Road network efficiency and environmental impact assessment of Driver Assistance Systems

Constantinos Antoniou
Massachusetts Institute of Technology, 77 Massachusetts Ave., NE20-208, Cambridge, MA 02139
Tel: 617-2521126, Fax: 617-2521130, email: costas@mit.edu

George Yannis
National Technical University of Athens, 5, Iroon Polytechniou st., GR-157 73 Zografou, Athens, Greece
Tel:+301-7721326, Fax: +301-7721327, email: geyannis@central.ntua.gr

John Golias
National Technical University of Athens, 5, Iroon Polytechniou st., GR-157 73 Zografou, Athens, Greece
Tel:+301-7721276, Fax: +301-7721327, email: igolias@central.ntua.gr

SUMMARY

The **objective** of this research work was to produce an indicative assessment of the impact of selected Driver Assistance Systems on road network efficiency and environmental impact at both a local scale (using microscopic models) and network level (using macroscopic models). A methodology has been developed that integrates **several degrees of analysis** and facilitates the flow of information from microscopic to macroscopic and traffic to environmental models, as appropriate. A number of parameters have been considered in the determination of the scenarios that were used as the basis for the simulation. The presented model system application suggests that positive impacts may be obtained from the introduction of the considered Driver Assistance systems (Adaptive Cruice Control and Intelligent Speed Adaptation) to traffic efficiency and fuel emissions. Furthermore, results about the safety impact of the introduction of these systems can be indirectly obtained from the traffic efficiency results. The sensitivity of the obtained results to small variations of the inputs has also been tackled.

INTRODUCTION

One of the main problems related to contemporary metropolitan areas is the increase in traffic, which often results in the breakdown of the urban networks (at least during peak times) as well as degradation of the environment (1, 17). Many potential solutions have been presented by researchers and scientists, none of which has yet proven to be a panacea. The demand keeps increasing constantly, and it has been proven that increasing the supply (i.e. building more roads) does not have the desired effects in the long term.

However, there are several proposals that seem promising, including the wide-spread adoption of Driver Assistance Systems (DAS). Driver Assistance Systems are a very active area of research (3, 4, 8). Most of the past and ongoing research, however, concentrates on the technical aspects of these systems. As a result, a multitude of systems have been designed; some of these systems have even reached a level of maturity that has allowed them to be commercially available in high-end vehicles.

As these systems become more mature and accessible, their penetration will likely increase. The introduction of such systems in large numbers is likely to affect the traffic dynamics of sensitive urban networks, as well as the environmental conditions in the cities where most people live. Therefore, it is important to know a priori the expected impact of these systems, so that the research and development resources can be steered towards the more socially beneficial systems. In order to be able to do this, however, it is important to have an efficient methodology that can assess the impact of several deployment scenarios in a comprehensive way.

Several experimental studies have already been performed using properly configured driving simulators, as well as vehicles equipped with prototype DA systems. Most studies, however, have focused on the impact of the system on the driver's behavior and workload (for example 2, 5, 9, 20). Results from the use of a modified traffic simulator, SmartAHS, for the evaluation of a Driver Assistance System (Adaptive Cruise Control (ACC) and Stop and Go) have been presented by (15). An analysis of the impact of a similar (ACC) system on fuel consumption of equipped vehicles has been presented by (16).

While clearly DAS are an active area of research, the lack of a methodology to estimate the expected impacts of their introduction cannot be overseen. The European Union (EU) co-funded **ADVISORS project** attempts to formulate a common impact assessment methodology and organisational / legal framework to promote the implementation of Advanced Driver Assistance Systems (ADAS). Previous experience on the field has been taken into consideration in the organization of the work in a number of work-packages, following the typical structure of recent EU projects.

OBJECTIVE AND METHODOLOGY

As part of Work Package 4 of the ADVISORS project, the **objective** of this research work was to produce an indicative assessment of the impact of selected DAS on road network efficiency and environmental impact at both a local scale (using microscopic models) and network level (using macroscopic models).

In order to accurately capture the traffic and related impacts of Advanced Driver Assistance Systems, a methodology has been developed that integrates **several degrees of analysis**. As shown in Figure 1, detailed existing models examine the impact of ADAS at the microscopic level and their findings are used as input for a set of macroscopic models in order to examine the ADAS impact on a network level. Necessary inputs to the methodology include system penetration level, the demand level of the network elements, the various modeled ADA systems' functional characteristics, the driver behavior parameters, the traffic demand and composition and the vehicle consumption/emission characteristics.

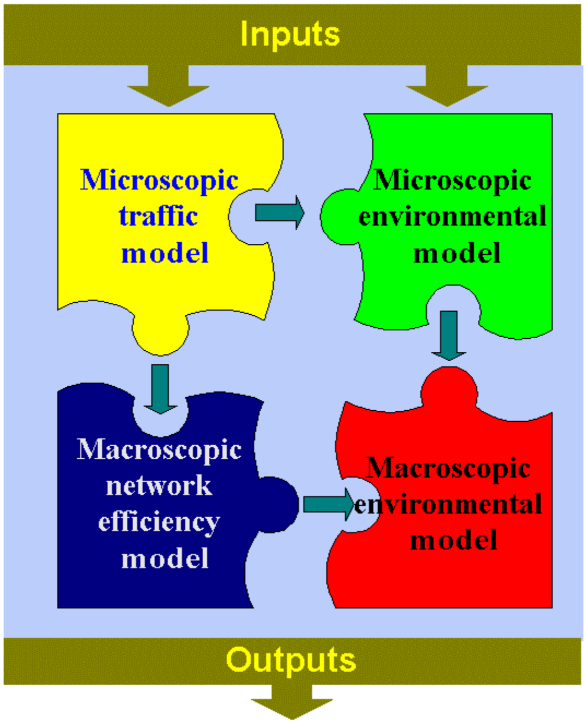

Figure 1. Overall methodology

According to the proposed methodology, a **microscopic** traffic model produces a set of outputs, including capacity information and headway curves, which are used by the macroscopic traffic model, and speed profiles that are used by the environmental models. A microscopic environmental model calculates emissions and fuel consumption per vehicle. A macroscopic traffic model produces information on average speed for each link and the whole network considered while a macroscopic environmental model calculates emission factors and changes in pollutants per link and on a network basis (Figure 1).

The scenaria that have been considered in the models are composed by a selection of the following key dimensions (of course, a number of other parameters and assumptions have been used, on a case by case basis):

- **Type of impact:** Traffic/ network efficiency and environment;
- **Level of impact:** Microscopic and macroscopic;
- **Type of longitudinal control ADAS:** the two longitudinal systems that have been selected for consideration within the scope of this task are **adaptive cruise control** (ACC) and **intelligent speed adaptation** (ISA). A combination of the two systems (ISA + ACC) has also been considered, while the no-ADAS base case has been included in the modeling and is used as the reference scenario.
- **Penetration level:** no penetration (0%) levels for the no-ADAS case, and a number of levels of penetration for the ISA, ACC, and combination of ISA and ACC (ranging from 5% to 100%); and

- **Network parameters:** Network configurations with **urban/interurban characteristics** have been used for the microscopic models. Similarly, for the macroscopic network efficiency and environmental models an **urban network** has been used.

The particular DAS were selected based on a number of criteria, considering their maturity, desirability and expected impact. Only longitudinal systems were considered for this task, as it would have not been possible to realistically simulate the lateral dimension of a system.

ISA and ACC are probably the most well known longitudinal control systems. A large number of variations of the ISA (also commonly known as Variable Speed Limiter, VSL) have already been implemented, varying mostly in the type of the intervention/recommendation, as well as the way it is implemented (4, 19). Systems range from mere speed recommendations to automatic speed reductions. In case of external intervention, systems differ with respect to their range (e.g. area wide or at an individual intersection level). Stop-and-go functions can also be considered a type of ISA, especially when they are part of an infrastructure-based implementation. The main rationale behind such systems is not improvement of traffic efficiency; however, the safety impacts from speed limiting systems can be significant as they offer an effective way to control speed and separation between vehicles.

Adaptive cruise control (ACC) is a more elaborate longitudinal control system based on the maintenance of safe separations with the preceding vehicles (11, 23). Even though limiting speed is not the primary system objective, in most realistic traffic situations the vehicle interactions would result in adjustment of the equipped vehicle's speed (18, 7). While the safety impacts of this observation are clear, one would not expect any traffic improvements from limitation of speed. However, as the vehicles' flow becomes more uniform, traffic dynamics might improve. Furthermore, as the number of read-end collisions could decrease dramatically as a result of the use fo the system, it can be assumed that the elimination of the related disruptions of the traffic will result in traffic efficiency improvements.

It should be noted, that for the purpose of this research effort it has been assumed that the DAS are being used by the drivers as intended. This, however, may not always be the case; as these systems will become accessible to diverse groups of people, it is likely that due to a multitude of reasons, misuses of the systems will occur - especially at the first stages of DAS penetration - and consequently the network efficiency and environmental impact may be altered accordingly.

THE MODELS

In order to extend the breadth of the modelling effort and capture a larger set of scenarios and situations, three **microscopic models** are used, in particular the Dutch model SIMONE (13, 14) from the TRAIL/University of Delft, the English model SISTM of the Transport Research Laboratory (21), and the Finnish model HUTSIM (10) developed by the Helsinki University of Technology. All these models simulate traffic conditions, while SISTM and HUTSIM also simulated environmental conditions, based on the traffic simulation that they performed.

Table 1 shows the basic assumptions of the miscoscopic simulation models with respect to the technical characteristics of the considered DAS. The assumptions used by HUTSIM are presented in green, the assumptions used by SIMONE in red and the respective SISTM assumptions in blue (in this order). If only one (black) value is present, then the value is common to the three systems. The assumptions used in the models do not necessarily coincide due to restrictions related to the availability of models and validated/calibrated networks for their application. Also, because of the need for a better sensitivity assessment, a broader range of simulated cases was chosen instead of comparing multiple results on a limited number of scenaria.

Functional Characteristic	***System***			
	No-ADAS	**ACC**	**VSL**	**ACC+VSL**
Minimum speed of ADAS equipped vehicles (km/h)	0 km/h	0 km/h 30 km/h 0 km/h	0 km/h	0 km/h 30 km/h 0 km/h
Maximum speed of ADAS equipped vehicles (km/h)	No limit mean: 115 stddv: 6 142 km/h	No limit 170 km/h 142 km/h	40/70 km/h 170 km/h 142 km/h	40/70 km/h 170 km/h 142 km/h
Acceleration rate range for ADAS equipped vehicles (m/s^2)	0 to 1.9 m/s^2 2.5 m/s^2 0-2.68 m/s^2	0 to 1.9 m/s^2 4 m/s^2 0 – 0.28 m/s^2	0 to 1.9 m/s^2 2.5 m/s^2 (manual acceleration) 0-2.68 m/s^2	0 to 1.9 m/s^2 4 m/s^2 0 – 0.28 m/s^2
Deceleration rate range for ADAS equipped vehicles (m/s^2)	0 to -2.2m/s^2 -7 m/s^2 -7.86 m/s^2	0 to -2.2m/s^2 -2.5 m/s^2 -1.25 m/s^2	0 to -2.2m/s^2 -2.5 m/s^2 -7.86 m/s^2	0 to -2.2m/s^2 -2.5 m/s^2 -1.25 m/s^2
Minimum gaps for lane change (s)	2.1 s mean 1.6 s, min 0.8 s (no lateral support implemented) depends on driver behaviour (aggressiveness and awareness)			

Table 1. Key system assumptions per system (HUTSIM, SIMONE, SISTM)

The **macroscopic network efficiency model** (6, 22) uses the microscopic traffic estimates to simulate the sensitivity of traffic impacts of the introduction of ADAS. Similarly, the **macroscopic environmental model** [TEMAT, see (12)] uses macroscopic traffic information (from the macroscopic network efficiency model) to estimate the macroscopic environmental impacts of the introduction of ADAS.

The impacts of the introduction of ADAS are determined through a **with/without analysis** of several scenarios. The necessary information for this analysis is obtained by first running the models for a fleet without ADAS-equipped vehicles, and subsequently running the models again for each ADA system and combinations thereof. Thus, ceteris paribus the change in the network efficiency and environmental conditions may be attributed to the introduction of these systems; such changes describe the impact of the introduction of ADAS.

The **application of the proposed methodology** allowed to test the validity of the methodology, which was shown to be realistic and flexible and produced a series of interesting results for the DAS impact on road network efficiency and the environment, as these are summarised in the following paragraphs.

RESULTS FROM THE MICROSCOPIC MODELS

From the application of the three **microscopic models** (SIMONE, SISTM, HUTSIM) a number of important conclusions can be drawn, which are presented below.

IMPACT ON AVERAGE SPEED

- For high velocities and low traffic volumes, changes caused by ACC are hardly noticeable; the free speed is practically unaffected.
- Impact of ACC systems on average speed becomes increasingly more evident as system penetration and traffic flow increase.
- As traffic volume increases, the speed at capacity (so-called critical speed) is higher for the ACC.
- Speeds observed at congested conditions do not change substantially with the introduction of ACC.
- Where the ISA limit is above the average traffic speed, there are minimal traffic effects.
- The impact of ISA systems on average speed depends on several parameters of the road configuration and the traffic, making the extraction of straightforward conclusions impossible.
- The combination of ACC and ISA systems generally provides better results than any of the two systems alone, but not as good as the cumulative impact of the two systems.

IMPACT ON HEADWAYS

- If an ADAS headway parameter is set significantly above 1.8s, flow falls; if a very short headway parameter is chosen, then flow will increase.
- Reducing headway variability will increase the stability of traffic, reduce lane changing and overtaking and allow increased flows.
- Headway distribution is more uniform at higher ACC penetration levels.

- The introduction of the ISA does not have a significant impact on the headway distribution.
- Impact on headway distribution depends on the flow level and the ADAS penetration level.

IMPACT ON TRAFFIC CAPACITY

- ISA has either no effect or a small negative effect on capacity, depending mostly on the considered speed limit.
- The increases in average speeds in some scenarios imply that the capacity is increased in those cases

IMPACT ON TRAFFIC SAFETY DUE TO CHANGES ON AVERAGE SPEED

- For the ACC scenarios, the small reduction in average speed reported is expected to have a direct impact on traffic safety.
- Regarding ISA, no traffic safety conclusions can be drawn as no definite results for the ADAS impact on speed were found.
- From a safety point of view it is speed variability and the top-end speeds that have the most profound effects. ISA, by **reducing the most excessive speeds** and **reducing variability**, is expected to have a great effect on safety. The message from the simulations is that it is necessary to choose the speed limit wisely in order to maintain traffic flow at the same time.

IMPACT ON TRAFFIC SAFETY DUE TO CHANGES ON HEADWAY

- From a safety perspective, it is the short headways that are most important to consider. Consequently, as the proportion of average headways less than 1 second is reduced by the introduction of ACC, a clearly positive impact on safety is expected.
- Additionally, the avoidance of very short headways (high-risk situations) observed by the introduction of ACC, results also to positive safety impact.
- Of course, the actual headway situation is dependent on driver behaviour. If it was found that drivers invariably selected shorter headways than they would without ACC, this would be an important behavioural adaptation that could have negative safety consequences.
- For ISA, the change in the proportion of short headways for higher flow levels can lead to positive impact on traffic safety.

IMPACT ON TRAFFIC SAFETY DUE TO CHANGES ON TIME-TO-COLLISION

- The **reduction in the proportion of** low time-to-collision values for both ACC and ISA implies improvement in terms of traffic safety.
- For ACC and lane drop situations, the reported reductions in "dangerous" time-to-collision measurements are positive for safety, whereas increases in "uncomfortable" TTC measurements are negative for traffic safety.

- For the on-ramp situation both time-to-collision measures imply decreases in safety.
- Regarding ISA, positive safety effects in the lane-drop situation and negative effects at the on-ramp were found.

IMPACT ON TRAFFIC SAFETY DUE TO CHANGES ON LANE CHANGING

- For ISA-based scenarios there was an (expected) reduction in lane changing.

IMPACT ON THE EMISSIONS

- The environmental impacts of the introduction of ADAS are mostly attributed to the changes in speed. As speed generally increases and becomes smoother with ADA systems, it is expected that the environmental impacts are also positive.
- CO emissions decrease directly proportionally to the penetration level (with the exception of ACC, which shows a sharp decrease for low and high penetration levels and almost half of that for medium penetration levels). ACC results in almost twice as steep a decrease than ISA, while ACC+ISA is slightly better that ACC alone.
- CO_2 emissions were little effected by the ADAS tested in any of the scenarios.
- The effect of penetration level on the emission of PM_{10} varied with flow level. At the low flows and more complex geometry, ACC produced about a 9% decrease in PM_{10} emissions at low penetration levels. This benefit dropped to a reduction of 3% – 5% when most vehicles were equipped.
- The **road geometry** had more effect on the results for PM_{10} emissions than for the other analysis parameters. With medium flows PM_{10} emissions increased slightly with the simple geometry and decreased slightly with the complex geometry, but the effect was the opposite at high flows.
- **Significant hydrocarbon emission decreases** for ACC and high penetration levels were observed, while for the other scenarios the decreases were not so evident.
- The effect of traffic conditions on NO_X emissions is different from the effect on other pollutants. **Emissions of NO_X increase with the cruise speed** when the vehicle is cruising in free flow conditions.
- As driving conditions become smoother, with less acceleration and deceleration, emission of most pollutants decreases. However, on motorways, smoother conditions result in more time cruising at a high speed and less time delayed at lower speeds, under such conditions emissions of NO_X increase.

IMPACT ON FUEL CONSUMPTION AND NOISE LEVEL

- Improvements in **fuel consumption** become more significant at higher ADAS penetration levels where traffic can be expected to be smoother (less deceleration and acceleration).
- As far as the predicted **noise level** is concerned it cannot be claimed that ADAS will have a significant noise reduction impact.

RESULTS FROM THE MACROSCOPIC MODELS

The most important conclusions extracted from the application of the traffic (SATURN) and the environmental (TEMAT) **macroscopic models** are presented below:

IMPACT ON AVERAGE SPEED

- The impact of all systems increases proportionally to the ADAS penetration level.
- With the introduction of all systems it was observed that as the traffic flow level is higher, the average speed increase becomes lower.
- ACC systems offer better network efficiency results than ISA systems.
- The benefits of a combined ACC and ISA system are only marginally better than the ACC system.

IMPACT ON THE EMISSIONS

- The implementation of an ADAS system (ACC, ISA or ACC+ISA) in an urban environment reduces the fuel consumption and the emissions of CO, CO_2, NOx, Pb, PM, SO_2, THC.
- The most significant emission reduction is observed in PM, followed by CO_2 (and fuel related emissions Pb and SO_2) and THC, CO and NOx.
- The emission reduction is larger when the penetration of the ADAS system is raised.
- Using ACC leads to major emission reduction than the respective reduction from the use of ISA. The combination of the ACC and the ISA has only an advantage compared to ACC alone for a penetration of 100%.
- When the demand level is higher, the emission reduction is more important for a certain ADAS system and penetration percentage.
- The emission reductions for the future (2005 and 2010) are comparable with the results for year 2000.

CONCLUSIONS

Within the framework of the ADVISORS project a methodology has been developed and applied to obtain a preliminary assessment of the expected impact of the introduction of Driver Assistance Systems (DAS) on traffic, safety and environmental conditions. Two of the most likely-to-be-implemented systems have been used in the analysis, as well as their combination and a base case with no DA system present. The sensitivity of the results to several parameters has also been tackled.

Several dimensions and degrees of analysis are required for the simulation of the impact of Driver Assistance Systems in traffic efficiency and the environment. The proposed methodology combines several models in a framework that uses a variety of inputs and processes them to obtain the final outputs. Information flows from the microscopic models to the macroscopic models and from the traffic to the environmental models. Results from detailed simulation of individual vehicles by microscopic models is aggregated and exploited by macroscopic models to obtain network-wide estimates of the impacts. Similarly, traffic simulation outputs are fed into environmental models of similar granularity (i.e. microscopic or macroscopic) that simulate the environmental impacts.

The presented model system application suggests that positive impacts may be obtained from the introduction of the considered DA systems to traffic efficiency and fuel emissions. Results about the safety impact of the introduction of these systems can be indirectly obtained from the traffic efficiency results, since safety is closely related with vehicle speeds and separations. However, it should be stressed that a number of assumptions have been made, possibly influencing the accuracy of the simulated impacts. One such key implicit assumption was that the users utilisze the systems as intended, which may not be absolutely realistic for general populations, at least for the first stages of the DAS wide implementation. However, given proper system design and a reasonable transition period it can be assumed that most of the drivers will utilize the available DAS in a near-optimal way.

The obtained simulation results should neither be generalized nor transferred to other situations (e.g. networks or DA systems) without thorough investigation of the applicability. Different network characteristics, operational parameters of the Driver Assistance Systems, or even driver behavior might result into significantly different quantitative results. It should be noted, however, that the results should not be dramatically different in reasonable similar situations, and could thus be well used as qualitative indications.

Within the scope of this research effort, an estimate of traffic and related impacts due to the introduction of DA systems was obtained prior to their actual deployment. Given the appropriate input and simulation models, this methodology can be used for the assessment of the impacts of virtually any DA system. The importance and urgency for implementation of each system can thus be assessed and their future development and exploitation can be assisted. Interesting further research would include the introduction of more parameters into the simulation models, such as different fleet compositions and driver behavior patterns.

REFERENCES

1. Bhargab, M., Sikdar, P. K., and Dhingra, S. L. (1999). Modelling congestion on urban roads and assessing level of service, Journal of Transportation Engineering, **125**, No 6, pp. 508-514.
2. Braban-Ledoux, C. and Ekdahl, T. (2000). Microscopic indicators for characterising driver behaviour, Proceedings of the 7th World Congress on ITS, Turin.
3. Brand, C., Davison, P., Lewis, A., Moon, D., Site, P. D., Gentile, C., Filippi, F., Landolfi, O., Dougherty, M., Korver, W., Harrell, L., van Toorenburg, J., Akerman, J., Eriksson, E. A., Hernandez, H., Weber, M., Dauner, A., Heckelsmueller, J., Hoffmann, A., Leiss, U., Linde, E., and Petzel, W. (1997). Forecast of New Technologies With Major Impacts, EU project FANTASIE, Deliverable 9.

4. Davison, P., Brand, C., Lewis, A., Moon, D., Site, P. D., Gentile, C., Filippi, F., Landolfi, O., Dougherty, M., Korver, W., Harrell, L., van Toorenburg, J., Akerman, J., Dauner, A., Heckelsmueller, J., Leiss, U., Linde, E., and Petzel, E. (1997). A Structured State-of-the-Art Survey and Review, EU project FANTASIE, Deliverable 8.
5. Duynstee, L. and Martens, G. (2000). Effects of intelligent speed adaptation on driving behaviour, Proceedings of the 7th World Congress on ITS, Turin, Italy.
6. Hall, M. D., Van Vliet, D., and Willumsen, L. G. (1980). SATURN – A simulation-assignment model for the evaluation of traffic management schemes, Traffic Engineering and Control, **21**, pp168-176.
7. Hayward, M., Becker, S., Nilsson, L., Brockmann, M., and Sala, G. (2000). *TR1004*, AC – ASSIST, Anti-Collision Autonomous Support and Safety Intervention System (incorporating ROADSTER), Submitted as Project Deliverable D3.1: Report on Users' Needs.
8. Heijer, T., Oei, H. L., Wiethoff, M., Boverie, S., Penttinen, M., Schirokoff, A., Kulmala, R., Heinrich, J., Ernst, A. C., Sneek, N., Heeren, H., Stevens, A., Bekiaris, A., and Damiani, S. (2000). Problem Identification, User Needs and Inventory of ADAS, ADVISORS Project Deliverable D1/2.1.
9. Ishida, S., Tanaka, J., Kondo, S., and Kawagoe, H. (2000). Evaluation of driver assistance system, Proceedings of the 7th World Congress on ITS, Turin, Italy.
10. Kosonen, I. (1999). HUTSIM - Urban traffic simulation and control model: principles and applications. Helsinki University of Technology Transportation Engineering Publication 100, Helsinki University of Technology, Finland.
11. Martin, P. (1993). Autonomous Intelligent Cruise Control incorporating automatic braking (SAE Technical Paper No. 930510). Warrendale, PA: Society of Automotive Engineers.
12. MEET (1999). Methodology for calculating transport emissions and energy consumption. Transport research, Fourth Framework Programme, Strategic Research, DG VII, ISBN 92-828-6785-4.
13. Minderhoud, M. M. (1999). Supported Driving: Impacts on Motorway Traffic Flow. T99/4 TRAIL Dissertation Series.
14. Minderhoud, M., and P.H.L. Bovy (1999). Modelling Driver Behavior on Motorways - Description of the SIMONE model. Report VK22206.302, Delft University of Technology, Transportation and Traffic Engineering Section.
15. Misener, J., VanderWerf, J., and Kourjanskaia, N. (2000). SmartAHS in evolution: adapting an AHS microsimulation tool to evaluate driver-assistance systems, Proceedings of the 7th World Congress on ITS, Turin, Italy.
16. Neunzig, D. and Breuer, K. (2000). Analysis of longitudinal vehicle control systems with minimised emissions and optimised driving comfort, Proceedings of the 7th World Congress on ITS, Turin, Italy.
17. NRC (1995). *Quantifying Congestion – Final Report (Draft)*, National Cooperative Highway Research Program Project 7-13, National Research Council.
18. Oei, H. (1998). Advanced Cruise Control (ACC). A literature study, SWOV, Leidschendam. [In Dutch]
19. Oei, H. (1998). Intelligent Speed Adaptation (ISA). A literature study, SWOV, Leidschendam. [In Dutch]

20. Regan, M. A., Tingvall, C., Healy, D., and Williams, L. (2000). Trial and evaluation of integrated in-car ITS technologies: report on an Australian research program, Proceedings of the 7th World Congress on ITS, Turin, Italy.
21. Stevens, A, Hardman, E and Burton, P. (2000). Scenario Analysis, Traffic Responsive Intelligent Speed and Headway Adaptation (TRISHA). Unpublished TRL project report, PR/T/121/2000.
22. Van Vliet, D. (1982). SATURN – A modern assignment model, Traffic Engineering and Control, **23**, pp. 578-581.
23. Winner, H., Witte, S., Uhler, W., and Lichtenberg, B., (1996). Adaptive Cruise Control System Aspects and Development Trends (SAE Technical Paper No. 961010). Warrendale, PA: Society of Automotive Engineers.