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INVESTIGATION OF SAFETY IMPACT OF DRIVER ASSISTANCE SYSTEMS THROUGH TRAFFIC SIMULATION MODELLING

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Summary

A methodology has been developed for the use of microscopic traffic simulation modelling for the investigation of road safety impact from the introduction of two advanced driver assistance systems (ADAS). The simulations modelled key parameters (headway, speed) for several scenarios of different traffic levels and assumed penetration levels of Adaptive Cruise Control and Intelligent Speed Adaptation systems. Results from the simulations, studied in the context of existing relationships between the number of road accidents and traffic parameters, allowed the estimation of the related traffic safety impact. This impact was investigated in relation to the corresponding changes in average speed, in headways, in time-to-collision and in lane changing. Even though an overall straightforward answer to the safety impact of ADAS systems was not possible due to the complexity of the traffic safety phenomenon, several positive effects on safety were identified.

Key-words: road safety, intelligent transport systems, driver assistance systems, traffic modelling

Sommaire

Une méthode a été développée, à fin d' être utilisée par un modèle de simulation microscopique, destiné à examiner l' influence sur la sécurité routière de l' introduction de deux systèmes d'aide au conducteur avances (SACA). Les simulations ont modelé des paramètres clés (espace d'avance, vitesse) pour plusieurs scénarios de différents niveaux de circulation et niveaux de pénétration supposé des systèmes de Contrôle de Croisière Adaptable et d' Adaptation Intelligente de la Vitesse. Les résultats des simulations ont été examinés dans le cadre des relations existantes entre le nombre des accidents et les paramètres de la circulation et ils ont donné la possibilité d' estimer l' influence sur la sécurité routière correspondante. Cette influence a été examiné en relation avec les changements correspondantes de la vitesse moyenne, de l'espace d'avance, du temps-jusqu'-à-collision et du changement de bande. Malgré le fait qu' une réponse directe globale au sujet de l' influence des SACA sur la sécurité routière n'était pas possible vu la complexité du phénomène de la sécurité routière, plusieurs effets positives ont été identifiés.

1. INTRODUCTION

The implications of driver assistance systems are adopting an increasingly high profile since these systems are expected to improve road safety, increase road capacity and reduce the environmental impacts of traffic (5). The advent of new technologies supporting vehicle intelligence (e.g. sensors, software and communications) makes the use of driver assistance systems more available to a wider public, promoting a safer and more efficient driving experience.

The negative impacts of road accidents, including fatalities, injuries, material damage, and disruption of traffic are easily apparent, so safety questions are inherently associated with the introduction of any new technology. Advanced driver assistance systems (ADAS) have the potential to improve road safety by influencing exposure to traffic hazards, by reducing the probability of crashes and by reducing injury consequences (4). More precisely, driver assistance systems support modification of the driving task by providing information, advice, and assistance (10). They also influence, directly and indirectly, the behaviour of users of both equipped and non-equipped vehicles and can alleviate accident consequences by in-vehicle intelligent injury reducing systems (2,7).

Within the EU co-funded project ADVISORS, work is in hand to estimate the impact on road safety from the introduction of advanced driver assistance systems using a set of microscopic traffic simulation models (9). The models' input parameters describe individual vehicle behaviour under different traffic conditions. For example, parameters describe the functional characteristics of ADA systems, the driving style of the driver, the ADAS penetration level, the traffic composition, and the prevailing level of service.

The simulations within this project have examined a series of ADAS providing longitudinal driving support and have modelled key parameters such as headway and speed information for each scenario studied. The methodology is flexible and can be used to examine the sensitivity of impacts under different conditions such as traffic level and assumed ADAS penetration, etc.

Information from the simulations, studied in the context of existing relationships between the number of road accidents and traffic parameters, has allowed road safety impacts due to the introduction of specific ADA systems to be estimated prior to their actual deployment. The results contribute to strategic decisions concerning the importance and urgency of implementation of each ADAS, and can therefore play an important role in their future development.

2. THE MICROSCOPIC SIMULATION MODELS

Prior to the synthesis of the results obtained by the three microscopic models, it is interesting to examine the three models in parallel, in order to identify their similarities and differences. Keeping these findings in mind, it is easier to extract meaningful conclusions from the simulation results.

The British model, SISTM (12), can be used to evaluate qualitatively and quantitatively the effect of different layouts or operating conditions on a length of motorway. In particular, relative to the ADVISORS scope, SISTM can simulate: a) lanes reserved for specific vehicle types or for vehicles making certain Origin/Destination movements, b) different levels of traffic demand, and c) changes in vehicle characteristics (e.g. incorporation of ADAS). SISTM has been used to investigate a simple geometry consisting of 10km of 3-lane motorway with a 2-lane entry slip road located 2km along the section. A second more complex geometry with entry and exit slip roads and road gradients yielded essentially the same results. The model was also run to investigate the blocking of one lane, but again essentially the same relative effects were observed as in the 3-lane case. Traffic speeds were 80-90kph and flow rates investigated were between 1200 and 2000 vehicles per hour per lane.

The Dutch simulation model SIMONE (6) is designed to analyse traffic flow impacts of a wide variety of driver support system compositions of the vehicle fleet under various roadway configurations and traffic demand conditions. An experimental scenario consists of a specific combination of roadway configuration, traffic demand, and system composition. The outcome of the simulation is a mixture of microscopic and macroscopic data generated at specified detector sites. For the macroscopic data, an aggregating time interval must be specified between one and sixty minutes. SIMONE has concentrated on modelling two critical situations of inter-urban traffic, specifically an on-ramp (3 running lanes +1 joining lane) and a lane drop situation (3 lanes decreasing to 2). Critical traffic speeds are 86-96 km/h and flow is 2000vehicles/hour/lane.

The Finnish model HUTSIM (8) can deliver traffic indicators, but its main strength is in environmental modelling. Environmental analysis in HUTSIM is divided into emissions and fuel consumption. The analysis is based on each vehicle’s kinematics. A post-use software called HUTSIM Analyzer creates a database from HUTSIM’s output file. The database contains information of vehicle speed and acceleration and is used for the calculation of the results that the user requests, for example fuel consumption or emissions. These latter use emission matrices (quantities of certain emission as a function of chosen factors, e.g. vehicle's instantaneous speed, acceleration, or their product). HUTSIM has been used to simulate a motorway between Helsinki and Espoo, which suffers little congestion, as well as a busy, four-lane street with tram rails in central Helsinki.

3. SIMULATION ASSUMPTIONS

This section presents the simulated systems' functional characteristics per simulation model. This information is particularly relevant as it defines the actual behaviour of the simulated vehicles. The information provided in this section can provide important insight while comparing the obtained simulation results and preparing their synthesis. The functional characteristics of systems simulated by each microscopic model are presented in Table 1. Each column refers to an ADA system, while each row describes the value ranges for a functional characteristic, allowing for easy comparison between systems. As has been discussed above, the simulated systems are Adaptive Cruise Control (ACC), Intelligent Speed Adaptation (ISA), and a combination of the two (ACC+ISA). The functional characteristics pertain to the speed, acceleration and distance-keeping and gap acceptance behaviour of the various types of simulated vehicles.

Table 1 presents the functional characteristics of the simulated ADA systems for the three microscopic models used. There are several reasons why these assumptions are not uniform across all three models. As each model has already been validated with particular sets of assumptions, it was considered beneficial for the validity of the simulations to use values from these sets, where applicable. The same applies for networks that have already been calibrated and tested with each model. Keeping these restrictions in mind, a conscious decision was made to model a broader range of simulated cases instead of comparing multiple results of a limited number of scenarios.

Assumptions	No ADAS			ACC			ISA			ACC+ISA		
	SIMONE	SISTM	HUTSIM	SIMONE	SISTM	HUTSIM	SIMONE	SISTM	HUTSIM	SIMONE	SISTM	HUTSIM
Minimum speed (km/h)	0	0	0	30	0	0	30	0	0	30	0	0
Maximum speed (km/h)	115	142	No limit	170	142	0	170	142	40 (urban)/ 70 (highway)	170	142	40 (urban)/ 70 (highway)
Acceleration rate (m/s^2)	2,5	0 - 2,68	0 - 1.9	4	0 - 0,28	0 - 1.9	2,5	0 - 2,68	0 - 1,9	4	0 - 0,28	0 - 1.9
Deceleration rate (m/s^2)	-7	-7,86	0 - 2,2	-2,5	-1,25	0 - 2,2	-2,5	-1,25	0 - 2,2	-2,5	-1,25	0 - 2,2
ACC headways (s)	---	---	---	~1-2,5*	1,5-2,0	**	---	---	---	~1-2,5*	1,5-2,0	**
Minimum gaps (s)	Various values for different configurations											
Other	Various values for different configurations											

* function of speed and system control settings
** based on a normal distribution with average 0,7 seconds

Table 1. *Microscopic simulations functional characteristics*

In the SISTM simulations, ACC + ISA scenarios were modelled, with ACC headway of 1.5s and 2.0s.

SISTM also investigated a lane change parameter. With ISA +ACC, the "normal" setting of the parameter constrained the ACC vehicle to follow in ACC mode for at least 10s before making a lane change. The parameter was then increased to force 30s of ACC following before a lane change.

4. INVESTIGATION METHODOLOGY

Much has been written about the cause of accidents and many may be due to subtleties of interaction and chance lapses of concentration that cannot readily be represented within micro simulation models. However, the models can derive certain characteristics that can, cautiously, be used as indicators of safety. Note, however, that the introduction of new driver assistance systems may result in behavioural changes that may result in effects considerably different than those reported from these modelling studies.

The table below represents the outputs actually available from the models in the data produced during this first phase of modelling. Further modelling could enable a greater range of outputs to come from each model.

Output	SISTM	SIMONE	HUTSIM
Average speed	X	X	X
Headway	X	X	
Time to collision	X	X	
Lane Change rate	X		

***Table 2**. Summary of simulation model outputs (safety)*

Increase in speed is associated with an increase in the frequency and severity of accidents. Higher speed leaves drivers with less opportunity to react to unforeseen events and increases the kinetic energy that may be dissipated in a crash. In the UK a quoted empirical finding is that a 5% reduction in accidents is associated with a 1 mph (1.6kph) reduction in average speed. Although this is broadly true, the sensitivity in urban areas is greater and that on faster inter-urban roads is considerably less. No research seems to have been undertaken to derive a relationship specifically for inter-urban roads, but this is likely to be less than 2% per mph (13) and perhaps can be assumed to be a 1% reduction in accidents for every 1 mph reduced.

Clearly, a reduction in average headway affords the driver less time to respond to unforeseen events and so must be associated with an increase in the frequency and severity of accidents (11). In a number of European countries (e.g. the UK and Germany) recommendations or rules are in effect concerning a "2-second headway". However, surveys of actual headway distributions on motorways show that this rule is widely ignored. Indeed, on busy inter-urban routes a 2s headway may be viewed as "deviant behaviour" by other drivers who will overtake and cut in front of the careful driver.

Another factor is the variability in headway. Although capacity is not affected unless the average headway is changed, homogeneity is expected to increase the safety of traffic.

Time-to-collision (TTC) has been proposed as an indicator of safety as there needs to be relative speed between vehicles for a collision to occur. Studies have suggested that drivers are comfortable with TTC above 10 seconds but become increasingly uncomfortable as TTC reduces. If ADAS provide a degree of automatic headway control (e.g. ACC systems) then the short TTC may not be so inherently unsafe as the ADAS alerts the driver and reacts to a reducing TTC in a shorter time than the driver could do alone. As with headways, there may be behavioural changes in terms of acceptance of reduced TTC or headway promoted by reduced stress of assisted driving. These adaptation effects are not inherent in the simulations.

An increase in lane changing behaviour is associated with reduced safety. Lane changing exposes the driver to the additional hazard of other vehicles (perhaps in the driver's "blind spot") and this is more hazardous in congested traffic, at night, or if drivers are not paying full attention to the traffic situation. Inappropriate lane changing can also introduce traffic perturbations requiring other control actions and may lead to increasing driver stress.

As can be deduced from the discussion above, associations can be made between the indicators and safety, but quantitative relationships cannot be expressed. Apart from possible behavioural changes (1,3) (that may be very significant), there are likely to be other parameters such as road geometry and traffic conditions that determine the relationship between the parameters and safety (15). Therefore, within one model the combined effect of (say) a decrease in average speed of 5% and a decrease in headway of 5% can be computed but the actual safety effects in real traffic cannot be simply deduced. Indicators from the different models are discussed further below.

5. IMPACT ON TRAFFIC SAFETY DUE TO CHANGES ON AVERAGE SPEED

For the ACC scenarios, SISTM reports a small reduction in average speed (at least in the medium and high flow scenarios). SIMONE does not report any significant changes, while HUTSIM reports a small increase in speed. The different findings may be due to the different conditions studied. SIMONE studied merge and lane drop situations exclusively, while SISTM and HUTSIM's scenarios were more concerned with flow between junctions. Furthermore, HUTSIM flow was very low in comparison with the other two and this allows greater scope for increased traffic speeds.

Regarding ISA, SISTM reports an overall increase in average speed while SIMONE reports a decrease in both situations studied. However, this can readily be explained. SISTM imposed a limit of 112km/hr (the national maximum) and this was above the maximum observed average traffic speed in the simulation of about 95km/h. SIMONE chose a limit of 70km/h on one section, and this was below the previous average speed. Therefore, the impact was to reduce average speed.

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 considerable positive 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.

6. IMPACT ON TRAFFIC SAFETY DUE TO HEADWAY CHANGES

For ACC scenarios, the average headway depends on the proportion of ACC traffic and the ACC set headway. However, from a safety perspective, it is the short headways that are most important to consider. SISTM reports the proportion of average headways less than 1 second and ACC is found to reduce this proportion slightly (which is positive for safety). SIMONE reports the proportion of average headways less than 1.5s but does not detect any differences. However, it is possible that an effect actually occurs in the SIMONE simulation, which could be captured by future simulation collecting the headways that are lower than 1 second. Of course, the actual headway situation is dependent on driver behaviour. If it were 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, SISTM reports no change in the proportion of short headways at low flow but a slight increase at higher flow. SIMONE finds no significant change in short headway.

7. IMPACT ON TRAFFIC SAFETY DUE TO CHANGES IN TIME-TO-COLLISION

SISTM reports TTC values <10s and finds reduction in the proportion of these TTC values for both ACC and ISA, thus implying improvement in terms of safety due to the introduction of ADAS. SIMONE reports TTC values less than 3s (representing "uncomfortable" situations) and TTC <1.5s (representing "dangerous" situations) and provides mixed results. For ACC and lane drop situations, SIMONE reports reductions in "dangerous" TTC measurements but increases in "uncomfortable" TTC measurements. For the on-ramp situation both TTC measures imply decreases in safety. Furthermore, regarding ISA, SIMONE finds positive safety effects in the lane-drop situation and negative effects at the on-ramp.

It is therefore clear that SIMONE provides conflicting results with respect to the impact of the introduction of ADAS to TTC. There is considerable debate about the use of TTC as an indicator of safety in inter-urban situations. It could be useful to undertake a thorough review of field studies where inter-urban TTC have been reported to better understand the link between TTC and safety and to choose a common "short" TTC value to report and compare.

8. IMPACT ON TRAFFIC SAFETY DUE TO CHANGES ON LANE CHANGING

SISTM was the only model to report lane changing behaviour, although this is also available in HUTSIM and could be reported in future work. The unexpected result was that ACC seemed to promote an increase in lane changing behaviour. SISTM repeated one of the model scenarios with an internal lane change parameter set to 30s instead of the usual 10s. This inhibited ACC vehicles from changing lanes for at least 30s by requiring them to stay in ACC following mode for this time. Even in this case, lane changing increased from the no-ADAS scenario. For ISA-based scenarios there was an (expected) reduction in lane changing.

The SIMONE capacity results may provide a useful perspective on the lane-changing issue. SIMONE found capacity increases for ACC penetration up to about 50% (depending on the headway setting) and then capacity reduces as penetration is increased further. According to a hypothesis, this has been attributed to the under-utilisation of the "slow" lane. SISTM results do not show this reduction in capacity, but do show increasing lane changing behaviour. It is therefore plausible that the models are making different assumptions about drivers' use of lanes.

If ACC does promote increased lane changing or under use of one of the running lanes, then these are important effects and should be investigated experimentally.

9. SYNTHESIS OF INDICATORS FOR ACC SYSTEMS

The following table summarises the expected safety impacts of the indicators described above for the ACC system. From a quick overview of the results in the convenient tabular format, it becomes evident that there is a disagreement between SISTM and HUTSIM results with respect to average speed. This can probably be attributed to the relatively uncongested traffic prevailing in the HUTSIM simulated scenarios, which allowed for more significant speed increases (interpreted here as safety decreases).

ACC	SAFETY IMPLICATIONS		
Output	SISTM	SIMONE	HUTSIM
Average speed	+	0	–
Headway	+	0	
Time to collision	+	+	
Lane Change rate	–		

Table 3. *Synthesis of safety indicators - ACC*

As the average speed changes are small and TTC is controversial, the most important indicator for safety is likely to be headway. In this regard, driver behaviour is crucial. SIMONE, with a modelled headway of 1.25s, finds safety neutral, whereas SISTM models longer headways and finds safety improvements. A key question is whether drivers choose ACC headways shorter or longer than they would without ACC.

Finally, the increase in lane changing reported by SISTM is an interesting effect that may warrant further study in driving simulators and field trials.

10. SYNTHESIS OF INDICATORS FOR ISA SYSTEMS

The following table summarises the expected safety impacts of the indicators described above for the ISA system. Again, average speed produces diverging safety results. This can probably be explained by the choice of the ISA limit in the various models. SISTM used a limit above the average speed while SIMONE and HUTSIM used a limit below. However, this is likely to be overshadowed by the extremely positive safety effect of ISA by decreasing speed variability and reducing "top-end" speeders. For a further comparison, the DRACULA model (14) was used by the University of Leeds to investigate ISA. They found negligible change in motorway traffic flow and reduced overtaking.

ISA	SAFETY IMPLICATIONS		
Output	SISTM	SIMONE	HUTSIM
Average speed	–	+	+
Headway	–	0	
Time to collision	+	+, –	
Lane Change rate	+		

Table 4. *Synthesis of safety indicators - ISA*

For ISA the dominant effect is thought to be the reduction in "top-end" speeders and lower speed variability. Both of these factors are extremely positive for safety. An interesting area where modelling can be employed is in the choice of appropriate ISA limits so that impacts on traffic flow are optimised.

11. CONCLUSION

The use of microscopic traffic modelling allowed an investigation of safety impact from the introduction of Adaptive Cruise Control and Intelligent Speed Adaptation systems on interurban motorways. Safety impact was investigated in relation to changes in average speed, in headways, in time-to-collision and in lane changing resulting from introduction of the two systems examined. Even though an overall conclusion concerning the safety impact of ADAS systems is not possible due to the complexity of the traffic safety phenomenon, several positive effects on safety were identified. These positive effects varied according to the traffic situations and their presence also depends directly on the penetration level of the ADA systems.

Application of the proposed methodology showed that extraction of some conclusions about ADAS safety impact is possible through microscopic traffic modelling. Such modelling is also very useful in highlighting areas where further detailed experimental analysis is required to identify changes in driver behaviour. Further research using various types of road network and traffic situations with the proposed methodology will allow a clearer picture of ADAS impacts to emerge. This will identify areas where the highest potential for road safety improvements is expected and highlight key areas for future development of advanced driver assistance systems.

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