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Overtaking Assistant Assessment using Traffic Simulation

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Abstract

This contribution presents the results of a microscopic traffic simulation study of the potential effects of an overtaking assistant for two-lane rural roads. The overtaking assistant is developed to support drivers in judging whether or not an overtaking opportunity can be accepted based on the distance to the next oncoming vehicle. Drivers have been found to consider this to be a difficult part of an overtaking manoeuvre. The assistant's effects on traffic efficiency, driver comfort and road safety have been investigated using traffic simulation. The results indicate that this type of overtaking assistant can provide safety benefits in terms of increased average time-to-collision to the next oncoming vehicle during overtaking manoeuvres. This safety benefit can be achieved without negative consequences for traffic efficiency and driver comfort. A driver assistance system that supports the distance judging part of overtaking manoeuvres can therefore contribute to improved traffic conditions on the two-lane rural roads of the future.

Keywords: overtaking assistant, microscopic traffic simulation, rural road, overtaking frequency, delay, TTC

Overtaking assistant assessment using traffic simulation

1 Introduction

Two-lane rural roads make up the majority of the road network in many countries. Rural roads are also dominant in traffic fatality statistics. It has been estimated that more than 60% of all fatalities in traffic occur on two-lane rural roads (Lamm et al., 2007). Two important underlying factors behind safety, quality-of-service, and driver comfort on two-lane rural roads are the possibility to overtake slower vehicles and the ease of performing these overtaking manoeuvres.

A large number of in-vehicle driver assistance systems designed to support motorway and urban driving are currently being introduced to the market. Examples of such systems include adaptive cruise control, blind spot detection systems and other types of collision avoidance systems. Recently, developments towards systems that assist drivers on rural roads have started. One example is the “Dynamic Pass Prediction” system which uses navigation system data, e.g. curve and sign information, to inform the driver of road sections with two-directional traffic that are not safe for overtaking (Loewenau et al., 2006). Hegeman et al. (2007) proposed an overtaking assistance system for two-lane rural roads that gives support to the overtaking manoeuvre itself. This system assists the driver in judging whether or not an overtaking opportunity can be accepted based on the time gap to the next oncoming vehicle.

A priori evaluation of proposed driver assistance systems are necessary to assure real system benefits and to allow resources to be spent on the most promising alternatives. Driving simulators and instrumented vehicles play important roles in such system evaluations to study the proposed systems’ impacts on individual driver/vehicle behaviour. To estimate the

systems' impact on traffic as a whole, it is necessary to aggregate individual driver/vehicle effects to the traffic system level. Microscopic traffic simulation models that consider individual vehicles in the traffic stream are useful tools for such traffic system evaluations. These models allow inclusion of driver-assistance system functionalities together with induced driver behaviours in the sub-models that control vehicle movements. Microscopic traffic simulation is also part of the advanced driver assistance systems assessment methodology proposed by the ADVISORS (2002) project.

Previous microscopic traffic simulation based evaluations of driver assistance systems have mainly considered systems that support the longitudinal part of the driving task, i.e. speed limiters and (adaptive) cruise control. Examples include the works of Minderhoud and Bovy (2001), Liu and Tate (2004) and Hoogendoorn (2005). Notably, no attempt to use microscopic traffic simulation to study systems that support lateral driving tasks, such as overtaking manoeuvres on two-lane rural roads has been found in the literature.

This contribution presents a simulation-based study of traffic system effects of the overtaking assistant proposed by Hegeman *et al.* (2007). The main contribution of the article are new insights into the potential effects of an overtaking assistant, considering traffic system efficiency, driver comfort and road safety. The development of the overtaking assistant is currently at the idea stage. The purpose of the study presented in this article is consequently to provide guidance for further development of the overtaking assistant concept.

Simulation of traffic on a two-lane rural road requires use of a simulation model that considers interactions between oncoming traffic in, for example, overtaking situations. The model applied in this work is RuTSim, the Rural Traffic Simulator (Tapani, 2005). RuTSim is

developed for simulation of rural road traffic including vehicles equipped with driver assistance systems. The modelled road is an existing two-lane rural road in the centre of the Netherlands and the considered traffic condition corresponds to the average daily off-peak situation on this road. This traffic demand is also representative for two-lane rural roads located in other European countries.

The remainder of this contribution is organized as follows. The next section describes the method of the study. The description includes presentations of the overtaking assistant, of the RuTSim model, and of the modelled road and the applied performance indicators. The method section is finished by a discussion of the expected effects of the overtaking assistant for both assisted and non-assisted vehicles. Then, simulation results are presented and discussed before the contribution ends with conclusions and directions for further research.

2 Assessment methodology

2.1 The overtaking assistant

The overtaking assistant is developed to increase driver comfort during overtaking manoeuvres and to reduce the number of overtaking related accidents on rural roads. In the Netherlands, overtaking on two-lane rural roads is the main cause of about 2.6 % of the total number of traffic fatalities (SWOV, 2003). In the UK, it has been estimated that 7.9 % of the fatal traffic accidents are caused by overtaking on two-lane roads (Clarke et al., 1998). A task analysis of the overtaking task revealed that drivers consider the estimation of the time available for an overtaking manoeuvre before the arrival of the next oncoming vehicle to be difficult (Hegeman et al., 2005b). The overtaking assistant was for this reason designed to assist drivers in judging whether or not the next gap in the oncoming traffic stream is sufficiently large to safely overtake the vehicle in front. This functionality can improve driver

comfort and thereby allow drivers to pay more attention to other parts of the overtaking task. There is therefore also a potential to reduce the number of overtaking related accidents caused by driver observation or estimation error by introduction of the overtaking assistant.

The overtaking assistant calculates the duration of the gaps between vehicles in the oncoming traffic stream. When a gap that is larger than a certain threshold is found, the assistant indicates that overtaking is possible. The threshold of the assistant corresponds to the minimum time or distance required to perform an overtaking manoeuvre. An appropriate assistant threshold can be based on the result of an overtaking observation study. Hegeman et al. (2005a) observed vehicles overtaking an instrumented vehicle travelling at 70, 80 and 90 km/h in real traffic. The average overtaking duration recorded in this study was 7.8 s and the corresponding standard deviation was 1.9 s. The overtaking assistant threshold can be composed of this overtaking duration plus a safety margin. The safety margin should be added in order to keep a safe distance to oncoming vehicles at the end of overtaking manoeuvres. Three seconds is a commonly applied safety margin for, e.g., collision avoidance systems. A time to collision below three seconds has been found to be experienced as uncomfortable by drivers (Hoogendoorn, 2000).

< place fig 1 about here >

Figure 1 illustrates three example human-machine interface (HMI) designs of the overtaking assistant. The “traffic signal” design displayed to the left in Figure 1 was tested in a driving simulator experiment (Hegeman et al., 2007). The “traffic signal” is red when the gap in the oncoming traffic stream is too short to allow safe overtaking and green when the gap is large enough. In the driving simulator study the red light flashed three times before turning green to

indicate that an overtaking opportunity would come within three seconds. The other two HMI designs have not been studied, but were created on the base of participant's comments to give an idea of alternative design possibilities. The designs have in common that they provide an *advice* to the driver by means of visual and/or audile signals.

2.2 Experimental set-up

This section describes the experimental set-up, Since the aim of this study is to estimate the potential impact of the overtaking assistant. All simulations were therefore conducted with 100% vehicles equipped with the overtaking assistant. Full compliance with the advice of the assistant was also assumed. These assumptions allow estimation of the maximum impact of the assistant. In reality, both the proportion of equipped vehicles in traffic and the compliance with the assistant's advice is likely to be lower than 100 %. Data obtained in a driving simulator study of the overtaking assistant could be utilised to account for differences in driver behaviour with respect to the overtaking assistant. Such a study of the impacts of different driver compliance to the overtaking assistant is a topic for future research.

2.2.1 Threshold settings

The first aspect of the overtaking assistant that is studied in the traffic simulation study reported on in this contribution is the threshold setting, i.e. the minimum time gap needed to perform a safe overtaking manoeuvre. Traffic simulations with the assistant thresholds 8, 9.5, 11, 12.5 and 14 s have been conducted. Eleven seconds correspond to the average overtaking duration observed by Hegeman et al. (2005a), 7.8 s, plus a safety margin of 3 s. The assistant threshold used in the driving simulator study to study a prototype design of the overtaking assistant was 8 s (Hegeman et al., 2007). This was the shortest convenient threshold setting in the driving simulator. The advice of the overtaking assistant is likely to be less respected by the drivers the longer the assistant threshold. Therefore, 14 s was chosen as the maximum

threshold. The thresholds 9.5 s and 12.5 s were also studied to allow more reliable estimation of possible trends in the simulation results.

2.2.2 Penetration rates

The second aspect of the overtaking assistant that is considered in this simulation study is the proportion of drivers equipped with the overtaking assistant in the simulated traffic, i.e. the assistant penetration rate. The simulated penetration rates are 5, 10, 25, 50 and 100%. Low penetration rates are of interest to estimate impacts shortly after a future system introduction. As the assistant becomes more popular, the proportion of equipped vehicles will grow, possibly to 100 % in the distant future. As for the simulations with varying assistant threshold, assumptions have been made to estimate the maximum impact of the assistant. The different traffic penetration rates are therefore studied for the 8 s assistant threshold and with the assumption of full compliance to the assistant's advice. Table 1 gives an overview of all simulated scenarios.

< place table 1 about here >

2.3 *The rural road microscopic traffic simulation model RuTSim*

The Rural Traffic Simulator (RuTSim, Tapani, 2005) is a simulation model developed for simulation of traffic on common types of rural roads. This section gives a brief overview of the model together with a description of how the overtaking assistant has been modelled in RuTSim.

2.3.1 Model characteristics

RuTSim is a micro-simulation model, i.e. the model considers individual vehicles in the traffic flow. Since traffic is modelled with this level-of-detail, different road environments

will place different requirements on the simulation models. The requirements on a model used to simulate the traffic flow on a rural road are substantially different from the requirements on a model used for traffic in an urban or motorway network, due to fundamental differences in the interactions between vehicles and the infrastructure. The travel time delay in an urban or motorway network is dominated by vehicle-vehicle interactions, whereas the travel time delay on a rural road is also significantly influenced by interactions between vehicles and the infrastructure. For example, speed adaptation with respect to the road geometry has a more prominent role on rural roads than it has on urban streets. A model describing traffic flows on rural roads must therefore consider the interaction between vehicles and the infrastructure in greater detail than models for urban or motorway traffic. Interactions between vehicles are nevertheless important on rural roads, particularly in overtaking and passing situations on two-lane rural roads. 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. Time headways between vehicles that are to enter the simulation are also determined according to a platoon generation model that takes into account the ease of overtaking slower vehicles on the modelled road.

A time-based simulation approach with a user defined time step is applied in RuTSim. The model is developed to handle one rural road stretch in each simulation, i.e. rural road networks are not considered. The simulated road may incorporate intersections and roundabouts and the main road traffic may be interrupted by vehicles entering or leaving the main road at intersections along the simulated stretch. Traffic flows entering the road at various origins may be time dependent and off-turn percentages at intersections for each traffic flow are used to determine vehicle destinations. RuTSim is a stochastic simulation model. Random numbers are used in the assignment of vehicle properties, e.g. desired speed

and power to mass ratio, and in the overtaking decision process, to determine if an overtaking opportunity will be accepted or not. Simulations with different random number generator seeds will consequently give different results. Multiple simulations with different random number generator seeds have to be conducted to estimate distributions of the results. These distributions can be compared to day-to-day variations in real traffic.

The RuTSim implementation is designed to be as flexible as possible to allow future modification of the model including simulation of driver assistance systems. 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. Previous applications of the RuTSim model include rural road design analysis (Carlsson and Tapani, 2006) and a study of the effects of longitudinal control driver assistance systems (Lundgren and Tapani, 2006). A detailed description of the RuTSim model including both the general model properties and the models controlling vehicle movements is given by Tapani (2005).

2.3.2 Modelling the overtaking assistant

The overtaking decision-making process in RuTSim is governed by four conditions; the vehicle's ability to overtake, the possibility to overtake considering the surrounding traffic, possible overtaking restrictions and the driver's will to overtake. Stochastic functions of the following form are used to determine a driver's willingness to overtake:

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

where $P[s]$ is the overtaking probability given s , defined by the minimum between the clear sight distance, and the distance to the next oncoming vehicle. A and k are parameters that reflect the impact of road widths, types of overtaking, overtaken vehicles and sight limiting factors i.e. natural obstacles or oncoming vehicles on the shape of the probability distribution function $F(s)$. The threshold $s_{min}^{flying/acc}$ is the minimum required distance for flying or accelerated overtaking. The probability distribution functions of the equation above are fitted to empirical data collected on two-lane roads in Sweden. Distinct functions are estimated for different road widths, types of overtaking, overtaken vehicle and sight limiting factor, i.e. natural obstacles or oncoming vehicles. Complete descriptions of the overtaking probability functions, including the estimation process, are given by Carlsson (1990, 1991). Example overtaking probability functions for the road modelled in this simulation study, a two-lane road with good sight conditions that is narrower than 11 m, are shown in Figure 2. The overtaking probabilities for overtaking of cars are shown for situations when the car to overtake travels faster than 90 km/h and the overtaking probability functions for overtaking of different types of trucks are shown for trucks with speed lower than 90 km/h.

< place fig 2 about here >

The overtaking assistant has been modelled in RuTSSim under the assumption that the assistant influences only the assisted drivers' willingness to overtake. For equipped vehicles in the simulation, the stochastic overtaking probability functions have been replaced by a deterministic procedure:

$$P[t, s] = \begin{cases} 1, & (t, s): t > t_{min}^{assistant}, s > s_{min}^{flying/acc}, \\ 0, & otherwise, \end{cases}$$

where $P[t, s]$ is the overtaking probability given distance s and time t , to the next oncoming vehicle. The parameter $t_{min}^{assistant}$ is the overtaking assistant threshold and $s_{min}^{flying/acc}$ is the minimum clear distance for flying or accelerated overtaking. This implies that vehicles equipped with the overtaking assistant will accept an overtaking opportunity if the time to the next oncoming vehicle is longer than the overtaking assistant threshold. This simple model corresponds to full driver compliance with the overtaking assistant, which is supported by the experimental data.

Simulations using eight random number generator seeds were performed for all the considered alternative overtaking assistant threshold settings and traffic penetration levels. This number of replications was subjectively selected based on the widths of the resulting confidence intervals for the selected performance indicators. The resulting interval widths are different for different performance indicators. Intervals for overtaking frequencies, which are heavily dependent on the properties and the order of individual vehicles on the road, will be wider than intervals for travel speeds. Intervals for equipped vehicles in traffic with low overtaking assistant penetration rate will similarly be wider than intervals in traffic with high assistant penetration rate. It was determined that eight replications are sufficient in order to secure reasonably small differences in the selected performance indicators.

2.4 Studied road and traffic

The studied road is a part of the N305 between Almere and Zeewolde in the central part of the Netherlands. This is an approximately 20 km long and 8 m wide two-lane rural road with a speed limit of 100 km/h for passenger cars. Trucks and all vehicles with trailer have a speed limit of 80 km/h. Figure 3 contain a schematic picture of the studied road. The road is located

in level terrain with clear views. The conditions for overtaking on the road can therefore be considered to be ideal. A 5 km long section of the studied road, without intersections, is selected to study impacts of the overtaking assistant. This study of the overtaking assistant under ideal overtaking conditions will enable showing the maximum impacts of the overtaking assistant.

< place fig 3 about here >

The origin-destination matrix used for this study is based on traffic observations on the N305 during an off-peak period, between 13.00 and 16.00 in the afternoon. For this time period, there were two days of observations of traffic entering and leaving the selected 5 km stretch available (Hegeman, 2008). Data from one of these days were used for calibration of the model and the other for validation, i.e. only one set of traffic measurements was available for calibration and validation respectively. This data is not sufficient to allow estimation of the day-to-day variation in flows, speeds and overtaking frequencies. The results of the calibration and validation are presented by Tapani et al. (2008). In this contribution, we compare the relative situation for different overtaking assistant thresholds and traffic penetration levels. The purpose of the RuTSim calibration and validation in the context of this contribution is therefore to ensure correct orders of magnitude of the performance indicators derived from the simulation results. Small differences between the simulation results and observed data are of minor importance for the analysis presented in this contribution. Table 2 contains an overview of the simulation results for the calibrated RuTSim model and the observed data.

< place table 2 about here >

2.5 Performance indicators

Effects of the overtaking assistant on traffic efficiency, driver comfort and safety are to be studied. To measure whether or not, and to which extent, these dimensions of traffic are influenced by the overtaking assistant, performance indicators for each of the three traffic properties are needed (ADVISORS, 2002). Table 3 gives an overview of the selected performance indicators. All of these performance indicators are amongst the standard output measures of RuTSim.

Two commonly used and accepted indicators of traffic efficiency are Average Travel Speed (ATS) and delay. ATS is the average speed over a road section and delay is the extra time spent on the road in the current traffic condition compared to the time spent on the road under ideal conditions. RuTSim calculates ATS for arbitrary road sections along the simulated stretch. The travel speeds over a section are summed up and divided by the total number of vehicles that have travelled on the section to obtain the ATS of one simulation run. ATS is calculated for all vehicle types that are included in the simulated traffic. To obtain the delay, travel times calculated from the results of “free driving” simulation runs, without vehicle-to-vehicle interactions, are subtracted from the travel times from normal traffic simulation runs, including vehicle-to-vehicle interactions. Both the “free driving” and the normal simulation runs are performed using the same random number generator seed to ensure that travel times of vehicles with the same properties are compared.

< place table 3 about here >

To measure driver comfort, Percent Time Spent Following (PTSF) and overtaking frequency (OF) are used as indicators. PTSF in combination with ATS are often used to estimate the

level-of-service of a two-lane rural road (HCM, 2000). PTSF is obtained from the simulation results by summation of the times that vehicles travel with headway to the vehicle in front shorter than a certain threshold. The threshold used in this study is 5 s. This headway threshold is also suggested in the Highway Capacity Manual to estimate PTSF (HCM, 2000).

The second applied indicator of driver comfort is overtaking frequency, i.e. the number of overtaking manoeuvres per kilometre-hour. This indicator is for obvious reasons of high importance in a study of the impacts of an overtaking assistant. Overtaking frequency is obtained from the simulation results by counting the number of overtaking manoeuvres that have been performed on a section of the simulated road. To allow comparisons of the overtaking frequencies for assisted and non-assisted vehicles in traffic with different overtaking assistant penetration rates, overtaking frequencies per 1000 vehicles is presented. Each overtaken vehicle is counted as one overtaking maneuver, overtaking of multiple vehicles during one overtaking manoeuvre is counted as multiple overtaking manoeuvres in the calculation of the overtaking frequency.

Time-to-collision (TTC) with an oncoming vehicle during overtaking is used to estimate safety effects of the overtaking assistant. TTC is the time left to collision between two vehicles if they remain on their paths and continue with constant speeds (Hayward, 1972). The two TTC based indicators introduced by Minderhoud and Bovy (2001) are also used. These measures use a critical TTC threshold to distinguish safety critical situations from situations in which the driver remains in control. Time exposed TTC (TET) is a summation of the times spent with sub-critical TTC and therefore an indicator of the extension of possibly safety critical situations. Time integrated TTC (TIT) is the time integration of the difference between the critical and actual TTC during the time spent with sub-critical TTC.

TIT can therefore be viewed as a measure of the severity of safety critical situations. The critical TTC was set to 3 s to calculate TET and TIT. This value was also used by Minderhoud and Bovy (2001). TET is obtained from the simulated vehicle trajectories as

$$\text{TET} = \sum_{i=1}^N \sum_{t=0}^T \delta_i(t) \cdot \tau,$$

where

$$\delta_i(t) = \begin{cases} 1, & 0 \leq \text{TTC}_i(t) \leq \text{TTC}^* \text{ and vehicle } i \text{ is overtaking,} \\ 0, & \text{otherwise,} \end{cases}$$

$\text{TTC}_i(t)$ is the TTC with an oncoming vehicle during overtaking for vehicle i in time step t .

The simulation time step is denoted τ , N denotes the total number of vehicles and T is the simulation horizon. TIT is obtained by

$$\text{TIT} = \sum_{i=1}^N \int_0^T (\text{TTC}^* - \text{TTC}_i(t)) \cdot \delta_i(t) dt.$$

The notation used to define TIT is the same as the notation used for TET.

2.6 Expected impacts of the overtaking assistant

Table 4 presents the expected effects of different overtaking assistant threshold and traffic penetration rates. A long overtaking assistant threshold implies that large gaps in the oncoming traffic stream are needed to allow overtaking. This leads to fewer overtaking opportunities for the equipped vehicle than a short overtaking assistant threshold. ATS is therefore expected to decrease with increasing overtaking assistant threshold. PTSF and overtaking frequency are for the same reason expected to decrease with increasing overtaking assistant threshold. Lager assistant threshold is expected to result in longer TTC with the first oncoming vehicle at the end of overtaking manoeuvres. TET and TIT are for this reason expected to decrease with increasing overtaking assistant threshold.

< place table 4 about here >

Larger overtaking assistant penetration rates means that more vehicles are equipped with the overtaking assistant. Averages of the performance indicators for the assisted vehicles will therefore be calculated over a larger group of vehicles and the group of non-assisted drivers will become smaller. It is expected that larger assistant penetration rates will result in increased ATS and decreased delay for the assisted vehicles. In traffic with a larger proportion of equipped vehicles, there is a possibility that more drivers will choose to overtake. There can consequently be fewer vehicles left to be overtaken. PTSF is therefore expected to decrease with increasing overtaking assistant penetration rate. The impact of the overtaking assistant penetration rate on overtaking frequency is difficult to predict, there is a possibility that more vehicles will perform overtaking manoeuvres, but fewer vehicles may be left to be overtaken. The net effect on overtaking frequency is difficult to predict. To allow comparisons, the overtaking frequencies are given per 1000 vehicles. This is done to avoid the effect that more vehicles of certain type will result in a higher overtaking frequency for that vehicle type. For non-assisted vehicles, all of the selected performance indicators are expected to be uninfluenced by the overtaking assistant penetration rate.

3 Simulation results

This section presents the results of the simulations with different overtaking assistant threshold and traffic penetration rate. The previously presented Dutch rural road section and traffic situation is used as a basis of the simulations. The studied overtaking assistant thresholds are 8, 9.5, 11, 12.5 and 14 s, with 100 % traffic penetration rate and 100% compliance with the assistant's advice. The assistant threshold 8 s is used for simulations with 5, 10, 25, 50 and 100 % overtaking assistant traffic penetration rate. Effects of the overtaking assistant threshold and traffic penetration rate are investigated using the indicators ATS,

delay, PTSF, overtaking frequency per 1000 vehicles, TTC, TET and TIT. All simulations are repeated using 8 random number generator seeds. Average values and corresponding 95 % confidence intervals are presented for all of the selected indicators.

3.1 Effects of different overtaking assistant threshold

Figure 4 shows ATS and delays for assisted vehicles with different assistant threshold and for non-assisted vehicles. Direction Almere – Zeewolde (A-Z) is the direction with the higher traffic flow, about 400 veh/h. Direction Zeewolde – Almere (Z-A) is the opposite direction with a traffic flow of about 290 veh/h. The graphs contain averages with corresponding 95 % confidence intervals and fitted linear trend lines. The same structure, notation and abbreviations are used in all figures throughout the results section.

As can be seen in Figure 4, ATS decreases with increasing overtaking assistant threshold. The 8 s threshold results in the largest ATS, with this threshold the overtaking vehicles accept overtaking manoeuvres in gaps of 8 s or larger in the oncoming traffic stream. The speed in the direction with the higher traffic flow (A-Z) is higher than the speed in the opposite direction. This is due to that drivers in the direction with the higher traffic flow will meet less oncoming traffic than drivers in the direction with the lower flow. There will consequently be more overtaking opportunities for vehicles in the higher flow. The effect of the assistant threshold setting is smaller in the direction with the lower traffic flow. Apparently, an increase of the overtaking assistant threshold from 8 s to 14 s does not increase the number of overtaking opportunities as much as in the opposite direction. The larger effect of the assistant threshold setting in the direction with the higher traffic flow is not only explained by more overtaking opportunities for traffic in this direction. Longer vehicle platoons will also allow more vehicles to be overtaken during the overtaking manoeuvres. This will contribute to the larger effect of the overtaking assistant threshold. The ATS of the base scenario is close to the

ATS for the assistant threshold 11 s. ATS was expected to decrease for larger thresholds.

This effect is confirmed by the simulation results.

< place figure 4 about here >

The average delays for traffic in both directions are roughly between 12 and 15 s for all assistant thresholds. The length of the studied road section is about 5 kilometres, a delay of 15 s means that drivers who would have liked to travel at 100 km/h, has travelled through the section with a speed of about 92 km/h. Note that this calculation is only meant to give an indication of the size of the delays. The absolute values of the simulation results may differ from the real situation on the N305 since there are differences between the simulation results of the base scenario and traffic observations (Tapani et al., 2008). The delays in the direction with the higher traffic flow are slightly lower than in the direction with the lower traffic flow. As for ATS, the delays for the 11 s second assistant threshold are similar to the delays for the simulation with no assisted drivers. It was expected that the delays would increase with increased assistant threshold. The simulation results confirm this expectation.

Figure 5 displays the resulting PTSF. In both directions, drivers spent more than half of the travel time following another vehicle. Shorter assistant threshold results in lower PTSF. This effect is larger in the direction with the larger traffic flow (A-Z). Notice the narrow confidence intervals for the different thresholds. Apparently, the stochasticity of the model has little impact on PTSF. As for the indicators ATS and delay, the PTSF of the base scenario with no assisted drivers was similar to the PTSF for the assistant threshold 11 s. It was

expected that PTSF would increase with increasing overtaking assistant threshold. This expectation is confirmed by the simulation results.

< place figure 5 about here >

Figure 6 shows the resulting overtaking frequencies. In the direction with the larger traffic flow, the overtaking frequencies decrease from just over 30 to a just over 20 overtakings per kilometre and hour and 1000 vehicles when the overtaking assistant threshold is increased from 8 to 14 s. The confidence intervals for the overtaking frequencies are wide. The number of overtakings varies considerably between simulations with different random number generator seed. This variance is smaller in the direction with the lower traffic flow. In this direction, the overtaking frequency for the assistant threshold 8 s is about half of the overtaking frequency in the direction with the higher traffic flow. For the 14 s assistant threshold, the overtaking frequency in the direction with the higher traffic flow is more than double the overtaking frequency in the direction with the lower traffic flow. Together, this implies that the absolute impact of the threshold setting is larger in the direction with the higher traffic flow and that the relative impact is larger in the direction with the lower traffic flow. The overtaking frequency of the base scenario with no assisted drivers is in between the overtaking frequencies of the 9.5 and 11 s assistant thresholds. It was expected that overtaking frequencies would decrease with increasing overtaking assistant threshold. This effect is confirmed by the simulation results for both driving directions.

< place figure 6 about here >

Figure 7 displays the minimum TTC, TET and TIT during overtaking situations. The 8 s overtaking assistant threshold results in the shortest minimum TTC. The minimum TTC increases linearly with increasing overtaking assistant threshold. Note that the minimum TTC in the direction with the lower traffic flow becomes shorter than 3 s for the 8 and 9.5 s assistant thresholds. It was expected that TTC would increase with increasing overtaking assistant threshold. This is confirmed by the simulation results.

< place figure 7 about here >

The total time spent in safety critical situations, TET, and the severity of the critical situations, TIT, are as expected decreasing with increasing overtaking assistant threshold. The time spent with sub-critical TTC approach 0 s for the 14 s overtaking assistant threshold. A positive result of the functionality provided by the overtaking assistant is that for all assistant threshold settings both TET and TIT are smaller than in the base scenario with no assisted drivers.

3.2 Effects of different overtaking assistant traffic penetration rates

Figure 8 indicates that the ATS for assisted vehicles, in the direction with the larger traffic flow (A-Z), are higher than the ATS for non-assisted vehicles for all overtaking assistant penetration rates. The confidence intervals for assisted vehicles are wider than the intervals for non-assisted vehicles for low assistant penetration rates. This is caused by the relatively low number of assisted vehicles that the intervals are based on. In the direction with the lower traffic flow, there is no recognisable trend in ATS for different overtaking assistant penetration rate. The ATS in this direction are about 89 km/h for both assisted and non-assisted vehicles. It was expected that increased overtaking assistant penetration rates would increase ATS for the assisted drivers. This expectation is not supported by the simulation

results, the ATS for assisted vehicles is found to decrease with increasing overtaking assistant penetration rate. An explanation for this finding is that assisted drivers in the same platoon compete for the same overtaking opportunities. Therefore, as the overtaking assistant penetration rate increases, more assisted vehicles will be prevented from overtaking by other overtaking vehicles. The ATS of the assisted drivers will therefore decrease with increasing assistant penetration rate. The ATS of non-assisted drivers is, in accordance with the expectations, not influenced by the overtaking assistant penetration rate.

< place figure 8 about here >

As can be seen in Figure 8, there are only small differences in the delay for different overtaking assistant penetration rates. In the direction with the higher traffic flow (A-Z), there is a tendency of shorter delays for assisted vehicles in traffic with low assistant penetration rates. This effect can not be seen in the results for the direction with the lower traffic flow. The delay for non-assisted vehicles is, in accordance with the expectation, not influenced by the overtaking assistant penetration rate. It was expected that increased assistant penetration rate would result in decreased delays for the assisted drivers. This expectation is not confirmed by the simulation results. Delay and ATS are closely related, this finding can therefore, as for ATS, be due to increased competition for overtaking opportunities as the overtaking assistant penetration rate increases.

Figure 9 displays PTSF for different overtaking assistant penetration rates. There are no trends in the PTSF for different assistant penetration rates. Non-assisted vehicles have higher PTSF than assisted vehicles, there are however one exception and only small differences. Another finding is that assisted drivers spend less time than non-assisted drivers following

other vehicles in the direction with the lower traffic flow. Decreasing PTSF for assisted vehicles with increasing assistant penetration rate was expected. This expectation is not confirmed by the simulation results. However, in the direction with the higher traffic flow, PTSF for assisted vehicles in traffic with 50 % assisted vehicles is lower than in traffic with 10 or 25 % assisted vehicles. The PTSF for non-assisted drivers is, in accordance with the expectations, not influenced by the assistant penetration rate.

< place figure 9 about here >

The effect of the assistant penetration rate on overtaking frequency is small. Figure 10 shows that no relationship between overtaking frequency and the assistant penetration rate could be established. In addition, there are only small differences, with highly overlapping confidence intervals, between the overtaking frequencies of assisted and non-assisted vehicles. It was difficult to predict the impact of the assistant penetration rate on the overtaking frequency of assisted vehicles. An increase of the assistant penetration rate was expected to increase the number of vehicles that are willing to overtake. There will consequently be fewer vehicles left to overtake. These counteracting mechanisms may prevent any impact of the assistant penetration rate on overtaking frequency. Another possible cause of this finding is, as discussed above, increased competition for the overtaking opportunities with increasing assistant penetration rate. The overtaking frequency for non-assisted vehicles is, in accordance with the expectations, not influenced by the overtaking assistant penetration rate.

< place figure 10 about here >

Finally, Figure 11 displays the minimum TTC, TET and TIT during overtaking for traffic with different overtaking assistant penetration rate. These indicators are similar for assisted and non-assisted vehicles and no relationships between the indicators and the assistant penetration rate could be established. Traffic safety, in terms of TTC and TTC based indicators, are therefore not influenced by the overtaking assistant penetration rate. This finding is in accordance with the expectations. In general, the TTCs are longer in the direction with the higher traffic flow (A-Z) than in the other direction. This is a result of shorter gaps between vehicles in higher traffic flows.

< place figure 11 about here >

4 Main findings and conclusions

A microscopic traffic simulation study of potential traffic system effects of an overtaking assistant has been presented. The overtaking assistant assists the driver in judging whether or not an overtaking opportunity on a two-lane road can be accepted based on the time gap to the next oncoming vehicle. An overtaking advice is given to the assisted driver when a time gap larger than a certain threshold is established. The rural road traffic simulation model RuTSim is applied to model the overtaking assistant. The overtaking assistant functionality was implemented in RuTSim and effects of different assistant threshold setting and traffic penetration rate was investigated by means of traffic simulation of a Dutch two-lane rural road. The RuTSim model was calibrated and validated for this road using two traffic observations. The purpose of the model calibration and validation is to ensure correct orders of magnitude of the studied performance indicators. The results of interest are however the differences between assisted and non-assisted vehicles in the simulated traffic. The absolute values of the performance indicators are only of minor importance for this study.

4.1 Main findings

All impacts of the overtaking assistant threshold setting were in accordance with the expectations. The effects on traffic efficiency in terms of average travel speed and delay were small. A larger relative impact of the overtaking assistant threshold on overtaking frequency could be established. This leads to the conclusion that an overtaking assistant could improve individual driver comfort without negatively influencing traffic efficiency. Short overtaking assistant thresholds were found to have negative consequences for traffic safety in terms of TTC and TTC based indicators. Three seconds is a commonly used critical TTC to distinguish safety critical situations from situations in which the driver remains in control (Minderhoud and Bovy, 2001; Hoogendoorn, 2000). An appropriate overtaking assistant threshold should be selected to avoid TTCs shorter than 3 s. The simulation results indicate that an overtaking assistant threshold of 11 s is sufficient to fulfill this requirement. However, a short overtaking assistant threshold is desirable to maximise driver comfort in terms of overtaking frequency and percent time spent following. The shortest of the considered assistant thresholds, 8 s, was therefore chosen to study potential impacts of different overtaking assistant traffic penetration rate.

No impacts of increasing overtaking assistant penetration rate could be established. Contrary to the expectations, increased overtaking assistant penetration rate did not improve the performance indicators for assisted vehicles. This can be explained by increasing competition for the existing overtaking opportunities with increasing overtaking assistant penetration rate. Given the 8 s assistant threshold, assisted drivers will accept a given overtaking opportunity more often than non-assisted drivers. Increasing assistant penetration rate will therefore result in more vehicles willing to overtake and fewer vehicles left to be overtaken. This

counteracting mechanism resulted in unchanged overtaking frequencies for different overtaking assistant penetration rates.

The TTC based safety indicators were found to be similar for assisted and non-assisted vehicles for all overtaking assistant traffic penetration rates. The conclusion is therefore that an 8 s assistant threshold will not increase the risk of the overtaking manoeuvres of the assisted vehicles. There is also a potential to reduce the risk of overtaking manoeuvres by introduction of an overtaking assistant with a longer assistant threshold. An overtaking assistant with a threshold of 11 s can accomplish this without negative consequences for traffic efficiency and driver comfort.

4.2 Conclusions

The performed simulations have demonstrated that it is possible to use microscopic traffic simulation to study traffic effects of driver assistance systems that support overtaking manoeuvres. Changes in the drivers' willingness to overtake were aggregated to traffic effects through the simulation. The impacts of different assistant thresholds and traffic penetration levels were studied in a straightforward manner. Differences in the effects depending on the directional split of the flow on the road could also be observed. Microscopic traffic simulation is found to be an efficient tool for traffic impact studies of driver assistance systems that support overtaking manoeuvres.

4.3 Directions for further research

Full compliance to the advice of the overtaking assistant was assumed in this simulation study. Driver behaviour in relation to the overtaking assistant was therefore not considered. The next step in the analysis of potential traffic effects of an overtaking assistant would be to account for driver behaviour in relation to the overtaking assistant. This includes studies of

the effects of differences in driver compliance and overtaking behaviour. Driver behaviour observed in the driving simulator study performed by Hegeman et al. (2007) provides an appropriate starting point for this task. The overtaking assistant has so far been developed without consideration of the driver's knowledge of the road ahead. Road alignment, sight distances along the road and appropriate stretches for overtaking should be taken into account by a future overtaking assistant that is introduced to real traffic. More simulations should be carried out to study the impact of assistant penetration rate on traffic flow, i.e. to find an optimal overtaking assistant penetration rate. Combinations of other overtaking assistance developments, as with the in the introduction chapter referred "pass prediction assistant" enlarges the application area of the overtaking assistant. Impacts of such a further developed overtaking assistant can also be studied using traffic simulation.

More detailed analyses of the impacts of the overtaking assistant will become appropriate to support later stages of the system development. Analyses using inference statistics based on traffic simulation results can provide guidelines for both the system development and the following introduction of an overtaking assistant in the traffic system.

There is a general need for increased use of observed driver behaviour for microscopic traffic simulation studies of driver assistance systems. System functionalities such as speed limiters or distance controllers have been modelled in detail in previous simulation studies. Changes in driver behaviour due to driver assistance systems have usually not been considered. The driver will however for the foreseeable future remain responsible for the driving process. There is consequently a potential to increase the reliability of traffic simulation based estimations of the effects of driver assistance systems by increased use of observed driver behaviour.

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Table 1 Overview of the simulated alternatives

	Overtaking assistant Threshold [s]	Traffic penetration rate [%]	Driver compliance [%]
Base scenario	-	0	-
Overtaking assistant threshold scenarios	8, 9.5, 11, 12.5, 14	100	100
Overtaking assistant penetration rate scenarios	8	5, 10, 25, 50	100

Table 2 Observed traffic measures of the N305 Almere – Zeewolde and the corresponding RuTSim simulation results

	Almere-Zeewolde		Zeewolde-Almere	
	Observation	Simulation	Observation	Simulation
Average hourly traffic flow [vehicles/h]	396	401	288	289
Average spot speed[km/h]	88.3	88.8	87.9	88.3
Standard deviation of the spot speed [km/h]	6.8	7.7	6.9	8.0
Truck percentage of the traffic flow [%]	12.4	11.1	14.7	11.0
Overtaking frequency [#/(km · h)]	17.3	17.2	8.7	6.6

Table 3 Considered traffic properties and the selected performance indicators

Efficiency	Driver comfort	Safety
Average Travel Speed Delay	Percent Time Spent Following Overtaking Frequency	Time to Collision (TTC) Time exposed TTC Time integrated TTC

Table 4 Expected effects of different overtaking assistant threshold and traffic penetration rates

Expected effect	Increased assistant threshold will (increase/decrease) the indicator	Increased assistant traffic penetration rate will (increase/decrease) the indicator	
indicator		Assisted vehicles	Non-assisted vehicles
Average Travel Speed (ATS)	decrease	increase	No effect
Delay	increase	decrease	No effect
Percent Time Spent Following (PTSF)	increase	decrease	No effect
Overtaking Frequency	decrease	increase / decrease	No effect
TTC	increase	No effect	No effect
Time Exposed TTC	decrease	No effect	No effect
Time Integrated TTC	decrease	No effect	No effect

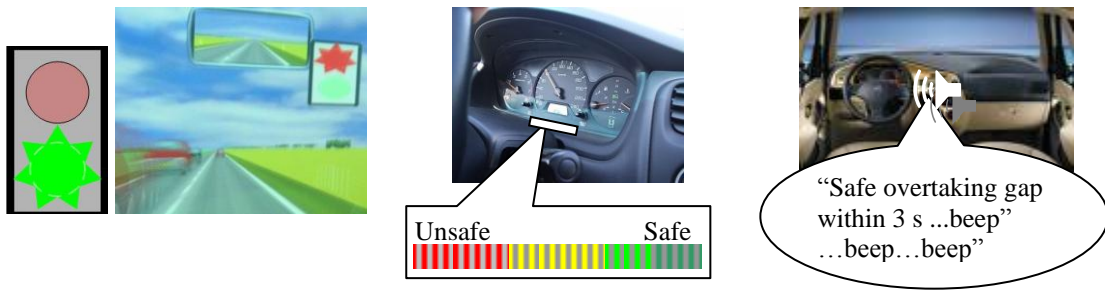


Figure 1 Example designs of the human machine interface of the overtaking assistant

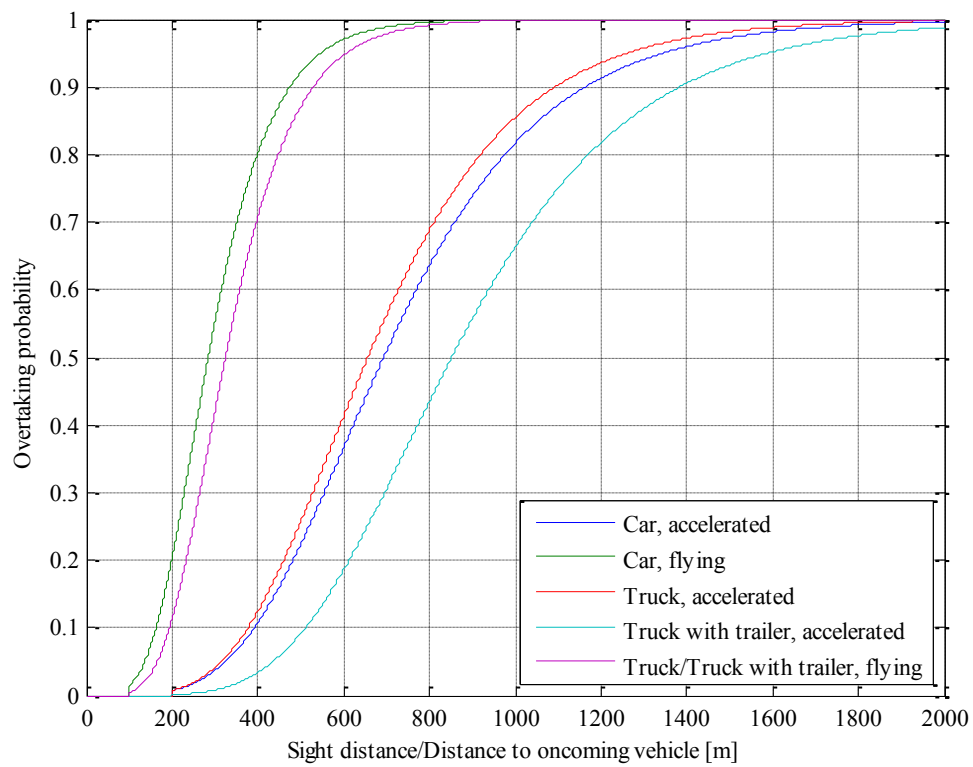


Figure 2 Examples of the RuTSim overtaking probability functions for accelerated and flying overtaking of different vehicle types on two-lane rural roads narrower than 11 m

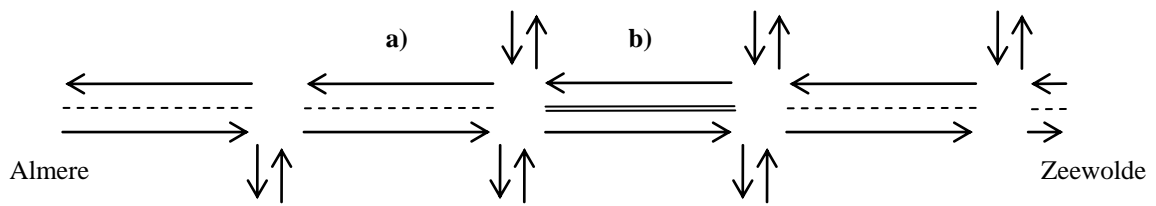


Figure 3 Schematic picture of the N305 Almere – Zeewolde in the Netherlands. Observation data were available for sections a) and b). Effects of the overtaking assistant are presented for traffic on section a)

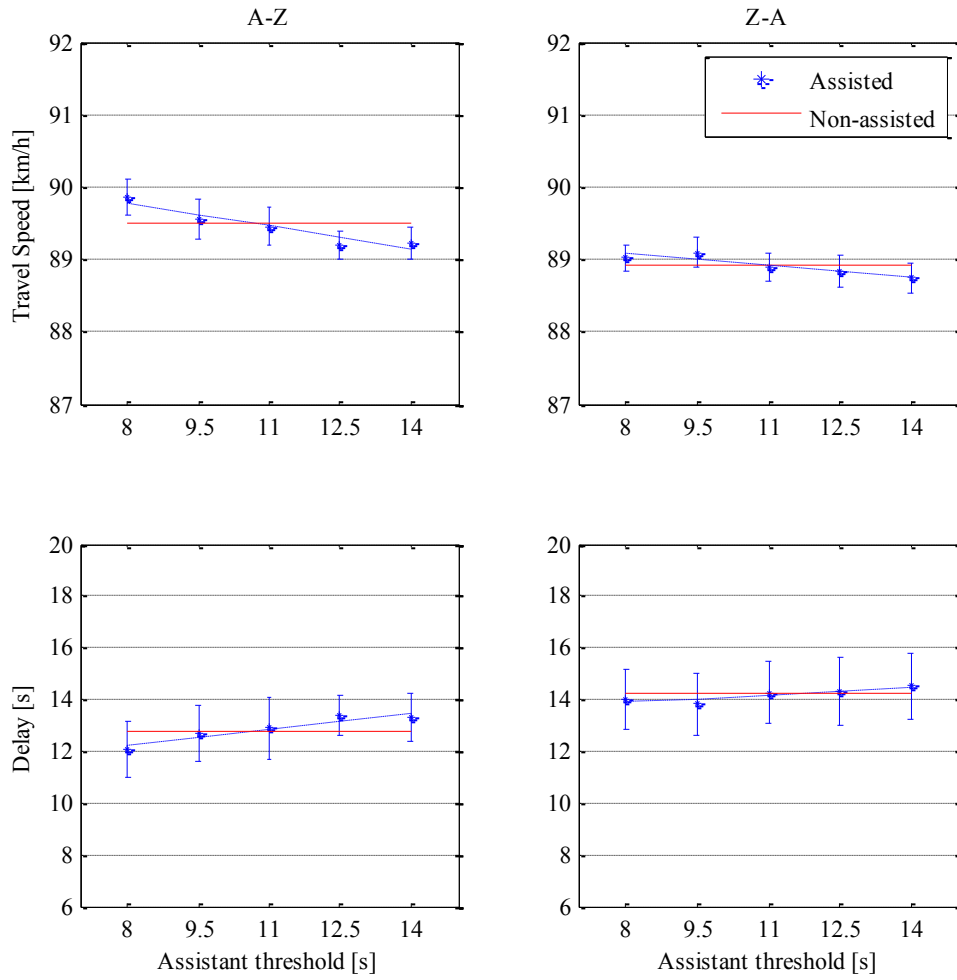


Figure 4 Average travel speed (ATS) [km/h] and delay [s] for assisted vehicles with different overtaking assistant thresholds, 95 % confidence intervals, and for non-assisted vehicles in direction A-Z and Z-A

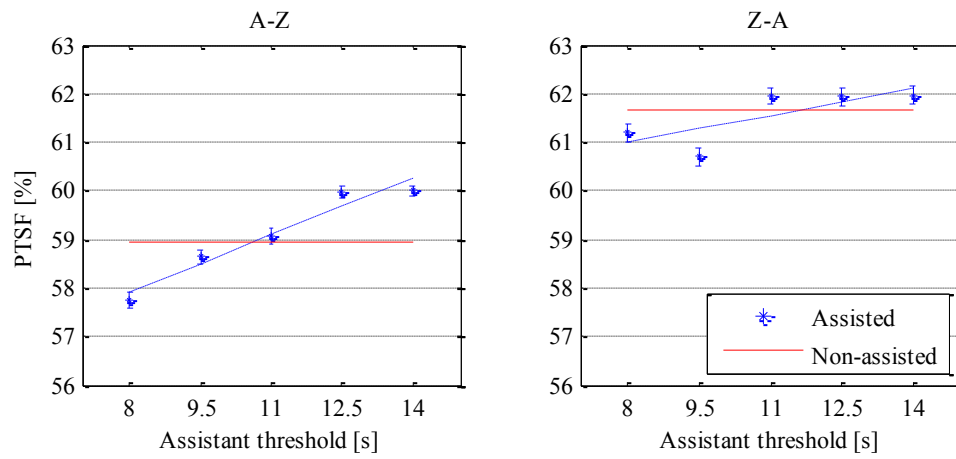


Figure 5 Percent time spent following (PTSF) for assisted vehicles with different assistant threshold, 95 % confidence intervals, and for non-assisted vehicles in direction A-Z and Z-A

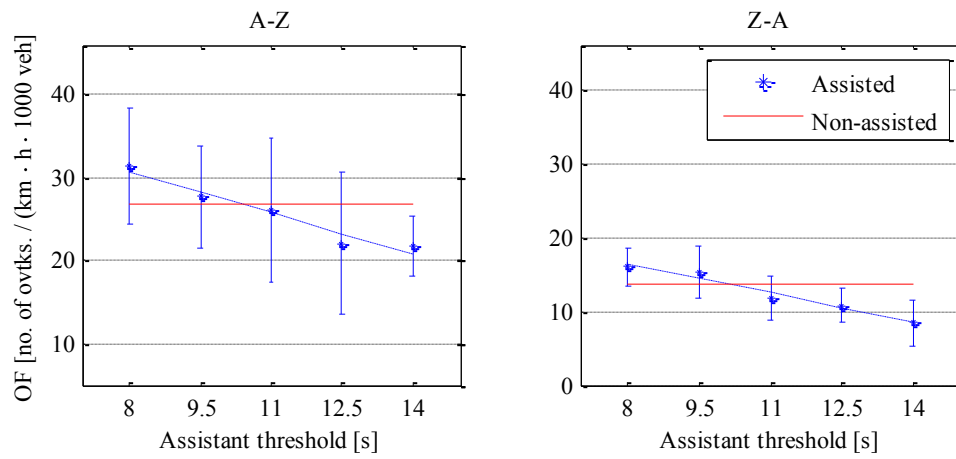


Figure 6 Overtaking frequency (OF) per 1000 vehicles for assisted vehicles with different assistant threshold, 95 % confidence intervals, and for non-assisted vehicles in direction A-Z and Z-A

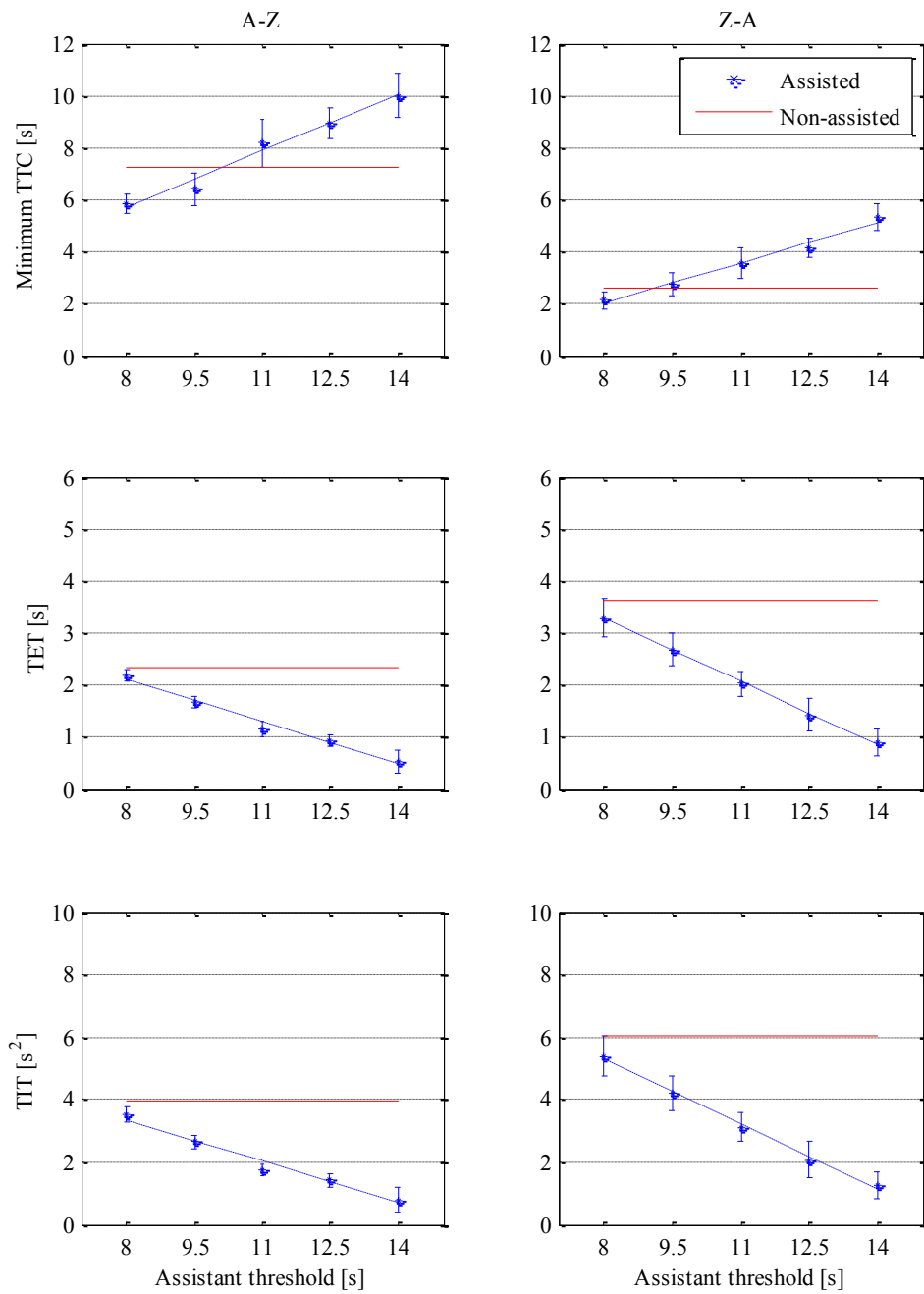


Figure 7 Minimum Time-To-Collision (TTC), time exposed TTC (TET), and time integrated TTC (TIT) for assisted vehicles with different assistant threshold, 95 % confidence intervals, and for non-assisted vehicles in direction A-Z and Z-A

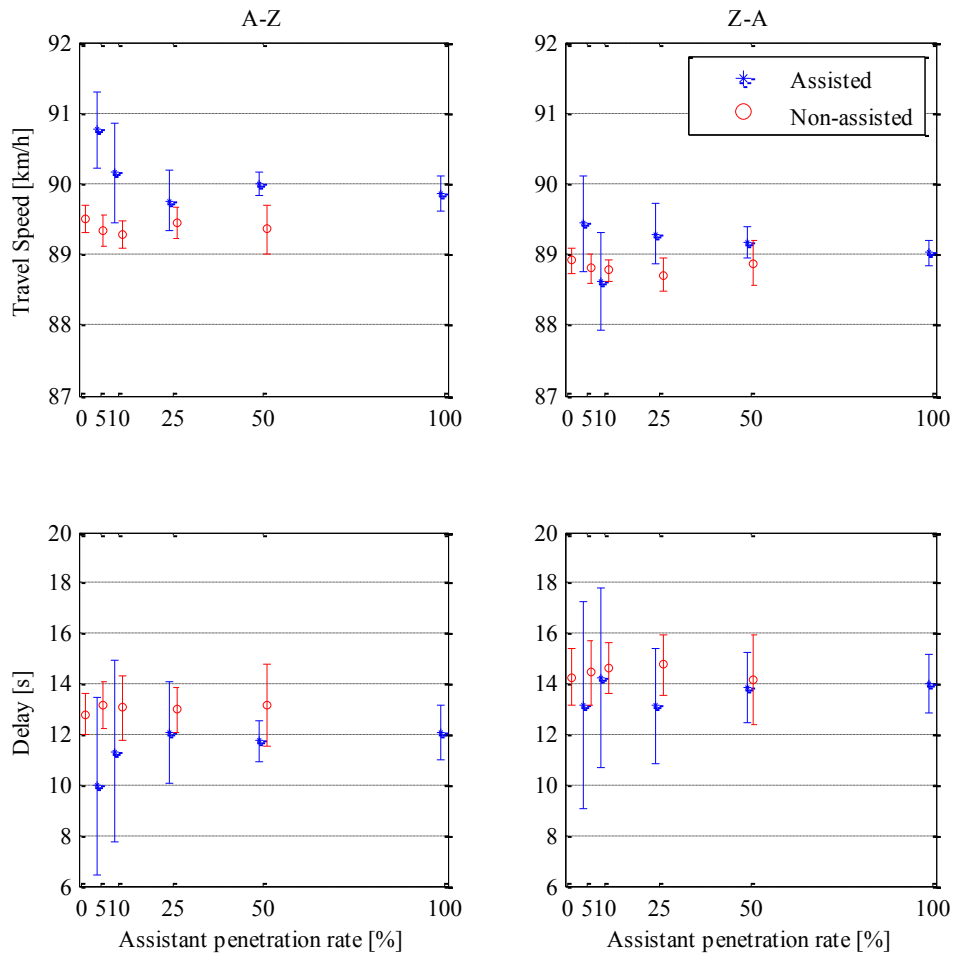


Figure 8 ATS and delay for assisted and non-assisted vehicles in traffic with different overtaking assistant penetration rate in direction A-Z and Z-A, 95 % confidence intervals

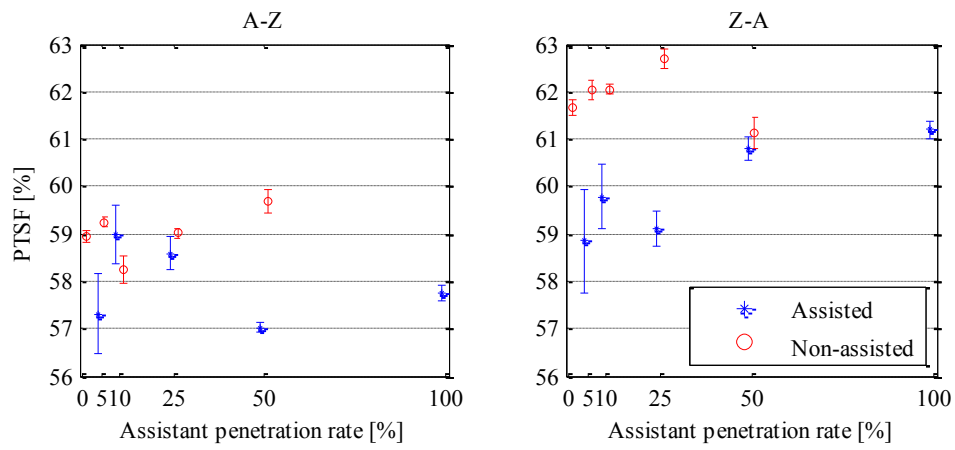


Figure 9 Average PTSF for assisted and non-assisted vehicles in traffic with different overtaking assistant penetration rate in direction A-Z and Z-A, 95 % confidence intervals

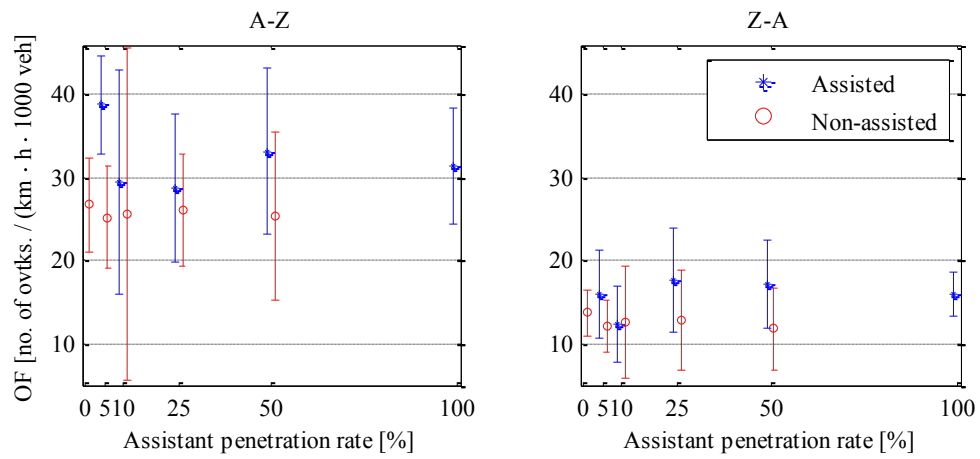


Figure 10 Average overtaking frequency per 1000 vehicles for assisted and non-assisted vehicles in traffic with different overtaking assistant penetration rate in direction A-Z and Z-A, 95 % confidence intervals

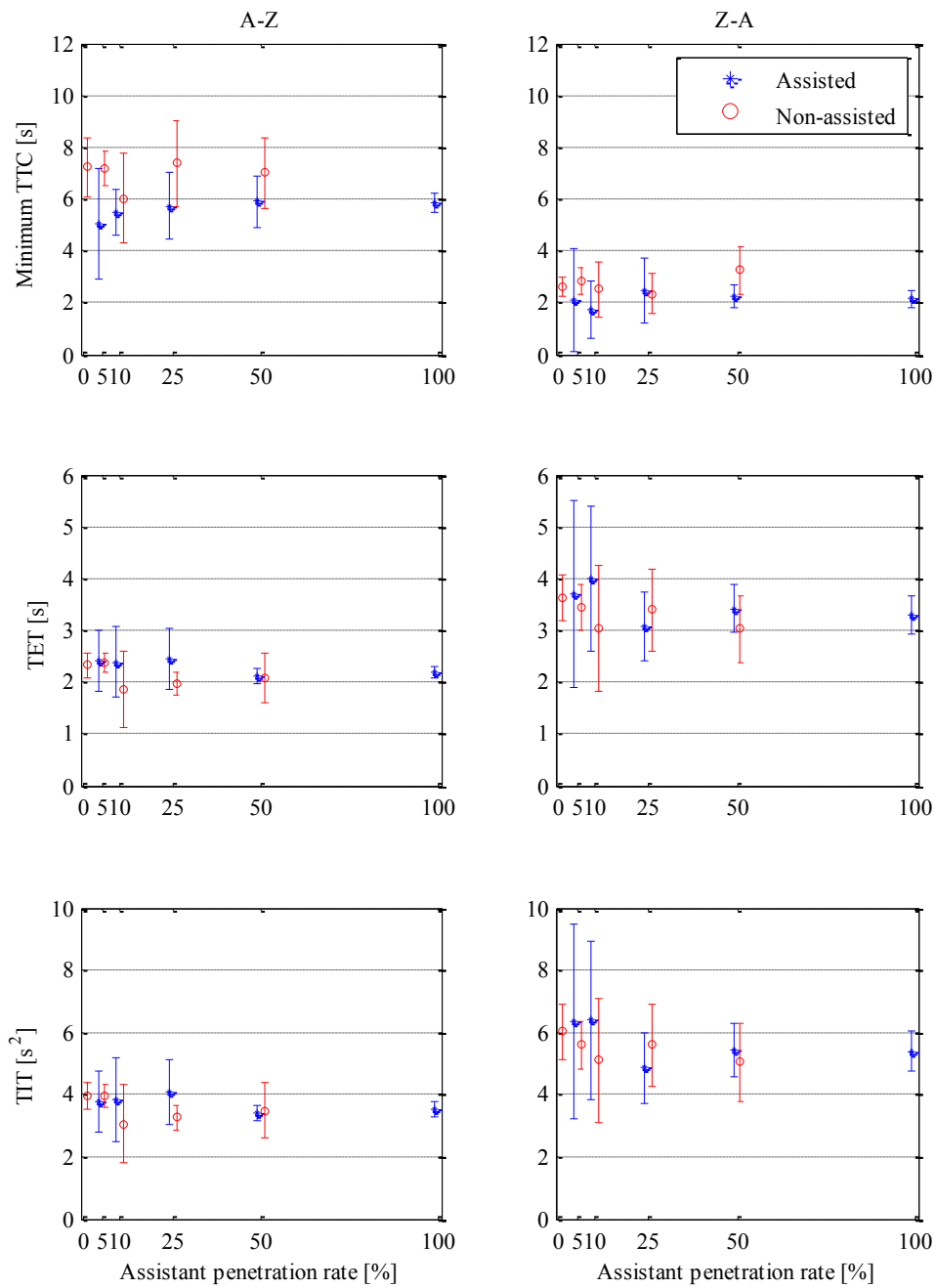


Figure 11 Average minimum TTC, TET and TIT with respect to oncoming vehicles during overtaking for assisted and non-assisted vehicles in traffic with different overtaking assistant penetration rate in direction A-Z and Z-A, 95 % confidence intervals