. minder inspanning
6. Met de inhaalassistent raak ik …….. geïrriteerd door langzame voorliggers
   a. meer
   b. evenveel
   c. minder

7. Met een inhaalassistent ga ik ………. inhalen dan normaal als ik haast heb
   a. meer
   b. evenveel
   c. minder

8. Met een inhaalassistent voelt inhalen…..
   a. veiliger
   b. even veilig
   c. minder veilig

9. De inhaalassistent die u in de rijsimulator heeft getest kan verder worden ontwikkeld, zodat zij in echte auto’s kan worden geïnstalleerd. Welk van de onderstaande ontwerpen zou u het prettigst vinden?
   a. Een systeem dat u zelf aan en uit kunt zetten
   b. Een systeem dat altijd ‘aan’ staat, zoals in de rijsimulator

10. En hoe moet de inhaalassistent communiceren?
    a. Zoals in de simulator, met rood en groen lampje
    b. Andere visuele weergave, b.v.
       ………………………………………………………………………..
    c. Met geluid
    d. Visueel en met geluid

11. Hoeveel zou u voor een inhaalassistent willen betalen?
    a. Zelfs als het gratis is, wil ik het niet in mijn auto
    b. Alleen als het gratis is
    c. 0 – 100 Euro
    d. 100 – 500 Euro
    e. 500 – 1000 Euro
    f. Meer dan 1000 Euro

12. Hoe lang denkt u nodig te hebben om te wennen aan de inhaalassistent?
    a. Minder dan 5 ritten van ongeveer een half uur
    b. Tussen de 5 en 10 ritten van ongeveer een half uur
    c. Tussen de 10 en 20 ritten van ongeveer een half uur
    d. Meer dan 20 ritten van ongeveer een half uur
**General questionnaire given at the end of the experiment**

Proefpersoonnummer: ____________________________

Niet invullen a. u. b.

In de simulator heeft u, in willekeurige volgorde, op een autoweg gereden, op een autoweg met inhaalstrook en op een autoweg met inhaalassistent. In deze laatste enquête vragen wij u deze drie varianten met elkaar te vergelijken.

3. Voor welke variant was inhalen het prettigst?
   a. De inhaalstrook
   b. De inhaalassistent
   c. De neutrale, zonder inhaalstrook, zonder inhaalassistent

2. Met welke variant kunt u het veiligst inhalen?
   a. De inhaalstrook
   b. De inhaalassistent
   c. De neutrale, zonder inhaalstrook, zonder inhaalassistent

3. Zijn er volgens u verschillen tussen inhalen in de simulator en inhalen in de werkelijkheid, met uw eigen auto?
   a. Nee
   b. Ja, namelijk: ________________________________________________________________

   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

4. Jaarlijks overlijden verkeersdeelnemers op autowegen door inhalen. Heeft u een idee hoe inhalen op deze wegen veiliger kan?
   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

5. Overige opmerkingen:
   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

   …………………………………………………………………………………………………
Appendix C

Explanation license plate recognition methodology
The license plate recognition methodology

License plate recognition is applied in different fields of transport, including parking management, street enforcement and traffic measurement (Dacolian, 2007). Overtaking frequency measurements belongs to the last group. In this case, the license plate recognition methodology includes unique identification of each vehicle that passes a start cross-section and an end cross-section of a road segment. If the order of passed vehicles at the start differs from the order at the end, overtaking manoeuvres have taken place. Figure C.1 shows an example, where four vehicles entered a road section in the order A, B, C, D and left the segment in the order C, A, B, D. For this situation, it is assumed that vehicle C has overtaken vehicle A and B.

Figure C.1 Observation overtaking frequency method: compare observed order at road section 1 with order at road section 2. Vehicle C has overtaken vehicles A and B

The licence plate method received its name by the fact that vehicles at both cross-sections are identified by means of their unique licence plate, observed by either human observers or cameras. The length of the observed road segment should be at least the length of an overtaking manoeuvre, however longer road sections decrease coincidences. The maximum length is limited by the existence of intersections, accesses and exits. These cannot be included in the observed sections, because at these points, new vehicles enter the road and other vehicles leave the road, which confuses the match of the vehicles observed at the start and end of the road segment.

Adjusted license plate recognition methodology

The existing license plate recognition methodology is adjusted for this specific overtaking frequency study. The main adjustment includes a combination of camera and human observers to extract the license plates. Automatic license plate recognition systems were under development when this experiment took place and reliance of the available systems was limited. Furthermore, these systems are fairly expensive and purchase and learning of it takes some time, which has lead to the decision to manually obtain the license plates of the vehicles.

A test observation was performed to test how the license plate recognition methodology should be applied to obtain the overtaking frequency as accurately as possible. First, the use of human observers and cameras were compared. Using observers, data are directly available and the ideal observation circumstances can be chosen and changed during the observation, for example the position with the best view to recognise the vehicles quickly. However, observers have a maximum data processing speed on the site, possibly being too slow to register all passing vehicles. To increase the maximum number of vehicles registered by
humans it was decided to only register the first two signs of the license plate\textsuperscript{31}. For this, the software tool Event-Rec was developed, that saves each two characters typed, together with the time at which the second character is entered. This is illustrated in Figure C.2.

![Figure C.2 Visualisation of applied observation method, using the software tool Event-Rec](image)

Since the first two signs of a license plate only are not unique, human observers should always be accompanied by cameras, to verify the observation results in case the first two characters of two observed vehicles were similar. Another possibility to obtain the order of the vehicles at both cross-sections, is to record the vehicles with cameras only, and extracting the order of the vehicles later, at your desk, also by noting down the first two characters of each recorded passing vehicle.

The test observation demonstrated that observers along the road equipped with a laptop, were able to observe all passing vehicles till a maximum of 500 veh/h (Hegeman, 2004a). For flows lower than 500 veh/h, observers made on average 2\% errors, including missed vehicles and mismatch license plate. For higher flows, two observers could be used: one observing the vehicles and recite the license plate and another typing it. The logistics of an observation with two observers per direction for two cross-sections become fairly complex. Cameras are then easier and also give the opportunity to analyse afterwards, at lower play speed to obtain all passing vehicle’s license plates. However, when speeds of the vehicles are to be analysed simultaneously, real-time processing is necessary, for which the number of made errors were higher compared to two observers along the road (Hegeman, 2004a). The higher error rate of license plate extraction afterwards from the video tapes was mainly caused by the changing focus point of the camera during the observation, resulting in unclear images. The focus point changes for example when a big truck passes, because the camera assumed it was getting dark. Then the camera automatically widened the diaphragm to obtain more light. When the

\textsuperscript{31}Dutch license plates exists of three sets of two numbers or characters, e.g. as the example in Figure C.2
truck has passed, the diaphragm does not close again and hence, the focus point has changed. However, this problem could be solved when using other cameras.

The test observation resulted in the choice to use a combination of a human observer at the less busy site of a cross-section and a camera at the busy site, with also the less busy site in view, to enable double check in case of mismatch for the human observed vehicles.

Overtaking frequency observation strategy
The strategy to obtain the overtaking frequency from the order observations on two cross-section is as follows. The overtaking frequency of a road segment is calculated by counting the number of order changes when the order of vehicles at the start cross-section and end cross-section of a road segment are compared. The order of vehicles at each cross-section was recorded with cameras and for most observations the less busy site was observed by human observers equipped with a laptop running Event-Rec as displayed in Figure C.2. The observers were instructed to enter the first two signs of the license plate of each passing vehicle. For each missed vehicle, two dots (..) were entered. When a wrong first character was entered, it was completed with a forward slash (e.g. d/), without entering the right characters afterwards. When three characters were entered instead of two, the third was completed with a forward slash as well. License plates of motorbikes were often difficult to read and since these almost always start with an M, it was agreed to enter another M when the license plate was unreadable. Observers did have a notebook to explain errors or any other noticeable events. Each observer observed 4 hours with a break of about 15 minutes. During this break 2 spare observers, who also controlled the cameras, took over the observation. The cameras were installed in such a way that the license plates were readable as long as possible. Some cameras were pointed at the back of the vehicles, to avoid sunshine that makes license plates unreadable. Camera data was processed in a similar way as the observers along the road entered the data, also using Event-Rec that included a feature to synchronise the processing time with the recorded time. Real-time processing was necessary to enable speed calculations as well. For high flows, two persons processed the camera data, one observing and reciting the first two characters of a license plate, the other typing it. Camera data was also used to uniquely identify vehicles with the same first two license plate characters.

Observer data and processed camera data together resulted in a databases for each observed direction at each cross-section, including all vehicle’s first two license plate signs and their passage time. The two data sets of the same driving direction are matched, that is, each vehicle at the first cross-section is matched with itself at the other cross-section. When the order of vehicles has changed, overtaking manoeuvres have taken place.

Road segments without and with overtaking prohibitions are observed simultaneously, to enable a fair comparison of overtaking frequencies on both road sections. Table C.1 shows an example of a part of a file where license plates are matched.
**Table C.1 Example table of license plate matching process**

<table>
<thead>
<tr>
<th>t</th>
<th>az-1 Lip²</th>
<th>az-2 Lip²</th>
<th>Compare³</th>
<th>#-1</th>
<th>#-2</th>
<th>Lookup⁴</th>
<th>pass⁵</th>
<th>Act. Man⁶</th>
<th>Passive⁷</th>
<th>P. Man⁸</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>37.08</td>
<td>9</td>
<td></td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>37.13 ofa</td>
<td>12</td>
<td>40.79 ofa</td>
<td>TRUE</td>
<td>14</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>37.17 og</td>
<td>12</td>
<td>40.86 og</td>
<td>TRUE</td>
<td>15</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>37.38 wy</td>
<td>12</td>
<td>40.99 wy</td>
<td>TRUE</td>
<td>16</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>37.63 xh</td>
<td>12</td>
<td>41.02 xh</td>
<td>TRUE</td>
<td>17</td>
<td>17</td>
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<td>0</td>
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<tr>
<td>12</td>
<td>37.76 yy</td>
<td>12</td>
<td>41.16 yy</td>
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<td>0</td>
</tr>
<tr>
<td>12</td>
<td>37.87 zj</td>
<td>12</td>
<td>41.44 zj</td>
<td>FALSE</td>
<td>19</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>12</td>
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¹Time at which vehicles cross section 1 and section 2, ²License plate identification, ³Comparison of the license plates in the row, ⁴Unique number for license plate at cross-section 1 and 2 and a lookup table that finds the unique number of the matching license plate, ⁵Number of overtakings, ⁶Total active drivers, ⁷Total active manoeuvres, ⁸Total passive drivers, ⁹Total passive manoeuvres.

**References**


Appendix D

The microscopic traffic simulation model RuTSim
Modelling overtaking and the overtaking assistant in RuTSim

The in Sweden developed Rural road Traffic Simulator, RuTSim (Tapani, 2005b) is applied to model the overtaking assistant. This section describes the model globally and specifically how overtaking and the overtaking assistant is modelled.

**General RuTSim description**

RuTSim is a simulation model developed for simulation of traffic in common rural road environments. Figure D.1 shows a flow chart of the main elements of the model of which a complete description can be found in Tapani (2005a). This appendix gives some extra information about RuTSim, with special attention to how overtaking and the overtaking assistant are modelled. In the following, vehicle is used to indicate the vehicle-driver combination.

**Figure D.1 Flow chart of the RuTSim model**

RuTSim is a rural road microscopic traffic simulation model that considers individual vehicles, interactions between vehicle-driver combinations and interactions with the infrastructure. The last is of more importance in a rural road model compared with freeway models or urban network model since delays in urban and freeway networks are dominated by vehicle-vehicle interactions. The travel time delay in rural roads is also significantly affected by interactions between vehicles and infrastructure. RuTSim includes detailed modelling of vehicles' speed adaptation with respect to the road geometry as well as interactions between oncoming traffic in overtaking situations on two-lane rural roads. A time-based simulation approach with a user defined simulation time step is applied in RuTSim. The model includes stochastic variables for which the values are dependent on a chosen random seed. Different random seeds represent inter driver differences.
**RuTSim input**

To use RuTSim, a network and traffic information is required. The model is developed to handle one rural road stretch in each simulation run, that is, rural road networks are not considered. Traffic entering and leaving the main road at intersections or roundabouts is modelled, taking into account information on for example flared approaches or number of lanes on the roundabouts. In addition to alignment of the road, RuTSim requires sight distance information, which is used especially for the overtaking model. This model also requires information on overtaking permissions and presence of shoulder lanes (which are not common in The Netherlands along rural two-lane roads).

In parallel with the network information, the model requires traffic input data. RuTSim can handle dynamic origin destination matrices that describe for each origin the off-turn percentages at the intersections to determine vehicles destinations. Four default vehicle types are included in RuTSim: passenger vehicles, vans or small trucks, trucks and long trucks (truck with trailer). The model includes default settings for these vehicle types, including, among other things, desired speed distributions, acceleration capabilities, length, desired following gap and reaction time. The users can adjust these settings to (country) specific settings. There is a possibility to specify different driver/vehicle sub-categories for each vehicle type. These sub-categories can be used to represent, for example, vehicles equipped with different driver assistance systems.

**Main RuTSim model**

The input origin and destination matrix is closely related to the traffic generation model, shown in the first block of the main RuTSim model in Figure D.1. Here, the flows per vehicle type with its characteristics are defined. The platoon generation model reduces the simulation warm-up time required before stable traffic conditions are formed. Time headways between vehicles that are to enter the simulation are also determined according to a platoon generation model that takes the ease of overtaking slower vehicles on the modelled road into account. The platoon length is, among other things, dependent on the overtaking possibility.

In addition to the traffic generation, RuTSim includes an acceleration model, an overtaking model, intersections and roundabouts model and a model for loading and unloading the vehicles, shown in the second block of the main RuTSim model in Figure D.1. These four models control the vehicle movements in RuTSim. The acceleration model includes the car-following model, which is an important part of micro simulation models. The applied car-following model in RuTSim is the intelligent driver model of Treiber (Treiber et al., 2000). The overtaking model is explained in more detail in Chapter 6. The intersection and roundabout model defines how vehicles enter the main road at these locations. These models are of less interest for this study, more details can be found in Tapani (2005a).

The third block of the main RuTSim model in Figure D.1 includes the main simulation loop. Similar loops are used in most micro simulation models, including all the steps to let vehicles move through the network. Special for the RuTSim model are the virtual queues where the vehicles to enter the network are stored. When a vehicle is immediately able to enter the network, it will do, however, when for example a vehicle wants to enter from a side road.
while there is not an acceptable gap available in the main traffic stream, it will wait in the virtual queue until a sufficiently large gap to enter is available. The size of this gap is dependent on the preferred headway of the vehicle to enter and its gap acceptance.

The fourth block includes the graphical user interface (GUI). Since RuTSim is not developed as a commercial product, most attention is paid to the right calculation of the vehicle movements and less to the beauty of the graphics. Nevertheless, it is possible to view the network on screen, enabling a check of the right geometry of the road and right positions of the intersections. It is also possible to adjust parameter settings on screen and to zoom in to see how the vehicles move along the road.

**RuTSim output**

The third block in Figure D.1 shows the output. After the simulation, the user can define points, sections and intersections for which the model outcomes are automatically aggregated. Where most micro simulation models leave the user with an enormous amount of output data, RuTSim enables automatic data processing. For example in this study, a road section can be chosen to calculate averages and standard deviation of the pre-chosen indicators to measure traffic system efficiency, drivers’ comfort and safety. These averages are calculated over all the runs performed with different random seeds. To calculate delays, RuTSim includes the feature to run a free simulation run, next to the interaction run. The interaction run is a simulation of the scenario as it occurs in reality. The free simulation run includes the same vehicles, but simulates them as free vehicles. This means that in a free simulation run all vehicles are able to complete their trip without interactions, with their desired speeds. Difference in travel times of the free simulation run and the interaction run enable calculation of the delays. The aggregated output data are produced in xml format, readable with Microsoft-Access from which it can be converted to any program to analyse the data further.

RuTSim has been applied to study overtaking in Sweden (Tapani, 2005b) and to evaluate safety effects of driver assistance systems (Lundgren and Tapani, 2006). The application of RuTSim in this dissertation aims to verify whether this Swedish model is applicable for Dutch rural roads. The calibration results are presented in more detail in Tapani and Hegeman (2008).

**References**


Summary

Overtaking on two-lane rural roads causes many accidents worldwide. One current solution aims at eliminating overtaking as accident cause by the implementation of overtaking prohibitions. However, this does not change the urge of drivers to overtake slower preceding vehicles to increase their efficiency and comfort. An alternative solution is overtaking lanes, which are extra driving lanes with limited length for one driving direction, allowing drivers the opportunity to overtake slower preceding vehicles. However, to build these lanes requires high investments, and particularly in a small and densely populated country as the Netherlands, the required space is often not available. Meanwhile, driver assistance systems are being developed to assist drivers with difficult aspects of driving. Overtaking is one such difficult driving task. Hence, driver assistance systems have the potential to assist drivers with overtaking, and to increase traffic system efficiency as well as drivers’ comfort and safety. In light of this, the main objective of this dissertation research is to thoroughly analyse overtaking performance on two-lane rural roads and study the opportunities of an overtaking assistant with respect to traffic system efficiency, drivers’ comfort and safety.

In the first phase of this research, overtaking on two-lane rural roads is measured. An instrumented vehicle is applied to collect empirical data on overtaking behaviour. The data collection took place on the N305 Almere – Zeewolde, referred to as Flevoland road. This road has been selected because of its ideal overtaking circumstances: relatively long stretches of flat road with no disturbing elements. The road has a speed limit of 100 km/h and the instrumented vehicle was driven at constant speed of 70, 80 or 90 km/h. Unknown drivers overtook the instrumented vehicle and their manoeuvres were recorded with several cameras on board. With these data, four overtaking strategies are distinguished. Accelerative overtaking is the strategy most often applied and first involves an adjustment of speed to match the preceding vehicle’s speed. As soon as there is an opportunity, that is, when there are no oncoming vehicles, the overtaker starts to accelerate and moves to the left lane. For the flying strategy, speed adjustments are not necessary: the overtaker can immediately overtake slower preceding vehicles. The strategy to follow a lead vehicle that overtakes another preceding vehicle is called piggy backing. When more than one vehicle is overtaken in one manoeuvre the name 2+ is used. Neither differences in overtaking strategy nor speed of the instrumented vehicle significantly influenced the duration of the overtaking manoeuvre. This duration is on average 7.8 s with a standard deviation of 1.9 s. Perception-reaction times,
which is the time between the passage of the last oncoming vehicle and the start of the overtaking manoeuvre, are fairly short: half of the overtakers have a perception-reaction time between 0 and 0.5 s. About two-thirds used their indicator at the start of the manoeuvre and about one-third at the end of the manoeuvre. The headway at the start of the manoeuvre and at the end of the manoeuvre vary between 10 and 60 m. Finally, 10% of the observed manoeuvres have a time-to-collisions (TTC) with the next oncoming vehicle smaller than 3 s. TTCs smaller than 3 s are experienced as uncomfortable and are therefore undesirable.

The next step in the analysis of overtaking is the determination of the subtasks of an overtaking manoeuvre and the matching assistance needs of those tasks. A task analysis is performed, dividing the overtaking task into five phases, consisting of more than twenty subtasks. These include, for example, check whether overtaking is permitted, maintain a safe headway with the preceding vehicle and check whether the gap until the first oncoming vehicle is sufficiently large to safely perform an overtaking manoeuvre. Ten matching assistance needs are distinguished. For the three example subtasks, these include required information on overtaking prohibitions, headway size information and available overtaking gap size information. All but one of the assistance needs can be produced by existing driver assistance systems, sometimes requiring some adaptations. Only for the last of the mentioned assistance needs, information on available gap size, no assistant is available and is therefore selected to design an overtaking assistant for.

The basic design cycle is applied to design the overtaking assistant. This cycle starts with a functional description of the system. The overtaking assistant is meant to be informing, meaning that drivers are advised what to do (to overtake or not) but still have to perform all physical tasks such as steering and accelerating. The information is descriptive rather than prescriptive, which means that the system decides whether a gap is large enough and does not give information on exact size. A set of needs of all stakeholders involved is made and used as a guide to further design the assistant. The resulting design has a pedestrian traffic light-like interface with a red and a green sign. Drivers switch the system on when they have an overtaking wish. The red sign is displayed and remains on until the system has collected all necessary data to calculate the available gap size. When the next gap in the oncoming traffic stream is large enough to safely perform an overtaking manoeuvre, the green sign is displayed. Three seconds before the switch from red to green, the red sign starts blinking to inform the driver to prepare for an overtaking manoeuvre. When the overtaking gap becomes critical, that is, equal to the threshold setting for a green sign, green starts blinking to indicate that the driver either has to hurry to finish the manoeuvre or should not start an overtaking manoeuvre. Three seconds before the next oncoming vehicle arrives, the red sign is displayed again.

As part of the evaluation phase of the basic design cycle, a driving simulator experiment has been conducted. Twelve male and twelve female participants experimented overtaking with the use of the assistant. An identical road was driven without assistance and with the assistant. The TNO low-cost driving simulator was used with a driving environment based on the same Flevoland road that was used for the data collection on overtaking manoeuvres. Using the assistant, female drivers overtake more, while male drivers overtake less. Deviations in lateral position turn out to be smaller when driving with the overtaking assistant, presumable due to
the fact that drivers do not have to look past the preceding vehicle to search for an overtaking gap. The TTC between the overtaker and the oncoming vehicle is significantly smaller when driving with the overtaking assistant and often drops below 3 s. Workload and activation level of the participants increase more when driving with the assistant compared to driving without the assistant. The system scores better on usefulness than on satisfaction. The results of the simulator experiment demonstrate that an overtaking assistant can have positive effects on overtaking efficiency, safety and comfort. As an alternative, a prescriptive overtaking assistant design (e.g. a time bar showing the time remaining until the next oncoming vehicle arrives) will likely improve the scores on particularly the subjective measures.

In a second evaluation study the effects of different threshold settings and penetration rates of drivers equipped with the assistant are studied, using microscopic traffic simulation. The Swedish two-lane rural road model RuTSim is selected, because previous experiences with this model in overtaking research and its flexibility to model driver assistance systems. Detailed overtaking data are needed to calibrate and validate the model for Dutch roads. To obtain these data, an overtaking frequency study has been conducted. Overtaking frequencies were measured on two Dutch roads, including the Flevoland road. The average measured overtaking frequency is about 50 per kilometre-hour. Overtaking frequency turns out to be highly dependent on the spread of flows in both directions: the less equal the flows are, the more overtaking manoeuvres take place in the more busy direction. Similar spreads and different total flows result in similar overtaking frequencies. For example, when 62% of a total flow of either 500 or 1500 veh/h is driving in one direction the observed frequencies are both about 32 per km-h. Speed of overtakers, overtaken drivers and neutral drivers are analysed as well. The average speed gain of overtakers is about 15 s over a distance of 5 km. As expected, trucks are overrepresented amongst the overtaken vehicles and motorbikes amongst the overtakers.

Using the overtaking frequency data, a new formula to predict overtaking frequency is proposed. The formula includes the flow in the analysis direction and the flow in the opposing direction as the only independent variables, which results in an $R^2$ of 0.67.

All empirical data collected on the Flevoland road are used to model the reference scenario for the microscopic traffic simulation study. At first, RuTSim encountered some difficulties with the simulation of the fairly high flows in combination with fairly high overtaking frequencies. After calibration, the model is able to simulate the flows, speeds and overtaking frequencies of the off-peak period sufficiently accurate to enable evaluation of the overtaking assistant. First, simulation results with different assistant threshold settings are compared. The threshold setting is the minimum gap which the assistant recommends as a safe overtaking possibility. The thresholds 8 s, 11 s and 14 s are compared, of which 8 s was also used in the driving simulator experiment. The penetration rate is set to be 100% (all drivers are equipped) and 100% compliance is assumed (equipped drivers with an overtaking wish will always use the system). The efficiency and safety results of the 11 s threshold setting are similar to the reference without assistant. At the same time, comfort increases, measured by the indicators overtaking frequency and percent time spent following. Subsequently, different penetration rates of drivers equipped with the overtaking assistant are tested, simulating the rates 5, 10, 25, 50 and 100%. The 8 s threshold setting is used to ensure consistency with the simulator.
experiment and to explore the boundary possibilities of the system. For low penetration rates, equipped drivers gain efficiency and comfort. For higher percentages, the efficiency and safety of both equipped and non-equipped drivers is not much affected, while comfort of the equipped drivers is still positively influenced.

The overall conclusion of this research is that the overtaking assistant improves drivers’ comfort of overtaking on two-lane rural roads, without negatively affecting drivers’ safety and the traffic system efficiency. A next question is whether this solution performs better than alternative solutions. An example of such an alternative solution is the overtaking lane, mainly installed to improve traffic system efficiency. The effects of the overtaking assistant have been compared with effects of overtaking lanes in the driving simulator experiment. Overtaking frequency in the overtaking lane scenario is not higher than in the assistant scenario. That efficiency does not to improve is due to the fact that an overtaking lane in one direction is accompanied by an overtaking prohibition in the other direction. A more often applied solution in the Netherlands to reduce the number of accidents caused by overtaking, is an overtaking prohibition. During the empirical data collection on the Flevoland road, overtaking frequencies were also measured on road sections with overtaking prohibitions. The number of violators, as a percentage of overtakers on the section without prohibition, is 20%. This maximum is measured in the less busy direction at moments with highest oncoming flows. Since drivers do not expect overtaking manoeuvres when these are prohibited, overtaking violations are believed to be more dangerous than legal overtaking manoeuvres.

We conclude that both alternative solutions to solve the overtaking problem on two-lane rural roads, overtaking lanes and overtaking prohibitions, have disadvantages. This dissertation research demonstrates that the overtaking assistant improves drivers’ comfort without negatively affecting traffic system efficiency and drivers’ safety. With a threshold setting of 10 or 11 s, drivers’ safety can also be improved, as long as drivers obey to the system. Currently, technologies to enable the application of an overtaking assistant such as vehicle-to-vehicle communication, are being developed. As soon as the identification of all surrounding vehicles become technologically possible, the overtaking assistant will become an attractive device to improve drivers’ comfort and to reduce accidents with overtaking on two-lane rural roads.

Geertje Hegeman
Samenvatting

Inhalen op tweestrookswegen veroorzaakt jaarlijks meerdere dodelijke ongelukken over de hele wereld. Om dit soort ongelukken te voorkomen passen overheden vooral inhaalverboden en inhaalstroken toe. Bij een inhaalverbod mag een bestuurder niet inhalen en moet haar snelheid aanpassen aan de voorligger. Een inhaalstrook is een extra rijstrook afwisselend beschikbaar voor beide rijrichtingen. Voor de andere richting geldt dan telkens een inhaalverbod. Voor een inhaalstrook is vaak weinig ruimte beschikbaar, zeker in een dichtbevolkt en klein land als Nederland. Daarnaast kost de invoering van beide oplossingen, de inhaalstrook en het inhaalverbod, veel geld. Ondertussen komen allerlei technische systemen op de markt die bestuurders ondersteunen in hun rijtaak. Voor velen is inhalen een moeilijke rijtaak. Een ondersteuningssysteem voor inhalen heeft daarom kansen. Dit promotieonderzoek verkent de kansen van ondersteunende systemen voor inhalen op tweestrookswegen. Het onderzoek heeft als doel: Het grondig analyseren van inhalen op tweestrookswegen en het verkennen van de mogelijkheden van een inhaalassistent met aandacht voor veiligheid en comfort van bestuurders en de efficiëntie van het verkeerssysteem.

Allereerst is het verloop van inhaalmanoeuvres op tweestrookswegen waargenomen met een geïnstrumenteerd voertuig. De N305 Almere – Zeewolde is hiervoor gekozen vanwege zijn ideale inhaalinfrastructuur: relatief lange wegvakken van ongeveer 5 km zonder bochten, heuvels of kruispunten. De snelheidslimiet op deze weg is 100 km/u en het geïnstrumenteerde voertuig reed 70, 80 of 90 km/u. Andere weggebruikers haalden dit voertuig in, zonder op de hoogte te zijn van de proef. Het gedrag van de bestuurders die het geïnstrumenteerde voertuig inhalen, blijkt in vier strategieën in te delen. Het vaakst wordt accelererend inhalen toegepast. Dat betekent dat de inhaler de voorligger volgt, vervolgens een haat in het tegemoetkomende verkeer accepteert en dan versnelt om de voorligger voorbij te gaan. Bij een vliegende inhaalbeweging kan een inhaler een langzamere voorligger meteen inhalen zonder haar snelheid aan te passen. Soms voelt een inhaler een voorligger die een andere voorligger inhalen aan. Dit wordt in het Engels piggy backing genoemd. De vierde waargenomen inhaalstrategie heet 2+. Dit houdt in dat de de inhaler twee of meer voorliggers in één beweging inhalen. De gemiddelde duur van de waargenomen inhaalbewegingen is 7.8 seconden met een standaard deviatie van 1.9 s. De inhaalstrategie en de snelheid van het geïnstrumenteerde voertuig hebben geen invloed op de duur van de inhaalbeweging.
Een opvallend resultaat verder is de korte tijd tussen de passage van de laatste tegenligger en het begin van de inhaalmanoeuvre (linkerwiel inhaler raakt middenlijn). Deze ligt voor de helft van de bestuurders tussen de 0 en 0.5 s. Tweederde van de inhalers gebruikt het knipperlicht om aan te geven dat ze gaan inhalen. Eénderde gebruikt het knipperlicht om de beweging terug naar de eigen strook aan te geven. In Nederland is het gebruik van het knipperlicht verplicht voor iedere rijstroomwisseling. Aan het begin van de waargenomen inhaalbeweging rijden de inhalers op 10 en 60 meter van hun voorligger. Tenslotte had 10% van de inhalers minder dan 3 s tijd over met de eerstvolgende tegenligger. Met deze resultaten is veel inzicht verkregen in de uitvoering van inhaalmanoeuvres op tweestrookswegen.

Vervolgens is een taakanalyse van inhalen uitgevoerd, die meer inzicht heeft gegeven in het uitvoeren van de manoeuvre. Daarbij is ook de behoefte aan eventuele ondersteuning bekeken. Op basis van de taakanalyse van inhalen blijkt het mogelijk de inhaalbeweging in te delen in vijf fasen bestaande uit meer dan twintig subtaken. Voorbeelden van uit te voeren subtaken zijn: controleer of er een inhaalverbod geldt, behoud een veilige volgafstand met de voorligger en schat of het hiat in de tegemoetkomende verkeersstroom voldoende groot is om veilig in te halen. Voor het uitvoeren van alle subtaken zijn tien ondersteuningsbehoeftes onderscheiden. Voor de genoemde voorbeeld subtaken luiden dit: informatie over inhaalverboden, volttijd/volgafstand informatie en informatie over de beschikbare tijd totdat de eerstvolgende tegenligger arriveert. Reeds beschikbare ondersteunende systemen, zoals routenavigatie en cruise control, blijken in staat te voorzien in bijna alle ondersteuningsbehoeftes tijdens inhalen. Voor sommige is een kleine aanpassing of uitbreiding van het bestaande systeem noodzakelijk. Alleen voor de laatste voorbeeld subtaak, schat of het hiat in de tegemoetkomende verkeersstroom voldoende groot is om veilig in te halen zijn geen systemen beschikbaar. Gezien de moeilijkheid van deze taak ligt hier wel een grote behoefte. Daarom heeft het onderzoek zich verder gericht op het ontwerp van een inhaalassistent voor deze subtaak van inhalen.

Een inhaalassistent is ontworpen, die bestuurders informeert of het eerstvolgende hiat in de tegemoetkomende verkeersstroom voldoende groot is om veilig in te halen. Voor het ontwerp is de basisontwerpcyclus toegepast. Het ontworpen systeem is informerend, dat wil zeggen dat het alleen informatie geeft en niet ingrijpt in bijvoorbeeld sturen of versnellen. De gegeven informatie is voorschrijvend en niet beschrijvend, of te wel het systeem bepaald is na een hiat groot genoeg is en geeft geen informatie over hoe groot het hiat is. Een programma van eisen is samengesteld met eisen van bestuurders, de auto-industrie, de autoriteiten en de ontwerper zelf. Het resultaat is een assistent met een interface met een rood en groen licht, vergelijkbaar met een voetgangersverkeerslicht. Het rode licht brandt als het niet veilig is om in te halen. Zodra een voldoende groot inhaalhiat beschikbaar komt, gaat rood 3 s knipperen. Op het moment dat het hiat beschikbaar is, brandt groen. Dit blijft branden totdat het beschikbare hiat gelijk is aan de drempelwaarde voor een veilig hiat. Groen gaat dan knipperen, tot 3 s voordat de eerstvolgende tegenligger arriveert. Dan gaat rood weer branden.

Onderdeel van de basisontwerpcyclus is de evaluatie. De eerste evaluatiestudie van de inhaalassistent bekijkt de individuele effecten. Twaalf mannen en twaalf vrouwen hebben in de rijsimulator ervaren hoe het is om te rijden met een inhaalassistent. De geëxecuteerde weg was de N305, dezelfde als waar de waarnemingen met het geïnstrumenteerde voertuig hadden.
plaatsgevonden. De deelnemers reden deze weg zonder assistent en met assistent. De gebruikte drempelwaarde van de assistent om van rood naar groen te switchen was 8 s. In het experiment blijken vrouwen meer te gaan inhalen wanneer ze met de assistent rijden en mannen juist minder. Dit brengt het aantal inhaalbewegingen van mannen en vrouwen dichter bij elkaar. Afwijkingen in laterale positie (de plek van de auto op de rijstrook ten opzichte van de middenlijn en de kantlijn) gedurende 5 s voor de inhaalbeweging zijn kleiner wanneer de inhaalassistent wordt gereden. De resterende veiligheidsmarge tussen de eerstvolgende tegenligger is met de assistent vaker kleiner dan 3 s dan zonder de assistent. Bestuurders ervaren veiligheidsmargen kleiner dan 3 s als oncomfortabel en worden daarom als ongewenst beschouwd. Uit de ingevulde enquêtes blijkt dat het rijden met de assistent in vergelijking met het rijden zonder assistent te leiden tot een grotere groei in werkbelasting en een grotere groei in activering. De deelnemers vinden het systeem wel nuttig, maar zijn er minder tevreden over. Deze resultaten laten zien dat een inhaalassistent in een behoefte kan voorzien. De drempelwaarde van de assistent (minimale inhaalhiaat) heeft duidelijk invloed op de veiligheidsmarges. Deze is daarom meegenomen als onderzoeksvariabele in de tweede evaluatiestudie.

De tweede evaluatiestudie betreft de effecten van verschillende drempelwaardes en verschillende penetratiegraden van bestuurders met de inhaalassistent. Voor deze evaluatie was er eerst meer informatie nodig over de huidige situatie op een tweestrooksweg. Daarom zijn waarnemingen gedaan van inhaalfrequenties. Naast de N305 is ook de N255 in Zeeland gebruikt, met kortere wegvakken en meer recreatief verkeer. Inhaalfrequenties zijn bepaald door het waarnemen van de volgorde van voertuigen aan het begin en het eind van een wegvak. De gemiddelde inhaalfrequentie blijkt ongeveer 50 per kilometer-uur. De frequentie blijkt sterk afhankelijk van de verdeling van het verkeer in de twee rijrichtingen. De totale intensiteit is minder van belang. Bijvoorbeeld: twee waarnemingen met 62% van het verkeer in één richting en totale intensiteiten van 500 en 1500 voertuigen per uur hebben beide een inhaalfrequentie van 32 per kilometer-uur. Naast intensiteiten en inhaalfrequenties zijn ook snelheden van niet-inhalers, inhalers en ingehaalde voertuigen gemeten. De maximale tijdswinst die een inhaler kon halen door meteen aan het begin van het wegvak van 5 km een voertuig in te halen blijkt 15 s. Zoals verwacht, zijn vrachtwagens oververtegenwoordigd onder de ingehaalde voertuigen en motoren onder de inhalers.

Op basis van de inhaalfrequentie resultaten is een nieuwe formule voor het schatten van inhaalfrequenties opgesteld. Deze formule heeft als enige verklarende variabelen de intensiteit in de richting waarvoor de inhaalfrequentie wordt geschat en de intensiteit in de tegemoetkomende richting, wat resulteert in een $R^2$ van 0.67.

De waarneming van de N305 zijn gebruikt om de referentiesituatie te beschrijven in de microscopicke verkeerssimulatie, de tweede evaluatie studie van de inhaalassistent. Het Zweedse microscopicke verkeerssimulatiemodel RuTSim lijkt hiervoor het meest geschikt. Dit model is speciaal ontworpen voor inhaalonderzoek op tweestrookswegen, met grote flexibiliteit voor het modelleren van bestuurderondersteunende systemen. Het model had moeite om voor de hoge waargenomen intensiteiten de bijbehorende hoge inhaalfrequenties te simuleren. Na calibratie kwam het gesimuleerde verkeersbeeld buiten de piekperiode goed overeen met de waarnemingen. Deze periode is daarom vervolgens gebruikt voor de evaluatie.
Assisted Overtaking

van de assistent. Als eerste zijn simulaties uitgevoerd met drempelwaardes 8, 11 en 14 s. De verkeersscheeficentie en veiligheidsresultaten van een simulatie waarin alle bestuurders een inhaalassistent hebben met een drempelwaarde van 11 s, zijn gelijk aan de referentie situatie zonder assistent. Tegelijkertijd is het comfort van de geassisteerde bestuurders verbeterd, gemeten door middel van hogere inhaalfrequentie en meer tijd gereden als vrijrijdend voertuig (dus niet achter een voorligger). Vervolgens is de penetratiegraad van geassisteerde bestuurders vergeleken, oplopend van 5, 10, 25, 50 naar 100%, allen met een drempelwaarde van 8 s. Deze drempelwaarde is gekozen voor consistentie met het simulatorexperiment en om de grenzen van het systeem te bepalen: 8 s wordt gezien als de minimaal mogelijke drempelwaarde. Voor lage penetratiedegraden, 5 en 10%, verbetert de efficiëntie en comfort van geassisteerde bestuurders, zonder dat deze voor de niet-geassisteerde bestuurders verslechtert. De veiligheid voor zowel geassisteerde bestuurders als niet geassisteerde bestuurders is niet beïnvloed door de penetratiegraad van bestuurders met een inhaalassistent.

Samenvattend heeft dit onderzoek het inhalen op tweestroomswegen grondig geanalyseerd en de mogelijkheden van een inhaalassistent, met aandacht voor veiligheid en comfort van bestuurders en efficiëntie van het verkeerssysteem, verkent. Op tweestroomswegen wordt gemiddeld 50 keer per kilometer-uur ingehaald. De gemiddelde duur van deze bewegingen is ongeveer 8 s. Een inhaalassistent is ontworpen dat de comfort van de bestuurder kan vergroten, zonder dat dit ten koste gaat van de veiligheid van de verkeerssysteem, verkent. Op tweestroomswegen wordt gemiddeld 50 keer per kilometer-uur ingehaald. De gemiddelde duur van deze bewegingen is ongeveer 8 s. Een inhaalassistent is ontworpen dat het comfort van de bestuurder kan vergroten, zonder dat dit ten koste gaat van de veiligheid of de verkeersscheeficentie. Er is wel een duidelijke relatie tussen de veiligheid van inhalen en de drempelwaarde van de assistent. De minimale drempelwaarde is 8 s. Deze heeft ook de grootste, positieve invloed op het comfort. Een drempelwaarde van 10 of 11 s wordt aanbevolen om ook een positieve invloed op veiligheid te garanderen. Nog grotere drempelwaarden vergroten het risico dat de bestuurder het advies van het systeem gaan negeren.

Interessant is de vraag of deze oplossing voor de problemen met inhalen beter is dan bestaande oplossingen. De inhaalassistent is in het rijsimulatorexperiment vergeleken met een inhaalstrook. Het aantal uitgevoerde inhaalbewegingen blijkt niet groter in de variant met de inhaalstrook, vooral omdat als één rijrichting een inhaalstrook heeft, voor de andere richting een inhaalverbod geldt. Een andere oplossing om inhaalongelukken te voorkomen is een inhaalverbod. Bij de inhaalfrequentie waarnemingen zijn ook wegvakken met een inhaalverbod beschouwd. Het aantal overtreders van dit verbod loopt op tot 20%, als percentage van het aantal inhalers op het aangrenzende, vergelijkbaar wegvak zonder inhaalverbod. Overtreding van het inhaalverbod kan gevaarlijker zijn dan reguliere inhaalmanoeuvres, omdat andere bestuurders geen inhaalmanoeuvres verwachten. Beide huidige oplossing voor inhaalproblemen, de inhaalstrook en het inhaalverbod, hebben daarom nadelen. De inhaalassistent heeft deze nadelen niet en lijkt dus een betere oplossing. Op dit moment zijn de technologieën om de inhaalassistent te realiseren volop in ontwikkeling. Voertuig-voertuig communicatie tussen alle voertuigen is noodzakelijk om een inhaaladvies te kunnen geven. Wanneer dit is ontwikkeld, is er toekomst voor de inhaalassistent.

Geertje Hegeman
About the Author

Geertje Hegeman was born in Froomboch, The Netherlands on March 20th in 1977. Geertje obtained her VWO diploma from the dr. Alletta Jacobs School in Hoogezand in 1995. Hereafter, she started studying civil engineering and management at the University of Twente in Enschede. She specialised in traffic modelling, added with traffic psychology subjects and some extra traffic modelling subjects followed at the Institute of Transport Studies (ITS) in Leeds, UK. She completed her studies with an internship at TNO Institute for Traffic and Transport in Delft and a thesis project at Goudappel Coffeng in Deventer. Both projects included the modelling of driver assistance systems.

After her studies, Geertje worked as a traffic advisor at Goudappel Coffeng and as a research fellow at ITS in Leeds, UK. In January 2003 she started her Ph.D. 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. She has finished this dissertation research in February 2008.
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