JOINT USE OF DRIVING SIMULATION AND TRAFFIC SIMULATION FOR THE STUDY OF ROAD INFRASTRUCTURES AND EQUIPMENTS

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ABSTRACT

Traffic phenomena come on the one hand from supply / demand mechanisms and on the other hand from the interactions between the various actors involved. Simulation models have been developed for several decades by traffic engineers to reproduce the phenomena. Based on the identification of observed traffic, they are unfortunately limited when the study is related to future situations (*i.e.* non existing, thus non observable, ones). Driver models have also been developed for decades by psychologists, but these models are also often very limited (*i.e.* they deal with very few and very specific driving tasks) and not operational (*i.e.* they are conceptual models).

The simulation of the impact of a change in the traffic system is nevertheless a key issue, both from the safety and the capacity standpoints. The behaviour of drivers facing a new situation is extremely difficult to forecast, since human beings easily adapt their behaviour in response to infrastructure and equipments. They will not always use them according to designers' expectations (a rational use for collective optimisation) but, on the contrary, they very often follow individual issues, such as minimisation of constraints or economy of manoeuvres. These different standpoints often lead to incoherences between design and uses, which have a negative impact on safety as well as on capacity.

Designing tools allowing a systemic approach of changes in the traffic system is the main objective of the INRETS MSIS department. Based on the joint use of a driving simulator and behavioural traffic simulation, the proposed approach (called “integrated approach”) consists of a four stage iterative process which jointly uses a driving simulator and a behavioural microscopic traffic simulation model. To carry on studies according to this approach, MSIS team has designed a behavioural traffic simulation model and a driving simulator architecture, both novel.

In our presentation we will first explain the « integrated » approach. We will then introduce both the traffic simulation model and the driving simulator architecture. We will discuss the validation process of these tools and give an example of use for the assessment of a driver support system. We will conclude with our prospects.

KEY WORDS

traffic simulation, driven simulator, behaviour, multi-agents system

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INTRODUCTION

Inroads, " paths of communication ", were designed throughout the development to answer notably the commercial demand. Since some decades this demand is reinforced on the one hand by commuting journeys and, on the other hand, by the trips people make during weekends and holidays.

The increase of environmental preoccupations and the wish of a more durable transport system and of a more durable growth (including the point of view of the costs of financing and exploitation of infrastructures) limit the constructions of new roads and the extensions of the existing roads.

The optimisation of the use of the existing infrastructures, both in term of capacity and in term of safety is clearly a major economic and social stake. This optimisation is made possible by a better understanding of the mechanisms which govern the automotive traffic.

The traffic phenomena are complex phenomena which are studied since several decades to allow mainly the control of the offer-demand system. A peculiarity of the automotive traffic is that the infrastructure is designed, according to a planned demand existing at that time, in order to answer a collective optimum that still allows every individual to realises his/her journey by trying to reach an individual optimum (sometimes conflicting with the collective optimum).

The more the traffic situation becomes complex and dense, the more the drivers try to find individual solutions. To cope with the traffic growing, the road operators also try to find new solutions but the question is to assess as soon as possible the impact of the new measures. This assessment is quite complex since, as stated before, drivers' behaviour will evolve according to the new situation.

In order to simulate and to better understand the traffic phenomena, and its evolution, we propose a novel approach which consists in a joint use of driving simulators and a behavioural traffic simulation model.

In this paper, we will first introduce the common traffic simulation models and their limits. We will also introduce how psychologists studies drivers' behaviour. We will then expose our novel approach and the tools we developed. We will finally give an example of the use of this methodology and conclude on our prospects of development.

TRAFFIC SIMULATION MODEL

The modelling of the road traffic is a domain of separate research and development and the literature which is dedicated to it is extremely plentiful for several decades. The first works started in the 50s, authors such as [Norman 42], [Wardrop 52], [Lighthill 55], [Richard 56], [Chandler 58], [Gazis 61] studied the phenomena of traffic and presented mathematical models for its simulation. Since then, numerous mathematical models of the traffic, often the variants of the "historic" models, were designed as well as numerous tools of simulation.

The mathematical models simulate the traffic by means of mathematical laws. These laws are identified from real data of traffic and have for objective to reproduce the observed conditions of traffic. For the macroscopics models, laws of traffic of stream are used whereas for the microscopic models, it is about laws governing the movement of vehicles such as pursuit laws , change of way, etc. [Lieberman 97].

In fact, the mathematical tools of simulation, either macroscopic or microscopic, follow the same design principle: feign the traffic by means of equations. The inconvenience of this method, seen the complexity of the phenomenon of the road traffic, is that it always shows not to be satisfactory enough as for the results and for the features which she allows to supply. The main reason comes from their concepts: identification of statistical laws from actual situations. That means that:

1. The laws are statistic and so, they do not take care of the specific context of the situations (driving is a complex task, the drivers take information on the infrastructure and on the traffic to take their decisions);
2. The laws can only reproduce observed phenomena and so, it is very hazardous to extrapolate for a new (unobserved) situation (any change in the road profile, the road equipment or the car equipment may change the laws).

As long as the carried out studies when using such models deal only with traffic capacity and/or average speed, these limits are not too much of a problem, but if the studies take into account safety issues, they are quite problematic.

The model proposed by Gipps [Gipps 81], [Gipps 86] is particularly representative of the work realised in the 80s, it is always used in numerous commercial software solutions of traffic simulation, among which AIMSUN2, SISTM and PARAMICS are examples.

His model consists of a set of differential equations where the movement of every vehicle is calculated with respect to the movement of the preceding vehicle. The driver "estimates" the maximal braking that the driver who precedes him can achieve and adopts a distance of safety which allow him to stop in case of braking. This distance takes into account the own response time of the driver and an incompressible safety margin.

With this mathematical model, the only element taken into account by the driver to regulate his speed concerns the front vehicle, while studies in psychology of the behaviour demonstrate the importance of anticipation in driving: "to drive is to anticipate". This model will thus be limited as soon as there will be question of reproducing transient phenomena such as the insertion of a slower vehicle in front of an other vehicle (before an exit for example) or the insertion of a vehicle accelerating in front of a vehicle (a merging vehicle for example). In this last case, the lack of recognition of the situation, and of its transient character, will lead the model to make the driver brake. However, in the reality, the driver will accept a short safety margin due to recognition of the fact that the situation is transient because the entering car is accelerating.

One other interesting example of the limits of microcopic models based on pursuit laws is the study of an autonomous intelligent cruise control (AICC). The AICC systems use a pursuit law to adapt the speed of a vehicle to the speed of the vehicle in front of it. Using models based on pursuit laws, the study becomes a comparison between two laws... ignoring drivers' acceptances and practices.

DRIVER BEHAVIOUR MODELLING

The study of the behaviour of the drivers, under its psychological angle, implies complex and expensive experiments. The first listed works go back to the 30s [Gibson 38] but the blossoming of models of behaviour, centred mostly on risk-taking, is situated in the 80s [Näätänen 74], [Fuller 84], [Summala 85] for example. The 3 levels (strategic, tactical, operational) for describing the activity of the driving task come from Michon [Michon 80], [Michon 85]. This model is still used today.

At the INRETS, the Laboratory of Psychology of the Behaviour (LPC) leads works from the 80s on the study of the behaviour of drivers [Saad 88], [Saad 92]. These works present the originality that they use a methodology of detailed analysis, based on the confrontation of data collected in actual driving situations and those collected by post-interviews. The obtained data are extremely rich and allow to identify the underlying motives of decision-making.

Drivers achieve a journey using an instrumented experimental car. A video is recorded and a psychologist takes notes during the journey. After the trip, the drivers are put in front of the video and have to explain their decisions and the elements they have taken into account. A conceptual model of driver has been designed, treating motorway situations.

In this model, the drivers take into account information from several zones for their decision making. Zones can be close by but also far away, depending of the traffic context. The driver anticipates the situation and sometimes accepts short safety margins because the situation is transient. One example is the overtaking manoeuvre, where the driver catches up with a slow vehicle before changing lane. In this case, the accepted safety distance (for a short period) is often smaller than the mandatory one, notably if the manoeuvre can not be achieved immediately.

This last example explains, once more, why mathematical and/or statistical models are not suitable for the simulation of AICC systems (among others). These models will not produce the short, but important phase, of anticipation where the driver accepts short time headway. As this is the difference between human behaviour and AICC systems which makes them unacceptable for drivers as soon as the traffic is dense, these models are not reliable for the study of such situations (AICC systems in dense traffic). Based both on pursuit laws, both the simulated drivers and the vehicles equipped with AICC will avoid the situation, thus the comparison between traffic flows with equipped and non equipped vehicles will give false results.

DRIVING SIMULATOR AND BEHAVIOURAL TRAFFIC SIMULATION MODEL

The study of driver behaviour allows to understand how they sample information on the road environment, and contributes to the identification of the strategies which they implement and causes of possible dysfunctions. Experiments conducted on the road are the best way to study (and understand) drivers' practices, but they are very complex and expensive. It is very difficult to put a population in the same road situation and, for some situations it is also risky. Driving simulators are thus more and more used for conducting safe and reproducible experiments. Despite their various limitations, and so long that they are used "scientifically" (i.e. while taking care of the transferability of the obtained results within virtual situations toward the actual situations), they are irreplaceable tools.

Thanks to computer performance improvement, it is now possible to design new traffic simulation models, based on individual behaviours and on the emergence of collective behaviour. Two families of models are achieved, one hand those which aim at automatic driving [Reece 93], in the other hand those which aim at simulating the traffic by mimicking drivers' behaviour and the interactions between them [Espié 94], [Espié 95]. The first ones are inspired by automatics, while the second ones are inspired by driving psychology.

For automating the driving task, and for the design of autonomous vehicles, it is necessary to design, at least, a model of perception, a model of sensorimotor control (operational tasks) and a tactical model (decisions). Each of these topics is a topic of research in itself. The perception model is the bottleneck, because without a good perception of the context of the situation, the pilot can not take appropriate decisions. The way drivers obtain information from the environment is very complex, the way they update their knowledge also. A driver is able to reconstruct partially invisible objects, to memorise objects transiently invisible objects, to search for information, to look far away or very near by, etc. All these abilities allow a driver to adapt his behaviour to the driving context. A simulation of a video sensor, even the most sophisticated, is nowadays incapable of achieving the same performance. This is why simulated drivers using a "robotics" approach have a poor anticipatory behaviour.

Based on psychological findings, the second approach avoids the problem of perception and of operational controls. It focusses on the tactical aspects of driving. A symbolic vision model provides the simulated driver with all the elements which are in the surroundings. The simulated drivers do not control the actuators of the vehicle (pedals, steering wheel,...), but directly the longitudinal and lateral accelerations. The "unlimited" perception (in fact limited by a distance parameter) is not considered to be a problem for motorway situations as the real drivers are able to avoid occlusion. For very limited situations where occlusion is a crucial aspect, a time-consuming algorithm can take this issue into account.

The INRETS-MSIS ARCHISIM (behavioural traffic model) and SIM² (driving simulator architecture) tools have been designed to cope with the problem of a-priori evaluation of changes in the traffic system. ARCHISIM is a traffic model based on the INRETS psychological findings [Saad 92]. It is a novel model which is able not only to simulate traffic, but also to host a driving simulator.

The traffic model uses a multi-actors approach (in computer science: multi-agents system) to simulate traffic phenomena coming from the individual behaviours of the various actors of a road situation and from the interactions between them. Each simulated driver is provided with a symbolic description of the elements in its surrounding. These elements describe the infrastructure, the road equipments, the objects in the vicinity of the road and the other road users. By using this knowledge, the simulated driver choose his preferential lane by taking into account: the existing lanes, the local regulation, the traffic characteristics (ahead and rear, close and far) on these lanes (average speed, stability...), his own characteristics (desired speed, favourite time-headway...)... ARCHISIM has been validated for motorway situations [Champion 02], current works are focussing for urban situations. One originality of this simulation model is its ability to host driving simulators. This feature comes naturally from its multi-agent architecture. Subjects driving the simulator are immersed in the virtual traffic and they are considered as one of the road users. They thus interact with the simulated traffic.

The SIM² driving simulator architecture is modular. The 3D visual loop, the car dynamics model, the 3D sound model and the traffic and the scenario supervisor are modules which can be exchanged. This architecture is nowadays used by various research labs. The hardware is also modular, this allows to construct driving simulators from the cheapest (using joystick or game steering wheel and monitor) to the more costly (full cab, motion base, 360° visual rendering using projectors).

At the INRETS-MSIS department we promote what we call an "integrated approach" for the studies of the impact of changes in the traffic system. This approach is based on the joint use of the driving simulator and of the behavioural traffic model. The aim of the proposed methodology is to assess "a priori" the impact at both the individual level and the collective level, in order to obtain trends for safety and for capacity. The novelty of this approach is that it takes into account the drivers' practices for future situations. By future situations we mean situations which have never been encountered, either because the infrastructure or the proposed equipment are novel. In these cases, it is impossible to record traffic data and to identify a pursuit law, etc. Extrapolation from already identified driver behaviour is very risky, as the adaptation by the drivers to the new situation is often far from designers' expectations. Therefore, the study of the drivers' behaviour facing the future situation while using a simulator seems the only way to mitigate mistakes. After identification of the drivers' behaviour in the future situations, the use of the behavioural traffic simulation model allows to extrapolate from individual behaviour to collective behaviour and thus to obtain trends on the future safety and capacity. To summarise, the proposed approach has four steps:

1. Identification of driver's behaviours for the future situations, in actual driving situations or with a driving simulator. When the future situation consists of a vehicle equipment (such as a driver support system), the behaviour is studied for equipped vehicles.
2. Modelling of drivers' behaviour as identified in step 1 (currently subject to a few hypotheses and simplifications at this stage). Implementation in the behavioural traffic simulation model.
3. Simulation of the future traffic flow. Traffic studies related to impact of changes, from capacity and safety standpoints (impact of penetration rate, sensibility analysis to hypothesis).
4. Identification of non-equipped drivers' behaviour immersed in “equipped” virtual traffic. This step (optional, for on-board systems) is very important if we want to understand drivers' behaviour when facing “unusual” situations due to, for example, the use of an alert system by a leading driver.

Using such a methodology is not "the" solution (the study of behaviour in a virtual environment has various limits), but seems to be much more reliable than extrapolations on the currently identified behaviours. This methodology has already been used for the study of the future impact of ITS technologies. The Stop&Go system has, for example, been assessed using the "integrated approach" during the Stardust European project (5th FP).

EXAMPLE OF USE: THE STOP&GO SYSTEM ASSESSMENT

These works aimed to evaluate the impacts of the Stop&Go (SG) system in an urban environment. The SG is a system which takes control of the car by adjusting the speed of the equipped vehicle to the one of the vehicle in front of it (if any). The SG system had already been studied, however there was a lack of studies on the adaptation of the drivers to these systems in an urban context.

The first step of the study has been the study of drivers' behaviour. These studies were

Figure 1: One INRETS simulator in Arcueil facility

carried out by researchers from the Stardust consortium [Piao 03], [Tripodi 03]. At the INRETS, the studies were focused on the lateral aspects, and in particular, on the question if the drivers achieve more lane changing manoeuvres with than without the system. (The expected impact of the system is a better efficiency of the equipped drivers - less reaction time - but the question is the system acceptance: will the pilot stop the system and/or will the pilot change lane to avoid the activation of the system?). To do this, the INRETS' driving simulator (see figure 1), hosted by the traffic model ARCHISIM, has been used. To simulate the Stop&Go system, a formula has been implemented in both tools. Twenty-one subjects have tested the system for an arterial road situation (with platooning) and their subjective opinions (answers to a questionnaire) and their driving performance have been recorded. This allowed us to understand the impact of the system on the drivers' behaviour.

The opinions of the subjects are generally good after they used the system. The majority of the drivers were helped by the system and they do not want switch off the system. The simulator trial did not indicate any behavioural adaptations to the new driver support system (i.e. no change in the number of lane changes). A different experiment, conducted in Norway and also using a driving simulator, showed no significant behavioural adaptation in comparison with baseline driving in terms of changes in headway, neither mean nor variance.

The ARCHISIM behavioural traffic simulation model was modified for taking into account the behaviour of the equipped drivers. A simulation model of an SG system was implemented, which took longitudinal control of the vehicle at low speeds when an obstacle (a vehicle) was sufficiently close in front of the equipped vehicle (the simulated system followed the algorithm of the SG system under study). No changes were made for choice of driving lane by the simulated drivers.

To analyse the impacts of the ITS introduction into the flow, we simulate the traffic for a urban-motorway (see figure 2). The distance between D2 and D1 (respectively D3 and D2) was 1.5 km (respectively 1.5 km). The speed limit was 130 km/h. For all simulations which have been done, the traffic demands were obtained from actual data. These actual data were collected on an urban motorway near Paris with both peak hour and non-congested traffic situations (see figure 3).

The desired speed and the desired time gap have to be defined and were chosen following a Gaussian law: 144km/h ± 15km/h for the desired speed and 1.06 s ± 0.18s for the desired time gap. For the equipped vehicle, the selected time gap was 1.2 s. Peak hour was simulated in all cases. Thus congested a traffic situation should appear. To measure the impacts of the SG system, we used as indicators:

1. the mean speed and its standard deviation. The greater the speed variability, the higher the accident risk. The more often a driver reaches a high speed (relatively to the traffic) the more safety could decrease for the driver and the other road users

2. the mean of instantaneous speeds at a fixed point
3. the number of stops. This observable could allow to identify a change in the capacity level.

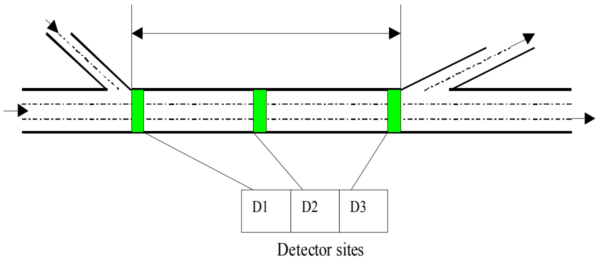

Figure 2: urban motorway in UK

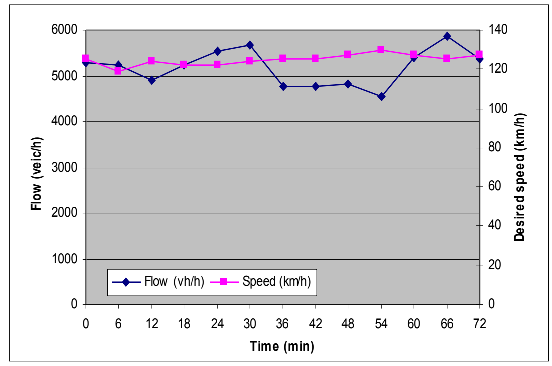

Figure 3: demand on motorway

The figures 4 and 5 show the impact of the SG system on the traffic flow: it increases the mean speed during congestion. The table 6 gives the number of stops between D1 and D3.

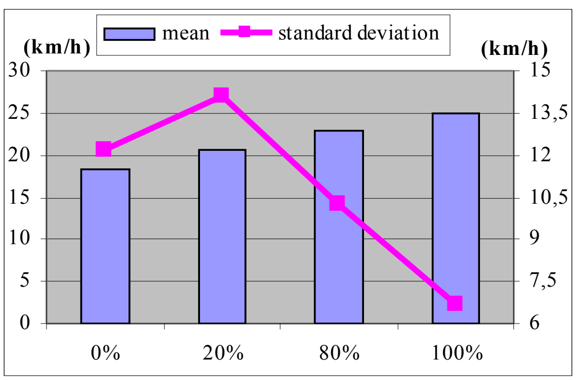

Figure 4 mean speed and standard deviation between D1 and D3

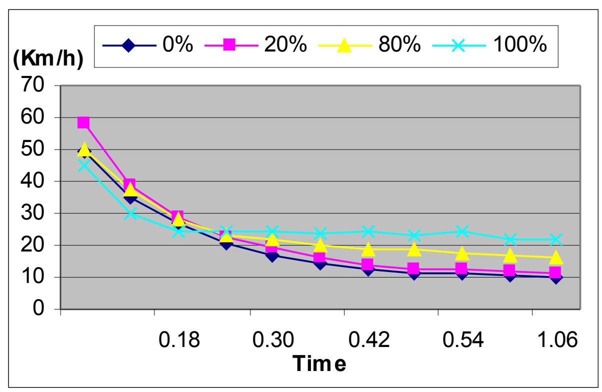

Figure 5 mean of instantaneous speed at D3

	0%	20%	80%	100%
Number of Stop/Vh between D1 and D2	7,85	4,63	1,53	0,89
Number of Stop/Vh between D2 and D3	4,87	3,16	1,36	0,85

Figure 6: number of stop between the detector sites

CONCLUSION

The optimisation of the use of the existing infrastructures, both in terms of capacity and in terms of safety is clearly a major economic and social stake. This optimisation is made possible by a better understanding of the mechanisms which govern the automotive traffic. One of the problems for the decision-makers is the possible discrepancy between the expected and the observed results. This inadequacy problem can easily arise for novel systems: to cope with the growing traffic, the road operators try to find new solutions to optimise their networks. However, the more the traffic situation becomes complex and dense, the more drivers try to find individual solutions which are sometimes in conflict with the optimal collective solution. So, the drivers' practices are often not the ones expected facing the new solutions.

The question is to assess as soon as possible the impact of the new measures. This assessment is quite complex since, as stated before, driver behaviour evolves according to the new situation. To cope with this problem, we propose a novel approach which consists in a joint use of driving simulators and of behavioural traffic simulation model. With this so-called integrated approach, the final road users (the drivers) will be directly involved in the design process of proposed devices.

The use of driving simulators particularly allows i) to study driver behaviour in non-existing situations and ii) to conduct experiments without risk. The use of a behavioural, psychology-based traffic simulation model allows to take into account driver behaviour modifications and to study the impacts of the changes on both the capacity and the safety levels.

Of course much work remains to be done (complexity of the considered traffic situations, transferability of the situations studied in virtual environment, etc.). However, the results obtained are encouraging and show the interest of our integrated approach for the study of the road traffic system.

AKNOWLEDGMENTS

A part of this work was performed as part of the EC funded project STARDUST (Contract No: EVK4-2000-00590). The authors would like to thank all members of the consortium who have discussed the implications of driver behaviour with us.

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