Evaluating ADA technologies in the Netherlands by means of demonstration projects and micro-simulation modelling

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ABSTRACT

At the beginning of the 1990’s the philosophy of Sustainable Safety was developed. This resulted in the implementation of the Start-up programme, a pro-active road safety programme that entailed re-classifying the road network, expanding 30km/h urban residential areas and 60km/h rural areas, assigning priority on arterials, safety for cyclists and bicycles, roundabouts etc. Evaluations suggest that these measures have significantly contributed to a further 7% reduction in traffic fatalities over the period 1998-2003. However, the most dangerous roads, namely the rural and urban distributor roads, have not been re-engineered. Since these roads are especially difficult and require large-scale investment and large areas of land, it is not anticipated that all roads will ultimately comply with the requirements of sustainable safety. Furthermore, it is not realistic to expect all roads to be engineered in such a way that road user behaviour always complies with intended behaviour. Considering the limitations in terms of finances, traffic management and engineering measures, and innovation is going to play an all-important role in providing future solutions (for example 3-lane roads, crash barriers, ADA/AVG, ISA etc).

Specific attention will need to be paid to heavy goods transport in the future. Projections indicate that heavy goods vehicle (HGV) traffic will double by 2020 and will constitute 40% of the total traffic on the major road network. The consequences of accidents involving HGV are well known. To compound the problem in the Netherlands is the fact that the country has an ageing society which means that in time society as a whole becomes more vulnerable. Because of these developments, road safety is being seriously threatened, especially since road accidents involving HGV almost always result in fatalities or serious injuries. In the future road designers and the automobile industry will need to consider these matters when designing roads or designing vehicles with advanced driver support systems.

It is important to stimulate developments in the vehicle sector, especially with respect to in-car safety devices for vehicle occupants but also to mitigate the effects of accidents involving vulnerable road users. Specific attention needs to be paid to developments with respect to advanced vehicle guidance systems (especially collision warning and avoidance systems). Although effects are generally assumed to be positive, policy makers must be aware of any potential negative effects and therefore research into causative factors of vehicles with such technology needs to be conducted.

Amongst others this paper discusses the results of the second phase of the Dutch FOT examining the effects of lateral support systems [AVV, 2001], namely the traffic effects of the Chauffeur Assistant (CA) Driver Assistance System (AVV, 2004). The research included a literature study, the (changes to) driver behaviour with CA assessed in the TNO Human Factors' driving simulator, and finally the incorporation of these results into the TNO Inro MIXIC traffic simulation model. The model was used to assess the traffic flow effects of large scale CA implementation in the HGV sector. The CA control algorithms were developed and adapted by TNO Automotive and TNO Human Factors and based on information provided by Daimler-Chrysler in terms of the HMI and functionality of the CA.

Overall it is concluded that the introduction of Chauffeur Assistant in the HGV sector, assuming its use is limited to the primary road network of the Netherlands, will have no negative effects on traffic flow. The results of the MIXIC simulations do not suggest that significant changes will occur in any of the variables describing the quality of traffic flow (travel times, speeds, density etc.) and traffic safety (shockwaves, TTC, headways etc.) should CA be introduced in the HGV sector. The drivers participating in the driving simulator study did indicate that their perceived workload decreased when CA was used. As mentioned, compensating behaviour in these cases is not yet known, but worth examining in the future.

The drivers participating in the driving simulator study did indicate, though, that their perceived workload decreased when CA was used. As mentioned, compensating behaviour in these cases is not yet known, but worth examining in the future.

The effectiveness of CA system could significantly be enhanced if the system were applicable in other circumstances as well: whether by equipping other types of vehicles, such as passenger vehicles, with the system, or by extending the operational range to below the standard minimum speed by integrating a stop&go system in the CA.

Introduction

Being a geographically small and densely populated country with a highly developed road network, the Netherlands is continually being challenged to meet the growing demand for mobility whilst ensuring acceptable levels of congestion and sustainable levels of road safety. Until now the Netherlands has been able to maintain the delicate balance between the supply of road capacity and traffic demand. However, government has realised that infrastructure provision is in itself no permanent remedy to meet the growing demand. Given the limited availability and cost of valuable land, building new roads is become less and less viable. This presents an interesting challenge to policy makers in the country, either accept growing levels of congestion or develop alternatives to either manage the demand or to increase the capacity of existing infrastructure. The first has been rejected in government policy. The National Traffic and Transport Plan sets out objectives to reduce the number, duration and length of queues on the primary Dutch road network. This is to be achieved by providing a package of measures that manage the supply and demand chain. On the supply side ways need to be developed with which to optimally utilise existing road space. On the demand side ways are being investigated to discourage private automobile use, stimulate public transport and other means of non-motorised transport and using in-vehicle technology as an enabler to increase roadway capacity. Irrespective of these ambitions, government has committed itself to ensuring that road safety is at worst not comprised and at best improved to even higher levels.

Within this context this paper explores opportunities relating to in-vehicle technologies and especially active lane keeping systems (lateral control), distance keeping systems (such as Automatic Cruise Control and enhancements thereof) and combinations of these two.

Background – Chauffeur Assistant

Lateral support systems are in-vehicle technologies aimed at helping a driver keep within the lane boundaries. These systems have particular potential for single-vehicle run-off the road incidents where driver fatigue, drowsiness or inattention play a role. Lateral support systems can be categorised into lane departure warning systems (passive systems such as LDWA) and lane keeping systems (active and semi-active systems such as LKS and Chauffeur Assistant). This paper discusses the active version of lateral support systems.

Chauffeur Assistant (CA) is a development within the greater European Chauffeur-2 project (Brandenburg et al., 2002) and comprises a lane keeping system (LKS) and a Smart Distance Keeping (SDK) system. The lane keeping system keeps the vehicle in the desired lane by continually tracking the lane markings and sending data (status information) to the CA-computer for analysis and action (steering is not necessary). The SDK system is based on adaptive cruise control (ACC) technology that monitors relative speed and distance to leading vehicles or obstacles in the roadway. It takes into account the dynamic capabilities of other vehicles and:

- Recognises the target object (car, obstacle truck etc.)
- Keeps the shortest gap distance under the prevailing conditions
- Warns the driver when a stationary object is detected
- Continually monitors and sends data to the CA-computer

The CA system is activated when a driver approaches a target vehicle and switches the system on. The system then keeps the vehicle in its lane whilst continually monitoring and maintaining a constant gap to the lead vehicle. The CA is a support system and does not totally take control of the vehicle. The driver is responsible for operating the system and it is up to the driver when to activate or deactivate the system

Goals of the Field Operational Test

The research plan for the Field Operational Tests (FOT) aimed at addressing three systems that belong to a class of Advanced Driver Assistance (ADA) systems (AVV, August 2001). The three systems included in the FOT were LDWA, Lane Keeping (LKS) and Chauffeur Assistant systems. This paper discusses the evaluation of CA.

The LDWA evaluation was based on field trails and driving simulator studies whereas the evaluation of CA is based on evaluations using a driving simulator and microscopic simulation using a suitable dynamic traffic model.

The main objective was:

To assess the primary and secondary impacts of (DE)CA implementation on traffic flow and especially on throughput.

The Research Framework anticipated that the effects on traffic flow would be estimated on the basis of primarily literature research followed by the development of implementation scenarios and finally on the outcomes of various microscopic traffic simulations.

Since (DE)CA is a new concept, subsequent behavioural and vehicle models will need to be developed which describe the driving behaviour in traffic with CA, for example, lane changing behaviour and following behaviour may be different with and without the CA. These models need to be developed, calibrated and validated on the basis on experiments in a mock up truck simulator equipped with a state-of-the-art DECA system. These models would need to be incorporated into a traffic simulation model that would be used to model the various implementation scenarios under the chosen road and traffic conditions. Subsequently, the information gained from the truck simulations were incorporated into the traffic simulation model MIXIC.

Selection of an appropriate model

Based on the broad objectives of the study it was decided to use the MIXIC model (van Arem et. al.) to simulate the various scenarios describing the implementation of Chauffeur Assistant in the Netherlands. A prime consideration in the selection of the model was the ability to simulate lane changing behaviour in combination with ICC/ACC operation. Although MIXIC did not have this capability it was decided to further develop the model to incorporate this behaviour. To facilitate this, the TNO Human Factors was commissioned to use their driving simulator to research the various behavioural parameters required to adapt MIXIC.

Adapting MIXIC to accommodate Chauffeur Assistant

The Chauffeur Assistant system described by deliverable D1 of Promote Chauffeur 2 (Brandenburg et al., 2000) incorporates a combined ACC and LKS. Considering that development of the systems is barely at the prototype stage implies that the traffic flow effects can only be estimated on the basis of traffic flow simulation. However the MIXIC model had to be further developed to incorporate the LKS functionality into the normal lane change behaviour. To define the different values of the parameters used by the vehicle and driver modules incorporated in MIXIC required further behavioural research using a driving simulator equipped with a Chauffeur Assistant system. Once these parameters were defined and incorporated into the model, the model could be tested and validated against the results obtained from the simulator.

The driving simulator study: The effects of CA on driving behaviour

TNO Human Factors developed a moving base truck simulator (Hogema, Hoekstra, Verschuren, 2003) that was used to determine the effects of CA on driving behaviour. The simulator uses a mock-up based on a DAF 95XF rigid truck cabin mounted on a moving base (Figure 1). The controls in the cabin are standard and incorporate a fully functional CA system. A computer model calculates the motion of the simulated truck through the world, based on the input of the driver. The simulator incorporates image and sound projection coupled to various computers. A supervisor computer controls traffic and other functions.

Figure 1: TNO Truck driving simulator (Picture courtesy of TNO Human Factors, Soesterberg, Netherlands)

To enable ACC operation the simulator was fitted with an automatic transmission. The ACC controller was based on that implemented in the MIXIC model (van Arem et. al., 1995) and based on the following:

Car following distance $D_{ref} = 6.0 + t_k \times V$

Where D_{ref} = Intended ACC following distance (m)

V = current speed (m/s)

t_k = following time (selectable at 1.0; 1.3 or 1.6 seconds)

The maximum deceleration applied by the ACC was 3.0 m/s^2. To demonstrate the validity of the simulator outputs, five scenarios were run and compared to the MIXIC reference model (Hogema, September 2003). The reference model of MIXIC refers to the model used in previous studies. The lateral and longitudinal control modules of this model were modified using the results obtained from the driving simulator. The results obtained with ACC operating in the driving simulator under the above scenarios showed a high degree of similarity to those obtained from the reference model.

The Lane Keeping System (LKS) in the driving simulator was based on information obtained from Daimler-Chrysler. In terms of the functionality and performance of their CA. The LKS was based on a straight lane design (Hogema and Burry, 2002) and modified to incorporate lane keeping (without offsets) in corners.

The vehicle model of the simulator receives steering wheel inputs from the LKS when the CA is active. Noise was introduced to ensure that lateral control performance was realistic. The noise level was adjusted to actual driving speed so that the standard deviation of the lateral position (SDLP) was at a user defined level. Off line tests with a reference SDLP value of 10cm showed that the realised SDLP was also 10cm and that the amplitudes were within the range specified by Daimler-Chrysler.

In practice the use of the CA system is voluntary and can be activated via a switch on the steering column. The CA system tested in this study had the ACC and LKS operating together and the driver could not activate the one without the other. In addition to using the on/off switch for engaging/disengaging the system, the CA is also deactivated when applying the brakes or turn indicators. When activated the CA dashboard display shows the ACC set speed and an indication of the ACC state (speed or headway control). The CA emits an audio warning when the maximum acceleration of the ACC is reached.

Data collection

Eighteen professional truck drivers with a minimum of 5 years driving experience and aged between 25 and 55 years participated in the driving simulator experiment (Hogema, July 2003). A within-subjects design was adopted in which drivers drove one test trip to familiarize themselves with the driving simulator, subsequently followed by 4 trips covering 4 conditions with 2 independent variables (Traffic volume and CA, each with two levels) and under two traffic conditions. Drivers drove on a standard motorway with gentle horizontal curves and under normal weather and visibility (daytime) conditions.

During the trial run, the functionality of the CA system was explained to the drivers. As part of this the 3 possible headway settings were demonstrated and following the trial run drivers were asked to select their preferred setting. They were instructed to use this setting for the remainder of the experiment.

In order to evaluate driver reaction with and without CA, a number of unexpected braking manoeuvres were programmed into the simulation. These were introduced on a quasi-random basis with a leading vehicle unexpectedly braking three times during a run, twice at 3,0 m/s^2 (within range of the CA system) and once at 4,0 m/s^2 (Out of range of the CA system).

Data for each run were captured at a frequency of 10 Hertz by the simulator computers. These included time, speed, position on the road, the state of the CA (on/off and speed/headway setting); steering wheel angle, position and speed of traffic in the immediate vicinity. In addition drivers were asked to complete a questionnaire the end of each run. The questionnaires are used as a measure of mental effort (Rating Scale Mental Effort) and to test acceptance of a particular concept or system.

Data Analyses

For the purpose of the analysis, conscious or intended lane changes (i.e. a lane change is defined as the middle of the vehicle crossing the lane boundary and remaining there for longer than 5 seconds) were excluded from the analysis.

Analysis of Variance (ANOVA) tests were performed on the various dependent variables, generally using traffic volume and CA-state as independent variables. Tukey post-hoc tests were used to determine the statistical significance of differences between specific conditions. The measurement of steering wheel angle whilst driving with CA was excluded from the analysis (CA includes a LKS which actively supports lane keeping).

Although drivers were instructed for which runs they had to activate CA, there were situations during the run where the CA state could be temporarily switched off (by the system itself, or by the driver). For this reason all data for the runs with CA-on were analysed twice. The first analysis included all the data for these runs and the second analysis excluded those data where the CA had been de-activated.

Results

Use and choice of headway settings

For the condition where the CA was on during the run it was active for 84 percent of the time when traffic volumes were low (<3400vph) and 87 percent of the time when traffic volumes were high (>6000vph). During the times that CA was on the majority of drivers opted for time headway settings (controlling following distance) of 1,3 and 1,6 seconds.

The average speeds recorded with vehicles where the CA was switched off, irrespective of volume were, around 81,3km/h. With the CA on the average speed ranged between 81,9 (low volume) and 80,5 km/h (high volume). The interaction between traffic volume and CA-state had no significant effect on average speeds. The standard deviations of speed (a measure of acceleration noise) at both low and high traffic volumes were slightly smaller with the CA-state on than with the CA-state off. However, these differences are not significant nor are they affected by the interaction between traffic volume and CA-state.

The analysis revealed that the percentage of the trip time spent in the right lane was affected by the interaction between traffic volume and CA on (more time is spent in the right hand lane with the CA on than with the CA off). This effect is more pronounced at lower volumes. Traffic volume has a significant effect on this behaviour. However, the mean number of lane changes per trip was not materially affected by traffic volume. As expected (CA incorporates a LKS), the average number of lane changes with CA on was lower than with CA off at the same levels of traffic flow. There was no significant effect on the number of lane changes resulting from interactions between the independent variables.

Mean lateral position

One would expect vehicles with CA to drive more in the centre of a lane than vehicles without. In this analysis the lateral position was measured from the edge of the right lane to the right hand side of the vehicle. A value of 0,5m would constitute driving in the centre of the lane (0,5 clearance right + 2,5m vehicle width + 0,5 clearance left = 3,5m lane width). Although the differences are marginal (and not significant), the CA on state resulted in the vehicle travelling more to the centre of the lane and irrespective of the traffic volume (Table 1). At high volume and with the CA active, drivers drove more to the centre of the lane.

Table 1: Mean lateral position

Independent variable		Mean lateral Position (meas. from right edge) (cm)
Traffic volume (vph)	CA state	
3400	Off	23,4
3400	On	24,5
6000	Off	22,8
6000	On	30,98

Standard Deviation of the lateral position (SDLP)

The standard deviation of the lateral position (SDLP) is an indication of the effort it takes a driver to maintain a straight line within a lane and over a distance travelled. In this evaluation SDLP was significantly reduced with CA on when compared to the situation with CA off and keeping traffic volumes constant (trucks swerve less with the CA on). There was also a noticeable effect between low and high traffic volumes (Table 2).

Table 2: Standard deviation of lateral position

Independent variable		Standard deviation (cm)
Traffic volume (vph)	CA state	
3400	Off	34,9
3400	On	12,4
6000	Off	36,3
6000	On	12,6

The analysis of standard deviation revealed that the values of the standard deviation of lateral position, especially with the CA off, were higher than one would normally expect on relatively standard cross-sections.

A number of possibilities may explain this behaviour:

1. The size of the mock-up cabin in the simulator environment could have played a role;
2. Driving in a simulator requires more effort than in a normal road situation resulting in a higher SDLP;
3. A number of parameters used in the lateral vehicle model (mass, moment of inertia, wheelbase etc etc.) collectively determine the relation between the driver input (steering wheel angle) and the vehicle response (yaw rate). The values of these parameters were provided by DAF. In retrospect, the dynamic behaviour of the model was somewhat too sluggish. This resulted in the vehicle reacting more slowly than normal on steering input and consequently the lateral movement was more pronounced.

Time to line crossing

Time to line crossing (TLC) is used as an indicator of traffic risk (Brouwer and de Ridder, 2003). The TLC is an indication of the theoretical time it would take the vehicle (assuming no change in course or speed) to cross the line marking. Should a vehicle travel parallel to the line the value of TLC is infinite whereas it continually decreases the closer the vehicle gets without any corrective action. TLC’s below 1 second are considered a high risk.

The time to line crossing was determined by:

$TLC = D/V_{lat}$

Where D is the distance to the line (m) and V_{lat} is the lateral velocity (m/s)

TLC’s were analysed on the basis of the average of all TLC’s below 10 seconds (Table 3) and also on the proportion of these times where the TLC’s were below 1 second (Table 4). The average value of minimum TLC was dependent on the state of the CA at both volume regimes. It is evident that the value of minimum TLC is significantly higher when the CA is active (See Appendix D for detailed analyses). Traffic volume has no significant effect on the value of minimum TLC.

Table 3: Average value of TLC minima (left) below 10 seconds

Independent variable		Average minimum TLC (left) (s)
Traffic volume (vph)	CA state	
3400	Off	2,47
3400	On	3,51
6000	Off	2,32
6000	On	3,36

Traffic volume and CA state had no significant effect on the proportion of time where the TLC was below 1 second (Table 4.7). Typically one third of the minimum TLC's (<10 seconds) were smaller than 1 second and there were marginal differences between conditions.

Table 4: Proportion of TLC's (left) less than 1 second

Independent variable		Time TLC (left) < 1 sec (%)
Traffic volume (vph)	CA state	
3400	Off	34,4
3400	On	33,9
6000	Off	34,9
6000	On	29,6

Mean headway

An analysis of the amount of time spent travelling at headways of less than 5 seconds revealed no significant effects resulting from either traffic volume or CA-state (Table 5). An expected trend was evident at higher volumes with more time being spent driving at smaller headways. The effect of CA was marginal and not significant.

Table 5: Proportion of trip time with headways less than 5 seconds

Independent variable		Prop. Time headway < 5 sec (%)
Traffic volume (vph)	CA state	
3400	Off	58,9
3400	On	60,0
6000	Off	65,8
6000	On	69,0

Seeing that CA uses fixed headway settings it would be reasonable to expect differences in the percentage of travel time spent at headways of equal to or less than 1 second (Table 6).

Table 6: Proportion of trip time with headways less than 1 second

Independent variable		Prop. Time headway ≤ 1 sec (%)
Traffic volume (vph)	CA state	
3400	Off	2,49
3400	On	0,50
6000	Off	4,50
6000	On	0,68

Considering that the headways of the CA in this experiment could not be set below 1 second it was expected that the proportion of time spent at headways smaller than this would be limited to occurrences where vehicles cut-in. The proportion of time spent at headways less than 1 second is significantly higher in conditions without CA. There also is a marked increase in this time at higher volumes and without CA.

The mean headways calculated from the sample of conditions where vehicles were assumed to be following (i.e. headway < 5 seconds) revealed that there were no significant differences between the conditions. Neither traffic volume nor CA had a material effect on the average headways although there appeared to be a trend effect with higher volumes causing marginally lower average headways in cases in which CA was on (Table 7).

Table 7: Average headway (all headways less than 5 sec.)

Independent variable		Avg. headway (s)
Traffic volume (vph)	CA state	
3400	Off	2,91
3400	On	2,86
6000	Off	2,75
6000	On	2,59

Braking Experiments

During each run in the simulator, drivers were confronted with three separate and unexpected events in which the leading vehicle would brake. Two events with moderate braking (3,0m/s^2) and one with extreme braking (4,0m/s^2) were randomly introduced in each simulator run. The drivers had one of two options in these situations, either change lanes or brake.

The above resulted in a total of 216 events where the lead vehicle unexpectedly braked. The events were evenly distributed over the two traffic volume regimes (see Schermers and Malone, 2004 for details). Six of these events were discarded because the scenarios were not correctly executed (Table 8). In 25% of these braking events (54 cases) drivers chose to change lanes. Only 16 per cent of the braking events with CA on result in a lane change whereas this proportion almost doubles (34%) with CA off.

Table 8: Lanes changes resulting from lead vehicle braking

Condition	Braking resulting in (number of manoeuvres)							
	No lane change		Lane change		Missed events		Total	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%
CA Off	66	61%	37	34%	5	5%	108	100%
CA On	90	83%	17	16%	1	1%	108	100%
Total	156	72%	54	25%	6	3%	216	100%

With respect to the degree of braking and disregarding CA state (on or off), a higher proportion of lane changes occurred when the lead vehicle braked hard (35% - Table 9). Some 20% of drivers following a vehicle that brakes moderately change lanes.

Table 9: Lanes changes forced by moderate to violent braking

Degree of braking	Braking resulting in (number of manoeuvres)			
	No lane change	Lane change	Missed events	Total
Moderate	101	26	0	127
Hard	43	24	0	67
Missed events	12	4	6	22
Total	156	54	6	216

The successfully conducted events in which no lane change took place (144 cases, the green-shaded cells in table 9) were further analysed to determine the potential safety risk in terms of the minimum time to collision and maximum deceleration criteria. Unfortunately a full factorial analysis of variance (ANOVA) was not possible due to the limited number of observations with complete sets of data. Consequently the following results are based on ANOVA's of only the main effects:

- The time to collision with the lead car braking moderately was significantly larger than under hard braking conditions (5,3 vs. 4,3s - Table 10).
- At the heavy traffic volume, a shorter TTC was evident.
- The situation with the CA switched on had a longer time to collision than when it was switched off (5,2 vs. 4,1s).

Table 10: Minimum time to collision

Condition	Min. time to collision (s)	Significant effect * denotes yes
Moderate braking Hard braking	5,34 4,26	F (1,15) = 8,12* P<0,0122
Vol < 3400vph Vol < 6000vph	5,16 4,47	F(1,16) = 5,11* P<0,0381
CA off CA on	4,09 5,21	F(1,16) = 10,63* P<0,0049

With respect to maximum deceleration, there were no significant effects on deceleration rates resulting from high or low traffic volume or from CA use (Table 11). Interesting to note is that with the CA in the "On" state, the (average) maximum deceleration rate is lower than in the "Off" state. This could imply that drivers rely on the CA to initiate deceleration to the maximum CA level (3,0m/s^2) before themselves braking and hence a less harsh braking action than with the CA off.

Table 11: Effect on maximum deceleration

Condition	Max. deceleration (m/s^2)	Significant effect * denotes yes
Moderate braking Hard braking	-3,47 -4,28	F (1,15) = 12,44* P<0,0031
Vol < 3400vph Vol < 6000vph	-3,73 -3,83	F(1,16) = 0.20 P<0,6587
CA off CA on	-4,30 -3,54	F(1,16) = 4,18 P<0,0578

Rating Scale Mental Effort

Drivers participating in the experiment were asked to complete a rating form (Rating Scale Mental Effort – RSME) following each trip in the truck simulator. The form gives a subjective indication of the mental effort required to complete a task. The analysis shows that traffic volume does not affect the perceived mental effort whereas the state of the Chauffeur Assistant has an effect (Table 4.15). The subjective mental rating with the CA "On" is significantly less than with the CA "off". This implies that the CA is perceived to make the driving task easier.

Table 12: Effect on maximum deceleration

Condition	Perceived mental effort (0=no effort, 102 = extreme effort)	Significant effect * denotes yes
Low vol < 3400vph	44,4	F (1,17) = 2,81
High vol < 6000vph	49,0	P<0,11
CA off	58,1	F(1,17) = 14,6*
CA on	35,2	P<0,001
Low volume CA Off	54,3	F (1,17) = 1,75; p < 0,20
Low volume CA On	34,4	
High volume CA Off	61,9	
High volume CA On	36,0	

The combination of traffic volume and CA-state has an effect on perceived effort (Table 12). At both volume regimes, the perceived mental effort is significantly higher with the CA switched off and with drivers rating the task as fairly to reasonably strenuous. Drivers rated the degree of effort with the CA switched on as "slight" and that irrespective of traffic volume. This result is different to a recent simulator study with a Lane Departure Warning Assistant (LDWA) system (Brouwer and de Ridder, 2003). In this study respondents perceived the mental effort of driving with an LDWA system to be significantly higher than driving without an LDWA system. LDWA differs from CA in several ways: LDWA is simply a lane departure warning system, whereas CA has (1) ACC, (2) lane *keeping* and (3) integration of ACC and LKS. This combination could reduce the perceived effort. On the other hand one must be cautious in interpreting these results. Little is known of the behaviour that drivers may adopt to compensate for the reduced mental workload. These effects will need to be carefully assessed and understood before definitive conclusions can be drawn regarding positive or negative effects.

Changes to the MIXIC model

The driving simulator study formed the basis for the proposed changes that would need to be introduced in the MIXIC model. When reviewing the results of the driving simulator consideration had to be given to the functionality of both the CA and the original MIXIC model (Hogema, September 2003). Of importance was the interaction between the CA system and the driver model in MIXIC. In real life there is an interaction between the driver and the CA. The driver may choose to switch it off or to leave it on. When switched on the CA can be deactivated when the driver uses the turn indicator to change lanes or when he uses the brakes (voluntarily or as advised by the CA).

To be able to take account of these issues the driver model in MIXIC had to be adapted on the basis of a choice between essentially two options requiring the driver model to take over control when situations requiring hard braking occur. In the first case the driver model monitors the car following situation and when certain criteria regarding headway, speed etc. are met, the driver model takes over control from the CA. In the second the model takes over control after a certain reaction time and when the maximum CA deceleration is reached and the audio warning is sounded.

System alerts the driver model

The MIXIC model was modified so that a warning (audible) is given the instant that the CA reached its maximum deceleration level. At this point the driver model deactivates the CA system and takes control of the vehicle (Hogema, September 2003). In an earlier version of MIXIC the warning was generated on the basis of a calculated braking distance (van Arem, et.al 1997).

With this control scenario the driver model will always deactivate the CA when maximum deceleration is reached. In real life a driver will assess the situation and decide on whether intervention is necessary. Both the brake control scenarios rely heavily on the maximum deceleration rate of the CA system and therefore it was decided to use the first strategy in preference to the strategy based on only warning.

Lane change behaviour

The driver simulator study suggested that driving with CA reduced the number of lane changes although this effect was just below the level of statistical significance (Hogema, September 2003). The CA did not materially affect the amount of time driving in the right hand lane. This latter result is surprising in the light of previous research with ACC that indicated that the proportion of time in the left lane increases with ACC use (Saad and Villame, 1996; Törnros et. al 2002 – in Hogema, September 2003). The effect on lane changing frequency was not always reported but in one study these were reported to decrease with ACC use (Saad and Villame, 1996 – in Hogema, September 2003).

These considerations need to be further examined in the future to determine the relevance for incorporating changes in lane change behaviour in the MIXIC model. These issues remain outside the scope of this study.

Traffic simulations with Chauffeur Assistant

The HGV simulator study formed the basis for adapting certain parameters in the MIXIC model to better simulate lateral and longitudinal driving behaviour of HGV in a traffic stream. The ACC algorithm used in MIXIC was modified for CA. A more realistic lateral vehicle movement was incorporated, based on driving simulation test results described in the research report (Schermers and Malone, 2004).

The original MIXIC model did not contain a sub model for lateral behaviour. It was assumed that the lanes were dimensioned in a way that vehicles would not be influenced in their longitudinal control behaviour by vehicles in adjacent lanes. In a later study (Tampere, 1999) a rudimentary form of lateral behaviour was added to evaluate the impact of narrow lanes on traffic flow and capacity. The model could be parameterised so that the LKS of the CA is emulated in various degrees of effectiveness. The parameters for lateral behaviour can be set in such a manner that simulated vehicles do not deviate from the centre of the lane as would be expected with a perfect LKS.

The MATLAB model developed by TNO Automotive served as the reference ACC model that was subsequently incorporated into the TNO Human Factors driving simulator. Driving behaviour in the simulator was found to correspond to the reference model. Based on this the MIXIC ACC model was modified and validated. A number of scenario’s were modelled and the results, despite some small differences, were similar (Schermers and Malone, 2004). These small differences in the modelled outputs were attributed (van Katwijk, September 2003) to differences in the time step intervals of the two models (0.1 second in MIXIC vs. 0.01 s in MATLAB). Furthermore the more complex nature of the MIXIC vehicle model requires a longer initialisation period resulting in some discrepancies between the two outputs at the beginning of the modelled period. Once the MIXIC model had stabilised the results were very similar to that produced by MATLAB.

Conclusion

It is concluded that the introduction of Chauffeur Assistant in the HGV sector, assuming its use is limited to the primary road network of the Netherlands, will have no negative effects on traffic flow. The results of the MIXIC simulations do not suggest that significant changes will occur in any of the variables describing the quality of traffic flow (travel times, speeds, density etc.) and traffic safety (shockwaves, TTC, headways etc.) should CA be introduced in the HGV sector.

The drivers participating in the driving simulator study did indicate, though, that their perceived workload decreased when CA was used. As mentioned, compensating behaviour in these cases is not yet known, but worth examining in the future.

The effectiveness of CA system could significantly be enhanced if the system were applicable in other circumstances as well: wither by equipping other types of vehicles, such as passenger vehicles, with the system, or by extending the operational range to below the standard minimum speed by integrating a stop&go system in the CA.

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