

ARCHISIM: a behavioural multi-actors traffic simulation model for the study of a traffic system including ITS aspects

S. Espié, J.M. Auberlet

INRETS-MSIS

2 avenue du Général Malleret-Joinville, F-94110 Arcueil,

Tel: +33 (0)1 47 40 70 00

espie@inrets.fr

auberlet@inrets.fr

The simulation of the impact of a change in the traffic system is 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. This often lead to incoherences between design and uses, which have a negative impact on safety as well as on capacity. The "integrated approach" developed by INRETS-MSIS allows a systemic approach of changes in the traffic system, and it 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.

Keywords: *driver's behaviour model, microscopic traffic model, multi-agent simulation, driving simulator, ITS evaluation*

1. Introduction

Roads, "paths of communication", were designed throughout human evolution, notably to answer commercial demand. For several decades this demand has been reinforced, on the one hand by commuting journeys, on the other hand by weekends and holidays trips. Traffic phenomena come on the one hand from supply/demand mechanisms, on the other hand from the interactions between the various actors involved.

Traffic phenomena are complex ones, which have been studied for several decades, mainly to allow the control of the supply/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 allowing every individual to realize his/her journey by trying to reach an individual optimum (sometimes in conflict with the collective optimum).

The optimisation of the use of the existing infrastructures, in terms both of capacity and 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. Depending on the objectives, two main ways are explored for the understanding of the traffic: traffic engineers, using sensors, try to identify traffic laws by observing it, while psychologists, using experiments, try

to understand the rules which govern the drivers' behaviours.

The limit of the traffic engineers approach is that they observe the phenomena more than they understand them, thus they have difficulties to extrapolate the future traffic situations from those currently observed, and this as far as the future situations have never been observed.

In this paper, we will first introduce the common traffic simulation models and their limits. We will also introduce how psychologists study drivers' behaviour. We will then expose our novel approach, the tools developed and the validation we have conducted. We will conclude on our prospects of development. The chapters related to the traffic modelling and to the psychologists work comes from already published papers [Espie 06].

2. Traffic modelling

The modelling of the road traffic is a research and development domain in itself, with an abundant literature dedicated to it for several decades. The first works started in the 50's, authors such as [Norman 42], [Wardrop 52], [Lighthill 55], [Richard 56], [Chandler 58], [Gazis 61] studied the traffic phenomena and presented mathematical models for their simulation. Since then, numerous mathematical traffic models, often variants of the "historic" models, have been designed, along with numerous simulation tools.

Mathematical models simulate the traffic by means of mathematical laws, identified from actual traffic data and aiming to reproduce the observed traffic conditions. For the macroscopic models, traffic laws of stream are used, whereas the microscopic models deal with laws governing the movement of vehicles, such as car-following laws, change of way, etc. [Lieberman 97].

In fact, the mathematical tools of simulation, either macroscopic or microscopic, follow the same design principle: simulate the traffic by means of equations. The drawback of this method, given the complexity of the road traffic phenomenon, is that it is not always satisfactory, neither for the results nor for the features it allows to supply. The main reason comes from the underlying concepts of these tools: identification of statistical laws from actual situations. It means that:

1. The laws are statistic, thus do not consider 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, thus it is very risky 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 works realised in the 80s; it is still used in numerous commercial software solutions of traffic simulation, among which AIMSUN2, SISTM and PARAMICS. This model consists in 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 safety distance which allows 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 behaviour psychology demonstrate the importance of anticipation in driving: "to drive is to anticipate". This model will thus prove limited as far as the question is to reproduce transient phenomena, such as the insertion of a slower vehicle in front of another vehicle (e.g. before an exit), or the insertion of a vehicle accelerating in front of a vehicle

(e.g. a merging vehicle). 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 car-following laws is the study of an autonomous intelligent cruise control (AICC). AICC systems use a car-following law to adapt the speed of a vehicle to the speed of the vehicle in front of it. Using models based on car-following laws, the study becomes a comparison between two laws... ignoring drivers' acceptances and practices.

3. Driver's behaviour modelling

The study of the drivers' behaviour, from 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]. 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 INRETS, Laboratory of Driver Psychology (LPC) leads works since the 80s on the study of the drivers' behaviour [Saad 88], [Saad 92]. The originality of these works is that they use a methodology of detailed analysis, based on the confrontation of data collected in actual driving situations with those collected in 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.

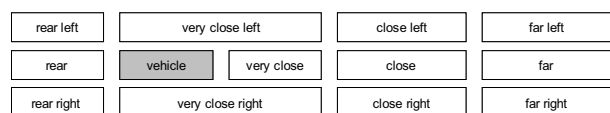


Figure 1 : zones of control

In this model, the drivers take into account information from several zones for their decision making. Zones are close by but also far away, depending on the traffic context (see figure 1). The size of the zones depends on the current speed. They were determined roughly from the experimental studies.

Within these zones, the drivers evaluate not only the speed and the density of the traffic, but also its stability. This last characteristics is very important for the predictability of the oncoming traffic situation.

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.

The rules generating intentions defined in the model obey the following patterns:

- interaction + long duration + possible suppression => suppression of interaction
- interaction + short duration + possible suppression => short-term adaptation
- interaction + short duration + temporary impossibility of suppression => short-term adaptation
- interaction + long duration + long term impossibility of suppression => long-term adaptation

where interaction is either immediate or anticipated.

The modality of the suppression of interaction is the change of lane, the modality of adaptation is speed regulation to ensure acceptable time headway. Parameters depend on driver's characteristics and traffic context. A short term adaptation is for example, in France, about 1sec time headway while a long one is about 2.5sec.

The importance of temporal aspects expressed through the concepts of anticipation and duration must be stressed. The drivers do not react solely to instant variations of situational parameters, but also take into account the expected duration of these variations.

This following example try to explain why mathematical and/or statistical models using car following are not suitable for the simulation of human behaviour. To demonstrate the problem we use a car following law used by an AICC system. The aim is to show that these kind of laws do not produce the short, but important, phase of anticipation where the drivers accept short time headways. In this example we used an AICC system based on the TNO algorithm. It is a linear car following model :

$$a(t) = K_d * [D_{cur}(t) - D_{des}] + K_v * [V_l(t) - V_f(t)] \quad (1)$$

$$D_{des} = l + t_g * V_f \quad (2)$$

with $-1.2m/s^2 \leq a \leq 2m/s^2$,
and where

- a acceleration of the following vehicle (m/s^2),
- D_{des} desired distance gap between vehicles (m),
- $D_{cur}(t)$ current distance gap between vehicles (m),
- t_g desired time-gap (seconds),
- V_{des} desired speed of the following vehicle (m/s^2),
- $V_l(t)$ current speed of the lead vehicle (m/s),
- $V_f(t)$ current speed of the following vehicle (m/s),
- l safety spacing (m),
- K_d and K_v are gains (the value is 0.05 for K_d and 0.5 for K_v).

In our scenario, a lead vehicle shows, by using its blinkers, to the following vehicle (either the AICC-vehicle, either the ARCHISIM vehicle) that it will go to the off-ramp lane (see figure 2).

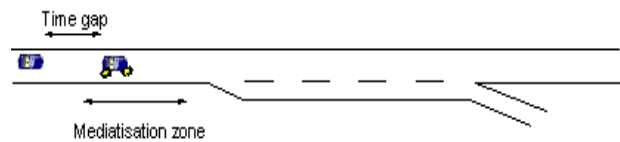


Figure 2: road with an off-ramp lane

The results (see figure 3) show that before this lane changing, the ARCHISIM vehicle reduces his time gap (because of anticipation, and as an actual driver does) whereas the car using the following law keeps a constant time gap.

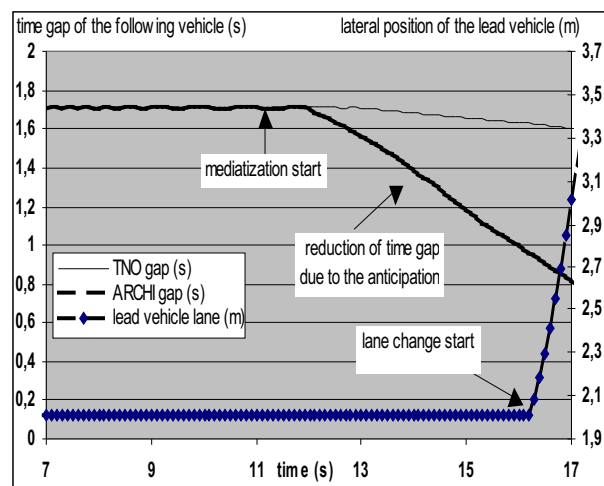


Figure 3: behaviours using a car following law versus ARCHISIM behavioural model

This example demonstrates a key problem for the evaluation of ITS devices (and particularly AICC) using

microscopic models based on car following laws. This problem is quite crucial since it happens not only for the demonstrated example (off ramp) but also for changing lanes manoeuvres.

4. Archisim concepts

Based on the analysis of the limits of the mathematical approach, we designed a novel approach of the traffic modelling. This approach uses the findings of psychologists, more precisely those of F. Saad at INRETS [Espié 94].

The main hypothesis used for this model is the emerging of collective behaviours coming from the individual behaviours and from the interactions between the individuals. This hypothesis is nowadays used in various phenomena modelling, particularly for ethology. The finite elements calculation can be considered as one form of this modelling method, since the result comes during the simulation from the interactions between the various considered elements.

In ARCHISIM, the various participants in a traffic simulation are called actors. Actors can be either the road users (car or truck drivers, 2-wheels riders or pedestrians) or the road operators (in charge of the road equipment, they try to optimise the network use) or the road designers (they offer the road supply). Road designers are considered as actors, since the geometric design of the road influence the users' behaviour (a large pavement with smooth bends may induce high desired speeds). Road operators also are considered as actors since the road equipments, in particular the vertical and horizontal marking, induce road users behaviours.

In order to allow the road users to make their decisions for carrying out their journey, it is necessary that each one perceives its surrounding and can anticipate its evolution. Thus in ARCHISIM there is a symbolic vision model which provides each road user with the various elements of its environment (others road users, horizontal and vertical road signs...). It is to be noticed that ARCHISIM focus on the tactical aspects of the driving.

This symbolic vision model is one of the major differences between ARCHISIM and the others traffic models (microscopic). It allows the road users models to take decisions based on the situation context and on its expected evolution. Since the vision allows the simulated actors to perceive close and far elements, it allows the actors to anticipate, which is a key point of a "realistic" human behaviour.

In the "classical" microscopic traffic simulation models, the simulated driver takes into account only the

nearest road users (often only the vehicles), this does not allow the anticipation mechanism. The behaviour of the simulated drivers is based on statistical measures (identification of a car following law) which imperfectly mimic the actual drivers' behaviour since they do not take into account a) the full context of the situation, b) the anticipation mechanism.

5. Modelling of motorway situations

The simulation model of drivers' behaviour used in ARCHISIM follows an economical principle. Each driver achieves his/her journey while minimizing constraints. The drivers adapt their behaviour to the current infrastructure, regulation and traffic. They try to reach their desired speed while avoiding conflicts with the others road users: they choose their traffic lane for minimizing the trouble due to a slower vehicle in front of them and/or due to a rear pressure by a faster vehicle. They can accept a transient situation, and a short transient time headway, since they anticipate the future of the current situation [El Hadouaj 01].

The simulation model for the drivers' behaviour while on-ramp also uses F. Saad findings. The behaviours are non-normative since a collaboration / competition process takes place: drivers coming from the on-ramp (without priority) bypass the regulation and try to enter even if there are cars on the motorway, drivers on the motorway accept and sometimes help these manoeuvres. These non-normative behaviours lead to a so-called "zip" effect, where drivers from the motorway and drivers from the on-ramp pass alternatively.

The model has been validated for motorways situations, including on and off ramps, for high and low traffic volumes [Champion 02], [El Hadouaj 04] (figures 1 and 2 show the results for ramps, figure 3 shows result for the motorway including a peak hour). It has been used successfully for traffic studies by CS-SRILOG company and at INRETS [Champion 02].

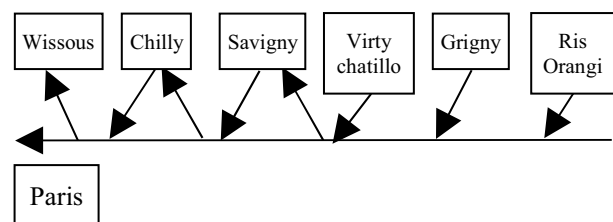


Figure 4: Scheme of the network (radial motorway near Paris)

One validation study has been conducted by comparing actual and simulated data for a section of the A6-highway near Paris, which is one of the main radial axes of Paris (see figure 4 the network description).

Traffic data were collected by the SIRIUS system thanks to measurement spots placed every 500m on the highway and on every on/off ramp. The collected data were aggregated and recorded by periods of six minutes.

In our microscopic model, the demand generation is realized in two steps from traffic data aggregated in a 6mn format. First of all, 6mn data are disaggregated, then the simulated network is initialized by the data of the period anterior to the first simulated period. Hence, all the vehicles on the network are simultaneously placed before the beginning of the simulation. Then, the generation is continuously created during the simulation, the vehicles being individually injected at the entrances of the network (on the A6 highway and on the five on-ramps).

The calculation of the precision, for the flow, leans on the statistical indicator of the Relative Quadratic Mean Deviation (RQMD):

$$RQMD = [\sum (Q_{real} - Q_{simulated})^2 / \sum Q_{real}^2]^{1/2} \quad (3)$$

In this equation, $Q_{simulated}$ relates to the simulated flow and Q_{real} relates to the real flow.

The results of the simulation (see figures 5 to 7) show that the behavioural model ARCHISIM is successful for the highway A6 - which is a complex network due to the geometrical configuration and the important number of junctions - whatever the traffic conditions. For each of the measure points, the precision indicator of the Relative Quadratic Mean Deviation based on 6mn dynamic data is lower than 12 % for the highway section and lower than 5 % for the on/off ramps. Knowing that the precision of the existing simulation tools is often between 10% and 20 %, ARCHISIM does well. It has to be noticed that the results are also good for speed (about 13 %) for the highway (actual data where not available for on/off ramps).

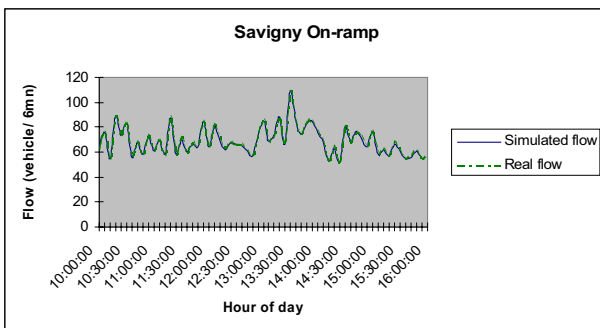


Figure 5: simulated flow for one on-ramp

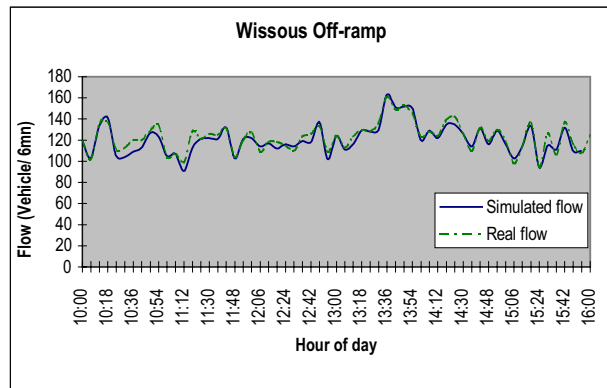


Figure 6: simulated flow for one off-ramp

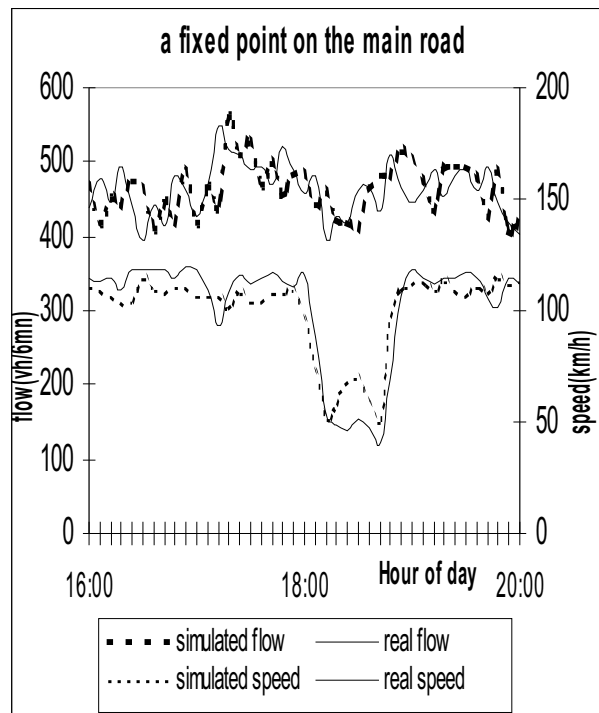


Figure 7: results on the main motorway including a peak hour

One interesting point is the influence of the advance direction sign in obtaining these results. In ARCHISIM, the vehicles can dynamically choose their paths following a turn percentage at an intersection. Thus in our study, in a first attempt, we forgot to put the road signs which announce the exits in advance (2km before the off-ramp). This led to problems at the exits, and to improper simulation of the traffic: some simulated drivers, using the fastest traffic lane, discovered the exit too late and had problems for achieving several changing lane manoeuvres on a short distance. By adding the missing road signs we solved the problem: the simulated drivers had the ability to anticipate their exit and to change lane early. This small example shows that the model can be used for analysing the impact of the road

equipments on the traffic flows, which is quite impossible with the "classical" models.

6. Intersections modelling

Driver's behaviour modelling in intersection is quite complex and is our current work. Psychological studies often focus on simple intersections (due to the complexity of the interactions), and "classical" microscopic models simplify the situations: in nearly all the models, the conflicts are avoided because a vehicle enter the intersection if and only if it can exit. This normative choice is based on the gap acceptance theory or is made by a supervisor which allows the vehicles to enter the intersection. This modelling of the functioning of an intersection is far from the actual one: drivers do not always follow the normative rules [Bjorklund 05] and enter the intersection (while using the full inner space) even if they will be blocked.

To simulate such a behaviour, where drivers compete / collaborate to optimise their own displacements, we use the framework for the game theory [Nash 50], [Champion 03], [Auberlet 07], and constraints network [Doniec 05]. Our aim is to let as many vehicles as possible enter the intersection, while avoiding fatal deadlocks. These deadlocks can occur due either to simple interactions or to more complex ones. The simple ones consist in two vehicles (e.g. making both a left-turn - French rules, see figure 8), the complex ones implying more vehicles (a chain of vehicles, see figure 9).

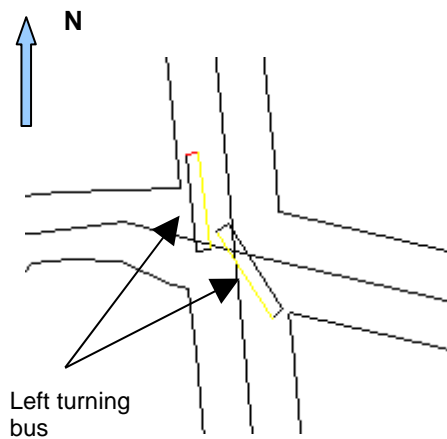


Figure 8: "simple" deadlock

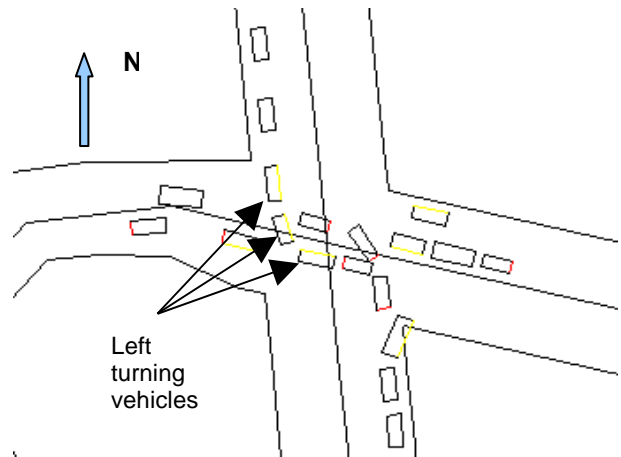
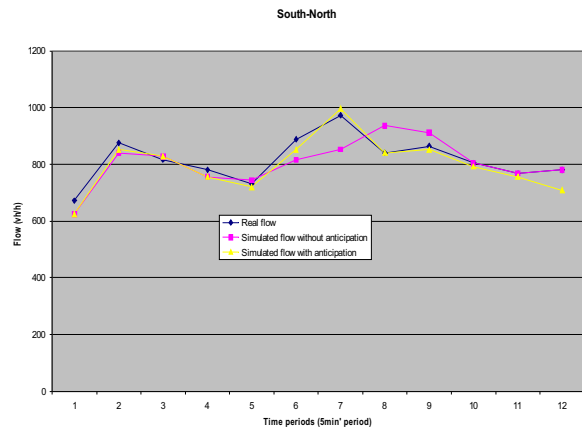


Figure 9: "complex" deadlock

The data for the validation of traffic simulation in an intersection are very difficult to obtain. The requested data concern, at least, the current speed, the desired speed, the traffic volume and the origin-destination. We used data coming from Reggio-Calabria University (Italy): the upstream flows and the turn percentages. Our first validation concerns a simple intersection (X type) with stop signs. The main road is the north-south one. The secondary one (east-west) is equipped with yield stop signs. Figure 10 shows the results for each direction.



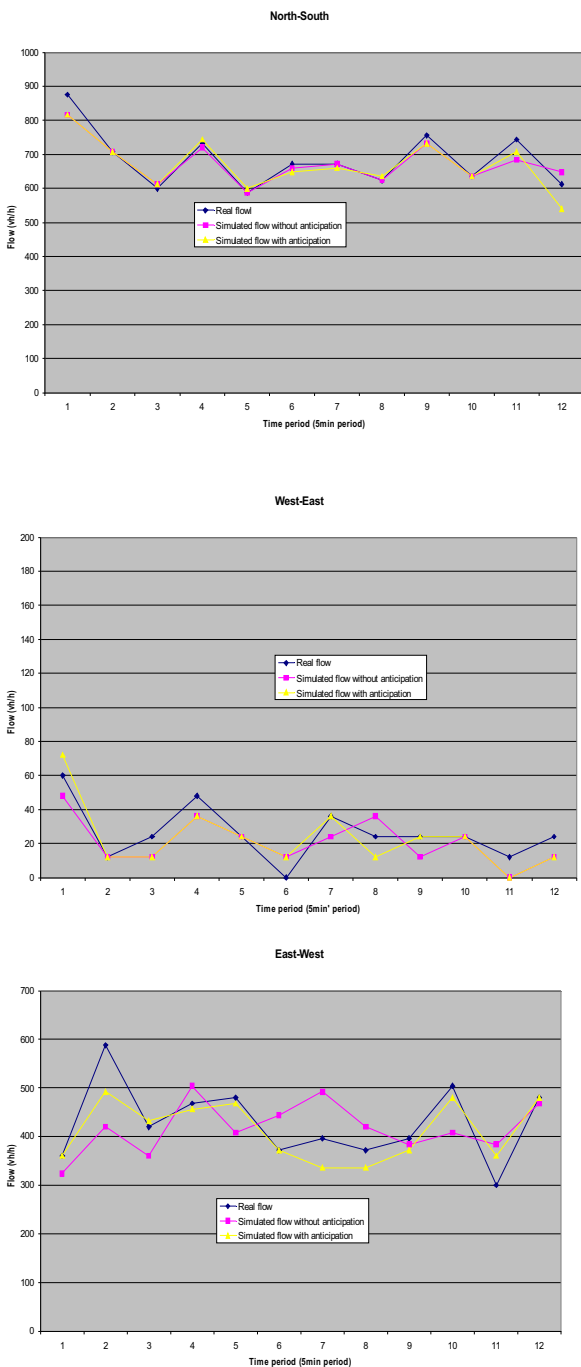


Figure 10: results for each directions

The results are promising, but the validation has to be improved with more accurate data, and more complex situations have also to be simulated, which is the aim of a future collaboration with a French University. Our researches for a better simulation of urban traffic are also focusing on the simulation of 2 wheels riders' behaviour, and on those of the pedestrians (including the interactions with car drivers).

7. Hosting of driving simulators and integrated approach for the traffic system

ARCHISIM traffic simulation model uses a multi-agents architecture. The simulation model takes into account the 3D network geometry and allows an actor (or several ones) of the simulation to be a driver of a driving simulator (using INRETS SIM² simulator architecture – see figures 11 and 12). The real driver is immersed in the virtual traffic and drive while interacting with the simulated actors [Espie 95].



Figure 11: MSIS Driving simulator in Arcueil



Figure 12: Example of simulated situations

Such a facility allows a new approach for the study of the impact of changes in the traffic system. This novel approach, which we call "integrated approach", uses 4 steps:

- study of the drivers' behaviour facing the future situations. The simulator allows to study situations which do not already exist (new geometry of the road, new equipments of the road or of the vehicle - ITS...) and to observe the real change in the drivers' behaviour (not the expected ones...)
- modelling of the new behaviours and update of the behavioural traffic simulation model (simplifications are made in this step)

- traffic studies using the new behaviours (if relevant, depending on equipment rate). These studies give trends about the impact of the changes at both the capacity and the safety levels.
- The 4th step is optional, it is required for on-board equipments (driver support systems). It consists in studying the compatibility issue between equipped and non-equipped drivers.

The interest of this approach is to use in the traffic simulation model the findings on the practices of drivers facing new situations. Since these practices are often far from the ones expected by the designers, such an approach seems particularly relevant. The use of driving simulators, despite their numerous limits, allows to study road situations which do not already exist, and thus are not observable. For these situations it is not possible to identify a car-following law, and it is very unreliable to extrapolate one law from the existing ones.

At INRETS , we have already used this approach in several research projects, among which Stardust and Diats European projects (respectively 5th and 4th FP). The conducted projects aimed at assessing either the impact of ITS technologies or the impact of new road design [Auberlet 04].

8. Conclusion and prospects

Traffic phenomena are complex ones. 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 which still allows every individual to realize his/her journey by trying to reach an individual optimum (sometimes conflicting with the collective optimum).

The optimisation of the use of the existing infrastructures, in terms of both capacity and safety, is clearly a major economic and social stake. This optimisation is made possible by a better understanding of the mechanisms governing the automotive traffic. A key issue is the a-priori assessment of changes in the traffic system (road geometry, road or car equipments...).

The limit of the approach used by traffic engineers is that they observe more than they understand the phenomena, thus having difficulties to extrapolate the future traffic situations from those currently observed, and this as far as the future situations have never been observed.

INRETS-MSIS ARCHISIM traffic simulation model is a behavioural microscopic model which uses a multi-

actor approach. Traffic phenomena come from the actions and interactions of the various actors of a given road situation. Thus, a change in the individual behaviour of one actor of the simulated situation will produce, by an emerging process, changes in the traffic behaviour.

This process can be seen as "magical", and traffic engineers are often sceptical. Two points have to be stressed:

- the model has been already validated for motorways situations, and the results for urban situations are promising;
- for non-observable (because non-existing) road traffic situations, the identification of car following laws is impossible, and the extrapolation of new laws from the current ones unreliable. The identification, using driving simulators, of new individual behaviours and the "propagation" of these behaviours towards the whole traffic system (with a behavioural traffic simulation model) seems more reliable, despite some limitations.

Behavioural microscopic modelling of the traffic system has been a research topic at MSIS for more than fifteen years. The designed models and tools (both traffic simulation model and driving simulator architecture) are and will be improved, for a better simulation of complex traffic phenomena. Our current work focus on urban situations, particularly on the simulation of the actions and interactions of the various road users (not only car drivers but also motorbike riders and pedestrians). One of the main applications of the designed tools concerns the assessment of the ITS technology.

One new prospect is the use of the tools for the training (or retraining) of drivers. The idea is to use the underlying driver model as a tutor which will detect abnormal decisions in the trainee's driving behaviour.

9. References

- [Auberlet 04] Auberlet J.-M. , Espié S. , Tripodi A. "How to evaluate the impacts of an its ? Example of the Stop&Go system in Stardust project." Proceedings of the 11th ITS Congress, October 18-22, Nagoya, Japan, 2004.
- [Auberlet 07] (to be appear) Auberlet J.-M. , Champion A, Mandiau R., Espié S. , Kolski C. - "From perception to conflict resolution: a priority managing mechanism for road intersection. First results" - in the proceedings of the 86th TRB annual meeting Washington D.C., USA, 21-25 January 2007
- [Bjorklund 05] Bjorklund G.M., Aberg L. Driver behaviour in intersections: Formal and informal traffic rules, in Transportation Research Part F, vol8, 239-253, 2005.

- [Champion 02] Champion A., Zhang M.Y., Auberlet J.M., Espié S. (2002) - Behavioural simulation towards high-density network traffic studies - in proceedings of the third international conference on traffic and transportation studies (ICTTS 2002), Guilin, China, 23-25 July 2002
- [Champion 03] Champion A., Espié S., Mandiau R., Auberlet J.-M., Kolski C. (2003) - A Game-Based, Multi-Agent Coordination Mechanism - Application to Road Traffic and Driving Simulations - in proceedings of Summer Computer Simulation Conference (SCSC 2003) - Montreal, Canada, 20-24 July 2003
- [Chandler 58] Chandler R.E., Herman R. & Montroll E.W. - Traffic dynamics; Studies in car following - Operations Research Vol 6 pp. 165-184, 1958.
- [Doniec 05] Doniec A., Espié S., Mandiau R., Piechowiak S. (2005). Dealing with Multi-Agent Coordination by Anticipation: Application to the Traffic Simulation at Junctions. EUMAS 2005 - Proceedings of the Third European Workshop on Multi-Agent Systems, M.P. Gleizes, G.A. Kaminka, A.Nowé, S. Ossowski, K. Tuyls, K. Verbeeck (Eds.), Brussels, Belgium, December 2005.
- [El Hadouaj 04] El Hadouaj S., Espié S., Drogoul A. - A multi-agent road traffic simulation model: validation of the insertion case - Summer Computer Simulation Conference (SCSC 2004) - 26-28 July 2004.
- [El Hadouaj 01] El Hadouaj S, Espié S., Drogoul A. - A traffic simulation model based on an economic approach - in 2001 International Conference on Artificial Intelligence (IC-AI 01) proceedings - Las Vegas, USA, 25 - 28 Jun 2001.
- [Espié 94] Espié, S., Saad, F., Schnetzler, B. & all. (1994) - Microscopic traffic simulation and driver behaviour modelling: the ARCHISIM project - VTI Konferenz - In proceedings of the Strategic Highway Research Program (SHRP) and Traffic Safety on Two - Lille, France, 22-24 September 1994.
- [Espié 95] Espié, S. - ARCHISIM: Multi-actor parallel architecture for traffic simulation - In Second World Congress on Intelligent Transport Systems proceedings - Vol IV, Yokohama, Japan, November 9-11, 1995.
- [Espié 06] Espié S. - Joint use of driving simulation and traffic simulation for the study of road infrastructure s and equipments - In the 11th International Conference on Computing in Civil and Building Engineering- Montreal, Canada, June 14-16, 2006.
- [Fuller 84] Fuller R. - A conceptualization of driving behaviour as threat avoidance - Ergonomics, 27, 11, pp. 1139-1155, 1984.
- [Gazis 61] Gazis, D.C., Herman, R. & Rothery, R. - Non-linear follow-the-leader models of traffic flow - Operations Research, Vol. 19, 1961, pp. 545-567, 1961.
- [Gibson 38] Gibson, J.J., Crooks, L.E. - A theoretical field analysis of automobile Driving - The American Journal of Psychology, 11, pp. 453-471, 1938.
- [Gipps 81] Gipps, P. G. - A behavioural car-following model for computer simulation. Transportation Research part B, vol 15 pp. 105-111, 1981.
- [Gipps 86] Gipps, P. G. - A model for the structure of lane-changing decisions - Transportation Research part B, vol 20B, pp 404-413, 1986.
- [Lieberman 97] Lieberman E., Rathi A.K. - Traffic simulation - in Traffic flow theory. chapter 10, Oak Ridge National Laboratory (Eds.), 1997.
- [Lighthill 55] Lighthill M.J and Whitham G.B. - On kinematic waves:II. A theory of traffic flow on long crowded roads - Proceedings of the Royal Society of London A, Vol. 229 (1178), pp. 317-345, 1955b.
- [Michon 80] Michon J-A. - The new driver. Human factors in transport research - Osborne & Levis ed. Academic Press, 1980.
- [Michon 85] Michon, J.A. - A critical view of driver behavior models: what do we know, what should we do? - In: Evans, L. and Schwing, R. (Eds.) Human Behavior and Traffic Safety. Plenum Press, New York, 1985.
- [Näätänen 74] Näätänen, R. and Summala, H. - A Model for the Role of Motivational Factors in Drivers' Decision-Making - Accident Analysis and Prevention, Vol 6, 243-261, 1974.
- [Normann 42] Norman F. - Results of highway capacity studies - Public Roads, vol. 23, no.4, pp. 57-81, 1942
- [Richards 56] Richards P.I. - Shock waves on the highway - Operations Research, Vol. 4 pp.42-51, 1956.
- [Saad 88] Saad F. - Prise de risque ou non perception du danger - Recherche Transports Sécurité, No 18-19, Elsevier, 1988.
- [Saad 92] Saad F. - In-depth analysis of interactions between drivers and the road environment: contribution of on-board observations and subsequent verbal report - In Proceedings of the 4th Workshop of ICTCT, University of Lund, Bulletin 110, 1992.
- [Summala 85] Summala, H. - Modeling driver behavior: A Pessimistic Prediction? - In Evans, L. and Schwing, R. (Eds.) Human Behavior and Traffic Safety. Plenum Press, New York.
- [Wardrop 52] Wardrop J. G. - Some theoretical aspects of road traffic research - Proceedings of the Institute of Civil Engineers, Part II, Vol. 1 pp.325-378, 1952.



S. Espié is Senior Research Scientist at the INRETS. He lead the modelling, simulations and driving simulators (MSIS) Department. He holds an accreditation to direct research in Computer Science. His main topics of research are the modelling and the simulation of complex systems including mankind and the design of tools allowing human behaviour studies. He is particularly involved in the design of behavioural traffic simulation, of driving simulators and of instrumented vehicles.



J.M. Auberlet is Research Scientist at the INRETS and is a member of the Modelling, simulations and driving simulators (MSIS) Department. He holds B.S. and M.S. degrees in Mathematics and a PhD in Biomathematics. Dr Auberlet's research interests includes model design of complex systems for simulation in various domains as in scheduling problem, physiology or as currently in psychology and road traffic.

Received date: June 9 2006

Received in revised form: December 1 2006

Accepted: December 28 2006

Editor: Takahiro Suzuki