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A Quick Scan of Quantified Effects of Advanced Driver Support Systems

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ADASE II Extension

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1 Introduction

The Transport Research Center (AVV) of the Dutch Ministry of Transport, Public Works and Water Management asked TNO Inro to carry out a quick literature scan of quantitative results available on the effects of Advanced Driver Assistance (ADA) Systems. ADA systems support the driving task at the maneuver and tactical levels. Specifically, AVV requested that a database of these results be created, making use of the categorization and systems defined in the ADASE II Roadmap [Ehmanns and Spannheimer, 2004], followed by an analysis of the systems described in and a comparison with the results contained in the “ADASE 2 Expert Workshop on effects of ADA systems on safety, throughput and comfort”. The goal was to create on the one hand the “state of knowledge” of the quantitative and qualitative effects of ADA systems, and, on the other hand, to compare those results with those of the experts. This document contains the analysis of the ADA systems and the comparison with results of the expert workshop.

“Advanced Driver Assistance systems in a road vehicle (also referred to as active safety systems) are systems that support a driver in his driving tasks, e.g., to maintain appropriate speed, headway or heading or to prevent accidents. ADA systems are believed to have a strong potential to improve traffic safety. For the introduction of ADA systems, a holistic approach is needed, integrating different R&D disciplines and integrating the interests of the different stakeholders that are involved.

ADASE-II is an EC IST funded thematic network that will help to introduce and implement active safety systems by offering a platform to achieve the required holistic process and therefore to have all major players in the ADASE II environment involved. Partners in this project are a cross-section of the European automotive industry, suppliers as well as government representatives. To achieve its aim ADASE-II covers a comprehensive range of activities. One of the activities is organising workshops, to meet and discuss with relevant players and main actors about the latest developments, gaps, bottlenecks and opportunities for ADA systems around key issues.

“The fifth and final workshop of the ADASE-II project was held in Stuttgart, Germany on May 17-18, 2004. It dealt with the impact assessment of ADA systems. The aim of the first day of the workshop was to obtain consensus about the effects of ADA systems on traffic safety, traffic efficiency and comfort. These results are integrated into the ADASE-II roadmap. Based on the results, the ‘white spots’ in knowledge on effects are identified. The second day of the workshop focuses on the Policy Framework and leads to more insight in the relation between (potential) effects of ADA systems and policy issues in EU countries” [Alkim, T. et al., 2004].

This document is structured as follows. Section 2 describes the approach, methodology followed, and assumptions used in carrying out the research, while Section 3 contains an overview of resources and findings. Section 4 presents the results, followed by the conclusions in Section 5 and, finally, the list of references.

2 Approach and Methodology

The approach employed in this study consisted of three activities:

1. Create a “state of knowledge” of ADA system effects by carrying out a quick literature scan;
2. Analyze the “state of knowledge” and document the findings; and
3. Compare the results of the quick literature scan with the findings in the ADASE 2 expert workshop about the effects of ADA systems.

This document contains the results of activities 2 and 3.

The products of the three activities named above are respectively:

1. A database of the references and the results. A sample record of the database is included in the Appendix.
2. A document analyzing the database
3. A document comparing the results from (2) with the results of the ADASE 2 workshop.

In the course of carrying out the study, it became clear that the presentation of the results from (2) and (3) would be more understandable if they were integrated in one document. Thus, this document embodies both (2) and (3).

This study is a *quick scan*. Thus, it does not contain a detailed analysis and comparison of the studies and their assumptions and results. In addition, differences by country of origin and their unique traffic situations were not taken into account. Finally, the differences in interpretation in the functions of the systems in the literature scan were not judged. Thus, there can be differences between the assumptions over for example what particular speed range a system can operate.

The systems analyzed in this study are identical to those in the ADASE 2 study and portrayed in Figure 1.

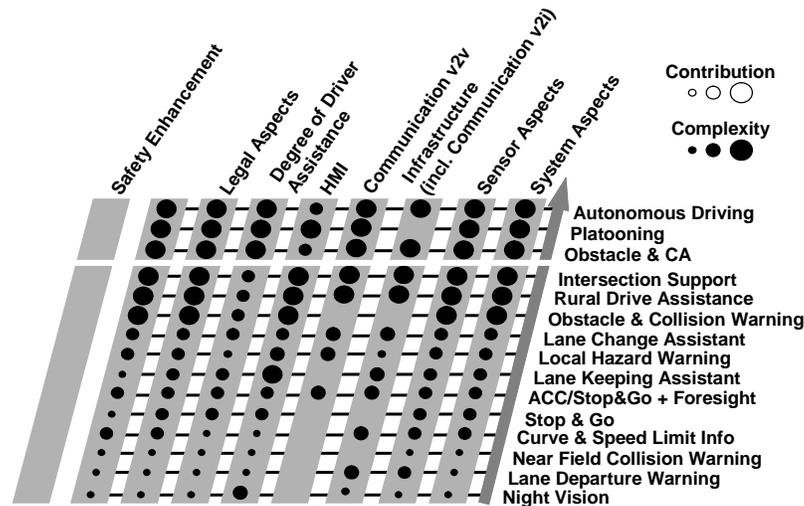


Figure 1: ADASE II Roadmap (source: [Alkim, T. et al., 2004]).

The fifteen systems are classified into 5 general functions, listed below.

- Safe speed & following
 - Stop & Go
 - ACC-Stop & Go + Foresight
 - Curve speed limit info
- Lateral support
 - Lane keeping assistant
 - Lane departure warning
 - Lane change assistant
- Obstacle detection and collision warning
 - Obstacle & collision warning
 - Obstacle & collision avoidance
 - Near field collision warning
- Intersection safety & complex situations
 - Intersection support
 - Rural drive assistance
 - Local hazard warning
 - Night vision
- Autonomous driving
 - Autonomous driving
 - Platooning

Due to its far end position in the roadmap, Autonomous driving was not discussed in the workshop, but the available results are included in the analysis in this document.

The classification of the quantitative results in the quick literature scan followed the same scaling as in the ADASE 2 workshop: --, -, 0, +, ++. In conjunction with the client, the translation from percentages to the normative scale was defined and used:

Table 1: Relation of percentage change (effect) to the normative scale.

Range of change	Normative scale
> 10%	++
2 – 10%	+
-2% - +2%	0
-10% - -2%	-
< -10%	--

Finally, the type of study producing the result was recorded. The available choices were:

- Literature review
- Expert session
- Model study - Mathematical model
- Model study - Driving Simulator
- Model study_ Traffic Simulator
- Pilot / Demo
- FOT (Field Operational Test)
- Already on Market

The type of study is ordered in such a way that the progression from top to bottom also moves from “softer” results to “harder” results. The harder results relate to actual use of the systems by drivers, in which the effects are measured in some way (log apparatus, surveys, instrumented vehicles, etc.). Measurements in the actual driving environment in true driving conditions are made. These are *empirical* results. Also, learning over time can be taken into account.

The comparison of the quantitative effects in the literature scan to the results of the expert workshop followed the following rules.

Firstly, the general *direction* was compared. That is, are the results both neutral, or are they positive (+ or ++) or negative (-, --)? Similarities and differences in direction are identified and documented.

Secondly, experts “voted” on every measure -- positive, neutral and negative. The quantitative studies, however, focus on one or at most several measures. Thus, an important assumption for the quantitative results was made: when no results were available for a specific measure, e.g., reduction in aside accidents, then the researchers did not focus on measuring this because no effect, either positive or negative, was expected. Thus, the results were interpreted as *neutral*. Additionally, the expert session was carried out in two parts. A larger group of experts from the ADASE II project participated in a workshop and produced results for the Stop&Go, ACC-Stop&Go + Foresight, Curve Speed Limit Info, Lane Keeping Assistant, Lane Departure Warning, and Lane Change Assistant. Due to the time constraints and practical matters, not all systems from the roadmap could be discussed during one workshop. Therefore, the remaining systems were rated and discussed by the ADASE II core team members instead of the 60 experts. This rating was carried out individually by e-mail, and not in a group setting. This difference in interaction level may have produced a different type of judgment for the remaining systems. However, this quick literature scan did not take this issue specifically into account when carrying out the work.

Thirdly, the safety effects measured in the studies were sometimes qualified in terms of reductions in headway variance or an increase in times to collision, etc. These types of findings were translated into reductions in longitudinal accidents such as head-tail. Similarly, the studies did not always specify the safety effects in such detail. In these cases, on the basis of the system itself, the safety effects were classified by the authors themselves. The assumptions used in this classification are shown in Table 2.

Fourthly, it appeared that the experts tended to estimate effects in terms of potential. For example, the results for ACC indicate that the experts judged the system in terms of the less complex, direct effects. In contrast, the literature reviews often revealed that the results can be more subtle: positive effects can be achieved, *on the condition that...* Furthermore, the direct and indirect effects are included in the results. The conditions under which they are relevant or valid are included in the analyses. The indirect effects are softer in the sense that they are sometimes not quantified to the full extent as the direct effects. However, logical arguments are provided. Furthermore, the traffic effects focus on the direct measurable effects and do not take into account the improved traffic performance as a result of accident *prevention*.

Table 2: Relation between system and type of accident prevented.

		Type of Accident				
		Decrease of aside accidents	Decrease of frontal accidents	Decrease of head-tail accidents	Decrease of accidents with vulnerable road users	Decrease of singular accidents
Safe speed & safe following	Stop & go			X		
	ACC / Stop & go + Foresight			X		
	Curve Speed assistant					X
Lateral support	Lane Keeping Assistant	X				X
	Lane Departure Warning	X				X
	Lane Change assistant	X				
Obstacle detection and collision warning	Obstacle & collision warning		X	X		
	Obstacle & collision avoidance		X	X		
	Near Field collision warning	X				
Intersection safety & complex situations	Intersection support	X	X	X		
	Rural drive assistance		X	X	X	X
	Local hazard warning		X	X		X
	Night vision		X		X	X
Autonomous driving	Autonomous driving	X	X	X		X
	Platooning	X	X	X		

3 Overview of sources and findings

The primary sources of information used to create this database are:

- AVV archives: This source produced 40 articles, books and reports for the database.
- EU projects: CarTALK 2000 deliverable, ADVISORS and STARDUST project-related publications.
- ADASE 2 Expert Workshop on effects of ADA systems on safety, throughput and comfort
- Symposia, Congresses, etc:
 - ITS World Congress proceedings 2001-2004
 - Intelligent Vehicles Congress proceedings 2001-2004
 - Transportation Research Board proceedings 2001-2004.

A summary of the findings at the Transportation Research Board symposium 2005 will be added as an appendix to this report at a later date.

In total, 75 sources contributed to the creation of the database. All documents are now available at the AVV archives. A color code has been used to find publications easily. The color coding is connected with the type of function. An overview of the color codes is given in table 3.

Table 3: Used colors to classify publications.

Type of function	Color code	System
Safe speed & safe following	Blue	Stop & go
		ACC / Stop & go + Foresight
		Curve Speed assistant
Lateral support	Red	Lane Keeping Assistant
		Lane Departure Warning
		Lane Change assistant
Obstacle detection and collision warning	Yellow	Obstacle & collision warning
		Obstacle & collision avoidance
		Near Field collision warning
Intersection safety & complex situations	White	Intersection support
		Rural drive assistance
		Local hazard warning
		Night vision
Autonomous driving	Green	Autonomous driving
		Platooning

The process of classification and analysis revealed that there are limitations in the ADASE 2 roadmap with respect to new or integrated systems. One example is integrated longitudinal and latitudinal support, for example, Lane keeping plus ACC in the Chauffeur Assistant. This system provides integrated safe distance and lateral support, but the classification of such a system is unclear given the roadmap itself. Another example of a system excluded is ISA.

The approach taken in this work aimed to include as many sources of information as was possible in the time and budget constraints of the project. The result is that 75 articles, books, and reports are represented in the database. To achieve this number, approximately 400 sources were scanned to find results. In total the database contains 128 quantified records on the 15 systems.

Table 4 provides an overview of the results by system by type of study. What is most striking in the table is that the distribution of results over systems is skewed. One system, ACC, contains approximately half of all the results, while 7 systems have too few (less than 3) for analysis. Four systems have no results available at all: Curve Speed Assistant, Near Field Collision Warning, Rural Drive Assistance and Night Vision.

Table 4: Number of records in database by system by type of study.

		Lit review	Expert session	Model study - Mathematical model	Model study - Driving Simulator	Model study - Traffic Simulator	Pilot / Demo	FOT	Already on Market	Total
Safe speed & safe following	Stop & go	1	1		1	1				4
	ACC / Stop & go + Foresight	9	4	3	9	34		6	1	66
	Curve Speed assistant									0
Lateral support	Lane Keeping Assistant	1	2			1				4
	Lane Departure Warning	3		1	1	2		3		10
	Lane Change assistant	3	1	1	1					6
Obstacle detection and collision warning	Obstacle & collision warning	3		1	3	2				9
	Obstacle & collision avoidance	2	1		3	5				11
	Near Field collision warning									0
Intersection safety & complex situations	Intersection support	1		1						2
	Rural drive assistance									0
	Local hazard warning	1				1				2
	Night vision									0
Autonomous driving	Autonomous driving		1							1
	Platooning	2	2			8	1			13
Total		26	12	7	18	53	1	9	1	128

4 Results: Analysis of systems and comparison to outcome of ADASE II Expert Workshop

This chapter presents an analysis of the literature quick scan results and a comparison to the outcome of the ADASE II expert workshop. Both results (literature quick scan and ADASE II expert workshop) are presented graphically by means of a bubble chart. For the literature quick-scan the size of the bubbles indicates the number of publications that are describing the effects of the ADAS on safety, traffic efficiency, comfort and environment. The classification of the quantitative results in the quick literature scan followed the same scaling as in the ADASE 2 workshop: --, -, 0, +, ++. In conjunction with the client, the translation from percentages to the normative scale was defined and used as presented in table 1. The bubble charts of the ADASE II expert workshop indicate the number of experts that have the feeling that the described ADAS influences safety, traffic efficiency, comfort and environment. The scale used in this workshop indicate the impact of the stated effect, ranging from very positive (++) to very negative (--).

4.1 Safe speed & following

Stop & Go

During stop & go traffic situation the longitudinal control of a vehicle will be partly carried out by a system. Therefore it is necessary to detect the traffic in front even in the near field. In extension to an ACC the detection of this area is necessary to react on other cars swerving into the near field [Alkim, T. et al., 2004].

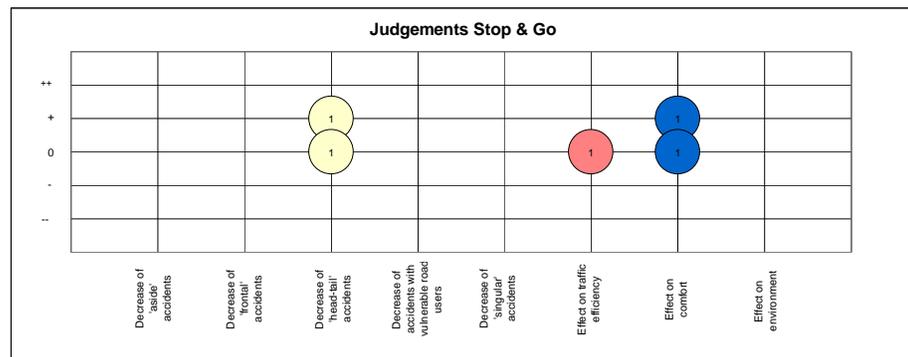


Figure 2: Judgments of Stop&Go from literature quick scan.

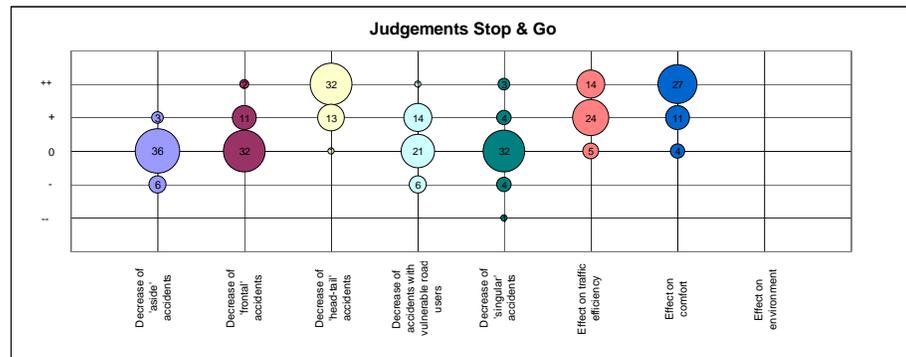


Figure 3: Judgments of Stop&Go from ADASE II expert workshop.

General

Four studies were found that are discussing the Stop & Go functionality. These studies are from 2001 and after. In the literature head-tail accidents and comfort have a slightly positive impact, whereas the effect on traffic efficiency is neutral.

The head-tail accidents results are based on a questionnaire and literature review. According to the questionnaire results (based on 494 completed questionnaires; questionnaire was conducted in Southampton only) +/- 40% of the respondents have the feeling that Stop&Go will result in a positive impact on driving safety [Piao, J. et al., 2004]. However, Louwse and Hoogendoorn [2004] have the feeling that the safety potential (accident reduction) is 0% on road sections or 0% on intersections.

The comfort results are based on a questionnaire and driving simulator study. According to the questionnaire results (based on 494 completed studies; questionnaire was conducted in Southampton only) +/- 40% of the respondents have the feeling that Stop&Go will result in a positive impact on driving comfort [Piao, J. et al., 2004]. However, the driving simulator results indicated that the drivers did not feel much helped by the Stop&Go system. Nevertheless the system does not disturb them. In general they do not want to drive nearer to the car ahead and they do not want to switch the system off.

Comparison to ADASE II Expert workshop:

Safety

The reduction of head-tail collisions is consistent between experts and the results of the literature quick-scan. However, the experts predict a slightly positive impact on a reduction of accidents with vulnerable road users, whereas no literature results are available.

Both experts and literature indicate that the impact of Stop&Go on a decrease of aside, frontal and singular accidents is neutral, as in the literature no impacts are described and experts rate the impact as neutral.

Throughput / traffic efficiency

The experts are more positive about the potential traffic effects than what is found in literature.

Comfort

Experts appear to be more positive about comfort improvement than the two studies with results on comfort.

ACC / Stop & go + Foresight

The ACC and Stop & Go function can be extended to a traffic related system by the means of communication. Far away driving vehicles will be involved into the longitudinal control. Thus, an end of a traffic jam can be included into the longitudinal control, before a driver is able to see it e.g. in a curve. Thus the traffic flow and the safety can be increased [Alkim, T. et al., 2004].

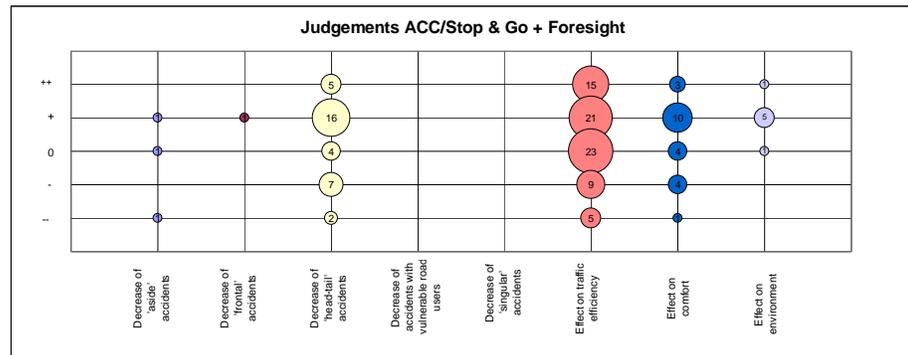


Figure 4: Judgments of ACC / Stop & go + Foresight from literature quick scan.

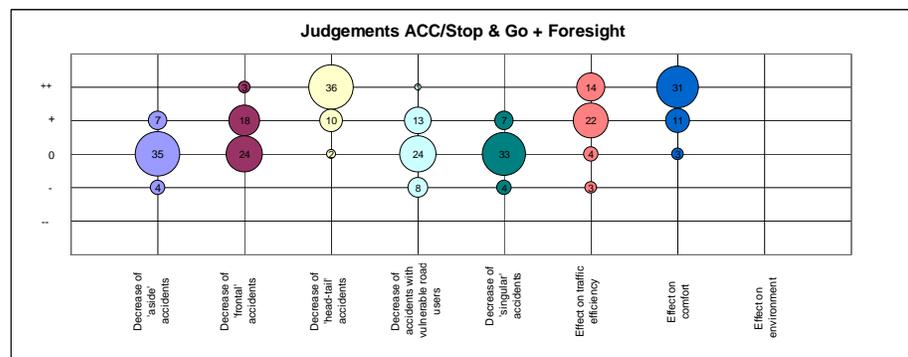


Figure 5: Judgments of ACC / Stop & go + Foresight from ADASE II expert workshop.

General

With more than 60 observations, ACC and ACC / Stop&Go + foresight are clearly the most quantitatively studied systems in the literature of the 15 systems in the ADASE II workshop. Over half of the results were achieved via traffic simulation studies. Large numbers of studies took place in both the 1990's up through 2004.

It should be noted that of the results, all but two were for ACC alone (Impact of intelligent cruise control on motorway capacity, Minderhoud & Bovy, 1999, and Traffic Effects of Inter-vehicle Communication Applications in CarTALK 2000, Malone, 2004).

Safety

Surprisingly there are very positive and negative results for this system. Minderhoud [1999] found some evidence for decreasing safety as the penetration

rate increases. Moreover he experienced an unsatisfactory time-to-collision indicator value at the time-headway setting of 0.8s. The results are based on a traffic simulation study. This result is reinforced by a driving simulator study in Sweden [Nilsson, L., 1995] which found that: "More collisions among ACC users than among unsupported drivers approaching a stationary queue were experienced during the simulations (four respectively one)." A SWOV driving simulator study in 2003 [Hoetink, A.E., 2003] also confirms this: "Drivers with ACC start braking at shorter Time-to-Collision values than drivers without ACC. Therefore four out of ten subjects crashed into the stationary tailback. The same is true when ACC drivers are approaching a moving tailback."

On the other hand, most studies indicate positive results for a reduction of head-tail accidents. The results of a driving simulator study demonstrated that the number of small (unsafe) headways was significantly reduced [UK & International Press, 1994]. Numerous other studies reported similar results.

Therefore it could be concluded that the safety improvement due to ACC / Stop & go + foresight can only be guaranteed when the negative impacts are prevented. It could be a task for both government and industry to pay more attention to solving the negative impacts on safety of ACC / Stop & go + foresight.

Traffic Efficiency

The results of the literature quick-scan shows that the impact of ACC / Stop & go + foresight on traffic efficiency is very sensitive to parameter settings – the combination of time headway and penetration rate. See also the remarks as summarized in 'requirements for stated effects' below. Very high penetration rates of ACC alone lead to a decrease in traffic efficiency. High penetration rates lead to homogenization of vehicle speeds, thus an indirect improvement on traffic efficiency through increased safety.

Comfort

Generally, ACC is aimed to make driving less stressful and thus more comfortable. As implemented, the response is overwhelmingly positive. However, the few negative reported effects on comfort concern particular aspects of or groups driving with ACC, specifically: lane changing / merging, lower TTC's, and fast drivers appreciate the system less.

Environment

The results of an expert session showed a 6.2% reduction of CO₂ and a 2.1% reduction of NO_x [Kojima, F. and S. Katsuki, 1999]. A Traffic simulation study [Bose, A. and P. Ioannou, 2000] reported significant reductions in fuel consumption and air pollution as a result of smooth acceleration.

Requirements for stated effects

The traffic efficiency results depend strongly on the combination of the choice of headway and the penetration rate. Higher penetration rates with smaller headways lead to improved efficiency. The penetration rate examined ranges from 10-40% and the time headways 0.6 s – 2.0 s. With the exception of the results of the study of Godbole et al [1999], 40% penetration rate with time headways greater than 1.5 s can have no direct positive effect on efficiency, although secondary effects

of a decrease in accidents is possible. Traffic efficiency gains are mostly marked at headways of 1.0s or less.

Comparison to ADASE II Expert workshop:

Very few quantitative results were available for the full range ACC + foresight. Thus, comparison with the expert workshop is difficult. However, it is clear that positive safety and environmental effects can be achieved with ACC, thus the same can be assumed for ACC / Stop& go + foresight. The *direct* traffic efficiency effects of conventional ACC alone, however, are sensitive to the specific settings of time headway choice and penetration rate (the secondary effects of safety improvements on traffic efficiency are important). The additional functionality of foresight to (full-range) ACC can possibly address both the direct traffic efficiency effects and the safety issues when approaching stopped or very slow-moving traffic with ACC, although there are few results to support this hypothesis.

On the most part, the results from the literature are consistent with those from the ADASE II expert workshop, although the results from the literature show a greater spread.

4.2 Lateral support

Lane Keeping Assistant

The function of a lane keeping assistant system includes the lane detection and the feedback to the driver if he is leaving a defined trajectory within the lane. An active steering wheel can help the driver with a force feedback to keep on this trajectory. The lane is detected by a video image processing system [Alkim, T. et al., 2004].

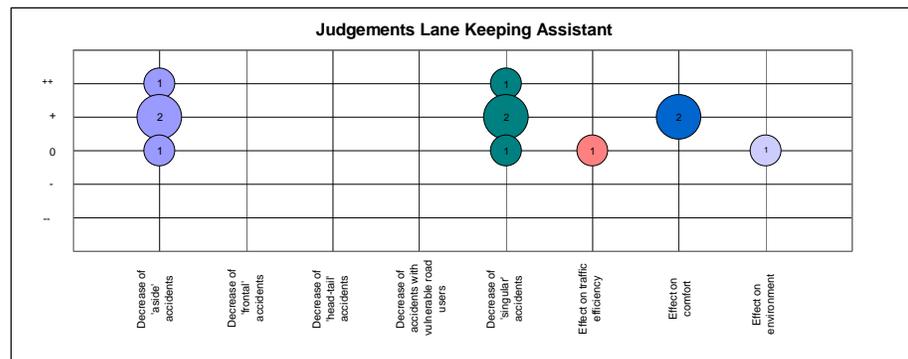


Figure 6: Judgments of Lane Keeping Assistant from literature quick scan.

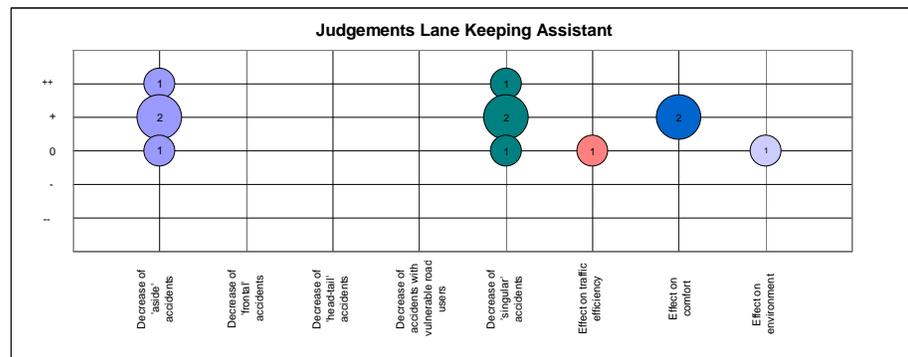


Figure 7: Judgments of Lane Keeping Assistant from ADASE II expert workshop.

General

Four studies, including a literature review, two expert sessions and one traffic simulation, were found that are focusing on Lane Keeping Assistance systems. The effects measured in these studies focused on safety, traffic efficiency, comfort and the environment. Concerning safety de Visser et al [1999] expected a 35% decrease in fatalities, 36% decrease in injuries and a 24% decrease in other accidents. These results are based on a traffic simulation and are valid for roads with 100 – 120 km/h speed limits.

The impact of a Lane Keeping Assistant system on traffic efficiency, comfort and environment are based on an expert session as organized by Marchau and Van der Heijden [1997]. Piao et al. [2004] have asked respondents in

Southampton if a Lane Keeping Assistant will result in a positive impact on driving comfort. Most of them confirmed this feeling.

Comparison to ADASE II Expert workshop:

A valid comparison is difficult, given the limited number of observations for Lane Keeping. Generally, however, the experts saw improvement in decreased aside and singular accidents; comfort and efficiency. These are the same categories for which the quantitative results are available. It is remarkable that the experts have the feeling that Lane Keeping can result into a slight decrease of accidents with vulnerable road users, whereas in literature no studies were found that are focusing on this impact.

Lane Departure Warning

If certain thresholds (like distance, time to lane crossing) allow a prediction of a lane departure this system warns the driver by means of acoustic, optic or haptic feedback. The detection of the lane markings results from e.g. video image processing [Alkim, T. et al., 2004].

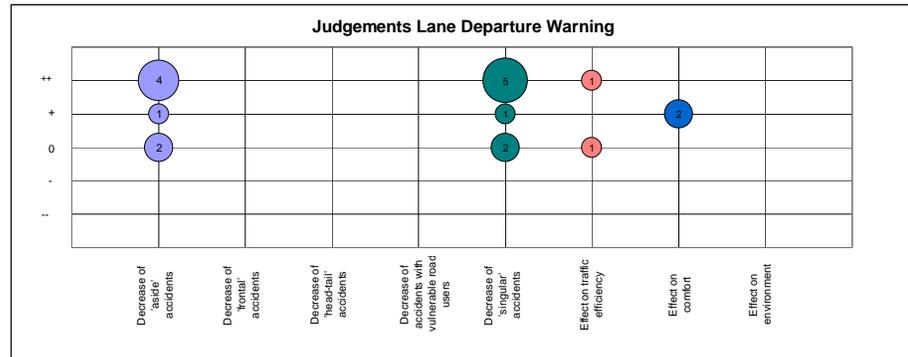


Figure 8: Judgments of Lane Departure Warning from literature quick scan.

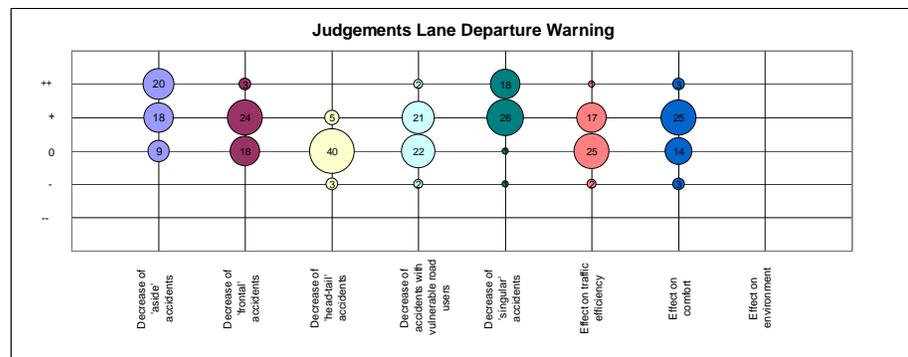


Figure 9: Judgments of Lane Departure Warning from ADASE II expert workshop.

General

Ten observations lead to the results as showed in the diagram above. Three judgements are based on a Field Operational Test and two are based on a model study. It appears that most studies have focused on commercial (truck) vehicles.

Safety

Similar to the Lane Keeping Assistant, safety improvements in the aside and singular accident categories are expected. The more positive results can result from the fact that there are simply more results available for Lane Departure Warning than for Lane Keeping Assistance. However, the Field Operational Test indicates that the consequences for traffic safety over time are not clear since drivers did not receive fewer warnings and did not decrease the amplitude and duration of line crossings, nor did the lateral position change over time [Alkim, T. et al., 2003]. This could indicate that Lane Departure Warning does not lead to improved driving as drivers only react to the system. Moreover, most of the results are based on the assumption that Lane Departure Warning has only impact on aside and singular accidents as only one study stated explicitly that Lane

Departure Warning has a 24% reduction of all singular accidents in the USA [Schermers, G. 2000].

Throughput / traffic efficiency

Korse et al [2003] shows the results of a Field Operational Test and demonstrated that the direct effects of Lane Departure Warning are neutral. However, in terms of indirect effects, improvement is expected due to congestion reduction as a result of a reduction in accidents. The expectation is that 11% of the current percentage of congestion due to road accidents (12%) could be prevented.

Comfort

The driving simulator and Field Operational Test results as carried out by Brown demonstrated that there was significant reduction in total workload across the sessions.

Requirements for stated effects

The Field Operational Test indicates that indirect (safety) effects are only valid when *all* trucks are equipped with Lane Departure Warning Systems. Moreover, the effects as described in some results are only valid on 80, 100 and 120 km/hour roads.

Comparison to ADASE II Expert workshop:

Safety

The decreases in aside and singular accidents are virtually identical for the expert session and the quantitative results. However, the expert session indicated a slightly positive impact of Lane Departure Warning on the number of frontal accidents and accidents with vulnerable road users. In the literature no explicit results for this are found, although a reduction in singular accidents will have at least a small positive indirect effect on vulnerable road users.

Throughput / traffic efficiency

The results of the expert session and quantitative studies are comparable. Both experts and literature stated that the direct effects of Lane Departure Warning are neutral.

Comfort

The expert session and quantitative results are comparable.

Lane Change Assistant

Before and during a dangerous lane change process, the lane change assistant will warn the driver. Several stages of such a system are possible from pure warning systems to even haptic feedback at the steering wheel to help the driver following a lane change trajectory. The detection of all vehicles around the own car is necessary as well as the detection of the lane [Alkim, T. et al., 2004].

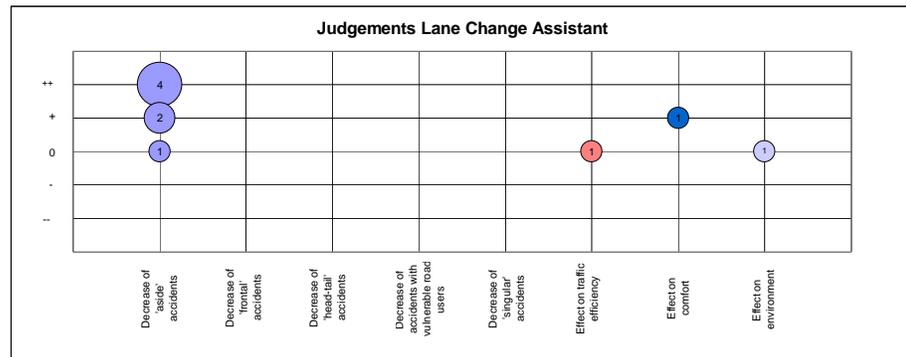


Figure 10: Judgments of Lane Change Assistant from literature quick scan.

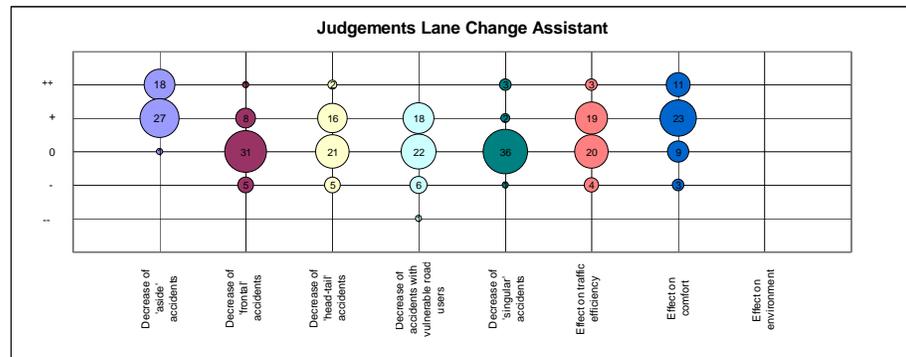


Figure 11: Judgments of Lane Change Assistant from ADASE II expert workshop.

General

Six observations lead to the results above. Four of them are based on literature reviews or expert sessions.

Safety

The results of the Lane Change Assistant are similar to Lane Departure Warning and Lane Keeping Assistant: reductions in some cases ([Schermers, G., 2000], [Mitretek Systems, 1999] and [Sisiopiku, V.P. and X. Tang, 2004]) of approximately 40% in aside accidents are achieved. These results are based on literature review or a mathematical model. Wang et al. [2003] conducted a driving simulator study. The results of this study are much lower: the percentage of crashes decreased by approximately 15% when the warning system was used. The experiments used are arranged in a highway scene and only nine aged drivers participated in the lane change experiments.

Throughput / traffic efficiency

No conclusive evidence of positive or negative effects was found in literature.

Comfort

According to experts the Lane Change Assistant is expected to increase comfort while driving [Marchau, V.A.W.J. and R.E.C.M. van der Heijden, 1997].

Environment

An expert session proved that the reduction of environmental impacts due to the introduction of a Lane Change Assistant is highly uncertain [Marchau, V.A.W.J. and R.E.C.M. van der Heijden, 1997].

Comparison to ADASE II Expert workshop:*Safety*

The expected reductions in aside accidents are similar to the findings from the ADASE II expert workshop. Both experts and literature review concluded that the decrease of 'aside' accidents due to a Lane Change Assistant is very positive. Even for the other types of accidents the results are similar, as from the ADASE II expert workshop it could be concluded that the impact is neutral and in literature no observations are found that had a glance at the impact of a Lane Change Assistant on other type of accidents than aside accidents.

Throughput / traffic efficiency

The result for traffic efficiency is similar to the ADASE II expert workshop, but too few to draw strong conclusions.

Comfort

The result for comfort is similar to the ADASE II expert workshop, but too few to draw strong conclusions.

4.3 Obstacle detection and collision warning

Obstacle & Collision Warning

The driver will be warned if a potential collision is detected with e.g. another car or obstacle. This warning can be for example acoustic or visual. Complex scenarios like evading can be included as well as warn breaking, which is a very short brake in order to give a kinesthetic feedback [Alkim, T. et al., 2004].

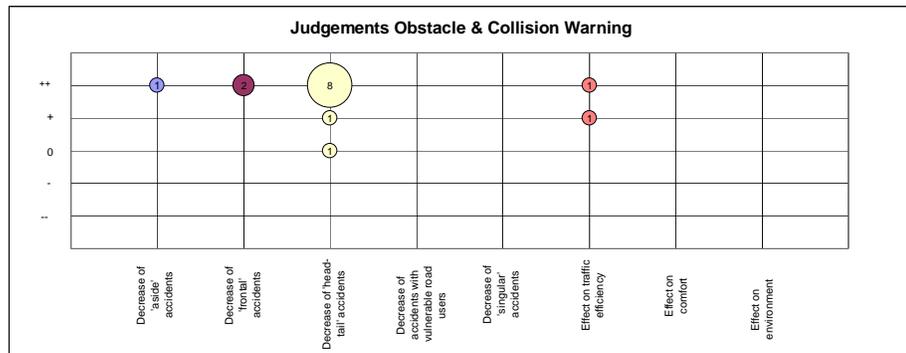


Figure 12: Judgments of Obstacle & Collision Warning from literature quick scan.

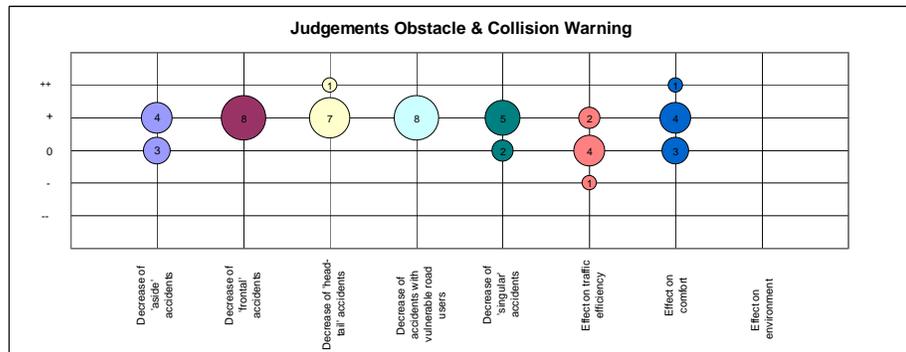


Figure 13: Judgments of Obstacle & Collision Warning from ADASE II expert workshop.

General

Nine observations were found that are discussing the Obstacle & Collision Warning functionality; five of which are model-based studies. In general the results are very positive, whereas Obstacle and Collision Warning is a complex system. Therefore it may be interesting to realise a Field Operational Test to demonstrate if these very positive impacts are also valid in real driving conditions.

Safety

All of the studies indicate positive or very positive safety effects, for aside, frontal and head-tail accidents. There are no results available with respect to vulnerable road users. One study showed that the impact on head-tail accidents is strongly

dependent on the warning time before an accident. Schermers [2000] demonstrated that 90% of all head-tail accidents could be prevented if vehicle drivers are warned 4 seconds before the vehicle hits an obstacle. The reduction will be 55% or 10% if the vehicle driver is warned 3 or 2 seconds, respectively, before the vehicle hits an obstacle.

Throughput / traffic efficiency

Indirect positive effects on traffic efficiency result from improved safety.

Requirements for stated effects

The assumptions about the timing of the warning varied from 0.5 s – 4 s.

Comparison to ADASE II Expert workshop:

Safety

Given the scale used in the literature review, the safety results can be characterized as very positive, whereas the results of the ADASE II expert workshop showed mainly positive impacts of the Obstacle & Collision Warning system. Moreover, in literature no research was found linking Obstacle & Collision Warning to a reduction of accidents with vulnerable road users and singular accidents.

Throughput / traffic efficiency

The two results of the literature quick-scan are similar, but limited for a valid comparison.

Obstacle & Collision Avoidance

This system has an extended functionality compared to the Obstacle and Collision Warning. An autonomous intervention overtakes partly the control of the vehicle in critical situations in order to avoid an accident. Longitudinal and lateral control will be done by the system [Alkim, T. et al., 2004].

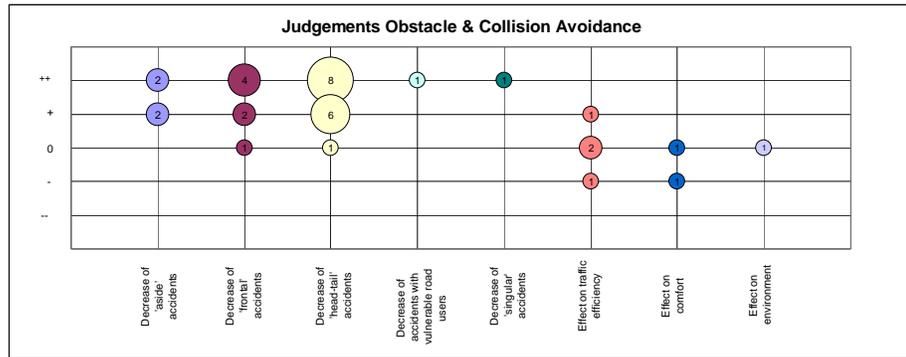


Figure 14: Judgments of Obstacle & Collision Avoidance from literature quick scan.

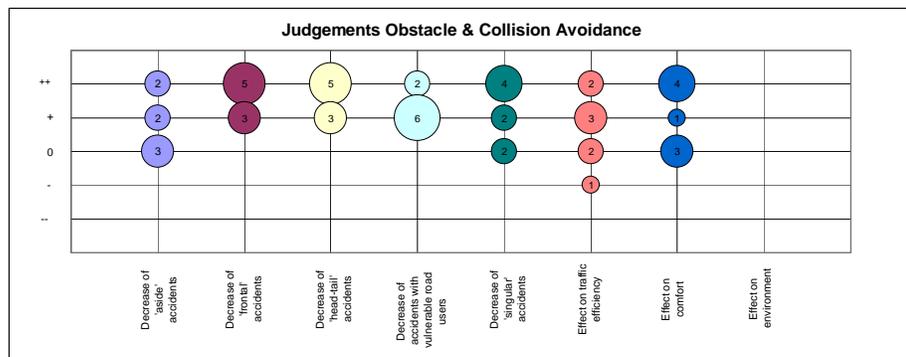


Figure 15: Judgments of Obstacle & Collision Avoidance from ADASE II expert workshop.

General

Eleven studies were found that are focusing on Obstacle & Collision Avoidance. Eight observations are model-based studies (driving-simulator: 3 observations; traffic simulation: 5 observations). Like the Obstacle & Collision Warning the results of the literature quick-scan are very positive for this system. Therefore, it may be interesting to start a Field Operational Test to demonstrate the stated effects in real traffic conditions.

Safety

The expected safety improvements are very positive, even with relatively low penetration rates. A sampling of some of the safety improvements from the review:

- Reductions in small headways (headways < 1s) [Janssen, W, and L. Nilsson, 1990];

- Reductions in rear-end collisions of 8%, 20% and 40% for an equipment rate of 10%, 25% and 50% respectively [Hayward, M., 1999];
- 10% market penetration, 9% reduction; 50% market penetration, 60% reduction of collisions when lead vehicle brakes and 20% reduction when lead vehicle stops [Sala, G. and Mussone, 1999].
- 8% or 40% reduction of 'head-tail' accidents on motorways; 8% only valid when 10% of all road vehicles are equipped with 'Anti Collision Assist'. 40% only valid when 50% of all road vehicle are equipped with 'Anti Collision Assist' [Schermers, G., 2000].

Throughput / traffic efficiency

One driving simulator study [Heino, A. et al., 1995] indicated that driving with an active gas pedal increased time-headway, with a negative effect on traffic efficiency. The indirect effect, however, can be considered positive. On the other hand, a separate study [Janssen, W, and L. Nilsson, 1990] showed an increase in average speed of 0.5 - 3.5 %, and an increase in driving in the left lane of 15-30%.

Comfort

On the one hand, a driving simulator study indicated that workload increases as it is not considered as comfortable to drivers [Heino, A. et al., 1995]. In contrast, according to experts, the increase of driving convenience due to the introduction of a front obstacle avoidance system is moderately certain [Marchau, V.A.W.J. and R.E.C.M. van der Heijden, 1997].

Environment

According to an expert session as organised by Marchau and Van der Heijden [1997] the reduction of environmental impacts due to the introduction of a front obstacle avoidance system is highly uncertain..

Comparison to ADASE II Expert workshop:*Safety*

The results of the literature quick-scan are similar across all types of accidents. Both the ADASE II expert workshop as the literature studies show a positive to very positive impact on accident reductions due to the introduction of an Obstacle & Collision Avoidance System.

Throughput / traffic efficiency

The effect on traffic efficiency is similar to the ADASE II expert workshop result. However, the quantitative results are somewhat more negative.

Comfort

The results for comfort are too few to draw strong conclusions.

4.4 Intersection safety and complex situations

Intersection Support

In an intersection situation especially in cities a driver has to fulfil several tasks in parallel. Thus the potential for information overload is given. In order to assist the driver in such situations it is necessary to support certain tasks like approaching a stop sign / traffic light or right of way of crossing traffic [Alkim, T. et al., 2004].

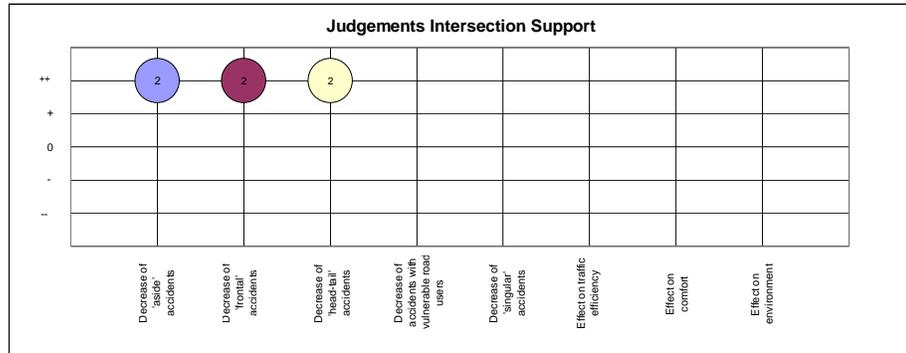


Figure 16: Judgements of Intersection Support from literature quick scan.

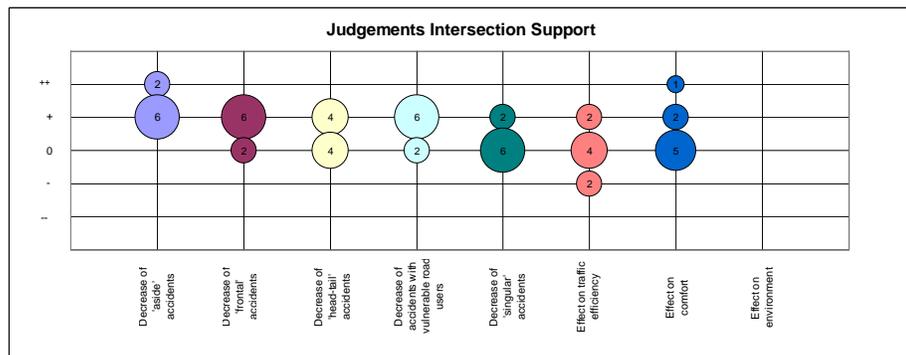


Figure 17: Judgements of Intersection Support from ADASE II expert workshop.

General

2 studies, a mathematical model [Sisiopiku, V.P. and X. Tang, 2004] and a literature review [OECD, 2003], produced the results. They are clearly quite positive about intersection support for safety improvement (aside, frontal, and head-tail accidents). Further analysis is difficult given the limited number of results – a literature review by OECD and a mathematical model. Furthermore, the exact functionality of Intersection Assistant can be interpreted different ways, dependent on the expert making assumptions about range, what can be detected, etc, and the traffic situation and needs in the context, e.g., country, in which the research took place. The Netherlands, for example, already has taken steps toward solving problems at intersections. Examples include roundabouts and the use of traffic (light) controls. Thus, in the Netherlands, there are fewer benefits of Intersection Support to be expected than in countries where these other types of measures have not yet been taken.

Comparison to ADASE II Expert workshop:

Generally, the experts were uncertain about all the effects. It appears that this results from the uncertainty regarding the driver behavior in a complex situation in the intersection and how the driver will react to the support. The quantitative studies focus apparently more on the potential safety effects, and they appear quite positive.

Local Hazard Warning

If a hazard occurs far away in front of the vehicle, so that the driver cannot see it, this system will warn him. By the means of communication it is possible to transfer this information over long distances [Alkim, T. et al., 2004].

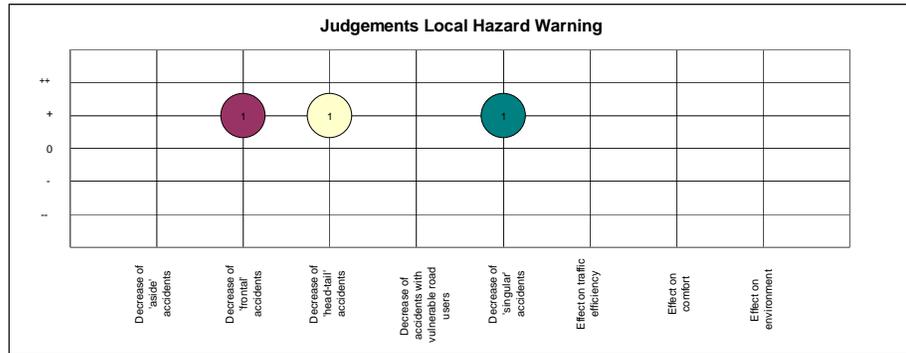


Figure 18: Judgments of Local Hazard Warning from literature quick scan.

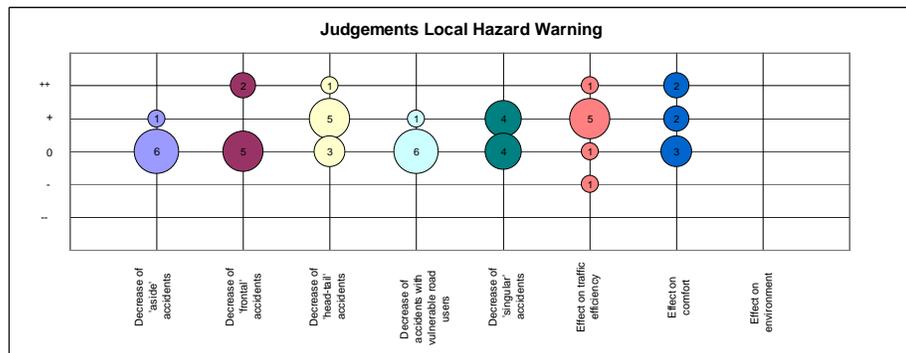


Figure 19: Judgments of Local Hazard Warning from ADASE II expert workshop.

General

Two studies, a literature review [OECD, 2003] and a traffic simulation study [Sisiopiku, V.P. and X. Tang, 2004], produced the observations. Again, the exact functionality assumed for the local hazard warning (“local” can be interpreted as close to the vehicle, as in near field collision warning, vehicle-vehicle communication parameters and ranges, and information about the hazard itself) is open to interpretation. So, the results / systems are difficult to compare.

The results indicate that a moderately safety improvements is expected, in terms of frontal, head-tail and singular accidents. When not specified in detail, the safety improvements were assumed to fall in the frontal and singular categories.

Comparison to ADASE II Expert workshop:

The limited results from the two studies do not merit a comparison to the expert workshop. However, the experts were positive to very positive about the reduction in frontal and head-tail accidents. This was also the case from the literature review, which also scored positively on singular accident reduction. No results from the literature review revealed traffic efficiency or comfort effects,

whereas the experts were quite positive about the potential for improvement on these indicators with a local hazard warning system.

4.5 Autonomous driving

Platooning

Several cars are connected electronically (e.g. by the means of communication) and follow one after the other in a platoon. An example is the connection of trucks in order to save space, fuel and to increase the traffic flow. As the following vehicles are driven automatically, the system is complex concerning all aspects. The takeover of the driver at e.g. gateways has to be taken into account as well as the behaviour in mixed traffic at driveways. [Ehmanns and Spannheimer, 2004]

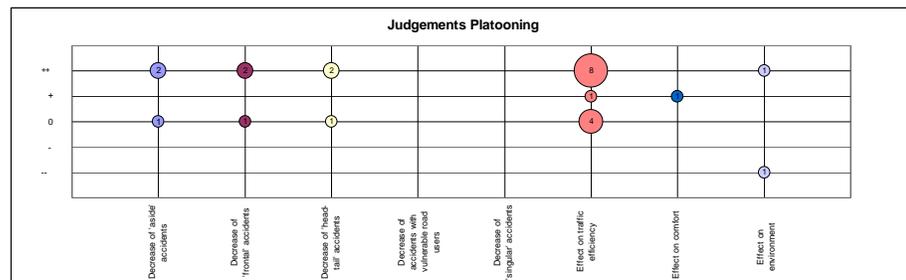


Figure 20: Judgments of Platooning from literature quick scan.

General

Eleven studies produced the results in the diagram above. The majority of the methods used were traffic simulation studies. The research focus lies on Traffic Efficiency.

Safety

With respect to safety, the opinions varied from neutral to very positive: At an acceptable level of safety, and with the current braking ability of cars a big increase of road capacity even with full automation is not expected. A key possibility to increase capacity lies in an emergency strong braking and vehicle-vehicle communication.

Traffic Efficiency

Platooning is first and foremost a traffic efficiency approach to driving. All of the 13 results produced an observation for efficiency. The following summarizes the findings, which focus on the highway environment:

- Using automated vehicles in a highway lane allows throughput to double (to 3000 veh/h) per lane [Gomez, C. and M. Goursat, 2000].
- An achievable flow of 7200 veh/h is reported, which represented a tripling with respect to mentioned maximum flows on today's freeways of 2400 veh/h [Zwaneveld, P.J. and B. van Arem, 1997].
- The capacity increases from 2200 veh/h/lane to 4000 veh/h/lane or 7.200 veh/h/lane when a headway of 0.9 s respectively 0.5 s is used. The capacity stays the same when a headway of 1.6 s is used [Yokota, T., 1998].
- The travel time in autonomous driving is shorter than that in manual driving [Tanaka, N. and H. Kawashima, 1998]. Another study reported decreasing travel time by over 50% with a penetration rate of 100% platooning vehicles [Yokota, T. and M. Kuwahara, 1998].

- Congestion occurs over 2000 veh/h in manual driving. In autonomous driving, there isn't congestion [Tanaka, N. and H. Kawashima, 1998].
- The potential advantages of co-operative following with respect to throughput could not be confirmed [Alkim, T. et al., 2000].
- Capacity increases when the convoy sizes increases. If the convoy consists of 10 vehicles the capacity will grow from 2000 veh/h to 5000 veh/h [McDonald, M. et al, 1999].

Environment

Surprisingly, the results for environmental effects (2) produced polar opposite results. According to one study [Tanaka, N. and H. Kawashima, 1998], the emission of NO_x becomes large in autonomous driving (> 10%), while a Pilot for trucks indicated that, in combinations of on-road and wind tunnel tests, trucks operating in automated close-formation platoons can save 15%-20% of fuel consumption when they are cruising at highway speeds [Yin, Y. et al., 2004].

Requirements for stated effects

Time headways, platoon size, mixed or exclusive traffic are all critical parameters for the traffic efficiency effects.

Comparison to ADASE II Expert workshop:

Not possible, as Platooning was not examined in the expert workshop

Autonomous Driving

This is the theoretical highest level of driver assistance. The vehicle drives controlled by an algorithm in each situation. It is predictable that this stage assistance cannot be reached on the current road network. The complexity of Autonomous Driving is comparable to Obstacle and Collision Avoidance. [Ehmans and Spannheimer, 2004]

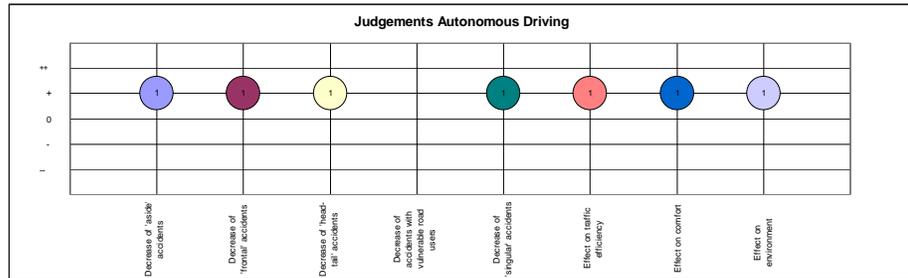


Figure 21: Judgements of Autonomous Driving from literature quick scan.

General

One study, an expert session [Marchau, V.A.W.J. and R.E.C.M. van der Heijden, 1997], generated the results above. On all aspects of autonomous driving, moderately positive effects are expected. Due to the limited sources of literature, and the fact that the study above also was based on an expert session, a further comparison with the ADASE II workshop will not be carried out.

5 Conclusions and recommendations

This analysis took the approach of a literature quick scan. The results provide an overview of which systems have been examined (in detail), the types of studies used, and the findings. Some conclusions can already be drawn based on the results. The authors did not, however, critically analyze the studies placed in the database for assumptions, validity, or potential conflicts. The need for a critical and thorough analysis of results on effects of ADA systems remains. The conclusions and recommendations in this last section focus first on looking back over the systems analyzed in the literature quick scan followed by general conclusions and recommendations.

Effects on safety, traffic efficiency, comfort and environment

The quantified results found in the literature on safety indicate that ADA systems will have a positive impact on safety. However, the literature reveals both positive and negative effects. The Safe speed & following function achieves mostly neutral to very positive effects in the head-tail safety category. Some negative results with respect to ACC-equipped vehicles were found, in special cases such as approaching a stationary tailback. The Lateral support function improves safety in the categories of aside and singular accidents. Here the results were found to be neutral to very positive. The Obstacle detection and collision warning function achieves positive impacts on safety in almost all of the safety categories, but predominantly in the head-tail, frontal and aside accidents. The limited results in the Intersection safety and complex situations function revealed safety improvements in all categories with the exception of accidents with vulnerable road users. Finally, the Autonomous driving function shows moderately positive results for aside, frontal and head-tail accidents.

With respect to traffic efficiency, the Safe speed and following function showed a spread in results. Achieving a more efficient traffic flow directly depends on some critical system parameters such as time headway as well as the penetration rate of the system. However, secondary effects on traffic efficiency can be achieved through accident reduction due to safety improvements. This secondary effect, however, was not quantified in all studies. Of the Lateral support functions, only LDW revealed a positive effect on traffic efficiency. The remaining systems were neutral. The Obstacle detection and collision warning function scored neutral on this measure, while no results for the Intersection safety and complex situations function were found. Finally, the Autonomous driving function scored neutral to very positive in terms of traffic efficiency.

In terms of comfort, the Safe speed & following function again showed a spread in results. Some drivers find systems more comfortable and less stressful while driving, whereas others find certain aspects of driving with this function less attractive. The Lateral support function scored positively for all systems in terms of comfort. The few results for the Obstacle detection and collision warning function revealed a slightly negative comfort level, due to increased workload. In contrast, the Autonomous Driving function scored moderately positive on comfort. No results for the Intersection safety and complex situations function were found.

Very few results for the environmental effects of the ADA systems were found. ACC (Safe speed & following function) scored neutral to very positive. The Lateral support function showed neutral effects as did the Obstacle detection and collision warning function. Autonomous driving showed a large spread in the environmental effects, from very positive to very negative, depending on the specific environmental measure (No_x vs fuel consumption).

General conclusions and recommendations

Seventy-five sources contributed to the analysis and results contained in this study. Table 3 indicates that the distribution of results over the systems is skewed. As stated earlier, the number of results for ACC represents over half of the records in the database. The remaining information was for the remaining 14 systems. This produced a limited basis on which to draw general conclusions about the remaining systems. Additional studies could lead to different conclusions when there are in this document, for example, only two results for safety for a specific system. A better foundation for drawing general conclusions is therefore necessary.

Table 3 also demonstrates that the distribution of type of study is skewed: Moving left to right along the top of the table follows the same progression of soft to hard results mentioned in Section 3. Of the 128 records, only 11 are pilots / demos, FOT's, or measurements taken of systems already on the market. The remaining 116 records consist of literature review, expert sessions, and the various model studies.

In general there are relatively few empirical results for ADA systems. Taking the example of ACC, many studies have been carried out, including in real driving conditions. The results show a spread in the effects – predominantly positive but also negative. The negative effects appear in categories both in foreseeable categories (reduction in head-tail accidents at the cost of traffic efficiency for some parameter choices) but also for other effects, such as an increase in “aside” accidents under certain conditions. Given the effort invested in development of these systems, the need for tests in real driving conditions is necessary to determine what exactly the positive effects and the negative effects of new systems are. There are roles and responsibilities that can be defined for achieving the positive results while at the same time solving the problem of the negative effects. There are roles for both government and industry in addressing these issues. For government, a potential role is to examine the (social) costs and benefits of these systems.

With respect to specific results, the results for ACC provided a reliable foundation on which conclusions can be drawn. For both ACC and LDW, FOT's were carried out. Looking to two other systems, namely Obstacle and Collision Warning and Avoidance, these are two quite promising systems according to experts and the literature scan. For these systems, approximately 10 records were available from the literature quick scan. Both the experts and the literature scan resulted in (very) positive expectations. The literature quick scan did not reveal that either of these two promising systems has been tested in real driving conditions. Based on the analysis here, these two systems, plus ACC combined with Stop&Go + Foresight are good candidates for assessment in real driving conditions.

Finally, as mentioned earlier, the ADASE II roadmap provides a vision of driver support along with an indication of the relevant developmental and safety aspects. In carrying out the work presented in this document, a limitation of the ADASE II roadmap was recognized: new, integrated systems not already in the roadmap remain without a place. Extension of the roadmap with these additional systems or redefinition in terms of functionality (such as safe speed & following) provides solutions.

6 References

Alkim, T., G. Bootsma, E. Berghout, G. Ostin and P. Gendre, *ADASE 2 Expert Workshop on effects of ADA systems on safety, throughput and comfort*, ADASE 2 Deliverable D8E, contract number IST-2000-28010, 1 July 2004

Alkim, T. , M.J. Korse and S. de Ridder, *Field operational test with lane departure warning assistant systems - behavioural effects*, Adviesdienst Verkeer en Vervoer and TNO Human Factors, 10th World Congress on ITS, 2003

Alkim, T., H. Schuurman and C.M.J. Tampere, *Effects of external cruise control and co-operative following on highways*, Adviesdienst Verkeer en Vervoer and TNO Inro, IEEE Intelligent Vehicles Conference The Ritz-Carlton Hotel, October 2000

Arem, B. van , J.H. Hogema, M.J.W.A. Vanderschuren and C.H. Verheul, *An assessment of the impact of autonomous intelligent cruise control*, TNO Inro, 1995

Arem, B. van, A. de Vos, M. Vanderschuren, *The effect of a special lane for intelligent vehicles on traffic flows*, TNO Inro, March 1997

Arem, B. van, C.M.J. Tampere and K.M. Malone, *Modelling traffic flows with intelligent cars and intelligent roads*, TNO Inro, IEEE Intelligent Vehicles Symposium, October 2003

Baum, H. ,W.H. Schulz, K.M. Malone and T. Geißler, *Socio-Economic Assessment, CarTALK 2000 IST-2000-28185, Deliverable 12*, University of Cologne and TNO, September 2004

Benz, T., *Modelling and simulation of changed driver behaviour - A first approach to assess the effects of intelligent cruise control on traffic flow* , Benz Consult GmbH

Bose, A. and P. Ioannou, *Environmental evaluation of intelligent cruise control vehicle*, Center for advanced transportation technologies, dept. Of electrical engineering-systems, University of California, IEEE Intelligent Transportation Systems, October 2000

Brackstone, M., B. Sultan, M. McDonald, *A collision model for the assessment of the safety benefits of AVCSS*, University of Southampton, 1999

Brown, C.M., *New in-vehicle technologies: Are lane departure warnings a good thing?*, Road safety and motor vehicle regulation directorate, Transport Canada

Burgett,A., A. Chandlé and R. Miller, *Operational test results of an adaptive cruise control system and implications for level of deceleration-authority*, Advanced Safety Systems Research, National Highway Traffic Safety Administration, US DOT, 5th World Congress on Intelligent Transport Systems, 1998

Cremer, M., C. Demir, S. Donikian, S. Espie, M. McDonald, *Investigating the impact of the AICC concepts on traffic flow quality*, University of Hamburg, INRIA, INRETS & University of Southampton, 1998

Dagan, E., O. Mano, G.P. Stein and A. Shashua, *Forward Collision Warning with a single camera*, MobileEye Vision Technologies Ltd. and Hebrew University, IEEE Intelligent Vehicles Symposium University of Parma, June 2004.

Ehmanns, D., and H. Spannheimer, ADASE 2 Roadmap Development, Deliverable D2D, Version 1.0, July 2004.

Gebruikersonderzoek snelheidsregulerende in-car systemen, Adviesdienst Verkeer en Vervoer, March 2004

Godbole, D.N., N. Kourjanskaia, R. Sengupta and M. Zandonadi, *Breaking the highway capacity barrier: An adaptive cruise control based concept*, California Path headquarters, 1999

Gomez, C. and M. Goursat, *Calibration and simulation of an automated vehicles highway traffic*, INRIA - Rocquencourt, IEEE Intelligent Transportation Systems, October 2000

Hayward, M., *Advanced Driver Assistance Systems - a European perspective*, Advanced Driver Assistance Systems: Vehicle Control for the future seminar, April 1999

Heino, A., J.A. Rothengatter, M. v.d. Hulst, *Collision Avoidance Systems Safety Evaluation*, Traffic Research Centre, University of Groningen, May 1995

Hoedemaeker, M., *Driving with an Adaptive Cruise Control (ACC)*, Delft University, October 1997

Hoetink, A.E., *Advanced Cruise Control in the Netherlands: A critical view*, SWOV Institute for Road Safety, 10th World Congress on ITS, 2003

Hoetink, A.E., *Advanced cruise control en verkeersveiligheid*, SWOV scientific foundation, 2003

Hogema, J.H. & Janssen, W.H., *Effects of Intelligent Cruise Control on driving behaviour: a simulator study*, TNO Human Factors, 1996

Hoogendoorn, S.P., *Advanced Driver Assistance Systems: Traffic impacts assessed by micro-simulation*, Delft University of Technology, March 2001

Janssen, W. L. Nilsson, *An experimental evaluation of in-vehicle collision avoidance systems*, TNO Institute for Perception (The Netherlands), VTI (Sweden), 1990

Janssen, Wiel and Hugh Thomas, *In-Vehicle Collision Avoidance Support Under Adverse Visibility Conditions*, TNO Human Factors, Soesterberg, British Aerospace, Bristol, 1997

Jong, R. de, *Het effect van Adaptive Cruise Control op de doorstroming rond een invoeging*, Kenniscentrum AIDA, March 2004

Koenig, D., F. Guichard and J-M. Blosserville, *Peri-urban automated highway scenario design*, INRETS, ITS Toronto, 1999

Kojima, Fumitake and Shinichi Katsuki, *Examination of reform measures of the traffic environment by applying the latest technology*, Toyota-cho Toyota-shi, Aichi Japan, 1999

Korse, M.J., G. Schermers, N.M.D. Radewalt, A. de Hoog and T. Alkim, *Op koers!? Resultaten van de proef met het Lane Departure Warning Assistant systeem*, Adviesdienst Verkeer en Vervoer, September 2003

Louwerse, W.J.R. and S.P. Hoogendoorn, *ADAS safety impacts on rural and urban highways*, SWOV scientific foundation and Delft University of Technology, IEEE Intelligent Vehicles Symposium University of Parma, June 2004

Ludmann, J., D. Neunzig and M. Weilkes, *Traffic simulation with consideration of driver models, theory and examples* Institut für kraftfahrwesen, November 1996

Malone, K.M., *Traffic effects of inter-vehicle communication applications in Car Talk 2000*, TNO Inro (draft report), 2004

Marchau, V.A.W.J. and R.E.C.M. van der Heijden, *Expert opinions on future developments of driver support systems - Results of an international Delphi study* TRAIL Research School, December 1997

Marchau, V.A.W.J. and W.E. Walker, *Innovative policymaking for automated vehicle guidance systems: an adaptive approach*, Delft University of Technology 9th World Congress on ITS, October 2002

Marsden, G., M. Brackstone and M. McDonald, *Assessment of the stop and go function using real driving behaviour*, Transportation Research Group, University of Southampton, IEEE Intelligent Transportation Systems, 2001

Marsden, G., McDonald, M. & Brackstone, M., *Towards an understanding of adaptive cruise control*, Transportation Research Group, University of Southampton, Transportation Research part C, vol. 9, pp 33-51, 2001

Mauro, V., *Effectiveness of AICC: outline of an assessment*

McDonald, M. , J. Wu and M. Brackstone, *Convoy driving, the concept and its potential improvement on motorway capacity*, Department of civil and environmental engineering, University of Southampton, ITS Toronto, 1999

McDonald, M., J. Wu and M. Brackstone, *The integrated impacts of autonomous cruise control on motorway traffic flow*, Transportation Research Group, Department of civil and environmental engineering, ITS Seoul, 1998

Minderhoud, M.M., *Traffic flow and safety analysis of longitudinal driver support systems near a freeway on-ramp site*, Delft University, 1998

Minderhoud, M.M., *Supported driving: Impacts on Motorway traffic flow*, Delft University, 1999

Minderhoud, M.M., *Capacity impacts of automated driving: modeling and scenario analyses*, Delft University of Technology, 1999

Minderhoud, M.M. and P.H.L. Bovy, *Impact of intelligent cruise control on motorway capacity*, Delft University of Technology, Transportation Research Record 1679, 1999

Mitretek Systems, *Intelligent transportation systems benefits*, May 1999

Nilsson, L., *Safety effects of adaptive cruise controls in critical traffic situations*, Swedish road and transport research institute, Second Worlds Congress on Intelligent Transport Systems, 1995

OECD, *Road safety - Impact of new technologies*, OECD, 2003

Okabe, K., T. Hiraoka, O. Nishihara and H. Kumamoto, *Fundamental research about the effectiveness of a safe driving support system with information provision*, Human System Labs, Department of Systems Science, Graduate School of Informatics, Kyoto University, Society of Automotive Engineers of Japan, Inc. and Elsevier B.V., April 2003

Piao, J., M. McDonald and T. Voge, *An assessment of user acceptance of ADAS/AVG systems from a questionnaire in Southampton*, Transportation Research Group, School of Civil Engineering and the Environment, 11th World Congress on ITS, October 2004

Rakha, H., J. Hankey, A. Patterson and M. van Aerde, *Field evaluation of safety impacts of adaptive cruise control*, Virginia Tech Transportation Institute ITS Journal vol. 6, 2001

Rudin-Brown, C.M. and Y. Ian Noy, *Investigation of behavioral adaptation to lane departure warnings*, Transport Canada, Transportation Research Record 1803, 2002

Sala, G. and L. Mussone, *Evaluation of Impact on Traffic Safety of Anti-Collision Assist Applications*, Centro studi sui Sistemi di Trasporto and DSTM Politecnico di Milano, ITS World Congress Toronto, 1999

Schermers, G. and K.M. Malone, *Dutch Evaluation of Chauffeur Assistant - Traffic flow effects of implementation in the heavy goods vehicles sector*, Adviesdienst Verkeer en Vervoer, June 2004

Schermers, G., *Advanced Driver Assistance (ADA) systemen - Perspectief verkeersveiligheid*, Adviesdienst Verkeer en Vervoer, December 2000

Shladover, S.E., *Progressive deployment steps leading toward an automated highway system*, Institute of transportation studies, University of California, Transportation Research Board, January 2000

Shladover, S.E. , J. VanderWerf, M.A. Miller and N. Kourjanskaia, *Development and performance evaluation of AVCSS deployment sequences to advance from today's driving environment to full automation*, University of California, Institute of Transportation Studies PATH, 2001

Sisiopiku, V.P. and X. Tang, *Safety impacts of ITS technologies on commercial vehicle operation*, Civil and environmental engineering, The university of Alabama at Birmingham, 11th World Congress on ITS, October 2004

Stanton, N.A., M. Young and B. McCaulder, *Drive-by-wire: The case of driver workload and reclaiming control with Adaptive Cruise Control*, Department of psychology, University of Southampton Safety Science vol. 27, 1997

Tanaka, Naoto, Hironao Kawashima, *The effect of AHS on the Traffic Flow and the Environment*, Faculty of Science and Technology, Keio University ITS, 1998

Tomitaka, H. , H. Takahashi and M. Yokoyama, *Development of driving support system for patrol under poor visibility - evaluation of first pilot model*, Expressway Research Institute, Japan Highway Public Corporation, Expressway Technology Center and Department of Engineering, Japan Highway Public Corporation, 10th World Congress on ITS, October 2003

Traffic flow effects on intelligent vehicles, UK & International Press, 1994.

Tripodi, A., J-M Auberlet, S. Espié and D. Gattuso, *Study of the stop&go system on driver's behaviour in urban environment*, INRETS CIR-MSIS and Università mediterranea di Reggio Calabria, ITS Madrid, 2003

US Department of Transportation, *Intelligent transportation systems benefits*, June 2001

Vanderschuren, M., B. van Arem, G. Zegwaard, *Energievriendelijke variabele snelheidsbeheersing (EVS)*, TNO Inro, December 1997

VanderWerf, J., S. Shladover, H. Krishnan, N. Kourjanskaia and M. Miller, *Modelling the effects of driver control assistance systems on traffic*, California PATH, UC Berkley, 80th Transportation Research Board, January 2001

VanderWerf, J., S.E. Shladover, M.A. Miller and N. Kourjanskaia, *Effects of Adaptive Cruise Control systems on highway traffic flow capacity*, California PATH Program, Institute of Transportation Studies, University of California, Berkley, Transportation Research Record 1800, 2002

Visser, W. de, V.A.W.J. Marchau & R.E.C.M. van der Heijden, *The Cost-effectiveness of Future Driver Support Systems*, Delft University, 1999

Wang, B., M. Abe, Y. Furukawa and Y. Kano, *A driver-centered warning assist system of lane change operation for the aged driver*, Kanagawa institute of technology and Shibaura institute of technology, 10th World Congress on ITS, 2003

Winsum, W. van, Martens, M. & Herland, L., *The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance*, TNO Human Factors, 1999

Yahagi, S. and Y. Yanai, *Market response to adaptive cruise control*, Nissan motor co.. Ltd., 9th World Congress on ITS, October 2002

Yannis, G., J. Golias and C. Antoniou, *Combining traffic simulation and driving simulator analyses for Advanced Cruise Control system impact identification*, National Technical University of Athens and Massachusetts Institute of Technology, TRB, 2004

Yin, Y., M.A. Miller and S.E. Shladover, *Assessment of the applicability of cooperative vehicle-highway automation systems to freight movement in Chicago*, Institute of Transportation Studies, University of California, 83th Transportation Research Board, 2004

Yokota, T., *Evaluation of ahs effect on mean speed by static method*, ITS Division, Public Works Research Institute, Ministry of construction, ITS Seoul, 1998

Yokota, Toshiyuki and Masao Kuwahara, *A study of AHS effects on Traffic Flow at Bottlenecks*, Public Works Research Institute, Ministry of Construction, Japan, ITS Seoul, 1998

Zhang, X., *Intelligent driving - Prometheus approaches to longitudinal traffic flow control*, Steierwald schönharting und partner Vehicle navigation & information systems conference, October 2001

Zou, X. and D. Levinson, *Simulation and analysis of mixed adaptive cruise control / manual traffic* Department of civil engineering, University of Minnesota, 2002

Zwaneveld, P.J. and B. van Arem, *Traffic effects of automated vehicle guidance systems - A literature survey*, TNO Inro, December 1997

A.1 Explanation of the database

The results of the literature quick-scan have been documented in a MS ACCESS database. The database consists of several fields, in which the results of the review can be documented. The following fields have been distinguished:

- **Reference-ID:** This field is an auto numbering field and gives a new record automatically a successive number.
- **Title:** Title of the publication.
- **Author(s):** Author(s) of the publication.
- **Organisation:** Organisation the author(s) is/are employed.
- **Reference journal:** The journal in which the publication is published.
- **Report number:** If available the report number of the publication.
- **Date of publication:** The date the publication has been published.
- **ADA System:** The Advanced Driver Assistance System as described in the publication. One can choose between: Stop&Go, ACC-Stop & Go + foresight, Curve speed limit info, Lane Keeping Assistant, Lane Departure Warning, Lane Change Assistant, Obstacle & Collision Warning, Obstacle & Collision Avoidance, Near Field Collision Warning, Intersection support, Rural Drive Assistance, Local Hazard Warning, Night Vision, Autonomous Driving and Platooning.
- **Additional remarks:** An explanation to the potential effects of the described ADAS.
- **Limitations of effects:** An explanation to the limitations of the potential effects of the described ADAS.
- **Used method:** Method as used to determine the described effects of the ADAS. One can choose between: Literature review, Expert session, Model study – Mathematical, Model study – Driving Simulator, Model study – Traffic Simulation, Pilot/Demonstration, Field Operational Test and Already on the market.

The impacts of the described ADAS on safety, traffic efficiency, comfort and environment have been indicated by means of a check-box.

In the figure below an impression is given of the MS ACCESS database.

Microsoft Access - [References]

File Edit View Insert Format Records Tools Window Help

Type a question for help

Tahoma

Reference ID: 1

Title: Op koers? Resultaten van de proef met het Lane Departure Warning Assistent

Author(s): M.J. Korse, G. Schermers, N.M.D. Radewijk, A. de Hoog and T. Alken

Organisation: Adviesdienst Verkeer en Vervoer

Reference journal: Report Number:

Date of publication: September 2003

ADA System: Lane departure warning

	++	+	0	-	--	Additional remarks
Decrease of 'side' accidents	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	The number of accidents where trucks are involved could be decreased with 10% at maximum.
Decrease of frontal accidents	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Decrease of head-on accidents	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Decrease of accidents with vulnerable road users	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

Record: 1 of 120

Method used to identify effects

N.M.M.

A.2 Reporting of relevant results from Transportation Research Board symposium 2005

[to be added in January 2005]