PARAMETERS RELATED TO MODELLING INTELLIGENT SPEED ADAPTATION SYSTEMS WITH THE EMPLOYMENT OF A MICROSCOPIC TRAFFIC MODEL

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ABSTRACT: This paper addresses the incorporation of intelligent speed adaptation (ISA) systems into microscopic traffic models. The suggested model is Gipps' car-following model and the study involves the identification of the appropriate model parameters that need to be modified as well as the necessary steps towards the design of the modified model. Driver behaviour under the use of three different functionalities of ISA, namely – informative, warning and intervening – was investigated with the conduction of a driver simulator experiment. Specific parameters that would describe the implementation of the system were identified including parameters related to system operation and impact on driver behaviour. Driver behaviour as described through these parameters was also quantified to confirm the necessity of their modification or introduction into the model.

1 Introduction

Intelligent transport systems (ITS) comprise a fast developing field and are anticipated to contribute to a more sustainable road traffic network by improving road safety, traffic conditions, environmental conditions and mobility [1]. A prerequisite of their successful implementation is determining their anticipated impact which can be achieved with a variety of tools including on-road and simulator studies, laboratory experiments and simulations based on traffic/driver models. In relation to the latter tool, traffic models need to be updated to include the operation of intelligent transport systems.

In the recent years effort has been made into incorporating intelligent transport systems into traffic models. This offers the possibility of enhancing the utility of the models and the opportunities of intelligent transport system evaluation and consequently of the assessment of traffic management and road safety strategies. However, current applications mainly involve advanced traveller information systems, rather than advanced driver assistance systems, and more specifically the impact of information provision on driver route choice and consequently on road network conditions. Such examples include the traffic simulation programs AIMSUN [2], CONTRAM [3], PARAMICS [4] and VISUM [5]. In a rather different application [6] simulated the differences in lane changing and gap acceptance behaviour at congested road sections when drivers are informed of traffic incidents downstream, using the traffic simulation model SITRAS [7]. Intelligent speed adaptation has also been incorporated in the microscopic traffic simulation model DRACULA [8]. [9]. This application however concentrates on the operation of the system itself and its representation employing model parameters rather than the representation of the impact of this operation on driver behaviour.

This study discusses the specific aspects of the impact of intelligent speed adaptation systems on driver behaviour related to driving speed (speed, acceleration and deceleration), and the possible ways of incorporating them in a traffic model. The impact of the systems on driver behaviour is elicited from the analysis of simulator data and the model used to illustrate the proposed approach is Gipps' car-following model [10].

2 Intelligent speed adaptation simulator study

2.1 System operation

A study at the Transport Research Laboratory driver simulator to investigate driver behaviour under the use of intelligent speed adaptation (ISA) systems was conducted, and three different ISA functionalities – related to the human machine interface (HMI) were investigated: informative, warning and intervening.

A pictogram indicating the prevailing speed limit as well as its justification was transmitted through an in-vehicle screen during the informative ISA application. The operation of the warning ISA involved a tone repeated 3 times (0.5 sec on, 0.5sec off) the first time that the speed limit was exceeded and a single tone (0.5 sec) every 8 seconds that the driver was continuously exceeding the limit were transmitted. In addition, the auditory warnings were also supported by visual information of the prevailing speed limit through the in-vehicle screen. Last, the Intervening ISA did not allow the driver to adopt speeds higher than the prevailing speed limit. If the system determined that the accelerator pressure would cause the vehicle to exceed the limit, the pedal value was reduced automatically. A smooth deceleration was also applied when the vehicle was about to enter a speed limit zone with speed higher than the speed limit. The image of the prevailing speed limit was presented via the in-vehicle screen and a 0.5sec tone was transmitted, whenever the intervening functionality was triggered.

2.2 Simulation drives

Each driver made four drives, one without a system which will be referred to as "base condition" and one with each of the three ISA functionalities operating. The simulated road environment involved a 2-lane single carriageway road and consisted of rural road sections with 60mph speed limit, road sections through villages with 30mph speed limit and residential areas with 20mph speed limit. The vehicle was driving unimpeded by other vehicles (i.e. no vehicles were placed in front of it), with the exception of three different types of incidents which were simulated within the 60mph speed limit areas. The first involved an accident blocking the lane indicated by two stopped vehicles one of which was an ambulance. The driver had to overtake the stopped vehicles using the lane of the opposite direction. The second incident involved inserting a slow-moving vehicle in-front of the simulator vehicle, and the third involved the appearance of a green dot on the vehicle windscreen at which the driver was told – prior to the drive – to react by reducing vehicle speed to 10mph. The characteristics of the drives in terms of order of incidents and systems varied both within and between drivers, so as to eliminate possible order effects.

2.3 Participant characteristics

24 participants holding a driving license were recruited from the Transport Research Laboratory database and the quota applied for their selection involved driver age, as the objective was to have a balanced sample between young/novice drivers and experienced but not elderly drivers. Following the experiment 23 drive-sets fulfilled the requirements for data processing; and the characteristics of these drivers appear in Table 1.

Table1. Participant Characteristics

	Age (years)	Driving experience (years)	Annual mileage (miles)
Average	31.22	13.06	12909
Minimum	17.00	0.67	2000
Maximum	46.00	28.00	36000
St. Dev.	8.57	8.53	9506

3 Translation of implementation of Isa into traffic model parameters

3.1 Gipps' car-following model

Gipps' car-following model is discrete-time, continuous-space microscopic model. The model was initially intended for simulation of free-flow traffic, and hence used for simulating motorway roads, but is now being employed in various traffic simulation programs including MULTSIM [11], SIGSIM [12], AIMSUN, DRACULA and SITRAS. It is quite detailed, and there is a trade-off with the computational time, which is long by comparison with other simpler models. The variables that are calculated in each time-step are the vehicle's speed and through this its new position. The formula that is used to calculate the "updated" speed (speed at time $t+\tau$) is:

$$u_n(t+\tau) = \min\{$$

$$u_n(t) + 2.5 a_n \tau (1 - u_n(t)/V_n)(0.025 + u_n(t)/V_n)^{1/2}, \quad (1a)$$

$$b_n\tau + \sqrt{(b_n{}^2\tau^2 - b_n\left[2[x_{n-1}(t) - s_{n-1} - x_n(t)] - u_n(t)\tau - u_{n-1}(t)^2/\hat{b}\right])} \;\} \quad (1b)$$

where

$u_n(t)$ speed of vehicle n at time t,

a_n maximum acceleration which the driver of vehicle n wishes to undertake,

τ apparent reaction time, the same constant for all vehicles,

V_n speed at which the driver of vehicle n wishes to travel.

b_n most severe braking that the driver of vehicle n wishes to undertake (b_n<0),

$x_n(t)$ location of the front of vehicle n at time t,

s_n effective size of vehicle n, that is, the physical length plus a margin into which the following vehicle is not willing to intrude, even when at rest,

$\hat{b}$ value of b_{n-1} estimated by the driver of vehicle n who cannot know this value from direct observation.

The position of vehicle n at time $t+\tau$ is thus calculated to be:

$$x_n(t+\tau) = x_n(t) + 0.5\left[u_n(t) + u_n(t+\tau)\right]\tau \quad (2)$$

The model has been calibrated with the following values: V_n sampled from a normal population N (20.0, 3.2^2) m/sec, s_n sampled from a normal population N (6.5, 0.3^2) m, a_n sampled from a normal distribution N (1.7, 0.3^2) m/sec^2, b_n equated to -2.0a_n, $\hat{b}$ minimum of -3.0 and (b_n-3.0)/2 m/sec^2, τ 2/3 seconds.

3.2 Incorporation of driver behaviour under ISA into Gipps' model

The analysis of driver behaviour within this study involves the driver behaviour parameters related to speed (i.e. speed, acceleration and deceleration) that could be introduced into Gipps' model. Simulator data for the drives within the 60mph speed limit roads (where vehicle movement is unimpeded) is analysed, for which the threshold limit for ISA operation was set to be at 62mph.

3.2.1 Speed

First, the impact of the systems on driver speed was analysed. Mean and maximum speeds were calculated within appropriately defined periods within which drivers would have already accelerated/decelerated to their desirable speeds when entering from (or exiting to) different speed limit areas and within which vehicle movement was unimpeded, as the road sections in which drivers had to overtake due to lane closure (accident) or slow moving vehicles ahead were not included in the analysis. Driver speed behaviour is illustrated in Table 2.

Table 2. Driver speed under the different ISA systems (mph (m/sec))

	Base	Informative	Warning	Intervening
Mean	62.66 (28.01)	62.71 (28.04)	59.73 (26.70)	59.17 (26.45)
Variance	5.24^2 (2.34^2)	4.69^2 (2.10^2)	6.09^2 (2.72^2)	1.65^2 (0.74^2)
Maximum	67.13 (30.01)	68.73 (30.73)	63.97 (28.60)	60.38 (26.99)
Variance	5.01^2 (2.24^2)	6.87^2 (3.07^2)	6.45^2 (2.89^2)	1.00^2 (0.45^2)

Intelligent speed adaptation systems do affect driver speed both in terms of mean and maximum values but also in terms of deviation. Driver maximum speeds are higher than the posted speed limit, and average speeds exceed the posted speed limit at base condition and under the use of the informative system. Driving with the use of the informative system results in somewhat higher maximum speeds (in relation to the base drive); however the differences are not statistically significant (90% conf. level). Warning ISA results in considerably lower maximum speeds (statistically significant in relation to the informative system) and the intervening ISA produces the lowest maximum values (statistically significant in relation to all systems). In terms of mean speeds, the informative system produces similar ones to the base condition, whereas the warning and intervening systems produce quite lower speeds, with both being below the posted speed limit. Statistical analysis indicated that mean speeds follow a normal distribution for the base, informative and warning drives, but not for the intervening ones, which mainly involved similar speeds for the majority of the drivers with some outliers; this was expected as the speed under this system is more controlled.

The speed parameter V_n in Gipps' model involves maximum vehicle speed, which represents the speed that the driver would adopt when driving under free-flow conditions, which we shall refer to as driver desirable speed. Model dynamics are such that if there is enough empty space downstream, vehicles will eventually reach the desirable speed (assuming that the vehicle starts from being stationary) and will continue cruising at that speed if unimpeded. This concept of the desirable speed in Gipps' model does not correspond to the driver maximum speed in the simulator experiment, as drivers only reach that speed instantly, but to driver mean speed which describes speed when vehicle movement is unimpeded. Hence, for the implementation of ISA with Gipps' car-following model the V_n parameter would take the values of mean speed and their corresponding variance, as presented in Table 2, for each of the simulated ISA systems.

3.2.2 Acceleration

Vehicle acceleration was also analysed in order to be used as an input in Gipps' model. Driver maximum accelerations were recorded and averaged over the number of drivers; the results of this analysis are presented in Table 3.

Table 3. Acceleration under the different ISA systems (mph/sec (m/sec2))

	Base	**Informative**	**Warning**	**Intervening**
Maximum	7.08 (3.16)	6.63 (2.96)	7.01 (3.13)	6.49 (2.90)
Variance	4.68^2 (2.09^2)	4.11^2 (1.84^2)	3.44^2 (1.54^2)	3.25^2 (1.45^2)

Drivers employ rather similar acceleration rates with different systems as the differences are rather small (not statistically significant at 90% conf. level). Still, the trends indicate that drivers using the intervening ISA demonstrate lower acceleration rates, and considerably lower deviations, while use of the informative ISA produces the highest acceleration values. The acceleration rates between the systems, follow the same pattern as the maximum speeds (i.e. reduction with system intrusion), indicating that drivers who employ high speeds also employ high accelerations, thus driving somewhat more aggressively. Furthermore, statistical analysis indicated that accelerations follow a normal distribution only for the base condition and informative ISA drive. This can be attributed to two reasons (a) small sample size and (b) more controlled behaviour with the increase of system intrusion.

The acceleration parameter used in Gipps' model is a_n and denotes the maximum acceleration that the driver wishes to undertake. Model dynamics can be described as follows [13]: a stationary vehicle that starts to move has an acceleration of $0.3953\,a_n$ and continues moving towards V_n with increasing acceleration up to the point where speed is $\frac{0.95}{3}V_n$. It then continues increasing its speed towards V_n with lower acceleration. The evolution of vehicle speed as recorded from the simulator experiment data was somewhat different. Vehicles demonstrated higher acceleration rates, when their speed was lower than $\frac{0.95}{3}V_n$. Hence, the maximum recorded acceleration does not correspond to the model parameter. For this reason, a modified acceleration was calculated which is the maximum acceleration that was recorded from the time-step after which vehicle speed exceeded $\frac{0.95}{3}V_n$ (where V_n the driver desirable speed as calculated in Section 4.2.1). The resulting accelerations are presented in Table 4.

Table 4. Modified acceleration under the different ISA systems (mph/sec (m/sec2))

	Base	**Informative**	**Warning**	**Intervening**
Maximum	4.62 (2.06)	4.98 (2.23)	5.00 (2.24)	4.41 (1.97)
Variance	2.38^2 (1.06^2)	2.39^2 (1.07^2)	2.14^2 (0.96^2)	1.21^2 (0.54^2)

Modified maximum accelerations are substantially lower than the maximum ones (Table 3), as drivers employ high accelerations at lower speeds. These differences were found to be statistically significant for all systems except for the informative one. In addition, accelerations at base condition and under the informative system follow a normal distribution.

The incorporation of the ISA acceleration in Gipps' model involves testing which one of the two estimated maximum acceleration values (a) the maximum acceleration (Table 3) or (b) the modified maximum acceleration (Table 4) at base condition produces better model results and then using the corresponding values for the simulation of the different ISA systems.

3.2.3 Deceleration

To estimate maximum driver decelerations driver behaviour was investigated in all 60mph road sections, including those containing slow moving vehicles ahead, road closure and stimulus appearance at the windscreen to which the drivers were asked to react by reducing their speed to 10mph.

Table 5. Deceleration under the different ISA systems (mph/sec (m/sec2))

	Base	**Informative**	**Warning**	**Intervening**
Maximum	-16.18 (-7.24)	-15.44 (-6.90)	-16.40 (-7.33)	-15.65 (-6.99)
Variance	2.93^2 (1.31^2)	2.71^2 (1.21^2)	2.83^2 (1.26^2)	2.63^2 (1.17^2)

Driver decelerations appear to be rather similar between the different ISA systems, and do not follow similar patters as driver speed or acceleration. Driving under the informative system involves somewhat lower and driving under the warning system somewhat higher deceleration values. The calculated deviations are also similar.

In Gipps' model there are two parameters involving deceleration: one is the maximum deceleration that the driver wishes to undertake (b_n = -2.0 a_n) and the second is the maximum deceleration of the vehicle in-front as perceived by each driver ($\hat{b}$ minimum of -3.0 and (b_n-3.0)/2). The observed decelerations (Table 5) are greater than those calculated by the formulae proposed by Gipps. Deceleration in Gipps' model is applied when the movement of the simulated vehicle is impeded by that of a vehicle in front. It has been found that in the case of sudden braking by the preceding vehicle the required deceleration to avoid a crash can be higher than the vehicle's desired braking or the perceived deceleration for the preceding vehicle [13]. Hence, the values presented in Table 5, indicate more extreme deceleration than the ones represented by parameters b_n and $\hat{b}$, and subsequently the deceleration parameters used in the model shall follow model rules and should be provided by the calibration formulae that Gipps has defined.

As in this study driver behaviour within a 60mph road section is investigated, the operation of the intervening ISA involving the application of smooth deceleration values when entering a road section of a lower speed limit with higher speed, does not apply. It should be noted however, that in the case of different speed limit areas driver deceleration should take a fixed value (that applied by the system) rather than being calculated from the model formulae.

4 Discussion

Intelligent speed adaptation systems affect several aspects of driver behaviour and their impact varies in relation to the different system HMI functionalities. The impact depends on the degree of intrusion of the system on the driving task. In particular, driving speeds, both in terms of maximum and average values, decrease with ISA systems, and this reduction increases with the degree of system intrusion. The same pattern is observed with the values of driver maximum acceleration; however the differences between systems are considerable lower. Driver maximum deceleration is also slightly affected by the use of the systems, but no clear pattern emerges from the observations.

The elicited differences between the systems should be introduced in traffic models, through appropriate parameters. Initially this seems to be a simple task, but in reality attention should be paid into the (a) the actual meaning of the model parameters; for example maximum speed in the model corresponds to average speed as calculated from the observations, (b) other parameter assumptions; such as parameter distributions, and (c) the calibration of the model with the new proposed values, as model dynamics may be valid with somewhat different values than the observed ones.

Future work on this topic involves the investigation of the use of ISA on other parameters including driver reaction time and vehicle effective size, and ways to incorporate their impact into Gipps' model, as well as ISA impact in 30mph and 20mph roads. Following that, the use of ISA will be incorporated in a traffic model to investigate ISA impact on network conditions.

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6 References

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