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Traffic simulation: Experience and know-how

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Les modèles de simulation de trafic sont utilisés dans le but de représenter le trafic, de prévoir son évolution et de permettre d'effectuer des choix sur les politiques de transport. Les articles sélectionnés ont pour objectif d'étudier et de discuter de problématiques communes à différents champs de recherches liés à la modélisation du trafic. Les sujets principaux de ces articles concernent : l'élaboration d'une méthodologie pour le recueil et l'élaboration de données (utilisant le GPS), en vue d'enrichir les lois de poursuite, ;l'influence de l'information diffusée sur le comportement des conducteurs ; une méthodologie pour étudier des modifications dans le système de trafic, des outils pour visualiser et simuler des systèmes de transport (un téléphérique et un funiculaire) reliant l'université de Reggio de Calabre à son centre ; une étude des impacts d'un système de contrôle latéral dans un environnement urbain ; une analyse comparative des temps de parcours sur route urbaine obtenus par l'application d'un modèle statistique-expérimental calibré et de deux modèles de microsimulation, AIMSUN et ARCHISIM. Les discussions pendant ce workshop qui s'est tenu en juin 2003 ont mené à des collaborations entre les participants.</td></tr>
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Traffic simulation models are used in order to represent the traffic, to anticipate its evolution and to allow the choice of management policies. The selected papers aim at discussing the relation between different research fields related to traffic modelling. The major topics of the papers are: the development of a methodology using GPS systems for collecting and elaborating multiple car-following data, the influence of the information provided on drivers' behaviour, a methodology to study any modification in the road traffic system, tools to visualize and to simulate two transport systems (a cableway and a funicular) to serve the university city of Reggio Calabria, a study of the impacts of a Lane Keeping System in urban environment relating to the traffic capacity, a comparative analysis of the running time on urban road obtained by the application of a calibrated statistical-experimental model and two microsimulation models, AIMSUN and ARCHISIM. The discussions during this workshop gave birth to cooperations between the participants.</td></tr>
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Introduction

The problems related to road traffic are often a main axe of development followed by research teams in the transport domain. The number of traffic simulation programs and, at the same time, the number of applications of those programs to solve real-life transportation problems increase quickly.

Traffic phenomena are complex; they have been studied for many years, mainly to allow the control of the “supply - demand” system. The goal is to identify the phenomena in order to pre-empt their management as well as possible. One distinguishes long-term forecasts from mid-term and short-term. Long-term makes it possible to redefine the infrastructures and to inflect the demand, mid-term to give traffic information, while short-term allows traffic flow control.

Traffic simulation models have been used for many years in order to represent the traffic, to expect its evolution and to allow the choice of management policies. One can classify the models used for this problematic in two major classes:

— Macroscopic models

  The macroscopic models are based on an identification of traffic flow phenomena and compared to the flow of the fluids. The road network is considered as a network of drains, crossed by traffic flows. The characteristics of the network sections (maximum flow, mean velocity of the vehicles when the section is released…) and of the demand (volume of traffic, origin-destination of the vehicle…) determine how the network is crossed by the traffic flows. These “low-cost” models (in terms of calculus) are used for large road networks.

— Microscopic models

  The microscopic models are generally based on the identification of a car-following law. This identification is carried out, for a given geographical site, by a series of measurements. The measurements carried out by the sensors placed on the road (magnetic loops for example) make it possible to know the practices of the drivers and are used for the identification of the car-following law.

Several “philosophies” of interpretation, which often can seem distinguish between them, have been proposed. In any case, all the realised instruments and theories can be improved. For this reason their comparison are very important.

Unfortunately, this growth is not accompanied by a set of established rules and guidelines describing the best practice of application of those fairly complex models. Especially the challenge of calibration and validation of traffic models seems to lack a well established and shared procedure.

In the framework of the collaboration between Inrets and the University of Reggio Calabria, these problems lead S. Espié (Inrets) and D. Gattuso (University of Reggio Calabria) to organise a workshop in June 2003, aimed at study the relation between different research fields related to the traffic modelling. The participants work on the same activity domain, but deal with different themes. Thus, it was possible to get the different positive aspects of the on-going research and to understand what the possible common developments could be . The participants presented their recent works; discussions followed.

Furthermore, to illustrate the researches conducted at INRETS, some demonstrations were presented. These exhibitions aimed to present the behavioural traffic simulation model ARCHISIM, the driving simulator architecture SIM², which can host a full cab driving simulator as well as a low cost driving simulator, and the potential of the integrated approach with the use of ARCHISIM and SIM².

The discussions during this workshop led to collaborations between the participants.

Evaluation of car-following models through accurate experimental data

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Abstract

Car-following behaviour, a fundamental element of the traffic microscopic analysis and simulation tools, has always needed to face the data problem of accuracy and consistency. In the past, data were collected through complex mechanical and electric systems in controlled traffic flow conditions. Recently new techniques such as video and radar screening have highlighted clear limits in the spatial analysis approach for the first one, and in the effort of synchronizing data in multiple car-following experiments for the second. The recent development of satellite positioning techniques (K DGPS) opens a new horizon in traffic engineering, allowing multiple car-following data collection with extreme accuracy, in real traffic flow conditions and for large time periods.

The first research objective is, therefore, to develop a methodology for the collection and the multiple car-following data elaboration through K DGPS.

The proposed methodology has been applied to gathered data: a series of experiments developed with four vehicles on urban and extra-urban roads has allowed the collection and the calibration of the speed and acceleration profiles, of the spatial and time distances among vehicles and the reaction times of the drivers in different flow conditions.

Data collected have been used to make a comparative evaluation of two car-following models: the model developed by Gipps (1981) and the consequent changes proposed by Punzo (2001, 2003).

Experiments made by K DGPS

The high accuracy grade and the simultaneity of data are what makes particularly difficult the measure of the car-following state variable.

Traditional in-vehicle systems are mounted separately on each vehicle of a platoon. This may cause problems in synchronization of revealed data. On the other hand, all the rovers that are connected with the Global Positioning System have an extremely precise common timing. That is the reason why such equipments are often used for applications where it is necessary to synchronize tools set one from the others. Therefore, the GPS system allows to avoid the problem of synchronization of different vehicles data.

It is common wisdom that all the GPS rovers are able to estimate their position measuring the distance from the satellites, with an accuracy from 5 to 10 meters. The simultaneous use of the two rovers, one of which is fixed at a point of fixed coordinates, allows to increase the measures obtained with the mobile rover, reaching an accuracy of around 0.5 meters. This can be made both in real time and post-elaboration, and its relative technique is called Differential GPS (DGPS). A further development of this technique is the Kinematic GPS (K GPS), the use of which in real time is called Real Time Kinematic GPS (RTK GPS). A phase measure of the two carriers of the GPS signal (pointed out with L1 and L2) allows to reach higher accuracy, both in the position and in the speed computation, obtained by using the Doppler signal effect. The expected accuracies are around 8-10 mm for the horizontal position and 0.16 km/h for the speed. These values are comparable to the accuracies reachable with the most sophisticated traditional equipment (for a comparison see Gurusinghe, 2001).

Equipment used

For the experiments have been used 5 rovers Topcon, Legacy-E type, which allow to also use the information of the Russian Glonass satellite constellation. The expected accuracies are 8 mm + 2 ppm for the horizontal position and 0.16 km/h for the speed. The output information frequency is 10 Hz. The informations available for output are the rover position and the speed. Among these only the first one has been used as described in the following section.

Experiments

The experiments have been led in actual traffic conditions in both urban and extra-urban context, in the province of Naples (Italy), with four vehicles.

The planning of the paths and of the time periods during which to do the experiments need to respect some constraints:

— streets need to be free from obstacles which can hide the satellite signal (for short time periods too), such as high buildings, trees, etc. Streets need not to belong to zones where the signal is hidden (such as vast areas in the metropolitan area of Naples);

— car-following dynamics should prevail on the other driving dynamics. This means that streets should have one lane for direction with no overtaking (in urban roads in which the overtaking is allowed and in extra-urban roads with more lanes – e.g. the bypass of Naples – drivers were forced to not overtake or change lane);

— during the experiments, the maximum satellite availability along the chosen paths should be available, and different traffic conditions have to be addressed.

For this purpose a series of trails have been made to test the GPS quality signal on the selected paths. For the choice of the time in order to have the maximum satellite availability, the Topcon (Pinnacle) software has been used. The latter is able to give information on the satellite ephemeris. The choice has been difficult, due to the numerous constraints and the need for all the vehicles to have a good signal.

The drivers of the following vehicles, all of them university students, have been thought on the path to choose, but they have not been informed of the objectives of the experiments. The latter have been also filmed, to eliminate “anomalous” or disturbed situations.

Once the paths have been identified, data have been collected for 6 hours. Data actually used for car-following studies, obtained from these with the procedure described in the following section, have been 40 minutes long. In fact (a) all data where the signal of at least one vehicle is disturbed or absent for more than 3 seconds (such interval has been considered the upper limit in order to consider acceptable the results obtained), (b) data relative to anomalous driving behaviour and (c) incomplete driving cycles, have been deleted .

Methodology for data collection, processing and analysis

Numerous are the causes of error in the computation of the position through the GPS system; the *spatial segment* errors (on the ephemeris), the propagation errors of the signal in the atmosphere (in the ionosphere as a function of the sun activity and in the troposphere as a function of the meteorological conditions), multi-path errors (reflex of the surfaces next to the rover antenna), errors of the rover itself. Should also be considered the temporary absence of the signal due to the presence of obstacles and the difficulty in making a survey in a kinematic way. For the first two errors not much can be done, only for the tropospheric propagation for which compensation models can be used and satellites with an angle over the horizon less than 15° can be cut. An attempt has been made to reduce the error spring with an accurate planning of the survey and with the use of double frequency rovers. Thus a series of 11 trials have been collected, lasting at least 3 minutes, with a qualitative level of data sufficient for the following analysis and elaborations.

However, given the data sample frequency (10 Hz) and the high accuracy required by the analysis, a procedure has been developed for the correction of the positioning data obtained from the differential correction, and for the estimation of the speed and acceleration values.

This processing procedure, developed in Visual Basic Application with the use of MATLAB optimisation functions, is reported in Figure 1.

The first step of the procedure is the application of a filter on rough data through which all the epochs with a GPS error higher than a pre-specified threshold (e.g. RMS >100) will be deleted from the database.

Therefore the computation of the curvilinear abscissa described by the rover, as the distance between the coordinates of two successive points, is performed. The error made in the linearization of the trajectory is negligible due to the high data acquisition frequency. The abscissa computation is made only between subsequent points: the obtained curve is a piecewise-linear with non constant time steps.

Abscissas in the missing instants are retrieved through an interpolation by using a SPLINE function.

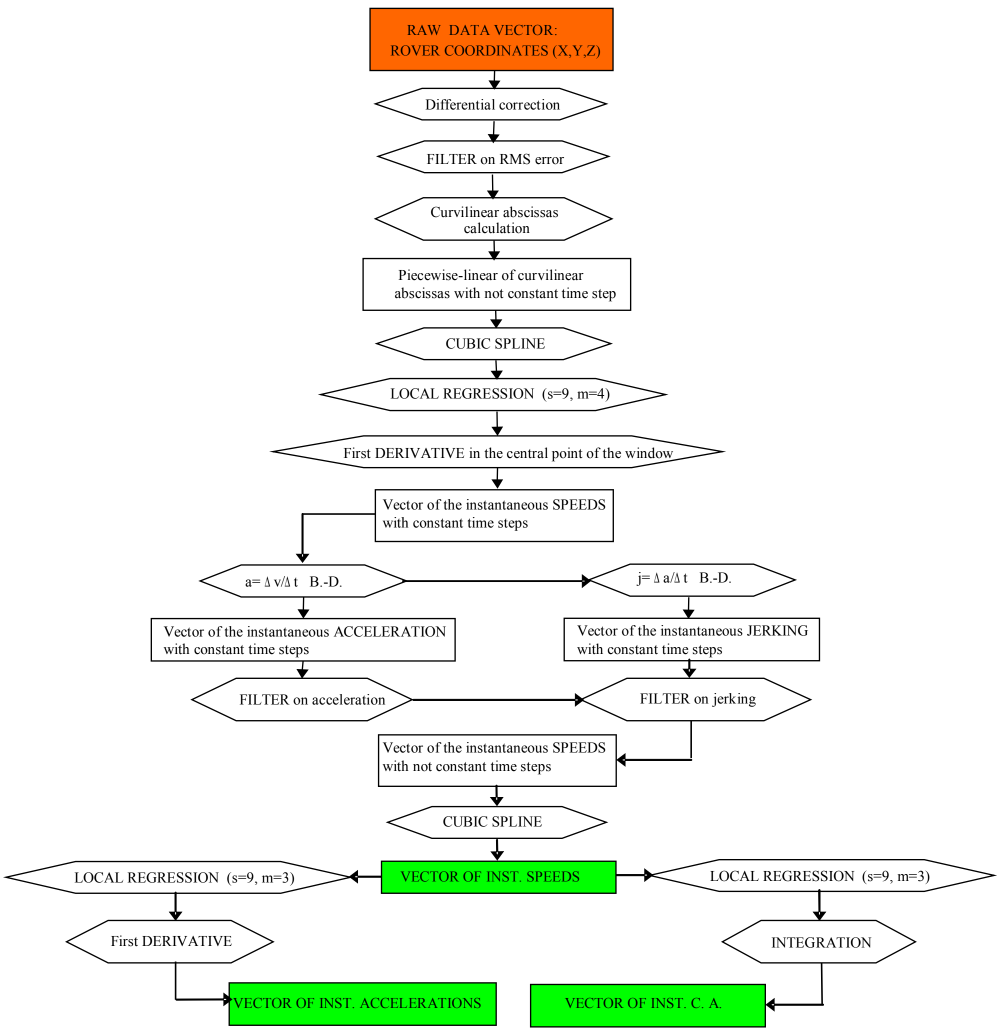

Figure 1 Data processing procedure

The latter is a polynomial function which is made up of m n- order polynomials to connect m+1 points. In the connection points the continuity is given by the derivates of order less than n:

$$f_i(s) = a_i + b_i s + c_i s^2 + ... + x_i s^n \quad (1)$$

where s, the curvilinear abscissa has been considered in the local system and a_i, b_i, c_i … x_i are defined the polynomial coefficients. The chosen polynomial, thanks to the sensitivity tests, has been that of the third order. Therefore, in that case, the problem of the definition of the coefficients has been determined by writing 4m equation in 4m unknowns (a_i ; b_i ; c_i ; d_i). With respect to the extreme conditions of each part, two equations for each polynomial can be written ($f_i(s) = f_{i+1}(s)$); two other equations can be obtained by assigning the inner connection conditions ($f'_i(s) = f'_{i+1}(s)$ e $f''_i(s) = f''_{i+1}(s)$), finally giving [2m + 2(m-1)] equations. At the latter are added the two conditions obtained by assigning null to the second derivates at the extremes. A continuous and derivable function has been obtained which describes the curvilinear abscissa, even if in such a function only the values assumed in the measure instant are taken.

The given function does not allow the computation of the instantaneous speed and of the acceleration. For this reason, the adoption of regression procedure has been carried out in order to mediate the measure errors in the subsequent instants. The chosen methodology is essentially based on *local regression* techniques. Once defined a window of observed points of width s (the curvilinear abscissa), the n-order polynomial coefficients are estimated, which minimize the distance of the polynomial itself from the observed data through (2), and the derivate in the central point has been computed, equal to the value of the instantaneous speed. By simply removing one point at each time in the computation window and by resolving the minimum problem given by (2), with simple derivates the speed values can be computed in all the revealed points:

$$\min_{\beta^{t,s} \in R^n} \left[X(t,s) - T(t,s) \cdot \beta^{t,s}\right]' \cdot P(t,s) \cdot \left[X(t,s) - T(t,s) \cdot \beta^{t,s}\right] \quad (2)$$

where:

- t is the time period when the estimate is needed
- s is the size of the window
- $X(t,s)$ is the discrete observations vector of the trajectory relative to time t and window s
- $T(t,s)$ is the independent variable matrix $c, t_n, t_n^2, \ldots, t_n^n$
- $\beta^{t,s}$ is the parameter vector at t and s
- n is the polynomial order
- $P(t,s)$ is the diagonal matrix of the weights.

The window width *s* and the order *n* of the regression curve have been chosen through a sensitivity analysis. The infinite couples of possible values are subject to the following constraints:

- the polynomial order which describes the regression curve should always be less than the number of points of the chosen window, otherwise the regression curve would interpolate all the points;
- from the polynomial grade it is possible to infer the number of function inflexion points of the curvilinear function and, therefore, the sign acceleration variations. The polynomial order should be able to not allow a number of sign acceleration inversions not physically feasible in relation to the window width;
- it is preferable that the window has an odd number of points;
- in order to have a non constant counter blow, the acceleration function should be derivable with continuous derivates, and therefore the polynomial should be at least of the fourth order.

Therefore a comparison has been made for the following couples of values on a sample of 600 continuous points with an RMS < 100:

s= 7, *n=4*

s= 9, *n=4*

s=9, *n=5*

s=11, *n=5*

s=11, *n=6*

s=13, n=6

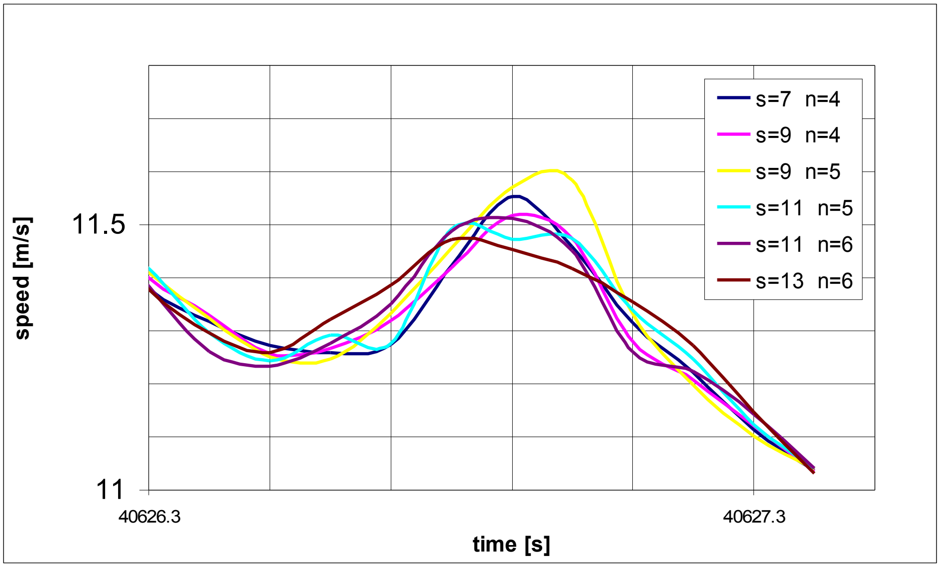

Figure 2 Speed profiles as a function of s and n

In Figure 2 some speed profiles are reported as a function of *s* and *n* and the qualitative effect of the two parameters can be highlighted on the regression results. In particular, it is possible to notice that the deviation among the different curves is not particularly high, resulting in speed values in a spindle having maximum width equal to 0.424 m/s and average width equal to 0.047m/s, with the frequency distribution that can be highlighted.

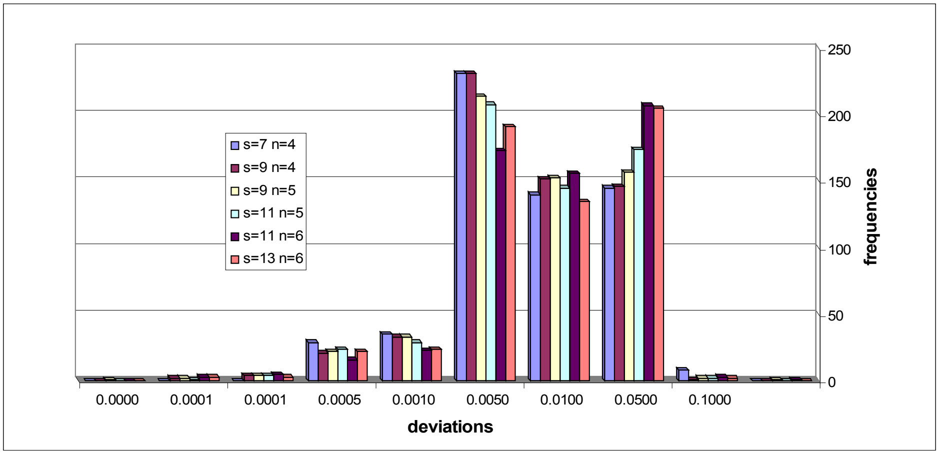

Figure 3 Frequencies of the width of the instantaneous speeds

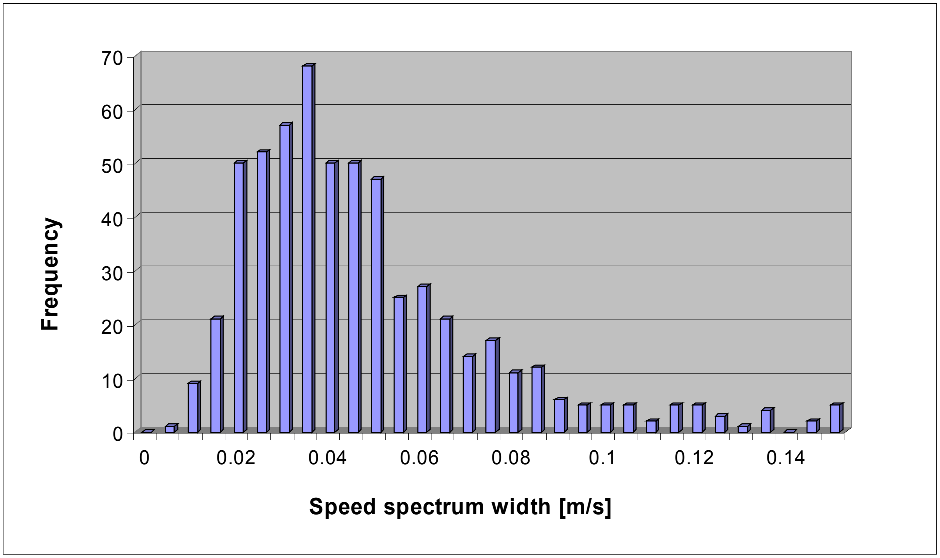

Figure 4 Frequencies of the deviation of the curve with rough data

From Figure 3 it is possible to deduce how the functions with (s = 9, n = 4) and (s = 11, n = 5) show more regular profiles.

In Figure 4, where the frequency deviations of the curvilinear abscissa of rough data from the values assumed by the regression curves in the central point of the window are reported, it is possible to highlight that the curves which are very close to real data are those with (s = 9 and n = 4) and (s = 7 and n = 4).

In conclusions the parameters (s = 9 and n = 4) give the best compromise between measure reliability and computational effort; moreover it seems to be the closest to reality.

The obtained results have been subject to further filters, with which the acceleration values and the not feasible counterblow have been deleted.

In Figure 5 it is possible to notice the result in the processing made on a data interval of disturbed positions. The obtained results have been compared with those obtained directly from rough position data and those given by the post-processing software and differential correction. It is possible to observe how in the specific case only the developed procedure has been able to give a derivable speed profile. It is necessary to highlight how to use the revealed data as input trajectories for the calibration of a car-following model, *i.e.*, as actual data with which evaluate the model performances, it is necessary to have a continuous and derivable speed profile for the total length (in particular for the first application).

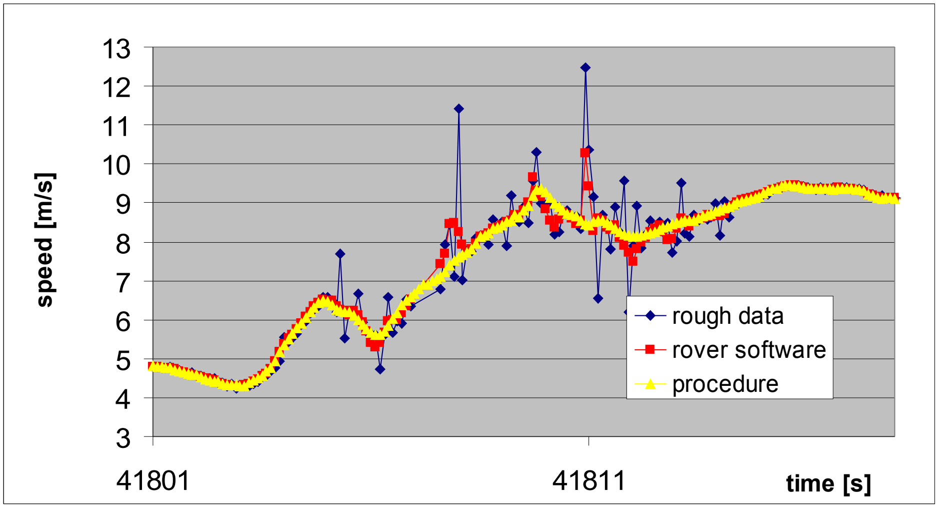

Figure 5 Comparison among the different speed profiles

Data analysis

The speed values, accelerations and distances of vehicles collected according to procedure described above are used to define the driving behaviour of the different drivers.

In the following diagrams it is possible to observe the trend of headway and spacing as functions of the speed, for two different drivers of the platoon, for 5 different data series (respectively Figure 6 and Figure 7 for the first driver, and Figure 8 and Figure 9 for the second). It is interesting to notice that within each trial, with a different driver, drivers observe time distances not very susceptible to variations of the speed (Figure 7 and Figure 9). The evolution path of headway and spacing among the different trials is furthermore similar for the two drivers. These two considerations seem to confirm that headway in an urban context is not influenced by the speed with which once proceeds, but from the different environmental conditions (such as street typology and level of congestion).

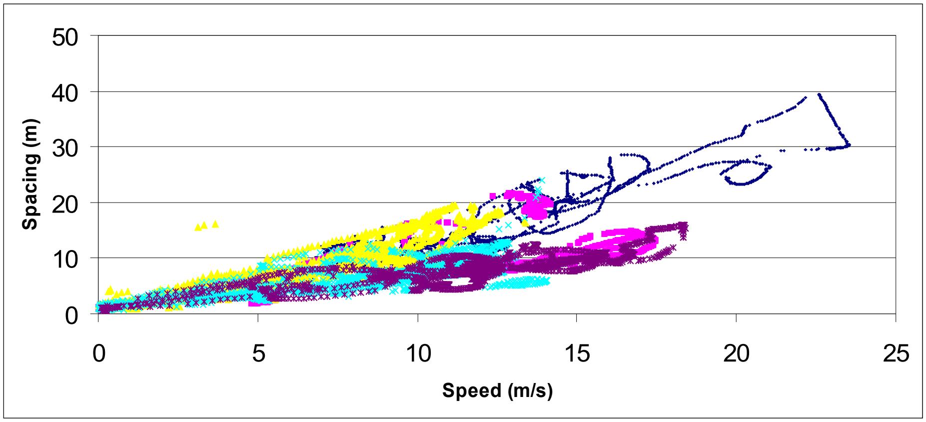

Figure 6 Spacing from the leader as a function of the speed (First driver)

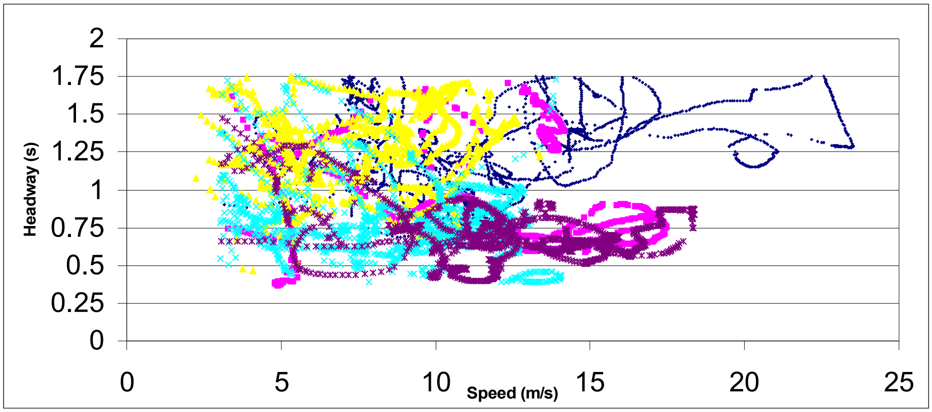

Figure 7 Headways from the leader as a function of the speed (First driver)

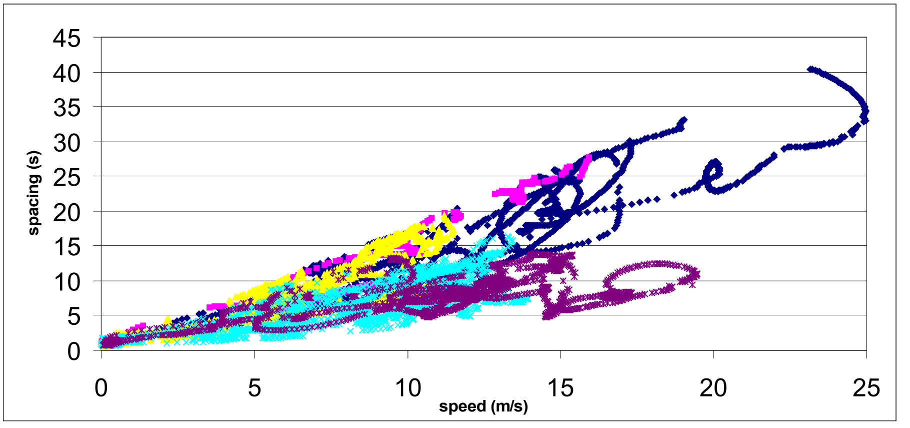

Figure 8 Spacing from the leader as a function of the speed (2nd driver)

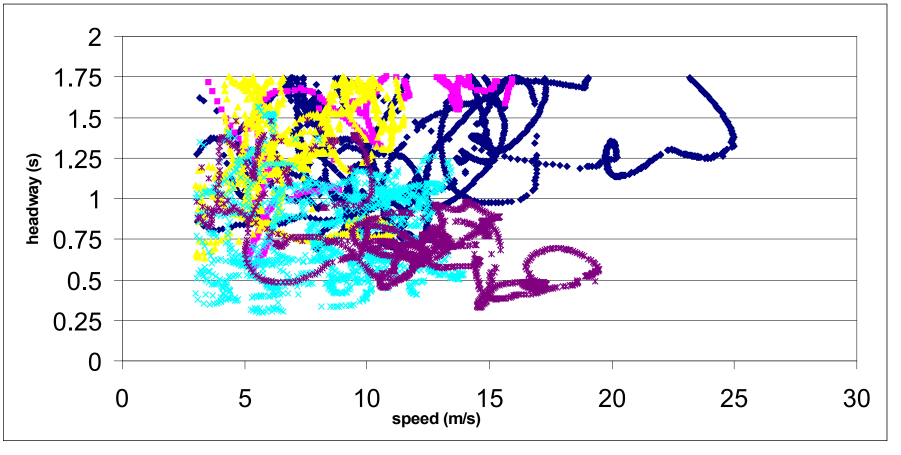

Figure 9 Headways from the leader as a function of the speed (2nd driver)

With the collected data it has been possible to compute drivers reaction times. By putting on a same graphic the relative speed of two vehicles and the acceleration of the following vehicle, it has been possible to identify the reaction times as those intervals measurable between the instant when the relative speed slope changes (stimulus) and the one when the following vehicle acceleration varies (response). The inference made on reaction times (around 400 values) has confirmed the hypothesis made on the log-normal distribution. The estimated distribution is:

$$f = \frac{1}{0.237\tau\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(\tau) - 0.284}{0.237}\right)^2}$$

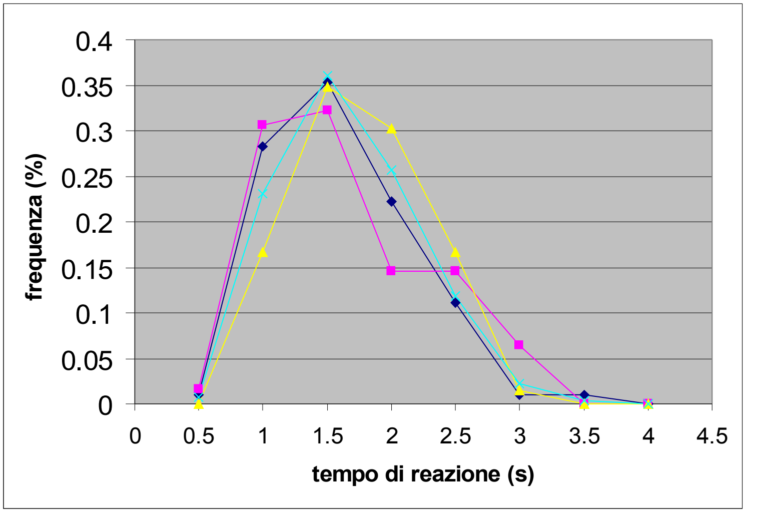

Figure 10 Frequency percentage distribution of the driver reaction time

In Figure 10 the frequency percentage distribution of the reaction times of each driver are reported. In Figure 11, on the other hand, the time reaction trends of the driver as a function of the time are reported, relative to the cycle of Figure 16. In Figure 12, the reaction time values along the platoon are reported for two different cycles.

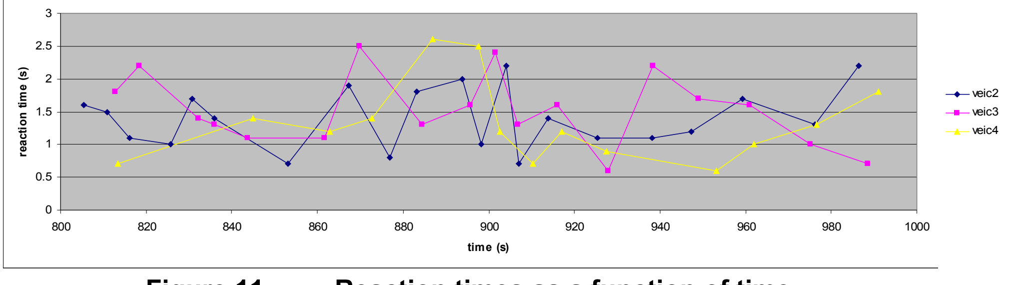

Figure 11 Reaction times as a function of time

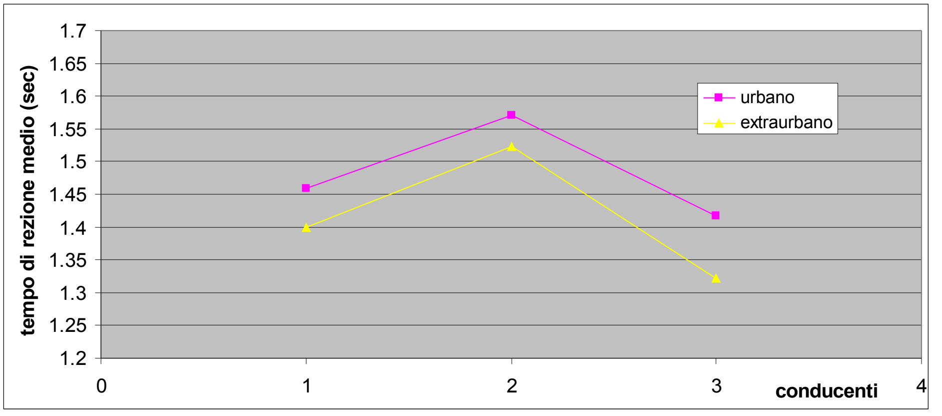

Figure 12 Reaction time along the platoon for different cycles (same driver order) Sensitivity analysis, calibration and validation

The obtained data have been used to validate and compare two car-following models: the Gipps model 1981 and the model proposed by Punzo 2001, 2003. For both models a sensitivity analysis, a calibration and a subsequent validation have been carried out through those data.

Sensitivity analysis

The two output chosen performances measures (*responses*) have been the instantaneous speed and the spatial distances among vehicles. The common methodology for the quantitative measure of the performances has been the summation of the squares of the differences between the simulated and observed values:

$$\varphi_{speed} = \sum_{G} \sum_{V} \left(v_i^{sim} - v_i^{oss} \right)^2 \tag{3}$$

$$\varphi_{distances} = \sum_{G} \sum_{V'} \left(d_i^{sim} - d_i^{oss} \right)^2 \tag{4}$$

where with v_i and d_i the instantaneous values of the two measures have been defined (revealed every 0.1 sec.), respectively speed and distance, the set of groups of trajectories has been set equal to G (in number of 3), with V is defined the set of vehicles (in number of 4) with V' is defined the set of couples of vehicles (in number of 3). The input parameters (factors), chosen for the analysis, have been 5 for the Gipps model and 6 for the proposed model and respectively:

— the common driver reaction time τ, the desired speed V_n, the maximum accelerations and decelerations a_n and b_n, of driver n, and the estimate made from the maximum deceleration rate of the front vehicle, $\hat{b}$;

— perception and reaction times, p_n and r_n, the desired speed, V_n, the maximum acceleration and standard deceleration, a_n and $\overline{b}_n$ and the approaching perception threshold $(d\omega/dt)_n$, of driver *n*.

The experiment planning has been made by using a factorial fractional technique, at two levels (2^{k-p}), with a resolution equal to III for the first model and to IV for the second (2^{5-2}_{III} e 2^{6-2}_{IV}). For the first model all parameters are significant (for both types of responses). While for the second the approaching perception threshold θ_n, is significant only for distances. As an example, for the Gipps model in Figure 13 the results of a more detailed analysis made on parameter τ are reported (24 levels on a unique data set).

Both responses are influenced by the parameter. As expected, the trend of the response function of the model relative to the distances is a parabolic type and is due to a systematic error, first as underestimate and then, for increasing values of τ, as overestimate. In the case of the instantaneous speed it is possible to observe,

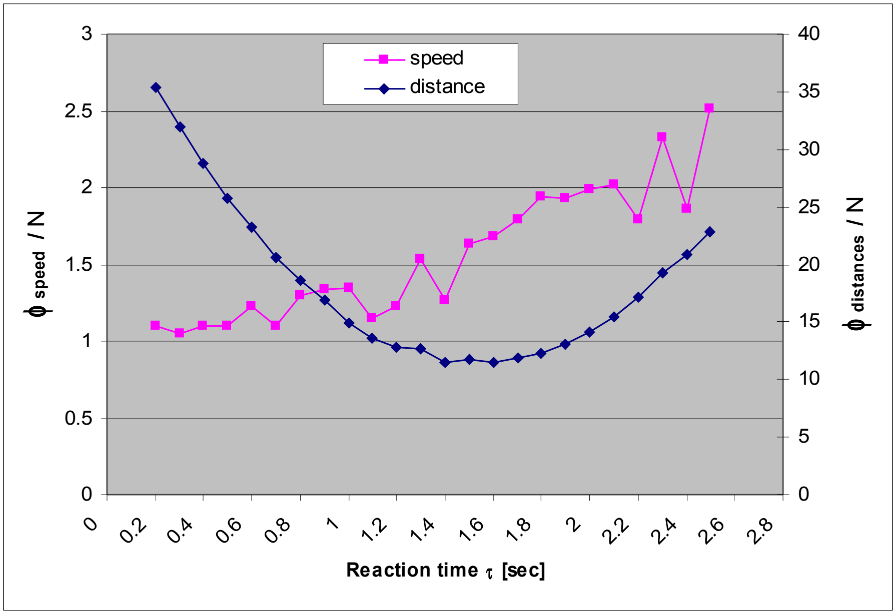

Figure 13 Gipps – Trend of the φ responses as a function of the reaction time τ

for increasing values of τ, an increase of the term got from the Theil statistics which is significant of the model ability to reproduce the data original fluctuations (U^S, “variance proportion”; Theil, 1966). In Figure 14, on the other hand, the actual trajectory of the first vehicle is reported and the simulated trajectories of the second vehicle got from the previous analysis is reported as well, while τ varies. The trends highlight the behaviour of the model as a function of τ and allow to clarify the response trend $\varphi_{speed,}$ shown in Figure 13. For low values of the reaction time τ – defined by Gipps "apparent" – the trajectory of the second vehicle obtained from the model is very close to that of the leader (actual trajectory reported in the figure). The lowest is τ the one the following vehicle is able to "imitate" its leader trajectory. Such a "behaviour" is fundamental in the Gipps model.

For increasing values of τ, the speed computation made by the driver for the subsequent instants is more conservative. The effect is an increase of the average spatial distance and an adjustment of the trajectories which, in the case of Figure 14, for the simulations made with τ =1.4 and τ =1.8, causes the absence of the stop of the following despite the stop of the leader.

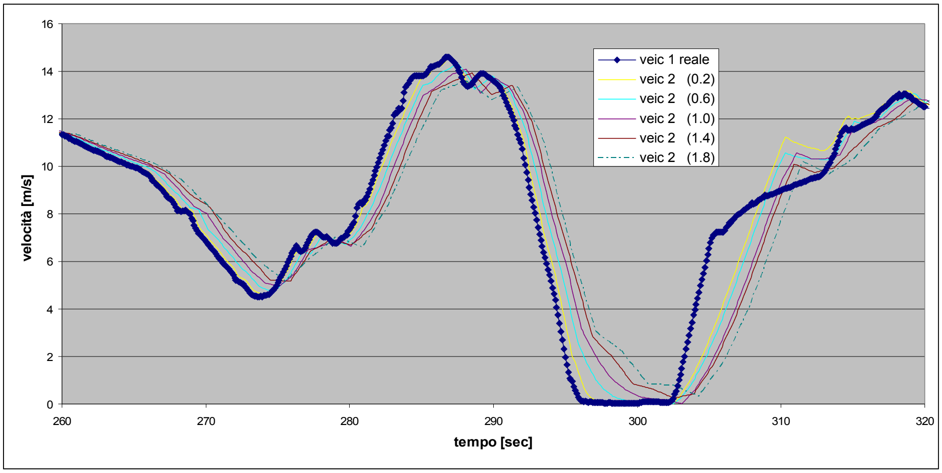

Figure 14 Gipps – Simulated trajectories of the following vehicle while τ varies

Calibration and validation

The expected result of the calibration phase has been investigating the capacity of the two models to interpret and reproduce the real system. From this perspective two different sets of trajectories have been chosen, one representative of urban traffic flow conditions and the other of extra-urban traffic flow. The second set has been collected a few minutes after the first and the drivers, the vehicles and the platoon order were unvaried.

Behavioural parameters of the single driver have been calibrated, in the two different groups of trajectories, by minimizing the response distance of the observed values through (14): in each experiment the observed front vehicle trajectory has been assigned as input and the output has been the simulated trajectory of the unique following vehicle. After the calibration, the evaluation of the models ability in reproducing the single trajectories has been carried out.

For both groups the movement of the whole platoon has been simulated with the parameters previously calibrated and the error amplification effect along the vehicles line for the two models has been computed as well.

In Figures 15 and 16 the instantaneous speed profiles of the two trajectories groups have been used. The urban ones, of 6 minutes, present an average speed of 28 km/h and a series of slowing downs and restarts. The extra-urban ones are on the other hand made up by a unique sequence 3 minutes long and with an average speed of 47 km/h.

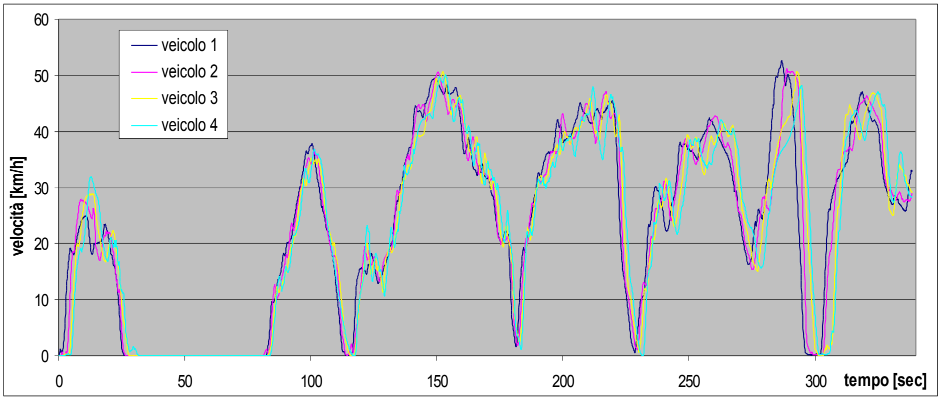

Figure 15 Urban trajectories used for the evaluation

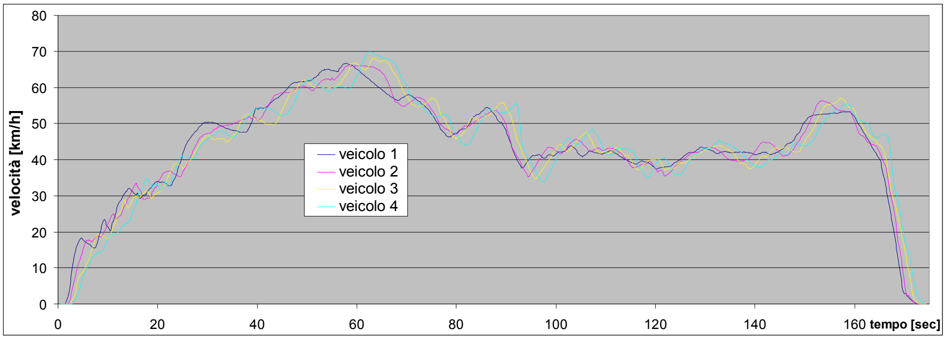

Figure 16 Extra-urban trajectories used for the evaluation

To compare the responses of the models with the actual system behaviour, it has not been possible to use the common statistical tests (t, χ^2 for two samples, Kolmogorov-Smirnov two samples, etc.) with i.i.d. data. In the case under study, both the values of a same series (the w^x_{1j} with the w^x_{1j+1}), and the corresponding values of simulated and real series (the w^{sim}_{ij} with the w^{oss}_{ij}) are correlated. The distribution of such variables are not stationary, for example as a function of the traffic flow conditions. Therefore for the performances evaluation of the models the RMS error statistic has been used (Root Mean Squared error) both on the instantaneous speeds and on the distances:

$$(RMSe)_i = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(w_{ij}^{sim} - w_{ij}^{oss}\right)}$$

where w_{ij}^{sim} and w_{ij}^{oss} are respectively the *j*-th estimated and observed values of the measures relative to the trajectory *i*, with j=1…N.

In the following table the calibration results are reported.

	Measures	**RMSe (v_{ij})**		**RMSe (d_{ij})**	
Trajectories		Gip.	changes	Gip.	changes
I Group Single sim.	II vehic.	*0.59*	*0.39*	*10.9*	*6.5*
	III vehic.	0.64	0.40	11.0	7.0
	IV vehic.	0.48	0.37	11.7	5.4
I Group Total sim.	II vehic.	*0.59*	*0.39*	*10.9*	*6.5*
	III vehic.	1.30	0.99	20.3	14.5
	IV vehic.	2.70	1.60	41.5	27.8
II Group Single sim.	II vehic.	*0.27*	*0.24*	*5.2*	*4.5*
	III vehic.	0.32	0.27	5.8	3.9
	IV vehic.	0.35	0.22	4.9	3.7
I Group Total sim.	II vehic.	*0.27*	*0.24*	*5.2*	*4.5*
	III vehic.	0.68	0.55	8.9	7.8
	IV vehic.	1.32	0.98	14.5	12.0

Table 1 Performances measure of the models obtained in the calibration phase

The responses in the two performances measures are concordant in all the simulations. In the following only the RMSe values computed on the instantaneous speeds are highlighted. If the simulation results where the vehicle have been calibrated on the single trajectory of its leader are observed, on can notice that the performances are better for the changed model. The RMSe decrease, in this case, goes from a minimum of 11% and a maximum of 37%, resulting in an average of 31% for urban trajectories (I group) and of 21% for those extra-urban (II group). It is necessary to highlight how the distance between the two models should be intensified if the error measures were computed only in the phases properly of car-following, since the differences of the models in the free acceleration regime are negligible.

By observing the results from the trials in which three vehicles in line in the platoon have been simulated with the parameters estimated singly in the previous simulations, the amplification error can be highlighted along the file of vehicles. In this case, each vehicle moves as a function not of the actual trajectory of the vehicle which comes, but of the simulated trajectory of the vehicle itself (Punzo et alii, 2003). In this case, the highest deviation between the measured error in the single simulation with respect to the total simulation is obviously the one of the last vehicle of the platoon. This increase is for Gipps equal to 565% in the urban cycle, and to l 377% in the extra-urban one, while remaining stable around values of 440% for the changed model.

Conclusions

Historically, the development of the car-following models has followed a “quasi purely” deductive approach. Based on simple assumptions on driver’s behaviour, some basic relationships have been derived. They describe the car-following phenomenon at least from a phenomenological point of view (*i.e.* without investigating the complex dynamics of driving and actual behaviours of drivers) in a very simple manner. The appeal of such a theory is based on the easiness of computation together with the formal consistency with macroscopic theory of traffic flow. Despite the great efforts produced and due to the technological issues of gathering actual car-following data with the required accuracy, the evaluation of model performances hasn’t given reliable results, until now. The calibration efforts too have been not widespread.

The recent availability of technologies like GPS allows the collection of accurate and self consistent car-following data. This obviously results in a deeper insight in car-following phenomena and in the chance of calibrating parameters of developed models on the “actual” behaviours of the system.

In this work the whole process of car-following model calibration, throughout the developing and testing of data collection and estimation procedures, and the model evaluation, is described.

More in detail, a procedure for the estimation of the instantaneous speeds and accelerations from RTK- GPS data is presented. Then the results of its application to a collected database of multiple car-following experiments are shown. This led in particular to the estimation of the reaction time distribution of “alerted” drivers.

Finally, the evaluation and comparisons, in a rigorous framework, of two different car-following models is presented. The evaluation allowed to derive some interesting considerations about one of the more widely used car-following model (Gipps, 1981) and the quantitative comparison of the latter with the model resulting by the substantial modifications proposed by Punzo, 2003.

Acknowledgements

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Incorporating information in path choice processes

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Abstract

Randomness is mostly used in choice models to represent uncertainty and therefore the potential for different choices; in such a case, choice probability is the outcome of the model processing. In this paper, instead of Probability theory, the use of Possibility theory is examined in detail, with regard to transportation problems; then the influence of information provision on drivers' behaviour is examined according to Uncertainty-base Information Theory.

Introduction

Understanding choice processes in transportation is a relevant issue. People make travel choices such as mode, departure time and route, according to their knowledge of the system and personal preferences. If users had perfect information about current travel time on each path, they could easily plan the travel choosing the best path from their point of view. However, complete and precise information about network conditions is hardly ever available, so that uncertainty causes anxiety and stress for decision makers.

Several researchers have dealt with conceptual models of drivers' behaviour - see for example Ben Akiva *et al*. (1991), Khattak *et al.* (1991), Adler *et al*. (1992). In these studies, uncertainty has been usually modeled through random utility models. The basic idea in these models is that each user or service provider behaves rationally: he compares the costs of several alternatives and chooses, among them, the best one from his standpoint. Since the knowledge of alternatives is rarely perfect, uncertainty affects single person's decision. Randomness is then used to represent uncertainty and therefore the potential for different choices. In such a case, the probability of a choice can be calculated. This approach, when applied to the transportation assignment problem, leads to a stochastic equilibrium (Daganzo and Sheffi, 1977).

Very complex structures of random utility models have been analyzed to obtain both day-to-day and within-day decision processes (see for example Cascetta, 1989 or Cascetta and Cantarella, 1991). Additionally, a simulation system for dynamic traffic assignment (DYNASMART) was developed (Jayakrishnan et al., 1994) to take into account various information strategies. For this kind of models, the unavailability of complete and reliable data limits the capabilities of calibrating model parameters: if incomplete data are used, estimates will contain significant levels of uncertainties. On the other hand, traditional choice models do not provide neither levels of uncertainty imbedded in the estimates, nor easily a perspective on the confidence on the estimates.

On the contrary, the concepts of approximate reasoning can be helpful in the treatment of uncertainty.

A modeling framework based on Evidence Theory represents the uncertainties in the perception of travel attributes and measures the *Belief* rather than the *probability* of a choice. Belief and its dual Plausibility establish a system of uncertainty measures when dealing with incomplete data. More explanations about Evidence Theory will be given in section 4.

Recently, approaches based on Fuzzy Theory have been followed to obtain choice models (Akiyama and Tsuboi, 1996) or control strategies (Niittymäki and Pursula, 1997). The correspondence of fuzzy models with generalized logit models has been studied (Henn, 1997). Also users' behaviour in presence of information has been modeled through a set of *if…..then* rules (Lotan and Koutsopoulos, 1993).

In this paper, the influence of information provision on drivers' behaviour is examined in detail, according to Uncertainty-based Information Theory. In particular, Evidence Theory is used to obtain, by means of basic probability assignment functions, a relation between released and actually received information sets. Since several studies point up that the drivers' trust in information services is a function of Uncertainty, a relation between uncertainty and trust level has been developed; finally, the effects of information are illustrated through a numerical example.

Decision making mechanism and processes: a brief overview

First of all, a distinction between static and dynamic choice has to be made: in the static case, mode, route and time departure are decided in pre-trip planning; decision is influenced by historical experiences and by information provided before the trip. In the dynamic case, en-route switching choice is made according to current perception of dynamic conditions of network.

In both cases, travelers can be influenced in making choices both by day-to-day variations in travel time and by their capabilities of learning from personal experience (Bovy and Stern, 1990), as well as from available information. Three sources of information are generally used to make routing decision (Adler and Blue, 1998):

— historical experiences;

— current perceptions of the network conditions;

— information acquired via an informative system.

It is worth noting that within-day decision process is influenced by values of traffic and network characteristics at a given instant on a given day. Models of within-day pre-trip route selection and en-route path switching have been developed by Mahmassani and Stephan (1988), and Adler *et al*. (1992).

Evolution of drivers' spatial knowledge over time and in particular day-to-day is better described by dynamic formulation; nevertheless, there are some issues regarding spatial cognition and path choice:

— path choice between two points in a network depends on mental representation of the network, that is, on how travelers imagine streets are linked to each other. Usually there are maps providing this kind of information. Missing these maps, the knowledge of a network can be obtained by making repeated trips through the network and developing a mental map. Notion of cognitive maps was discussed by Wenger *et al*. (1991) with respect to decision making and design of informative system;

— day-to-day and within-day variations of traffic patterns are experienced by users. Drivers repeating trips through the network are able to understand these variations. Travelers without experience have to learn traffic dynamics through informative systems;

— an experience increase can change behavioural tendencies. Over time, experienced people mature and some attitudes with respect to routing behaviour may change.

Information as a counterpart of uncertainty

Given a generic finite set S of messages, the measure of uncertainty related to this set was developed at first by Hartley (Hartley, 1928) and had the form:

$$U(S) = a \cdot \log_b |S|, \quad (1)$$

where:

— $|S|$ is the cardinality of S;

— a and b are positive constants (a>0, b>1) which determine the uncertainty unit of measure.

Assuming a = 1 and b = 2,

$$U(S) = \log_2 |S| \quad (2)$$

and total uncertainty is expressed in bits.

Consider now two states A and B and the corresponding uncertainties U(A) and U(B) with U(A) > U(B); information I(A,B) which produces the transition from A to B is defined as:

$$I(A,B) = U(A) - U(B)$$

or, in terms of Hartley function:

$$I(A,B) = \log_2(|A|/|B|) \tag{3}$$

If information eliminates all alternatives except one, $|B| = 1$ and

$$I(A,B) = \log_2(|A|) = U(A) \tag{4}$$

Then, from the relation (4) we can derive that Information and Uncertainty are two facets of the same problem, and they can be handled through the same mathematical tools.

Also another classical measure of Uncertainty developed by Shannon in 1948, calculated Uncertainty as Information associated with a message x_k:

$$I_k = -\log_2 P\{x_k\},$$

where $P\{x_k\}$ is the probability associated with the selection of message x_k. It was solely a probabilistic approach, since from a significant standpoint the actual message is one selected from a set of possible messages. The average Information (Uncertainty) is:

$$I = -\sum_{k=1}^{n} P\{x_k\}\log_2 P\{x_k\}. \tag{5}$$

This measure, called Shannon entropy, has been applied in any case as long as Uncertainty was faced only by Probability Theory. Afterwards, in consequence of wider studies, it became clear that Uncertainty is a multidimensional concept, and different mathematical frameworks were added to this type of measure to deal with different types of Uncertainty. In particular, the usefulness of Uncertainty-based Information Theory has been demonstrated (Ashby, 1972; Conant, 1981), and a modeling framework based on concepts of approximate reasoning was developed in the 1970s.

Handling uncertainty through evidence theory

The approximate reasoning is based on the hypothesis that, given the proposition “x is S”, the evidences (information) about x support only partially the predicate S. The problem in this model is to measure the truth of the proposition, that is how much evidences support the alternative expressed in the predicate.

Basically, there are three patterns in dealing with this problem (fig. 1):

— each element of evidence supports one and only one alternative;

— evidence supports more than one alternative (nested alternatives);

— combination of cases 1 and 2

In the first case, Probability Theory is the appropriate mathematical framework to measure Uncertainty; in the second case, Possibility Theory; in the third one, Evidence Theory (Dempster - Shafer Theory). Evidence Theory subsumes both Probability and Possibility Theory. It provides the most general definition of the Uncertainty measure (Shafer, 1976).

Let:

— X be a universal set;

— P(X) be its power set;

— A and B be two generic subsets of X.

A Belief measure is a function

$$\text{Bel}: P(X) \rightarrow [0,1]$$

satisfying the following axioms:

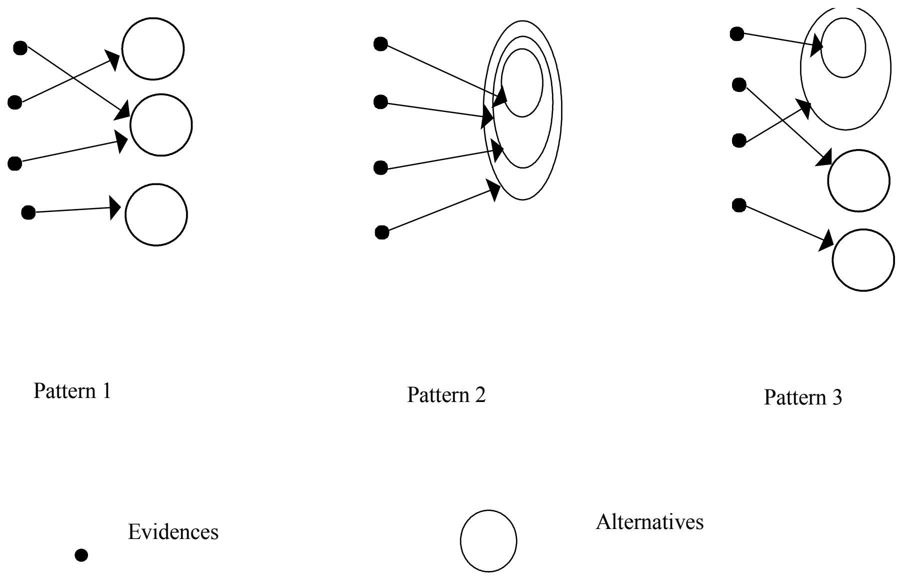

Fig. 1 – Evidences - Alternative Relationship

Source: Pericherry, V. and Kikuchi, S. - "A Planning Model for Large Scale Infrastructure under Uncertainty" - Budva, 1997

boundary conditions: $\text{Bel}(\emptyset) = 0$, $\text{Bel}(X) = 1$

monotonicity: $A \subseteq B \Rightarrow \text{Bel}(A) \leq \text{Bel}(B) \quad \forall A,B \in P(X)$ (6)

continuity: $\lim_{i \to \infty} \text{Bel}(A_i) = \text{Bel}(\lim_{i \to \infty} A_i) \quad A_i \in P(X)$

and the additional axiom:

$$Bel(A_1 \cup A_2 \cup \ldots A_n) \geq \Sigma_i\, Bel(A_i) - \Sigma_{i<j}\, Bel(A_i \cap A_j) + \ldots + (-1)^{n+1} Bel(A_1 \cap A_2 \cap \ldots A_n) \quad (7)$$

The first axiom states that an element definitely does not belong to empty set and definitely belongs to universal set, which contains all elements under consideration in each particular context.

The second one requires the Belief that an element belonging to a set must be at least as great as the Belief that the same element belongs to any subset of that set. The third axiom is valid only for infinite sets and requires that Belief is a continuous function. Finally, the axiom (7) is a weaker version of the additivity axiom of Probability Theory. It represents the main difference between these two theories. In fact, in Probability Theory axiom (7) is: $P(A_1 \cup A_2 \cup \ldots A_n) = P(A_1) + P(A_2) + \ldots P(A_n)$, because in this case each element of evidence supports one and only one alternative. Belief and Plausibility merge in the unique measure of Probability.

With Belief, associated measure of Plausibility can be defined as:

$$Pl(A) = 1 - Bel(\sim A) \qquad \forall A \in P(X)$$

This measure is a function:

$$Pl: P(X) \rightarrow [0,1]$$

satisfying axioms (6) and the additional one:

$$Pl(A_1 \cap A_2 \cap \ldots A_n) \leq \Sigma_i\, Pl(A_i) - \Sigma_{i<j}\, Pl(A_i \cup A_j) + \ldots + (-1)^{n+1} Pl(A_1 \cup A_2 \cup \ldots A_n) \quad (8)$$

Belief and Plausibility measures can be expressed in terms of a function:

$$m: P(X) \rightarrow [0,1]$$

such that

$$m(\varnothing) = 0$$

$$\sum_{A \in P(X)} m(A) = 1 \qquad (9)$$

According to Eq. (9), m(A) can be thought as the degree of evidence, or the degree to which we believe that an element of X belongs to the set A but not to any special subset of A.

Since Eq. (9) is similar to equation of Probability distribution, the function m is usually called "basic probability assignment" and expresses the proportion to which an element of X belongs to a generic subset A of P(X). Note that, because of ignorance or incomplete information, m(A) pertains only to the set A and does not regard subsets of A. Sets $A \in P(X)$ for which $m(A) \neq 0$ are called "focal elements".

Given a basic probability assignment, Belief and Plausibility measures are obtained by the formulas:

$$Bel(A) = \sum_{B \subseteq A} m(B) \qquad (10)$$

$$\mathrm{Pl}(A) = \sum_{B \cap A \neq \emptyset} m(B) \tag{11}$$

When subsets are nested like in pattern 2 of fig. 1, the degrees of evidence allocated to focal elements should not conflict with each other; the associated Belief and Plausibility measures are called consonant, and have the following properties:

$$\mathrm{Bel}(A_1 \cap A_2) = \min[\mathrm{Bel}(A_1), \mathrm{Bel}(A_2)] \quad \forall\, A_1, A_2 \in P(X)$$

$$\mathrm{Pl}(A_1 \cup A_2) = \max[\mathrm{Pl}(A_1), \mathrm{Pl}(A_2)] \quad \forall\, A_1, A_2 \in P(X)$$

Consonant Belief and Plausibility measures are called Necessity and Possibility measures, respectively, then:

$$\mathrm{Nec}(A_1 \cap A_2) = \min[\mathrm{Nec}(A_1), \mathrm{Nec}(A_2)]$$

$$\mathrm{Poss}(A_1 \cup A_2) = \max[\mathrm{Poss}(A_1), \mathrm{Poss}(A_2)].$$

Between Necessity and Possibility measures there is the dual relationship:

$$\mathrm{Nec}(A) = 1 - \mathrm{Poss}(\sim A).$$

Now, let

X, Y be two universal sets;

A, B be two sets defined in X and Y, respectively;

a joint basic probability assignment is defined:

$$m: P(X \times Y) \rightarrow [0,1];$$

Let R be a relation on $X \times Y$; projecting it on X and Y, sets R_X and R_Y are obtained as follows:

$$R_X = \{x \in X \mid (x,y) \in R \text{ for some } y \in Y\}$$

$$R_Y = \{y \in Y \mid (x,y) \in R \text{ for some } x \in X\}$$

In consequence, from sets R_X, R_Y and given a joint probability assignment m, marginal basic probability assignments m_X and m_Y can be calculated:

$$m_X(A) = \sum_{R \mid A = R_X} m(R) \quad \forall A \in P(X) \tag{12}$$

$$m_Y(B) = \sum_{R \mid B = R_Y} m(R) \quad \forall B \in P(Y) \tag{13}$$

For example, consider two sets X and Y, the elements of which are, respectively, released and perceived information. Note that, although released information can be crisp or vague, human mind always revises it in an approximate way; therefore, a relation between released and perceived information is always a fuzzy one, as represented in fig. 2. In the same figure, the meaning of R_X and R_Y is represented as well.

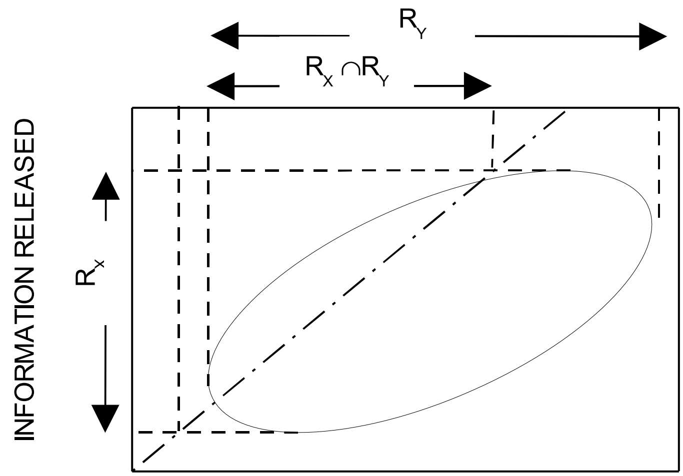

Fig. 2 – Relationship between released and perceived information

The 45°-straight line represents the information released and correctly perceived. In this simple communication model, we call $R_X \cap R_Y$ "information transmitted".

Assume that X= {a, b, c} and Y= {α, β, γ}, and that the matrix of joint basic probability assignments is the following one:

	X × Y									m(R_i)
	αa	αb	αc	βa	βb	βc	γa	γb	γc	
R_1 =	0	0	0	0	1	1	0	1	1	0.0625
R_2 =	0	0	0	1	0	0	1	0	0	0.225
R_3 =	0	0	0	1	1	1	1	1	1	0.125
R_4 =	0	1	1	0	0	0	1	1	0	0.250
R_5 =	0	1	1	0	1	1	0	0	0	0.125
R_6 =	0	1	1	0	1	1	0	1	1	0.0375
R_7 =	1	0	1	1	1	0	0	1	0	0.175

Table 1. – Joint basic assignments

Then, marginal basic probability assignments are:

$m_X(\{\alpha,\beta\}) = m(R_5) = 0.125$;

$m_X(\{\alpha,\gamma\}) = m(R_4) = 0.25$;

$m_X(\{\beta, \gamma\}) = m(R_1) + m(R_2) + m(R_3) = 0.4125$;

$m_Y(\{a\}) = m(R_2) = 0.225$;

$m_Y(\{b, c\}) = m(R_1) + m(R_5) + m(R_6) = 0.225$.

Given the information A, due to the fuzzy revision of human mind, the individual user perceives the information B|A, the possible marginal basic probability assignment of which is represented in fig. 3

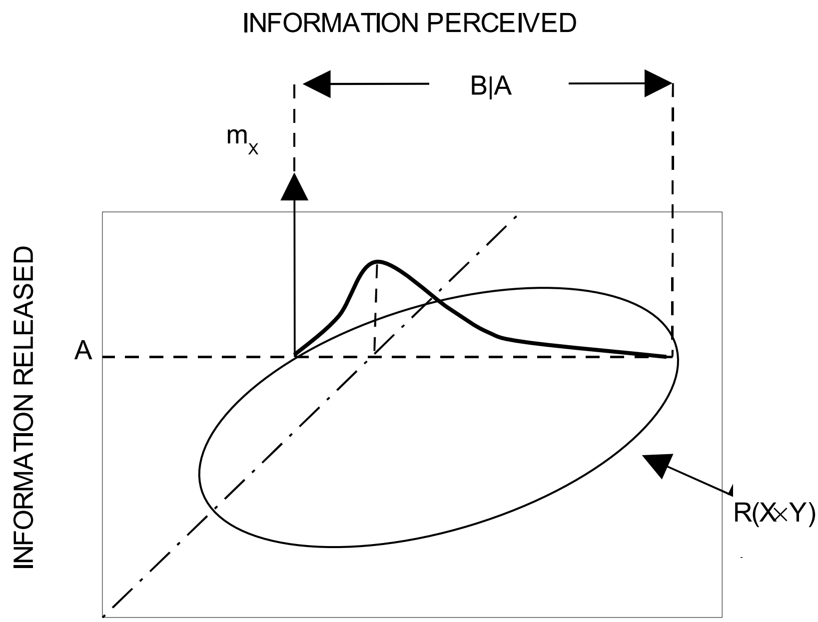

Fig. 3 – Marginal basic probability assignment of information A

Now, let:

F be the set of all relations R induced by m on X×Y;

F_X and F_Y be the sets of all focal elements induced by m_X and m_Y, respectively.

The Uncertainty related to the sets X and Y can be calculated as (Klir and Folger, 1988):

$$U(X) = \sum_{A\in F_X} m_X(A) \cdot \log_2 |A| \tag{14}$$

$$U(Y) = . \sum_{B\in F_Y} m_Y(B) \cdot \log_2 |B| \tag{15}$$

The relations (14) and (15) are called “simple uncertainties”; joint and conditional uncertainties can be also calculated as follows:

$$U(X, Y) = \sum_{A\times B\in F} m(A \times B) \cdot \log_2 |A \times B| . \tag{16}$$

$$U(X|Y) = \sum_{A\times B\in F} m(A\times B)\cdot \log_2 \frac{|A\times B|}{|B|}\ . \tag{17}$$

$$U(Y|X) = \sum_{A\times B\in F} m(A\times B)\cdot \log_2 \frac{|A\times B|}{|A|}\ . \tag{18}$$

U(X), U(Y), U(X, Y), U(X|Y) and U(Y|X) can be considered as some kind of measure associated with sets X and Y. Their meaning for the communication model is shown in fig. 4. I(X, Y) is the so-called "information transmission" and represents, in this model, information somehow transmitted, while U(Y|X) is residual uncertainty with respect to received information and U(X|Y) is noise, unwanted information. The higher the value of information transmission, the higher the quality and accuracy of informative system, and the higher the users' trust in provided information.

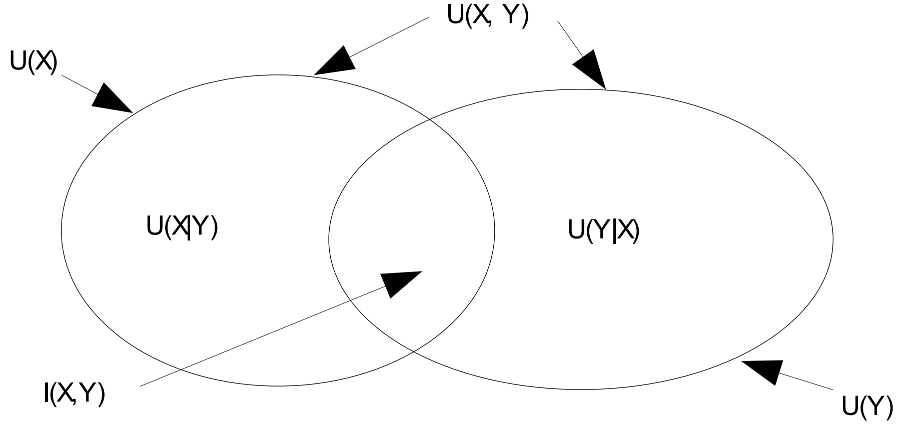

fig. 4.-Information transmission

If sets X and Y are disjoint, I(X,Y) = ∅; while if X = Y, I(X,Y) = U(X), so that:

$$\emptyset \le I(X,Y) \le U(X).$$

It is easy to see that:

$$I(X, Y) = U(X) + U(Y) - U(X, Y) \tag{19}$$

or

$$I(X, Y) = U(X) - U(X|Y) = U(Y) - U(Y|X) \tag{20}$$

Replacing (14) and (17) in (20), you obtain:

$$I(X, Y) = \sum_{A\in F_X} m_X(A)\cdot \log_2|A| - \sum_{A\times B\in F} m(A\times B)\cdot \log_2 \frac{|A\times B|}{|B|}\ . \tag{21}$$

For any informative system with given noise characteristics, the maximum of information transmission, according to Shannon definitions, is its Capacity:

$$C = \max I(X,Y), \qquad (22)$$

while the ratio $I(X,Y)/C$ is its Efficiency.

The problem of the system Capacity is quite a complex one, but an immediate consequence arises: increasing more and more the amount of released information would not be productive to improve knowledge of the transportation system, if the Capacity of informative system is reached.

Provision and updating of information

Urban traffic is becoming more and more congested in major city centers. Generally, countermeasures like expansion of existing road networks are infeasible, because of environmental impacts or physical structures of urban areas. Therefore, the research addresses the optimization of the use of existing roads. For this purpose, the introduction of new advanced information technologies seems at present one of the most promising tools.

Intelligent Transportation Systems (ITS) provide information both to users and to service providers to allow intelligent decisions. The strategies usually accepted for ITS are:

— Advanced Public Transportation Systems (APTS);

— Advanced Traveler Information Systems (ATIS);

— Advanced Traffic Management System (ATMS);

— Advanced Vehicle Control Systems (AVCS);

— Alternative Fuels (AF);

— Vehicle Safety Devices (SD) and

— Telecommuting (TC).

This paper evaluates the effects of information on private car drivers, thus attention is confined to ATIS. An informative system, like ATIS, may provide information to users before they begin the trip (real-time pre-trip information) or while they are moving (real-time en-route information). Travelers combine this information with their own experience to obtain a prediction about the cost of each path and to choose the best one.

To incorporate information on the system conditions in the choice process, it is assumed that the user:

— has some experience about the attributes of the transportation system;

— uses information to update his experience;

— chooses an alternative according to his updated experience.

This kind of sequential models simulates updating of user knowledge through the following relationship (Horowitz, 1984; Ben Akiva et al., 1991; Lotan. and Koutsopoulos, 1993):

$$ET_{j,i}^{\ t+1} = \alpha_i \times I_j^{\ t+1} + (1 - \alpha_i) \times ET_{j,i}^{\ t} \qquad (23)$$

where:

— $ET_{j,i}^{t+1}$ = cost perceived by i-th user for j-th alternative updated at time t+1;

— $ET_{j,i}^{t}$ = historical cost for i-th user and j-th alternative updated at time t;

— I_j^{t+1} = information on alternative j-th released by the system at time t+1;

— α_i = parameter representing the i-th user's trust in information released by the system, $\alpha_i \in [0,1]$.

The model (23) incorporates important aspects such as (Lotan and Koutsopoulos., 1993):

— dynamic nature of information integration. The cost of an alternative at time t+1 is influenced by the historical cost (user's experience and memory) at time t;

— reliability of the informative system. The more reliable the information, the more important the effect on the updated perception;

— non-linear relationship between information and updated perception. The parameter α itself is function of information, so that the perceived cost updated at time t+1 is a non-linear function of information;

— information quality. Additional vague information can lead to a more uncertain perception.

In this framework, it seems necessary to investigate more on the effect and the meaning of the parameter α. Experimental studies carried out in last years by different researchers (Iida et al., 1992; Vaughn et al., 1992) have found different values, 0.2 to 0.7, for this parameter. Such range of variability could be justified assuming that α is affected by the level of uncertainty embedded in information. Therefore we assume that:

— the user's trust in information decreases with the increasing of the uncertainty (negative elasticity);

— the need of additional information is proportional to the uncertainty.

On these hypotheses, the following relationship between α and the uncertainty level has been carried out:

$$(d\alpha / \alpha) / (dU/U) = - U \qquad (24)$$

and hence:

$$\alpha = 1/\exp(U) \qquad (25)$$

where U is the value of residual uncertainty about the perceived information, $U = U(Y|X)$.

Within the mathematical framework of the Evidence Theory, the conditional Uncertainty is expressed by eq. (18); then, through the relations (23) and (25), the model simulates the updating of the costs of alternatives, according to the information released by the system.

Although the nature of the historical costs (experience) could be stochastic, in the updating processes such costs are elaborated by the human mind in terms of approximate values; therefore, a possibilistic (fuzzy) choice model should be an appropriate framework to simulate the user's choice process (Henn , 1997).

Numerical example

The fig. 5 shows a link for the OD pair i-j; at the origin i there is an electronic device capable of displaying real-time traffic information, called Variable Message Signal (VMS). Assume that the users have the perception that the travel time for this OD pair lies in the range 12 to 22 minutes; or, in other words, they have the vague experience that the travel time related to the link i-j is "approximately 17 min". In fig. 6, the fuzzy set corresponding to this approximate value is depicted.

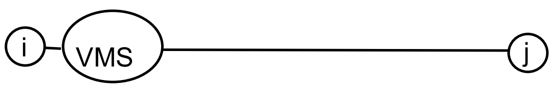

fig. 5. - Example link

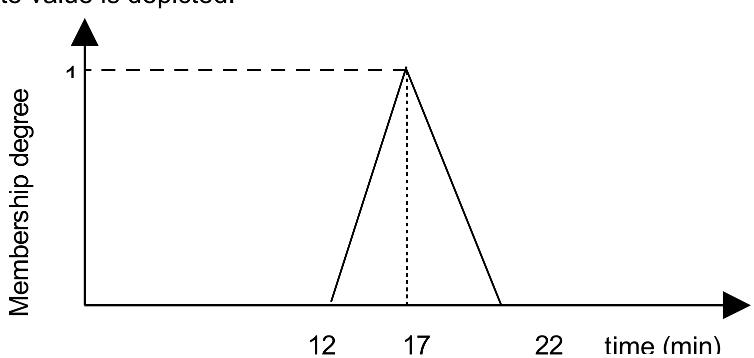

Fig. 6 – Fuzzy set "approximately 17 min"

Through the VMS, an ATIS service can provide the drivers with the following real-time en-route information about the traffic conditions on the link:

a) congestion;

b) queue;

c) road accident.

Assume additionally that drivers perceive those propositions like:

1) “travel time is 20 to 26 min”;

2) “travel time is 22 to 26 min”;

3) “travel time is 26 to 42 min”.

The allocation of propositions is represented in fig. 7, while table 2 shows the joint basic probability assignments for focal elements.

	$X \times Y$																		$m(R_i)$
	a 20	b 20	c 20	a 22	b 22	c 22	a 26	b 26	c 26	a 30	b 30	c 30	a 36	b 36	c 36	a 42	b 42	c 42	
R_1 =	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0625
R_2 =	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0.125
R_3 =	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0.025
R_4 =	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0.250
R_5 =	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0.025
R_6 =	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0.175
R_7 =	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0.025
R_8 =	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0.175
R_9 =	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0.1375

Table 2. – Joint basic assignments for released information

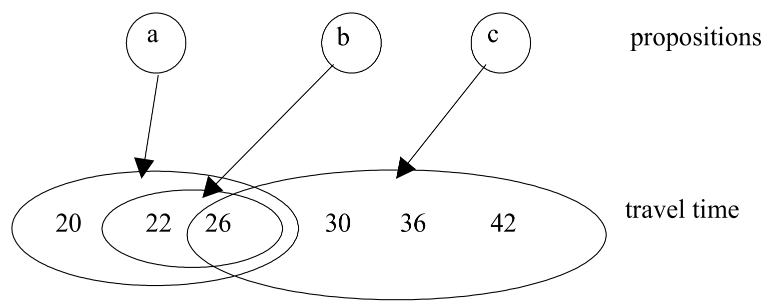

Fig. 7. – Allocation of propositions

Hence,

$m_X(\{a\}) = m(R_1) + m(R_2) = 0.1875$

$m_X(\{b\}) = m(R_3) = 0.025$

$m_X(\{c\}) = m(R_7) + m(R_8) + m(R_9) = 0.3375$

$m_X(\{a, b\}) = m(R_4) = 0.25$

$m_X(\{b, c\}) = m(R_5) = 0.025$

$m_X(\{a, b, c\}) = m(R_6) = 0.175;$

— U(X) = $\sum_{A\in F_X} m_X(A)\cdot \log_2|A|$ = 0.1875·$\log_2$5 + 0.025·$\log_2$2 + 0.3375·$\log_2$6 + 0.25·$\log_2$3 + 0.025·$\log_2$2 + 0.175·$\log_2$3 = 2.03;

— U(X|Y) = $\sum_{A\times B\in F} m(A\times B)\cdot \log_2 \frac{|A\times B|}{|B|}$ = 0.0625·$\log_2$1 + 0.125·$\log_2$1 + 0.025·$\log_2$1 + 0.25·$\log_2$1.5 + 0.025·$\log_2$2 + 0.175·$\log_2$3 + 0.025·$\log_2$1 + 0.175·$\log_2$1 + 0.1375·$\log_2$1 = 0.45;

— U(Y|X) = $\sum_{A\times B\in F} m(A\times B)\cdot \log_2 \frac{|A\times B|}{|A|}$ = 0.0625·$\log_2$2 + 0.125·$\log_2$3 + 0.025·$\log_2$2 + 0.25·$\log_2$1.5 + 0.025·$\log_2$1 + 0.175·$\log_2$1 + 0.025·$\log_2$1 + 0.175·$\log_2$2 + 0.1375·$\log_2$3 = 0.82;

Then, the amount of information transmitted is, from (19):

I(X,Y) = 2.03 – 0.45 = 1.58,

while the value of conditional Uncertainty allows calculating, through (25), the value of α:

$$\alpha = 1/(\exp^{U(Y|X)}) = 1/e^{0.82} = 0.44$$

Then, if information is for example “road accident”, the range of updated travel time can be calculated as:

— lower bound 0.44·26 + 0.56·12 = 18 min;
— center value 0.44·34 + 0.56·17 = 24 min;
— upper bound 0.44·42 + 0.56·22 = 30 min.

In other words, the updated travel time is:

ET = 0.44·(approximately 34 min) + 0.56·(approximately 17 min) = (approximately 24 min)

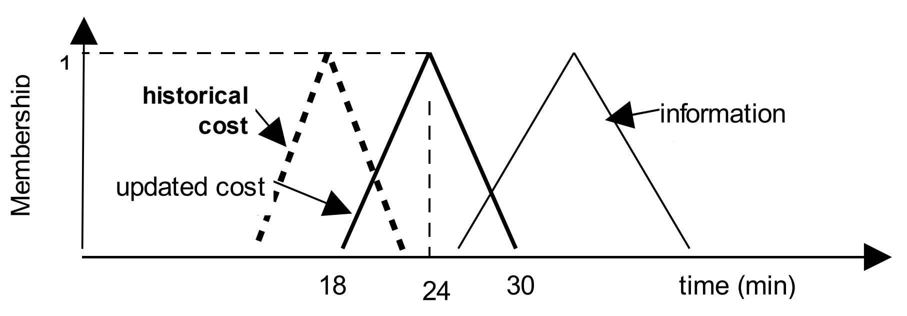

Fig. 8 – Comparison between historical and updated cost

In fig. 8 historical and updated cost (travel time), as well as information, are represented. It is easy to see that the outcomes of the application are theoretically consistent: information about a possible delay move the center value of expected travel time from 17 to 24 min; additionally, the support of resulting approximate travel time is a little larger (18-30 min instead of 12-22 min) than historical cost, due to information vagueness. In fact, a larger support means more uncertainty; in our case, uncertainty can be calculated in a convenient way, since from a numerical point of view membership degrees are equivalent to Possibility values, and the following relation holds between Possibility values and basic probability assignments:

$$m(A_i) = r(x_i) - r(x_{i+1})$$

where $r(x_i)$ is the Possibility value for i-th element of a set ordered in decreasing order, for which $r(x_i) \geq r(x_{i+1})$.

Then, the Uncertainty is expressed by:

$$U = \sum \left[r(x_i) - r(x_{i+1})\right] \cdot \log_2 i \qquad (26)$$

Calculating Uncertainty through eq. (26), for historical cost it results: U = 1.98; for updated cost: U = 2.22; for information: U = 2.62.

Applications of this methodology can be implemented for management of transportation networks: usually path choice models assume that users make choices comparing the costs of different alternatives; therefore, different additional costs could be provided through different VMS messages, so that it could be used as a kind of road pricing tool.

Conclusions

In this paper, the influence of Uncertainty in updating the knowledge of the attributes of a transportation system, namely the expected travel time on a link, has been examined in detail considering the ATIS environment. The presented model points out the relevant role of the Evidence Theory in calculating the conditional Uncertainty and then users' trust level in information. In consequence, the importance of conditional Uncertainty in updating knowledge of the system results evident.

Through the Evidence Theory a modeling framework, which represents the uncertainties embedded in the perception of travel attributes, has been developed. The model allows the quantitative calculation of the user's trust in information and, then, quantitative updating of expected travel time. In a wider framework, the outcomes of this paper can be used to carry out a path choice model that quantitatively takes into account information provision. Moreover, different additional costs can be calculated as perceived by users according to different messages provided by VMS, so that it could be used as a kind of road pricing tool.

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Integrated Approach: a new method to study the Intelligent Transport System

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Abstract

To model the road traffic flow, several approaches can be considered. According to its granularity, a traffic simulation model can be macroscopic (it describes the traffic stream in terms of flow rate, density and mean speed) or microscopic (it considers all the vehicles as individuals and mainly uses "mathematical" car-following). These traffic simulation models are based upon the identification of experimental traffic laws which come from observations of the actual traffic. Any modification in the "road traffic system" involves modifications in the individual drivers' behaviours which, consequently, modify the road traffic flow. The evaluation of the impact of these changes remains complex due to the difficulties to study the individual drivers' behaviours in the "modified" road traffic situation.

To answer these questions the INRETS[1]-MSIS team has been developing, for more than 10 years, both a new kind of traffic model and a driving simulator architecture. These innovative developments were carried out while following the approach according to a given road situation results from the interaction of various actors (road users, road infrastructure, road network managers...). Thus it was considered that each actor is more or less autonomous, has its own knowledge, its own goals and motivations and its own strategy to carry out its various tasks and to solve the possible conflicts which could occur. The road infrastructure (its engineers) and its equipment (installed and controlled by the traffic managers) "transmit" information to the users. For this reason, they are regarded as several actors of the traffic situation. These works were undertaken within the framework of the ARCHISIM and SIM² projects. The designed tools involved in the so-called integrated approach, allow to study nearly any

[1]*French National Institute for Research in Transportation and Safety*

modification in the road traffic system. The approach consists in several steps and can be iterative. The first step consists in identifying the drivers' behaviours in actual situations or with a driving simulator, for the future situations. In the second step the results of the experiments are used to model drivers' behaviours. These new behaviours are implemented in the behavioural traffic model during the third step. At this stage modified traffic flow can be simulated and traffic studies can be conducted. An optional fourth step consist in studying the drivers' behaviour immersed in the new "modified" virtual traffic. This last step seems very important for the understanding of the non equipped drivers' behaviour facing "unusual" situations due to the use, for example, of an alert system by a leading equipped driver. The main objective of this work is to participate in the enrichment of knowledge on the driver's behaviour by an iterative process and to develop tools to evaluate the impacts of modification in the road traffic system, such as new infrastructures or the introduction of ITS.

Two examples illustrate the suggested method. One is related to the study of a new road profile. It was supported by the French company SETRA. The other one concerns the study of the impact of an alert system. It was supported by the French research program PREDIT.

Introduction

To model the road traffic flow, several approaches can be considered. According to its granularity, a traffic simulation model can be macroscopic or microscopic. Macroscopic models describe the traffic stream, which is represented in some aggregate manner by scalar values of flow rate, density and mean speed. "Classic" microscopic models consider all the vehicles as individuals and mainly use pursuit laws (defined by mathematical formulas). These traffic simulation models are based upon experimental laws which come from observations of the actual traffic. Thus these models reproduce identified traffic laws *i.e.* i) obviously the traffic flow can be observed and ii) the models take more into account the traffic flow behaviour than the individual driver's behaviour. Another approach consists in considering that road traffic comes from the sum of the individual drivers behaviours and from the interactions which occur between the drivers and the environment. These individual behaviours are obviously related to the context (more often called road situation), *i.e.* related to the infrastructure, to the road equipment, to the surrounding vehicles behaviours...

Any modification in the "road traffic system" necessarily involves modifications in the individual driver behaviours and consequently modifies the road traffic flow. For example, the modifications can be related to the infrastructure (a new road profile), as well as to the equipment of the vehicles (introduction of new ITS).

Whatever the considered approach (based upon the experimental laws or the individual driver behaviours), the evaluation of the impact of these changes remains difficult. Indeed, the kind of changes does not always occur or, for example, the ITS system does not exist yet. Thus, it is difficult to study the individual driver behaviours in the “modified” road traffic situation.

According to the “experimental laws” approach, it is practically impossible to forecast the modified traffic flow. Indeed, first of all it is impossible to observe a non-existing traffic flow, and secondly the possible assumptions which can be made are related to the traffic flow behaviour and not to the individual driver behaviour. According to the “behavioural” approach, it is possible to forecast the modified traffic flow if and only if it is possible to identify the driver behaviour.

To answer these questions, for more than 10 years the INRETS[2]-MSIS[3] team has developed both a new kind of traffic model and an architecture of driving simulator. These works are undertaken within the framework of the ARCHISIM and SIM² projects[4]. These developments were carried out while following a particular approach. In this approach, a given road situation results from the interaction of various actors (road users, road infrastructure, road network managers...), each actor being more or less autonomous, having its own knowledge, its own goals and motivations like its own strategy to carry out its various tasks and to solve the possible conflicts which could occur. The road infrastructure (its engineers) and its equipment (put in and controlled by the traffic managers) "transmit" information to the users, and, for this reason, are regarded as several actors of the traffic situation. This approach allows in particular:

- to take into account the works of psychology research on the driving activity to gradually enhance the traffic simulation models,
- to conceive an architecture of driving simulator allowing to set a driver in "realistic" road situations.

On the integrated approach, some significative works have been previously realized concerning ADAS systems. Particularly the Stop&Go and Lane Keeping systems have been studied to understand the drivers’ behaviours using those systems and to introduce the results in traffic simulations (STARDUST project, European project FP5).

In this work, we propose to present this original approach to study the impacts of the modifications in the traffic system, then to present the tools used to implement this approach. Some studies already carried out or under development will be presented in order to illustrate the method. This presentation will be concluded by a discussion on the considered perspectives.

Integrated approach

Due to progress both in behavioural traffic simulation and in driving simulator architecture, we suggest a new approach called "integrated approach", aiming

[2] *French National Institute for Research in Transportation and Safety*
[3] *Modelling, Simulation and driving Simulator*
[4] *SIM² project deals about both the driving simulator and an architecture to host a driving simulator*

to evaluate almost any change in the road traffic system. This method could be applied with all softwares allowing to achieve each method step. The suggested methodology (see Figure 1) consists in:

- the identification of drivers' behaviours in a actual situation or on a driving simulator (for example in the case where experiments cannot be conducted in actual situations) for the future traffic system (design, validation and analyse of a new concept),
- the modelling of the new behaviours within the traffic simulation model,
- the traffic simulation with these new behaviours,
- analysis of the traffic behaviour relatively to the traffic simulation and,
- when needed, the study of the behaviours of the drivers immersed in the future traffic system (modified traffic behaviour).

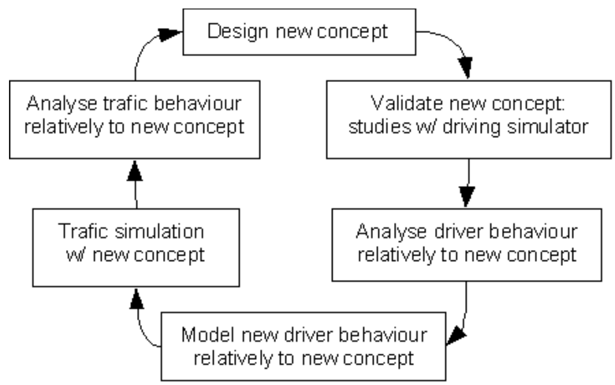


Figure 1: Integrated approach

The last step can be very important when dealing with traffic system modifications related to the introduction of on-board driver support systems, since these systems induce new interactions between drivers, particularly when all vehicles are not equipped. For example when an alert system is partially introduced, the equipped vehicles could decrease their speed (due to an alert) whereas the road traffic situation appears as normal. Thus the non equipped drivers could not understand this "abnormal" low speed, in that case some strong (and possibly unsafe) interactions could occur.

The "integrated approach" implies a "traffic-centred approach" for the simulator architecture (1), since we need to immerse the drivers in a "realistic" traffic. By "realistic" we mean valid in terms of traffic phenomena. The driving simulator allows to immerse a human subject in a virtual road traffic. Such a virtual traffic helps producing a realistic traffic situation, and not only a local visually realistic environment. This kind of approach has been followed and promoted at INRETS for more than 10 years, in the framework of the ARCHISIM and SIM² projects.

Tools involved in the Integrated approach

Behavioural Road Traffic Simulation with ARCHISIM

The main objective of INRETS ARCHISIM traffic model is to study the drivers' behaviour and how traffic phenomena occurs. In the ARCHISIM model, traffic phenomena occur from individual actions and interactions of the various actors of the road situation. The modelling of the actors participating in the traffic model consists of three subsystems: perception, "interpretation – decision-making" and action. Each simulated driver has a model of environment and interacts with the other participants of the road situation. Those other participants can be road users, road designers and operators (by the way of road design and equipment)... The actor has own goals, knowledge and strategy in order to achieve his journey (if he is a driver), and can potentially react to any situation. A behavioural model is used for driver decisions. This model results from in-depth studies carried out in driving psychology for actual situations (2, 3). These studies focus on the tactical part of driving activities.

The advantage of models based upon multi-actors approach is to provide a more open and interactive system than classic models do (4). It is possible to reproduce the drivers' behaviours, which comes from psychology works, and thus to identify the related traffic laws. The other models, conversely, reproduce the traffic laws, thus the behaviours cannot be identified. Moreover, it is possible to dynamically modify simulation conditions (virtual drivers preferences, traffic lights control algorithms...). ARCHISIM allows a better understanding of the effects of such modifications on the traffic, and an enhancement of the traffic model.

Figure 2: examples of traffic situations simulated with ARCHISIM

INRETS, ambition is to make ARCHISIM an open tool to study the “traffic system”. The modularity of the simulation architecture provides the opportunity to integrate various modules such as a scenario module, a 3D-imaging module, a data recorder module, etc. Moreover, the model has been developed for the traffic model to host a driving simulator. In this case, the human subject in the driving simulator interacts with the traffic within the simulation model (Figure 2). This step seems important to us because it makes it possible to compare the new concepts with the final users while following an iterative process.

ARCHISIM is a flexible tool the aim of which is to allow studies related to: new road design, introduction of new ATT systems (automatic incident detection, adaptive cruise control...), etc.; in fact, any study related to a modification of the “traffic system”. The ARCHISIM model has been validated and used in various highway situations (5, 6, 7, 8) and works are in progress to validate it in urban situations.

INRETS driving simulator: Sim²

The experiments on the INRETS SIM² class driving simulator can be carried out in Arcueil near Paris or in Bron near Lyon. At Arcueil, the current configuration of the prototype is fixed-base with 3 front screens with inlaid rear mirror. The software architecture is “traffic-centred”, the driver is immersed in the ARCHISIM traffic model. The 3D sound restitution is generated by the traffic model and thus takes into account the surrounding traffic. The 3D video restitution is generated with a minimal frame rate of 30hz. Figure 3 shows the Arcueil SIM² simulator.

Figure 3: INRETS SIM² driving simulator

For experiments which require to be very precisely reproduced, the scenarios are described by scripts executed in real time by a supervisor. The scenario description and encoding are greatly simplified by the fact that, since the events / actions in the used script language are related to the road network, we can use road kilometric coordinates (road, kilometric position, relative lateral position and heading...) rather than Cartesian geometric coordinates (x, y, z). The recorded data can be:

- on line data related to drivers actions (steering wheel, pedals position...) and to surrounding (position on the road, other vehicles relative position and speed ...),
- off line questionnaire dealing with drivers' feelings related to the road profiles variants (visibility, subjective disturbance, ...).

Examples using the method

Study of the new kind of road

The modification of current road profiles or the design of new ones are complex problems in which the designer has to take into account both capacity and safety of the future road. In the near past road engineers designed the new profiles by taking into account several heuristics rules (enumerated in official documents). The final road users (the drivers) were not directly involved in the design process and their future usage of the infrastructure was solely expected. This situation often lies in a misfit between the expected road usage and its actual one, misfit which can induce non optimal capacity or safety.

This study (9), supported by the French national company SETRA, deals with the prototyping and the evaluation of a new profile for medium traffic demand (less or under 7000 vehicles/day). The evaluation has to cope more with actual usage than expected one and, of course, the characteristics of the infrastructure at both safety and level of service have to be studied.

Since the studied profile does not exist at this time, the experiments in actual situations are not possible. Some studies can be conducted on road with profiles more or less equivalent, but since the requested studies deal with safety criteria (study of the cut in the maneuvers), they are difficult, expensive and risky. The use of a driving simulator is thus of great help in order to conduct in-depth psychological studies of specific situations. The aim of these investigations is to identify how the drivers will actually use the studied new infrastructure.

Some studies can also be done in order to assess the quality of the infrastructure from a traffic engineer point of view. The problem here is that the traffic laws for the infrastructure are not known and have to be predicted. Currently, and in most cases, the traffic laws are adapted by taking into account normative predicted uses. The misfit between the predicted uses and the current ones can be wide and give way to a bad evaluation of the quality of the infrastructure.

The studied road profile consists, for a direction, in consecutive sections of 1 lane and 2 lanes. The 2 lanes section are provided in order to allow over-taking maneuver. Three variants are studied. They differ mainly by the way in which the change from 1 to 2 lanes and 2 to 1 lane are designed (each variant allows a different time to make the cut-in maneuver).

The proposed road profiles have to be studied, firstly, from the driver point of view,and secondly, from a traffic point of view.

In the first step, the study particularly focuses on the cut-in maneuver, to identify the possible changes in the driver's behaviour due to the shape of the end of the overtaking zone on the new studied roads. The experiments consist in defining scenarii and in immersing a driver in relevant situations; 20 subjects took part in the experiments. A few scenarii have been defined to answer several questions raised from a test study. The scenarios focus on the beginning and the end of a 2 lanes section (figure 4), and take into account the presence or the absence of truck. The main result obtained from this study is that the way the driver makes the cut-in maneuver is more influenced by the expected traffic situation (traffic situation in the one lane section) than by the shape of the end of the overtaking zone.

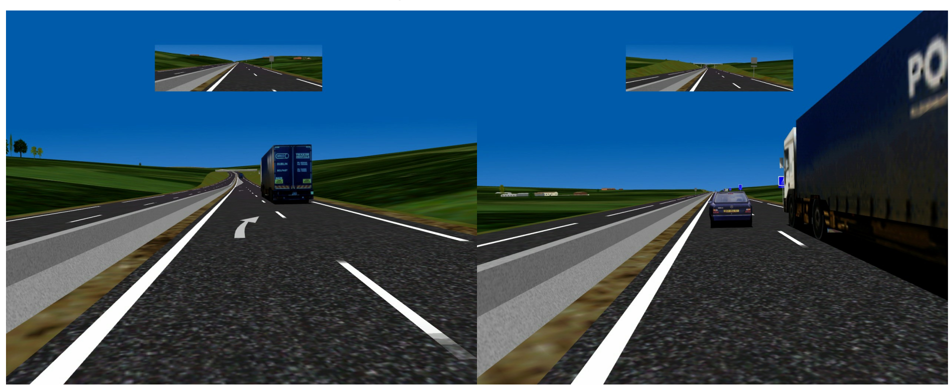
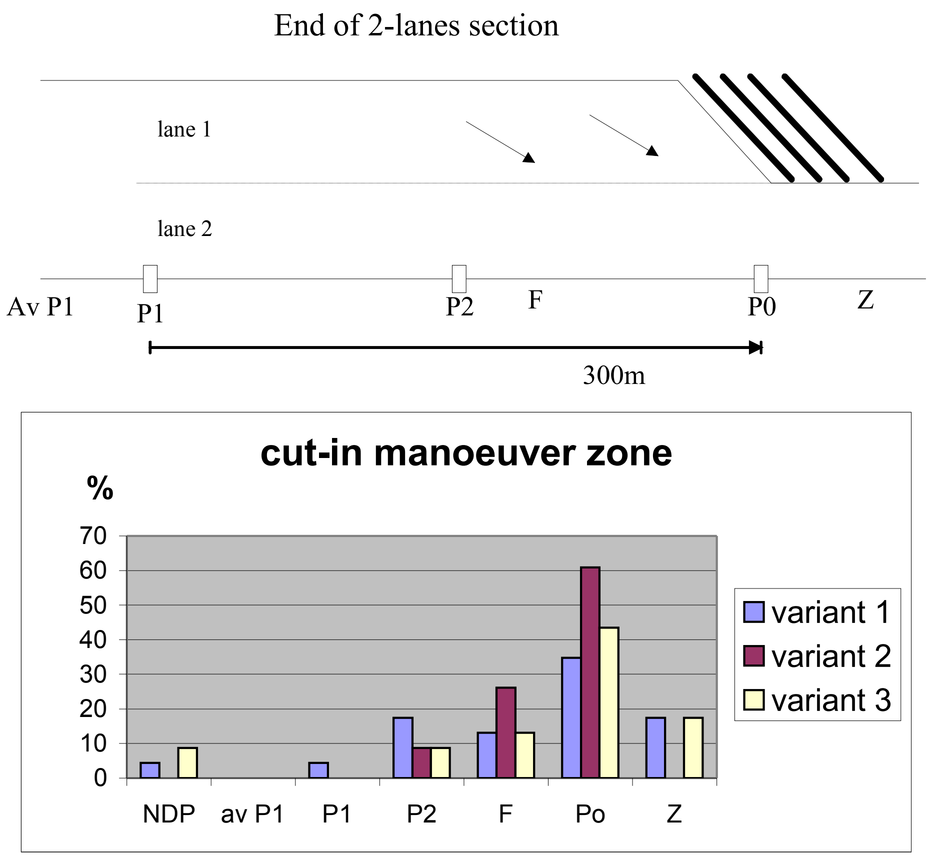


Figure 4: Two kinds of possible situation at the end of the overtaking zone

Indeed, for each scenario, the shape does not influence the choice of the driver. The following scenario illustrates this result: the subject overtakes a first low speed platoon (2 cars and 1 truck) and catches a second low speed platoon (car – truck – car – truck). If the subject does not break the rules (speed limitation), that he cannot overtake all the vehicles of the second platoon. Figure 5 shows, for each variant, most of subjects pulled in before the last traffic sign which indicates the end of the overtaking zone.

In the second step, the results demonstrate that the capacity of the studied infrastructure is sufficient for the expected traffic volume and the three variants have the same level of service. Indeed, several simulations with ARCHISIM were realized with different scenarii. Each scenario is a combination between a peak hour traffic demand volume and a percentage of trucks. Two examples of defined scenarii: i) a medium traffic (300vh/h) with a medium truck rate (15%), and ii) a high traffic (600vh/h) with a low truck rate (5%). Figures 6 shows the simulation results for the average speed of both cars and trucks.

Finally, one of the major questions becomes how the drivers will accept the disturbance and the impact of their possible impatience on their behaviour in cut-in maneuvers at the end of the 2 lanes sections. This study will be continued by new experiments on the driving simulator.



Legend
NDP: the subject does not overtake the group of vehicles in front of him
Av P1: the subject pulls-in before the first traffic sign (300m before the end of zone)
P1: the subject pulls-in on the level of the first traffic sign
P2: the subject pulls-in on the level of the second traffic sign (150m before the end of zone)
F: the subject pulls-in on the level of the arrows of folding back
P0: the subject pulls-in on the level of the last traffic sign which indicates the end of the overtaking zone
Z: the subject pulls-in crossing the zebra

Figure 5: location in the overtaking zone where the subject pulls in

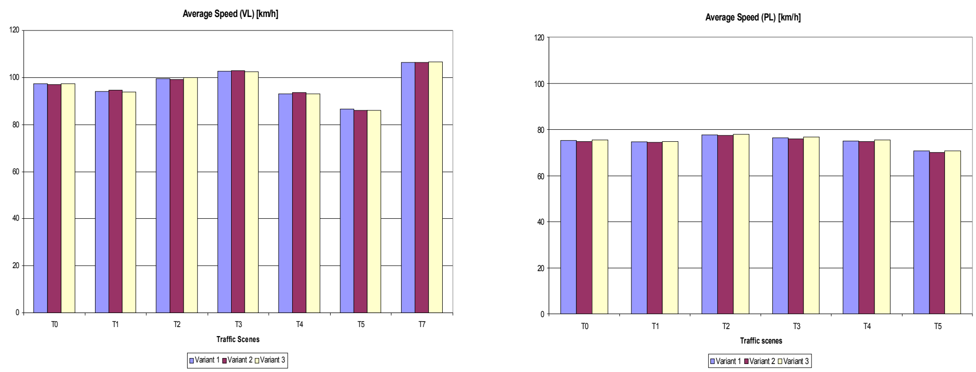


Figure 6: average speed of cars (VL) and trucks (PL) for each variant of road profiles per traffic scenario

Study of the new alert system by messages

This study (10, 11) lies within the framework of collaboration between the company EADS Matra Systèmes & Information and INRETS, the goal of which is to study an Alarm System by electronic Messages (SAM). This partnership was supported by the French national research program PREDIT 99, and more particularly by the “intelligent road” group: Alarm Systems for Drivers.

A major evolution resulting from road telematics incontestably lies in the field of in-vehicle devices in order to improve the road safety. One can thus consider alarm systems to warn the driver of effective or potential dangers related to an abnormal behaviour of his vehicle or incidents downstream on his road. Alarm aims to obtain a reaction from the drivers approaching the incident, by creating a constant attention state. Since the studies which could be carried out on roads deal with safety criteria, the drivers of non-equipped vehicles are not directly involved in the development of the system, their future behaviour with respect to equipped vehicles are only foreseen. Indeed what will be the behaviour of a non-equipped driver facing “unusual” situations due to the use of an alert system by a leading driver ? That situation sometimes lies in a misfit between the foreseen behaviour and the actual one, misfit which can induce non-optimal safety.

By opposition to infrastructure-vehicle communication systems (12), SAM is a vehicle-vehicle communication system. This system is based upon the analysis of the alarm situations and on the possible means to generate and transmit the alarm. Before the introduction on the market of such a system, it is necessary to evaluate its impact on the road safety. Some studies can be done on road, but since the requested studies deal with safety criteria, they are difficult, expensive and risky. The use of a driving simulator is thus of great help in order to conduct in-depth psychological studies of specific situations.

The first step of this study aims to identify the drivers’ behaviours of non-equipped vehicles facing an equipped vehicle which mediatizes an external alert (warning lights). The second step consists in evaluating the impacts of the system from the traffic point of view. At this stage, the identified behaviours of non-equipped drivers are integrated in ARCHISIM and we made an assumption on the equipped drivers' behaviour: they decrease their speed when they receive an alert.

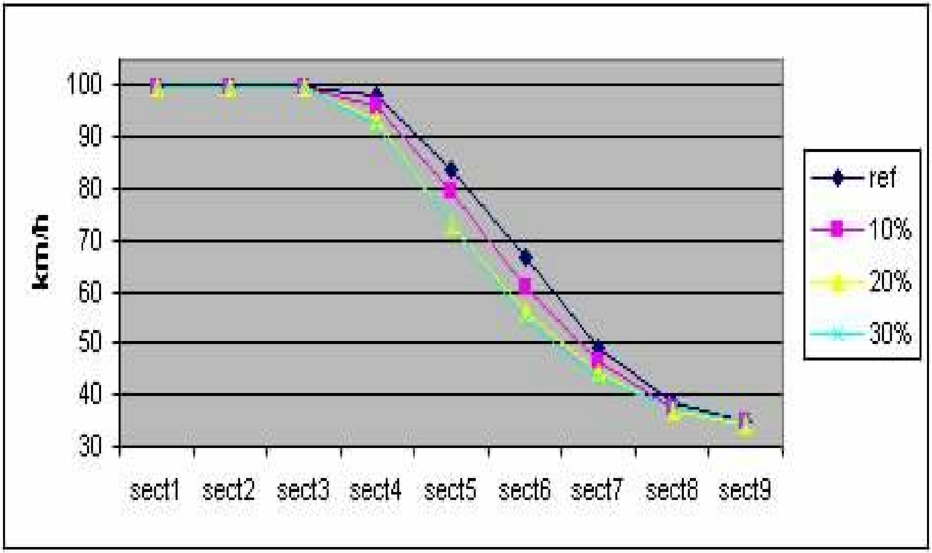


Figure 7: impact of equipped vehicle ratio on the mean speed at time T_0 along the 700m before an hidden incident. The 700m long road was divided in 9 sections.

In this study, several simulation results appeared. Two of them held our attention. The first one enables us to suppose that the deceleration of a part of the fleet spreads to the whole fleet. Indeed the drivers of the equipped vehicles detect the hidden incident and slow down earlier than the non-equipped vehicles. The deceleration of these equipped vehicles induces naturally a total deceleration of the fleet (see figure 7). The average speed of the fleet is thus lower with the approach of the incident. This kind of phenomena appeared in the experiments on the driving simulator.

The second result refers to times to collision (TTC), a traffic indicator that seems significant to us from a security point of view. It appears that the introduction of equipped vehicles in the traffic is favorable to the reduction of short TTC (lower than 2 seconds), specially near the incident (see figure 8). This shows a reduction of the back collision risk and consequently of other induced accidents. On the driving simulator, it appeared that the subjects started their overtaking rather in presence of SAM vehicles than without. Since TTC was not recorded on the simulator and these phenomena were observed in the traffic simulation, it would be possible that the overtaking contributes to smooth the speeds and then to reduce the short TTC.

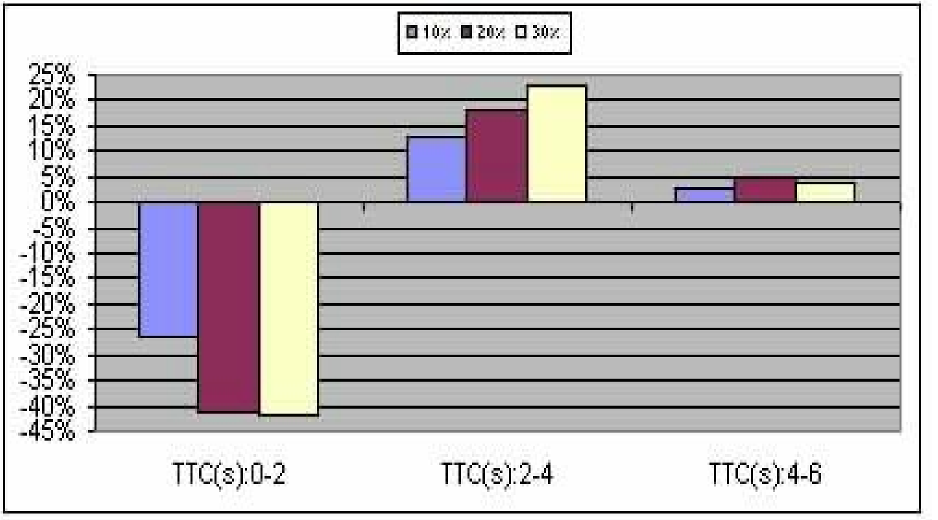


Figure 8: variation of the number of TTC, according to the ratio of equipped vehicles compared to the reference scenario (no equipped vehicles)

These results depend on the initial assumptions. Nonetheless, the introduction of a system such as SAM will modify the drivers' behaviours. The main difficulty is then to envision the users' behaviour relatively to this new system. What will be the attitude of a driver in an equipped vehicle in case of an alarm situation close to an incident? Will the drivers really slow down as we suppose here?

Conclusion

The works done since more than 10 years within the framework of ARCHISIM and SIM² projects authorize to produce (by simulation) a number of "realistic" road situations and to immerse a driver in these produced situation. The goals of these works are:

- to take part in the enrichment of knowledge on the driver's behaviour by an iterative process,
- to develop tools to evaluate the impacts of modification in the road traffic system, such as new infrastructures or the introduction of ITS.

This last objective becomes an essential stake because of the increasing supply in the advanced driver assistance systems. It seems imperative to evaluate as soon as possible the impacts of the proposed devices on the driving task and on the road traffic system. This evaluation has to be done both from a safety point of view (and acceptability point of view) for the driver, and from the point of view of the capacity of the infrastructures.

The use of driving simulators particularly allows i) to study the drivers' behaviour in non-existing situations and ii) to conduct experiment without risk.

However, the use of the driving simulators presents a certain number of limits: i) even the more “realistic” virtual traffic situation is very different from an actual traffic situation, ii) consequently we must remain very careful on the relevance of the results obtained on driving simulators since the conducted study of unsafe situations is done on an objectively safe tool, iii) and finally there are significative differences between the observed behaviours in actual situation and the observed behaviour in virtual situation.

The use of the ARCHISIM simulation tool allows to study nearly any modification in the road traffic system from a traffic capacity point of view, with the necessary condition to have to identify the drivers’ behaviours.

The couple ARCHISIM/SIM² allows to evaluate the impact of quite any modification in the road traffic system using a systemic approach. The so-called integrated approach can be defined by:

- study of the impact of the device on the driving task (acceptability, real use...),
- modeling and simulation of the equipped driver’s behaviour,
- study of the "modified" traffic according to the rate of device deployment,
- study of sensitivity on the defined assumptions,
- study of the impact of the introduction of the device on the non equipped driver’s behaviour (immersion of drivers in the "modified" traffic)

In this kind of approach, the final road users (the drivers) will be directly involved in the design process of proposed devices.

Of course much remains to be achieved (complexity of considered traffic situations). The results obtained are nonetheless encouraging and show the interest of the integrated approach for the study of complex systems (in our case the road traffic system). Future developments of the integrated approach will concern the improvement of the traffic model, especially on urban environment.

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3D Dynamic virtual representation and transport systems simulation

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Abstract

A virtual ambient was built to visualize and to simulate two transport systems (a cableway and a funicular), to serve the university city of Reggio Calabria. The model, made at INRETS (Paris), was optimized for the simulation in real time.

The 3D model was created using Autocad 2000 and RXscene, a virtual authoring tool. The latter was used to generate a virtual reality model. ARCHISIM, a microscopical behavioural model developed at INRETS, was implemented to allow the simulation of the two transport systems and of the vehicular traffic. Finally, the OpenGL performer was used to present the scene in the virtual reality and, joined with ARCHISIM, to make possible the simulation in real-time inside the synthetic environment.

The integration between virtual reality and microsimulation models will become, in the next future, an indispensable tool both in the planning phase and in the transport design one. The possible fields of application of these combined technologies don't only limit theirself to the planning and design but space out from the traffic and on driver's behaviour studies, to the check of the transport systems' working and to the study of the possible interaction with the others vehicles.

Introduction

The evolution in the visualization technology, hardware and software, has increased the application fields of representation in the virtual reality of 3D object. In the transport field, the use of this new technology, initially limited to the transport systems styling and in the synthetic environment creation for driving simulator, constitutes an totally innovative approach, particularly in the planning and designing fields.

Moreover, the possibility to combine this technology with transport support tools, in particular advanced simulation tools (microsimulation), revolutionizes the traffic studies. The three-dimensional representation allows, in fact, to realize a virtual world (real world reproduction, as accurate as possible). Besides, microsimulation models concur to reproduce, in realistic manner, driver’s behaviour: it is like a copy of a real world with which to act and to interact (ex. introduction of new transport systems, infrastructural changes, new circulation and semaphoric plans, etc.), in which it is possible to reproduce and study all the traffic phenomena, bringing back and applying the results in real contexts.

The advantage are obvious: no problem or disturbance for road user; times and costs for the virtual realization of the interventions greatly reduced in comparison to an experimentation in the reality; possibility to visualize and to interpret not only at 360° in plane but also in three dimensions.

Of course, considering its peculiarities and its innovative course, the three-dimensional representation is more effective and more economically advantageous for the planning and the design of important building.

Later on, an experimentation is brought regarding the combined use of 3D virtual representation methodologies and of microsimulation models. It deals with the visualization and simulation, using ARCHISIM (microsimulation behavioural model developed at INRETS), in real time of two transport systems, a funicular (3) and a cableway, inside a virtual environment, that reproduces a portion of the Reggio Calabria city.

Virtual environment real-time simulation

The fundamental characteristic of the virtual environment we want to realize is to be simulable in real time; besides guaranteeing the 3D model interactivity, it has to allow a complete integration with the microsimulation model, otherwise impossible.

To obtain a real-time simulation is necessary in order to quickly produce images on the computer monitor: an image appears on the screen, the user interacts with it and reacts, his commands influence what is subsequently visualized. The cycle of reaction and surrender of the image has a fairly rapid rhythm that the user cannot feel the single images, but the user is immersed in a dynamic process that appears to him as an animation. An application which succeeds in visualizing 15/18 frames for second can already be considered "a graphic real-time application" (1).

Among the different characteristics of a virtual environment, the one that mostly impugn its ability to be simulated in real time, is represented by the number of model polygons.

In the presented case, in order to reduce this number we are resorted, essentially, to an efficient modeling, able to guarantee the interactivity without sacrificing excessively the images realism:

– Superficial and not solid modeling;
– Removal of all the unnecessary or invisible polygons during the simulation;
– Curved surfaces poor representation.

Besides, in oder to contain the polygons number, every object has been modelled according to extremely simple geometries (generally as a parallelepiped); later on, on these geometric primitives, bi-dimensional images (the textures) that allow to improve considerably the degree (apparent) of model detail, have been mapped (7).

The three-dimensional virtual scene creation

The implemented virtual scene consists in two integrated macromodels: the urban environment of a portion of the Reggio Calabria city, that extends for around 2 Km, with a middle width of over 50 meters, from the Reggio Calabria "Lido" station to the seat of the university citadel; and the system of transport (infrastructures and means).

The urban environment virtual model

The creation of the virtual urban environment was done starting from a map (Fig. 1-1) in digital format (dwg) using, for one first coarse modeling, a software CAD (2) and, for the final phase of finishing touch, a tool for the real time (RXscene).

Through the use of the command Surfextr (in Autocad), are created some surfaces for extrusion along a linear path, in that way the height (the third dimension) is defined for all 2D objects of the map.

Considering the impossibility to measure the heights of all the represented elements, middle values are used: for the floor buildings a height of 3 meters is supposed (the number of plans has been calculated by the photos of the buildings), for the sidewalks a value of 20 cms and all the other objects have proportionally been dimensioned to the buildings.

To complete extrusion a first sketch of 3D is got, constituted by vertical polygons (underlined in red in the Fig 1-2) that individualize the side surface of the various elements of our model. The result has been converted in a new format, dxf, to allow the importation Rxscene, the graphic software used for completing the modeling. The imported model is still incomplete: through the extrusion the side surfaces (in red in Fig 1-3) of the virtual model are been created; then, through different Rxscene functions all the lacking surfaces (for example: terrestrial, roads, sidewalks, etc.) have been added, taking as reference the existing polygons.

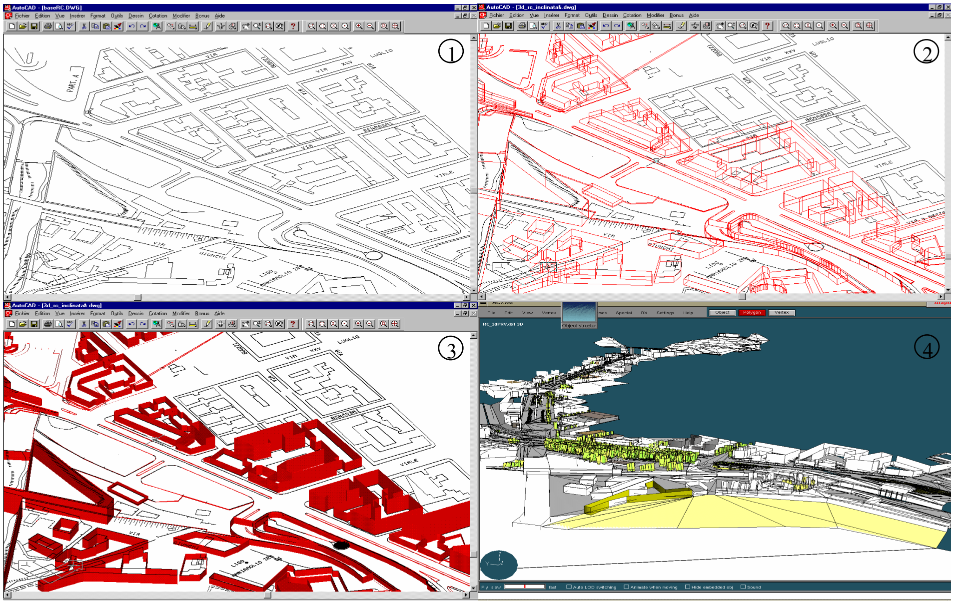

Figure 1: Process of urban environment modeling

Finally, in Fig. 1-4, the model is integrated with all the elements (trees, lamp-posts, road signs), not present in the digital map but fundamental to get a realistic representation.

Transport systems and infrastructures modeling

Also, for the two collective transport systems and the relating infrastructures, the first operation for 3D digital reproduction of the transport systems was carried out in Autocad. In particular, for the funicular and the square cableway model proceeds in the following way:

- Using the real dimension, the lateral, frontal and bottom views of the transport systems was drawn. Therefore, the views was joined along the common side (Fig. 2 – at left);
- The lateral and frontal views were rotated and positioned perpendicularly to the bottom views. Then, a linear model, indicative of the 3D one, was built (Fig. 2 – at right);

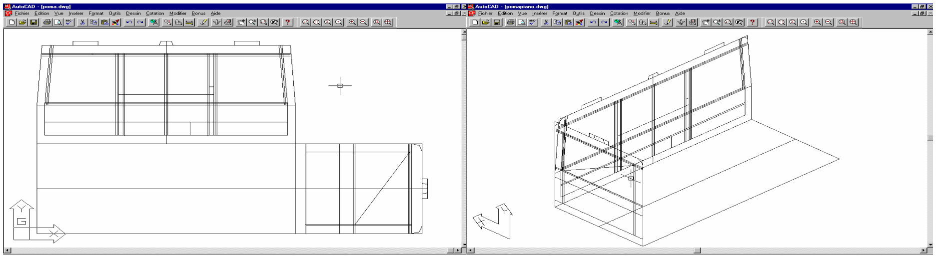

Figure 2: Model 2D design (left) and linear model (right)

– On this reference linear model was quickly draw the model surfaces (Fig. 3, in black), using the Autocad function 3dface, which allows to create surfaces with three or four side in a 3D space.

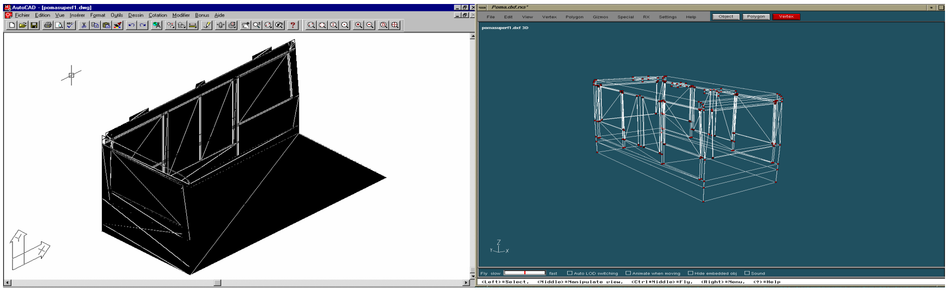

Figure 3: Surfaces tracing (left) and model wireframe (right)

After the surfaces application, the obtained model was converted and, subsequently, imported in Rxscene. Using the function “symmetry respect the grid”, was completed the six faces of the parallelepiped representing the vehicle (Fig 3 right, in red the contact point between the surfaces). Then, we provide a more complex and next to the real one form, finishing up the doors, the windows and the roof of the model (Fig. 4).

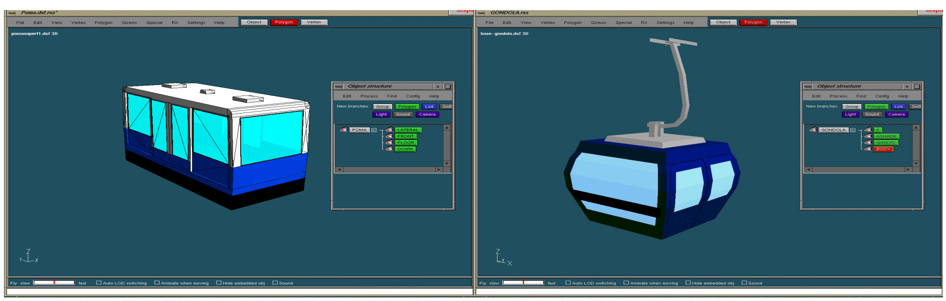

Figure 4: Funicular (left) and cableway (right) 3D model

To realize the round cableway model, considering its particular almost spherical geometry, was used the Autocad function, SURFREV, which allows to obtain surfaces through revolution of a curve path (the vehicle profile, in red, Fig.5) round an revolution axis (vehicle vertical axis, in green, Fig 5). Then a reference skeleton, lines formed, is built. On this skeleton, the model surfaces are been applied, quickly and with precision, through the command 3dface. The surfaces resulting from the revolution has been subjected, in Rxscene, to further operations of completion, refinement and optimization. The results of this operations are visible in Fig 5.

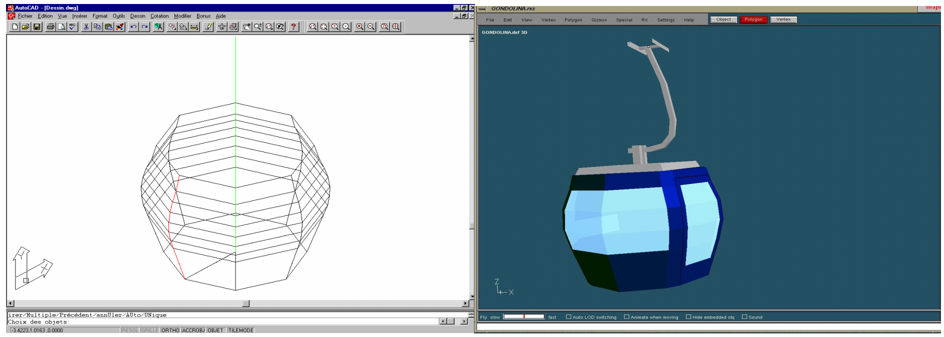

Figure 5: Revolution surfaces (left) and cableway 3D model (right)

The two collective transport systems were modelled, directly, using the Realax software. The infrastructural elements were created singly and, later on, were joined, positioned, rotated and scaled, considering the three-dimensional representation requirements on the virtual model of Reggio Calabria, through the single module's integration. In particular, to place the infrastructure in the 3D space, we are used as reference the longitudinal and altimetric profiles realized during a study conducted in the university of Reggio Calabria on the actual and future mobility of the university city of "Feo di Vito".

The dimensions and the used geometries are those of already existing infrastructures (3); in this way, the realism of the model is guaranteed. For both, funicular and cableway, two different station models (one for the terminals and one for the exchange station) was realized and positioned. Particular attention has been paid during the modelling of the cableway cable, considering its small dimensions and the possible aliasing problems.

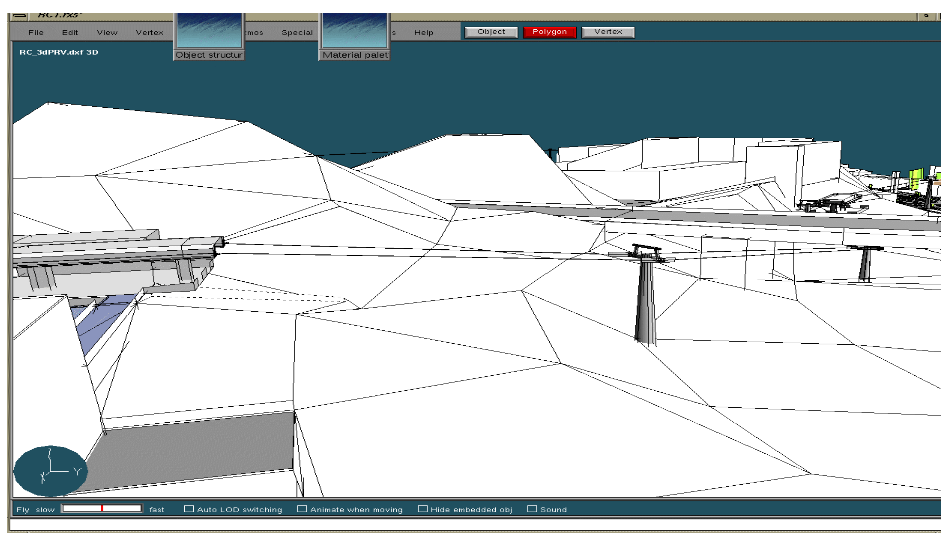

Figure 6: A view of the 3D representation of cableway infrastructural elements

Images treatment and texture mapping

To increase the environment reality and to reduce the polygons count, texture was associated (mapped) on the model polygons.

The image, used as texture, came mainly from 250 pictures of the building facade relative to the represented portion of the Reggio Calabria city. To obtain the texture, it was necessary to elaborate each image; the treatment, effected through the use of Photoshop 6.5, consists in the following operations:

- To distort the image to correct the perspective of a building facade, making it rectilinear;
- To clean the image eliminating all the disturbing elements (tree, car, pedestrian, etc.);
- To cut, to resize (the texture dimensions must be a power of two) and to convert in RGB (the image digital format allowed in Rxscene).

Finally, the texture obtained from this process, was mapped on the database. To reduce the amount of geometry needed to represent complex object, such as tree or pedestrian, two other techniques, some time combined, are used: *alphamap*, a way to add information to an image to make some of its portions transparent, and *billboarding*, which forces a flat object in a virtual environment to rotate so that it is always facing the participant, creating the illusion that it is really a 3D object (7).

The completion of this phase has required more time, mainly in the images treatment, but it has allowed to realize a full-information model, therefore more comprehensible for the possible user and in which the orientation, the movements and the interactions are more quick, easy and intuitive.

Simulation with Archisim

The simulation has been realized using the behavioural microscopic model developed at INRETS, ARCHISIM.

The model is based on exhaustive analysis on the drivers' behaviour in real situations (5). The vehicular flow is not regulated through the use of complex mathematics laws but the principal behaviours of the vehicles are schematized through simple expressions. The road circulation is simulated in ARCHISIM through a "multi-actor" approach: the vehicles are individualized and autonomous. They perceive what surrounds them and they plan their actions. They have their own conscience, own objectives and own strategies. According to this approach, the traffic phenomena result from the behaviour and from the interaction of the different actors, including the road infrastructure and its equipments (4, 6, 8).

For the simulation three circuits have been realized: one for the simulation of the road traffic, the others two to simulate the circulation of the two collective transport systems. The used procedure is schematized as following:

- definition of the axis (group of segments separated by two knots) of the infrastructure on which the motion of the vehicles occurs;
- "dressing" of the axe integrating the lane, the horizontal signing and the relative widenings or narrowings;
- insertion of the road objects, called "pseudo balises", which provide every actor of the circuit with information, in the form of messages, necessary to his choices;
- positioning on the circuit of the vehicles, object of the simulation, and definition for such vehicles of the motion characteristics and the behavioural parameters.

For our purposes and by exploiting the versatility of ARCHISIM, two vehicles typologies, able to reproduce the motion characteristics (essentially maximum speed, acceleration and deceleration) of a funicular and of a cableway, have been defined. Finally, a scenario having been defined for every single transport system, we come on with the simulation in real time (Fig 7).

Figure 7: The virtual model of the two transport systems. The funicular (left) and the cableway (right)

Conclusions

The combined application of traffic three-dimensional scenarii with microsimulation models will become, probably, a diffused tool in a next future.

It is important not to consider the techniques of three-dimensional representation as play tools, but as techniques of notable value in their application fields; in fact, if correctly and rationally used, they can give effective answers and optimal results, both alone or associated to support tools currently used in the field of the transports, in the followings fields:

– visualization of the great infrastructural projects future: planning studies and environmental impact's analysis;
– simulation and forecast of users' behaviours with relative infrastructure adjustment: evaluation of the infrastructure submitted to a generator of traffic and behavioural simulations - 3D macroscopic and microscopic forecasts, identification of bonds and actions on the control of access, test on the signing system and on the management of both people and vehicles flows;
– promotion of strategic projects already programmed: communication and marketing;
– other applications: research and training simulators, interventions management and geographical informative systems.

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The use of innovative technologies for the space reduction in urban environment: study of a Lane Keeping System

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Abstract

The decrease of the space dedicated to the road traffic has become a major issue for the sustainable development in urban environment. This decrease aims, for example, to improve the capacity of the public transports or to increase the pedestrian spaces... A decrease of this road traffic space can be achieved either by reducing the number of lanes, or by keeping the same number of lanes and reducing the width of the lanes. In both cases, it may induce a decrease of capacity. The current works aim to evaluate the impacts of a Lane Keeping System in an urban environment relating to the traffic capacity. To evaluate the impacts of a such system in actual conditions is not always possible due to ethic and safety criteria. Thus, simulation tools, such as driving simulators, become useful and necessary.

To study the potential impacts of this driving aid device, we propose to follow the so-called integrated approach, which uses both a traffic simulation model and a driving simulator. The approach consists in several steps and can be iterative. The first step consists in identifying the drivers' behaviours in actual situations or with a driving simulator for the future situations. In the second step the results of the experiments are used to model drivers' behaviours. These new behaviours are then implemented in the behavioural traffic model during the third step. At this stage, modified traffic flow can be simulated and traffic studies can be conducted. An optional fourth step consists in studying the behaviour of the drivers immersed in the new "modified" virtual traffic and to assess the compatibility between equipped and non-equipped drivers. These works were supported and took part in the European Research Project STARDUST (FP5), which aims to assess the extent to which ADAS (Advanced

Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development.

Introduction

The decrease of the space dedicated to the road traffic has become a major issue for the sustainable development in urban environment. This decrease aims, for example, to improve the capacity of public transports, to increase the pedestrian spaces or to introduce bicycle lanes...

The decrease of this road traffic space can be done either by reducing the lanes number, or by keeping the same number of lanes or by reducing the width of the lanes. Due to a loss of lanes, the first case obviously induces a decrease of capacity. The second case may also induce a loss of level of service: due to the difficulty of vehicle guidance in narrow lanes, the drivers' speeds would be lower; this decrease of speed would induce a loss of capacity. For the last choice, recent researches in the development of ITS for the urban environment, especially the lane keeping systems, could avoid this loss of capacity.

The current works aim to evaluate the impacts of a Lane Keeping System in an urban environment relating to the traffic capacity. This system helps the driver to keep his vehicle within the driving lane. This feature seems relevant in the traffic flow due to the proximity of vehicles in adjacent lanes in the case of narrow lanes. An expected impact of the system could be that the driver maintains his speed at a relevant level, and then to maintain the capacity level. To evaluate the impacts of a such system in actual conditions is not always possible due to ethic and safety criteria, furthermore studies carried out on road could be difficult, expensive and risky. Thus the tools dedicated to the simulation, such as a driving simulator, become useful and necessary to carry out this type of study.

To study the potential impacts of this driving aid device, a method consists in following the so-called integrated approach. This approach is developed and promoted by the MSIS team of the French National Institute for Research in Transportation and Safety (INRETS). The integrated approach uses both the traffic model ARCHISIM and the driving simulator SIM². This approach allows us to study nearly any modification in the road traffic system. The approach consists in several steps and can be iterative. The first step consists in identifying the drivers' behaviours in actual situations or with a driving simulator for the future situations. In the second step the results of the experiments are used to model drivers' behaviours. These new behaviours are then implemented in the behavioural traffic model during the third step. At this stage, modified traffic flow can be simulated and traffic studies can be conducted. An optional fourth step consist in studying the behaviour of the drivers immersed in the new "modified" virtual traffic. This last step seems very important in order to understand the drivers' behaviour facing "unusual" situations due to the use, for example, of an alert system by a leading driver

In this paper, we propose (i) to present this original approach to study the impacts of the modifications in the system of traffic, (ii) to present the tools designed to follow this approach, (iii) to present the carried out experiments on the INRETS Sim² driving simulator, and (iv) to present the carried out traffic studies using the INRETS behavioural traffic model ARCHISIM. This presentation will be concluded by a discussion or the considered perspectives

The study of the drivers' behaviours carried out by INRETS was supported and took part in an European Research Project STARDUST (5th Framework Program, Contract n° EVK4-2000-00590). The aim of STARDUST is to assess the extent to which ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development, not only in terms of direct impacts on traffic conditions and environment, but also in terms of impacts on social life, economic viability, safety, etc. The systems studied in the STARDUST project [1] are the adaptive cruise control (which automatically maintains a set time-headway and/or a desired speed between an ACC-equipped vehicle and a leader vehicle), the Stop&Go control (which is designed to be used in dense traffic with slow speed, it manages throttle and brake of the vehicle in function of a leading vehicle), the Intelligent Speed Adaptation system (*i.e.* speed limitation under a more acceptable term), the automated transport and the Lane Keeping system.

Integrated Approach and tools involved in the integrated approach

The method and the tools (ARCHISIM and the SIM² driving simulator) were previously defined and explained in this book in the paper called "*Integrated Approach : a new method to study the Intelligent Transport System*". We recall that the integrated approach consists in:

- the identification of drivers' behaviours in a actual situation or on a driving simulator (for example in the case where experiments cannot be conducted in actual situations), for the future traffic system,
- the modelling of the new behaviours within the traffic simulation model,
- the traffic study with these new behaviours and,
- when needed, the study of the behaviours of the drivers immersed in the future traffic system (modified traffic behaviour).

Furthermore, concerning the behavioural traffic simulation model ARCHISIM, we recall that the main objective of INRETS ARCHISIM traffic model is to study the drivers' behaviour and how traffic phenomena occurs. In the ARCHISIM model, traffic phenomena comes from individual actions and interactions of the various actors of the road situation. Each simulated driver has a model of environment and interacts with the other participants of the road situation. A behavioural model is used for driver decisions.

The last recall concerns the SIM² driving simulator(see Figure 1). The software architecture is “traffic-centered”, thus the driver is immersed in the ARCHISIM traffic model.

For experiments which require to be reproduced very precisely, the scenarii are described by scripts executed in real time by a supervisor.

Figure 1 : INRETS driving simulator SIM²

The recorded data can be:

- On line data related to drivers actions (steering wheel, pedals position...) and to surrounding (position on the road, others vehicles relative position and speed ...)
- Off line questionnaire dealing with drivers feelings related to the roads profiles variants (visibility, subjective disturbance, ...).

Study of drivers’ behaviours

The Lane Keeping System allows the driver to keep his vehicle within the driving lane. In the case where the lanes are narrower than usual, the drivers’ speeds can decrease due to the difficulties of guidance. This study aimed to analyze the impact of the system on the drivers’ behaviours, focusing the attention on the speed used by the drivers and the lateral position in the narrow lane. To carry out this study, 20 subjects took part in the experiments through INRETS driving simulator SIM² at Arcueil near Paris. The used 3D database, which is based upon a current arterial road in Paris, was approximately two kilometers long. Currently, there is no road mark and vehicles use the 3 “formal” lanes. To study the impacts of narrow lanes on drivers’ behaviours, the selected choice is to add a second bus lane, which is in the opposite direction and to dedicate two narrow lanes for vehicles. Currently the width of the lane for vehicles is almost 3.0m. In the “new configuration” this width is reduced to 2.2m. The figure 2 below shows a view of the used 3D database for the experiments.

Figure 2: 3D view of the Paris avenue

The subjects had to drive on the left lane with or without the system and they had to overtake stopped vehicles or vehicles in movement. The data analyzed came from questionnaires and recorded data on the SIM² simulator. Questionnaires deal with the subjects’ feelings about he Lane Keeping system, and the main recorded data were the speed and the lateral position on the lanes. The evaluations of impacts of the Lane Keeping system show three main results:

– on the lateral position most the un-equipped subjects drove on the left of the lane without the system rather than with. Figure 3 below illustrates the results on the lateral position. The standard deviation is higher without the system than with.

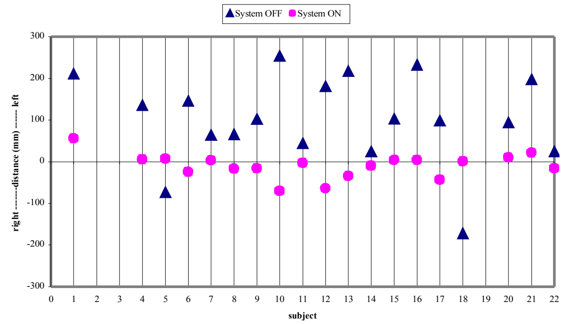

Figure 3: subjects' lateral position, with and without the system

- on the mean travel time: most of the subjects gained time with the Lane Keeping system ON. This gain is of almost 5 seconds for a distance of almost 1 km. This value corresponds to a mean gain of speed of almost 4.2 km/h.
- on the subjects' opinions: the overall subjects' feelings show that the level of favorable opinion is higher after the trials than before. Furthermore, most of subjects felt in confidence with the system ON, they did not feel the need for switching off the system, they felt to be helped by the system and felt themselves in safety using the system. At least half of the subjects declared to be ready to use Lane Keeping on their own vehicle.

To carry out the traffic simulations with ARCHISIM, the "identified" behaviours had to be introduced in the behavioural model. From the obtained results in the experiments shown previously, few assumptions had to be done:

- the usual mean speeds: the mean speed of a non-equipped vehicle decreases of 5km/h by driving in the narrow lanes in urban environment;
- the equipped drivers: they will be able to maintain their usual speed in narrow lanes;
- the acceptance of the Lane Keeping system: due to theirs overall feelings, equipped drivers will use it.

Traffic study

Urban network

The 3D database previously used supplies the network for the traffic simulations. This database, which is a current Paris avenue, is almost two kilometers long. There are more than 20 intersections along the network; 12 of these intersections are regulated by a traffic light. To be able to study the impacts of the lane keeping system, the road mark had to be changed and imagined since it does not exist yet. Figure 4 below shows an outline of the urban network.

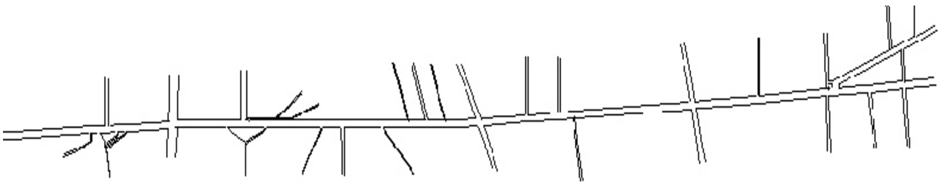

Figure 4: outline of Paris avenue

The “future” road is composed of four lanes. The central lanes are narrower than usual. The width of the “new” lanes is 2.2 meters (3 meters usually). These lanes are dedicated to the traffic flow. The other two lanes are dedicated bus lanes. The central lanes and the bus lanes are separated by concrete lane separators. The infrastructure is the one shown in Figure 2.

Specific sensors, simulating double electromagnetic loops, are laid out throughout the way in order to collect the data from the simulation.

Scenario

This traffic study aims to evaluate the impacts of narrow lanes with different equipment rate in urban environment. To carry out this study, few simulations had be done with different penetration rate:

- Baseline scenario, penetration rate is 0%,
- Scenario 1, penetration rate is 20%,
- Scenario 2, penetration rate is 80%,
- Scenario 3, penetration rate is 100%.

All simulations had be done with the same traffic demand.

Traffic demand

Since the Lane Keeping system is to help the driver to drive in a narrow lane, to evaluate the impacts it does not seem necessary to simulate congested conditions. The theoretical capacity of this road is approximately 2400 vehicles per hour. Thus, the chosen demand on the central lanes of the network is described in Figure 5 below.

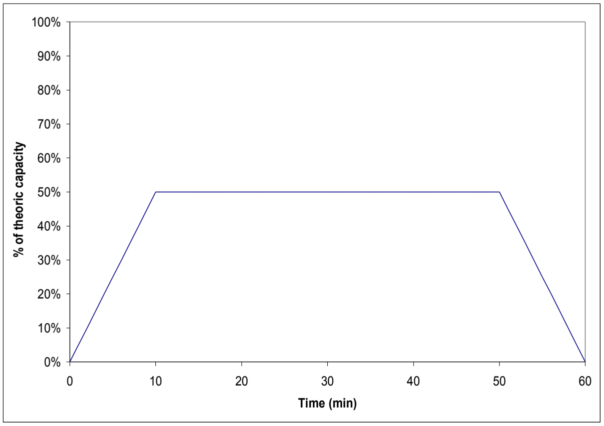

Figure 5: traffic demand on the main road

In the two dedicated bus lanes, the “demand” is 4 bus/hour/lane. These buses also have to stop at bus stops. Vehicles are also generated on other roads crossing the main one. For these roads the demand is supposed constant, its value is 300 vehicles per hour per lane. The traffic lights cycle is set on real data. The input data of the behavioural model Archisim are the traffic demand, the percentage of trucks, equipment rate and some behavioural driver’s parameters (desired speed, time headway...).

For this traffic study, in urban environment:

- it seems useless to simulate trucks. Thus the rate of truck is equal to 0;
- the desired speeds are chosen by following a Gauss’s law (mean = 50 km/h ; Standard Deviation = 5 km/h);
- the time headways are chosen by following a Gauss’s law (mean = 1.2 sec ; Standard Deviation = 0.2 sec).

The last inputs are based upon the current uses.

Results

To compare the results of the simulations, the following traffic indicators will be used:

- average speed and its standard deviation;
- average travel time;
- density.

An expected result is to evaluate the minimum equipment rate to maintain the level of service of an urban road with narrow lanes. In fact, the mean speed obtained with equipped vehicles was more closer to the one obtained on “normal” lanes. As expected, mean traffic density was higher without the system than with. Moreover, between 100% of equipped vehicles and 0% of equipped vehicles there was a difference of almost 5 km/h. The table 1 below shows the main simulation results on speed, travel time and density. Figure 6, instead, shows the mean speed and its standard deviation, on a section, for all the simulated scenarii.

	equipped vehicles	*Mean speed (km/h)*	*Mean travel time (sec)*	*Mean density (vh/km)*
width lane	0%	48,5	118	24,7
narrow lanes	0%	43,7	130	27,5
	20%	44,3	128	27,1
	80%	46,8	121	25,7
	100%	47,7	119	25,2

Table 1 : Main simulation results for all the scenarii.

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Figure 6: Mean speed and standard deviation on a section

Discussion

This work took part in an European Research Project and aims to study the impacts of space reduction in urban environment using the ITS Lane Keeping. The aim is to evaluate the possibilities to maintain a normal level of service in terms of capacity, by reducing the lane width.

The used method, to study the potential impacts of the system, is the integrated approach developed by INRETS-MSIS team. This approach consists in using the driving simulator SIM² and the traffic model ARCHISIM. The use of driving simulators particularly allows a) to study the drivers' behaviour in non-existing situations and b) to conduct experiment without risk. However, the use of the driving simulators presents a certain number of limits: i) even the more "realistic" virtual traffic situation is very different from an actual traffic situation, ii) consequently we must remain very careful on the relevance of the results obtained on driving simulators since the conducted study of unsafe situations is done on an objectively safe tool, and iii) finally there are relevant differences between the observed behaviours in actual situation and the observed behaviour in virtual situation. The use of the ARCHISIM simulation tool allows to study the road traffic system from both a traffic capacity point of view and a safety point of view, with the necessary conditions to identify the drivers' behaviours. The couple ARCHISIM/SIM² allows to evaluate the impact of almost any modification in the road traffic system using a systemic approach. The so-called integrated approach can be defined by:

- study of the impact of the device on the driving task (acceptability, real use...);
- modelling and simulation of the equipped driver's behaviour,
- study of the "modified" traffic according to the rate of device deployment;
- study of sensitivity on the defined assumptions;

– study of the impact of the introduction of the device on the non equipped driver's behaviour (immersion of drivers in the "modified" traffic).

In this kind of approach, the final road users (the drivers) will be directly involved in the design process of proposed devices.

The experiments carried out on the driving simulator consists in immersing 20 subjects in actual situations. They had to drive on a 3D database, which is based upon a Paris' avenue. Scenarii allowed to immerse the subjects in traffic conditions. Objective and subjective data had been collected. The main results are:

– most of the subjects drove on the left of the lane without the system than with. The system helps them to keep the vehicle into the lane;
– most of the subjects maintain their average speed during the drive with the Lane Keeping system ON. With the system OFF, most of the subjects drove with a lower speed;
– the general feelings about the system are mainly positive. At least, the half of the subjects declared to be ready to use Lane Keeping on their own vehicle.

Results of the experiments on the driving simulator had been used to modify the drivers' behaviours used in the traffic model. Thus these simulated behaviours allowed us to carry out the traffic study. An expected impact of this traffic study is to evaluate the minimum equipment rate to maintain the level of service of an urban road with narrow lanes. It appears that using the Lane Keeping System could be useful at least to maintain the level of service when reducing the lanes width.

At this stage, it would be interesting to:

– study the traffic behaviour with a more congested level of demand (in order to assess all the impacts of the system on the traffic flow);
– study the traffic behaviour with the system in a network with traffic lights;
– study the not-equipped drivers' behaviour in an equipped traffic flow (with another 3D database).

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Experimental models and microscopic simulation of the running time for urban roads

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Abstract

The running time, used by a vehicle to cover a road link between the initial node to the final node, can be estimated using theoretical-experimental models. In the microscopic models for the traffic simulation this variable is almost always derivative.

In this note a comparative analyse of the running time obtained by the application of two microsimulation models, AIMSUN and ARCHISIM, and by a statistic-experimental model of speed, specified and calibrated for urban road, is proposed.

The analyse allowed to show some limitations of the microsimulation tools, and lead to improve the possibilities of one of them (ARCHISIM) by changing some behavioural hypotheses of the model..

1. Introduction

The total cost that a driver perceive when covering a road link generally depends on the combination of different heterogeneous quantities (travel time, monetary cost, discomfort, etc.). This cost can be synthesized in an unique quantity, called *generalized cost of transport*, valuable as addition of the different quantities, homogenized by the application of opportunity coefficient. The mathematical relationship allowing to evaluate the single component of the generalized cost, or the generalized cost itself, are called *cost function*.

Generally, in the practical applications, the assumption is made that the most important component of the generalized cost for the users is the travel time; in fact, the most used cost functions in the literature give only the time used to cover a road link, or, dually, the motion speed. Particularly, those functions give the travel time *t* of a road link as addition of two quantities: the running time t_r used by the vehicle to cover the link from the initial node to the final one, and the waiting time t_w that the vehicle undergoes to cross the final junction.

To estimate the medium running time t_r on a link, in the past different formulations had been proposed (Bureau of Public Roads, 1964; Davidson K.B., 1966; Akcelik R.,1991; Festa D.C., Nuzzolo A.,1990). A statistical model has been recently worked out (Gattuso D., Meduri G., 2002) allowing the prediction of the speed on urban road; the novelty of this model is that it takes into account the explicit dependence between the running speed and the length of the road link.

The objective of this work has been to verify if that dependence is explicitly considered also in the microsimulation models, i.e. from the models allowing an analysis of the traffic phenomenon by the representation of the behaviour of the single vehicles on the road.

In the following, after recalling the Gattuso-Meduri speed model, are described two particular microscopic models, AIMSUN and ARCHISIM. Then an application of these models is presented, with an analysis of their quality regarding the dependence between the running speed and the length of the urban road link.

2. The experimental model

The proposed statistical model allows to calculate the mean speed of the vehicles on urban road and then he can be used in the estimation of the running time of a vehicle on an urban road link.

The model allows to find the mean running speed of the vehicles in function of different parameters, such as the length of a road link, the useful width of the link, the disturbing effect of the lateral stop and the saturation flow of the link.

Particularly, the structure of the model is the following:

$$v = b_0 + b_1 L_u + b_2 L + b_3 D + b_4 \rho$$

where:

- v is the running speed (km/h);
- L_u is the useful width of the road (meters);
- L is the length of the link (meters);
- D is the disturbing effect of the lateral stop (decimal values from 0 to 1);
- ρ is the saturation flow of the link (decimal values);
- b_k (k = 0,1,2,3,4) are coefficients coming from the calibration of the model, their values are quoted in table 1.

b_0	b_1	b_2	b_3	b_4
29,00	1,82	0,02	-7,20	-15,52

Tab. 1 – Values of the coefficient of the proposed speed model

The calibration phase has been realized with the minimum square method, taking into account 628 observations on a pattern of 17 road links localized in two different urban areas (Parma and Reggio Calabria). The running speed has been obtained from the travel time on the links; these have been calculated by timing the instant of passage of the vehicles on the initial section of each link and in a section at a distance from the last sufficient to consider negligible the effect on the running speed due to some vehicles waiting at the junction, or to slowing down due to the junction.

The results of the goodness statistic (R^2; corrected R^2, $\overline{R}^2$; F of Fisher; standard deviation, s; t of Student) show that the proposed speed model reproduce well the experimental observations from which it has been calibrated. In table 2 the values of the estimated coefficients of the model are quoted, along with the values of the goodness statistic.

When using the speed model it is necessary to take into account the experimental situations from which it has been realized; then, it is not correct to use the model out of the variability field of its independent variables. Particularly, the model can be used to calculate the mean running speed on urban road with a width between 3 and 11 meters, a length between 120 and 920 meters and saturation flows not higher than 1.

	b_o	b_1	b_2	b_3	b_4
values	29,00	1,82	0,02	-7,20	-15,52
t - Student	**8,5909**	**13,2937**	**13,0432**	**-1,3736**	**-3,4599**
R^2 = 0,495	**$\overline{R}^2$ = 0,492**	***F – Fisher*** **= 152,52**		***s*** **= 8,74**	

Tab. 2 – Model coefficients and verifying statistics

As we said, the theoretical model does not give information on the speed profile for flow values higher than the infrastructure capacity.

3. The running time coming from the microsimulation model

The running time on a road link is one of the various issues obtainable from the microsimulation model. A specific analysis has been carried out for this variable, using two specialized softwares, AIMSUN and ARCHISIM. Below the main characteristics of these tools are recalled.

3.1. AIMSUM

AIMSUN (Barcelò J.,Casas J., Ferrer J.L., D. García., 1998) is a microscopic traffic simulation software based on mathematical traffic laws. The software is developed and commercialized by the Spanish firm TSS (Transport Simulation System).

The behaviour of each vehicle in the network is continuously modelled, until it remains in the traffic system, according with different behavioural models (car-following, changing lane, etc.). This kind of model can be defined as “classic”, distinguishing it from the models based on the drivers behaviour analyses, called “behavioural”.

The input data of AIMSUN are a scenario to simulate and a set of simulation parameters defining the experiment. The scenario consists in the definition of the network parameters, demand data, control traffic plans, etc. The network data can be let in the software using a specific graphic editor (TEDI), the demand data can be expressed in terms of traffic flows and percentage of turning at the junctions, or in terms of Origin/Destination matrix and specific hypotheses for the path choice.

A microscopic traffic simulation principally needs of model simulating the motion of the vehicles in the network. AIMSUN uses, for the longitudinal shift of the vehicles, the multiregime car-following model of Gipps (1981). This model is based on the respect of a security distance between two vehicles. Some parameters of the vehicle (maximum acceleration, desired speed, etc.) allow to obtain some elements of heterogeneity in the traffic flow; it is also possible to create vehicle classes with different characteristics.

For the lateral shift of the vehicles, the software uses a forced/deterministic changing lane model. It is modelled as a decisional process considering the necessity, the wish and the possibility to change lane. These parameters depend on the position and on the desired speed of the vehicle on the network.

If the vehicles path on the network is not defined before the simulation, AIMSUN uses choice path models. It is possible to use different macroscopic models for the choice path (logit, C-logit, etc.). The choice of the minimum path is realized relatively to the perceived cost of the user on the different possible paths. The count of the travel cost on a link is realized using cost functions the expression of which takes into account the travel time on a link, the theoretical capacity and the current flow.

AIMSUN gives as output different indicators. It is possible to obtain variables like speed, flow, density, travel time. These variables can be related to the entire simulation period or to predefined temporal intervals. The indicators can concern the entire network, some parts of the network or also single links of the network.

3.2. ARCHISIM

ARCHISIM (Espié et al., 1993; Heudin, 1994) allows a traffic simulation based on the psychological analyses of the drivers’ behaviour. The simulation is realized following an approach considering that a traffic simulation is the result of the interactions of the actors participating to it. This microsimulator is not a commercial product; it is a laboratory tool developed by the Laboratory of Driving Psychology (LPC) and by the Department of Automatism and Traffic Regulation (DART) of INRETS. It is novel because it allows a total immersion of a driving simulator in the simulated traffic.

The approach, in ARCHISIM, is similar to the one defined as “artificial life” by Heudin (Heudin, 1994). The behavioural model is a decisional model based on the consideration, at subsequent instants, of the driving situations; during the simulation, each driver perceives a “rich” surrounding composed of the visible vehicles, particularly the vehicles preceding it, and the objects in the scene (signals, traffic lights, etc.). Based on a deep psychological investigation of the real driving behaviour, a wide database has been realized. This database is useful to identify the contest variables (infrastructure and/or traffic) and the knowledge basing the classifications of these contests by the drivers, as well as the strategies consequently used by them.

Then the generic driver activity is founded from the identification of general principles of shift management corresponding to the behavioural motivations (preservation of the desired speed, limitation of the number of manoeuvres, security, etc.). Relating to the subject motivations and to the contest of the situations, four great classes of intentions are considered (maintain of the speed, change or maintain of the journey, suppression of the interaction and adaptation). These intentions are defined by specific variables (infrastructure, traffic, other users behaviour, etc.). The different control fields of the driver are also specified. Eventually the generating rules of the different intentions and the way to act them (break, change lane, etc.) are defined. This approach rises from the parametration problem, typical of the mathematical formulations. The only significant parameter is the duration of an action, solved relating to the specific situation. If, for example, a driver is overtaking and suffers a pressure from the rear, the duration is the one necessary to achieve the manoeuvre; if he is behind a truck signalising the intention to leave the highway, he estimates the time before the out ramp.

The vehicles are divided in classes with different characteristics, while to the drivers are associated attributes allowing to specify to driving experiences and the way to interact with the other drivers and with the surrounding.

The road network is described by road axes coded with B-spline 3D oriented curves, an oriented graph (in which the junctions are represented by nodes and the sections by arcs), a set of objects describing the road environment with symbols.

The output variables, given by ARCHISIM, can be of different nature. Microscopic data on the vehicles can be obtained by recording, for example, the main variables of a virtual vehicle during its journey. It is also possible to simulate the presence, at some points on the network, of detectors (punctual or spatial).The punctual detectors simulate the operation, for example, of detectors such as magnetic spires, and they then receive information on the vehicles passing upon the detector. The received information can be aggregated for a chosen time interval. The different possible aggregations can concern a fixed point of the network, a section between two detectors or the entire network. The spatial detectors allow to make a “photography” of a network section during a time interval. Then aggregated data on the traffic flow will be obtained; this kind of detectors is used mainly for the calculation of the queue length. The obtainable data concern the vehicles speed, their acceleration, the travel time, time to collision, etc.

In ARCHISIM, the travel time for one vehicle is calculated as the difference between the passing time upon a detector and the creation time of the vehicle. In the same way, the travel time on different sections of the network can be known.

4. Application

The aim of this work is to verify if the influence of the length of a road section on the running speed is explicitly taken into account in the traffic microsimulation models. The study has been realized considering the models AIMSUN and ARCHISIM, which can be considered as representative of the different microsimulation model categories.

4.1. Simulated scenarios

Twelve urban links had been considered, six with one lane and six with two lanes; the lengths are variable between 150 and 900 meters, with intervals of 150 meters. All the links have an initial section below the first junction and a final section placed at a distance from the last junction that make negligible the effects due to possible vehicles waiting at the junction, or to some slowing due to the junction (see figure 1).

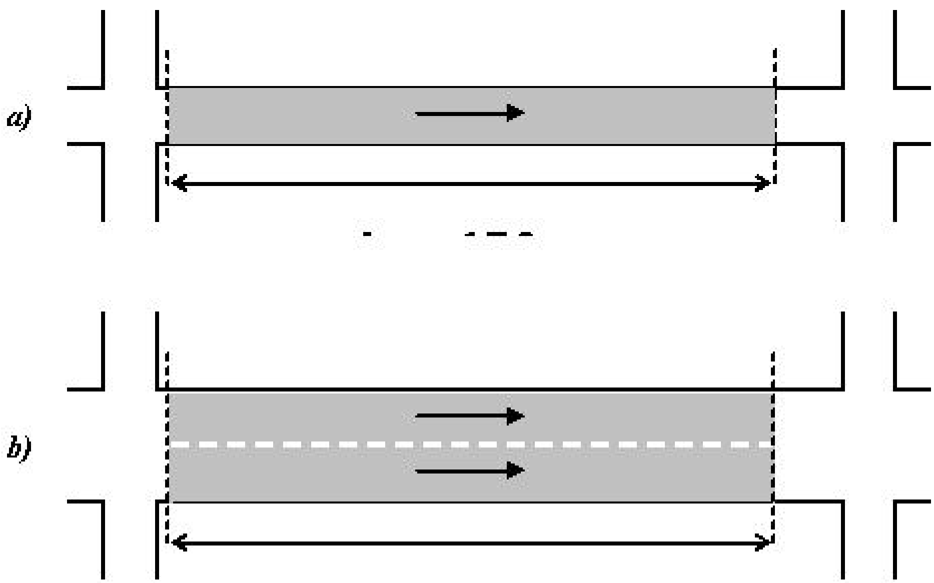

Fig. 1 – Representation of the urban links with one lane (a) and with two lanes (b)

The characteristics of the simulated sections are quoted in the table 3. For the desired speed the hypothesis of a Gaussian distribution has been made. The mean speed has been calculated using the theoretical-experimental model with a saturation degree equal to zero; these conditions are those of a free flow (only one vehicle in the network).The standard deviation value used in the Gaussian distribution has been chosen after some calibration trials. At this phase of the study, we have only tried to reproduce the same speeds profile obtained with the theoretical-experimental model.

Link	***Length (m)***	***Lanes***	***Capacity (vh/h)***	***Desired speed (km/h)***	
				mean	*st. dev.*
1	150	1	1200	50	12
2	**300**	1	1200	50	**12**
3	**450**	1	1200	50	**12**
4	**600**	1	1200	50	**12**
5	**750**	1	1200	50	**12**
6	**900**	1	1200	50	**12**
7	150	2	3000	50	12
8	**300**	2	3000	50	**12**
9	**450**	2	3000	50	**12**
10	**600**	2	3000	50	**12**
11	**750**	2	3000	50	**12**
12	**900**	2	3000	50	**12**

Tab. 3 – Characteristics of the simulated road links

The capacity has been chosen equal to 1200 vehicles/hour for the sections with one lane, and equal to 3000 vehicles/hour for the sections with two lanes.

In AIMSUN the capacity attends only in the calculation of the cost functions used for the path choice model. In this case, the attention being limited only at one road link, i.e. only one possible path, the capacity value as input data is not relevant. The car-following model of Gipps does not take into account the capacity of a section.

In ARCHISIM, on the contrary, it is not necessary to give the capacity as input of the simulation. The method used by this model is based on behavioural rules of the vehicles drivers. In this case, the concept of capacity does not appear explicitly because there is not mathematical functions regulating the motion of the vehicles. The capacity of a road link can be recovered as result of the simulation and it is directly related to the geometrical characteristics of the section and to the behaviours of the simulation users (desired speed, aggressiveness, experience, respect of the rules, etc.).

To give prominence to the dependence between the running speed of the road links and the traffic flow, different simulations with increasing values of demand have been realized. Particularly, traffic flows variables from 200 vh/h to 1400 vh/h (at interval of 200 vh/h) have been considered in the case of sections with one lane. In the case of sections with two lanes, the traffic flows were included between 400 vh/h and 3200 vh/h (at intervals of 400 vh/h). The simulations with traffic flows higher than the capacity allow to verify the congestion effect.

4.2. Obtained results with AIMSUN

Using the AIMSUN package, different simulations have been realized for roads with one and two lanes, and for increasing traffic flow values. Each scenario has been simulated one more time in order to obtain mean final results. Particularly measures of speed have been obtained in function of different saturation degrees of the infrastructure.

The results obtained from the simulation realized with the AIMSUN model are graphically represented in figures 2 and 3, respectively related to the sections with one lane and two lanes.

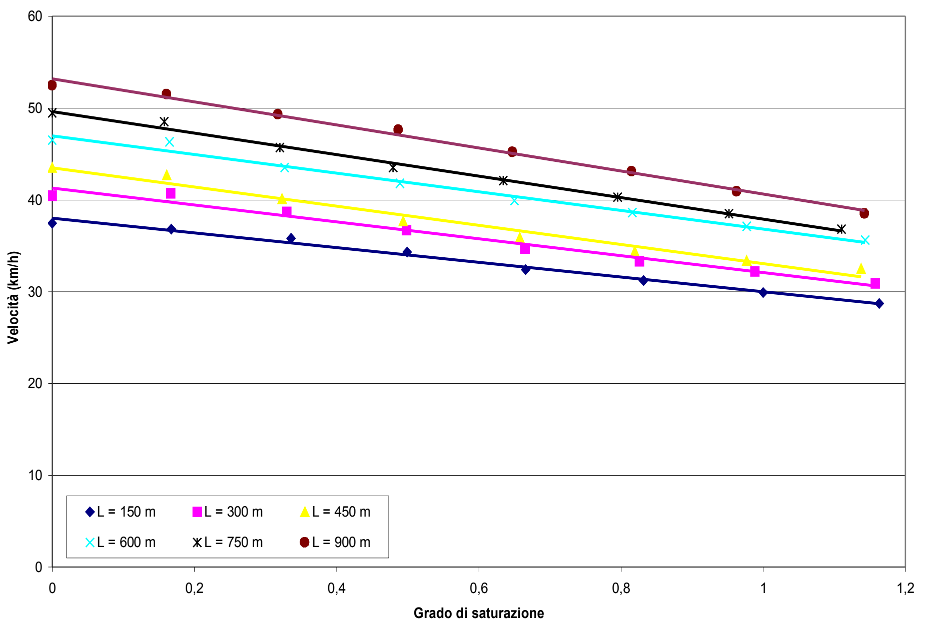

Fig.2.a - AIMSUN: speed-saturation degree profile for roads with one lane

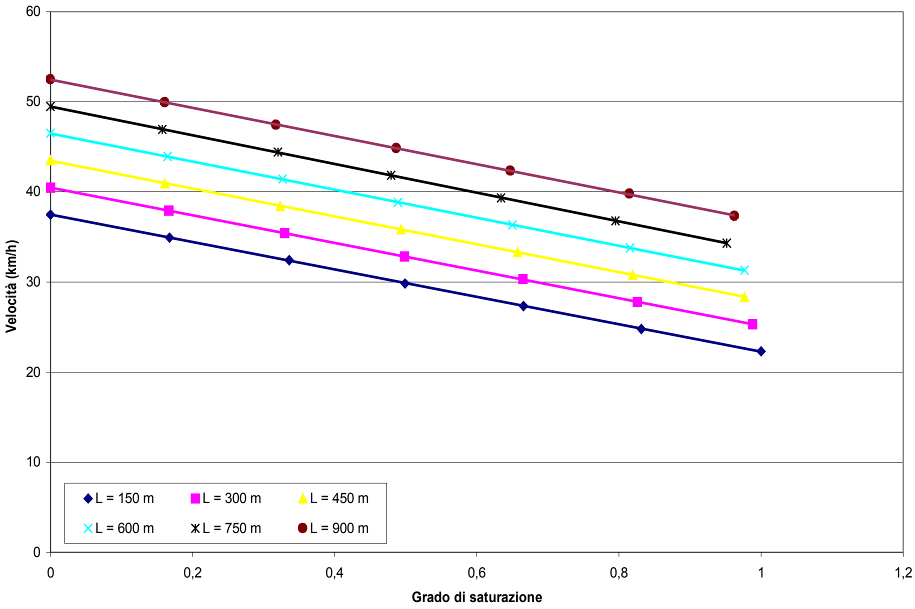

Fig.2.b – Experimental model: speed-saturation degree profile for roads with one lane

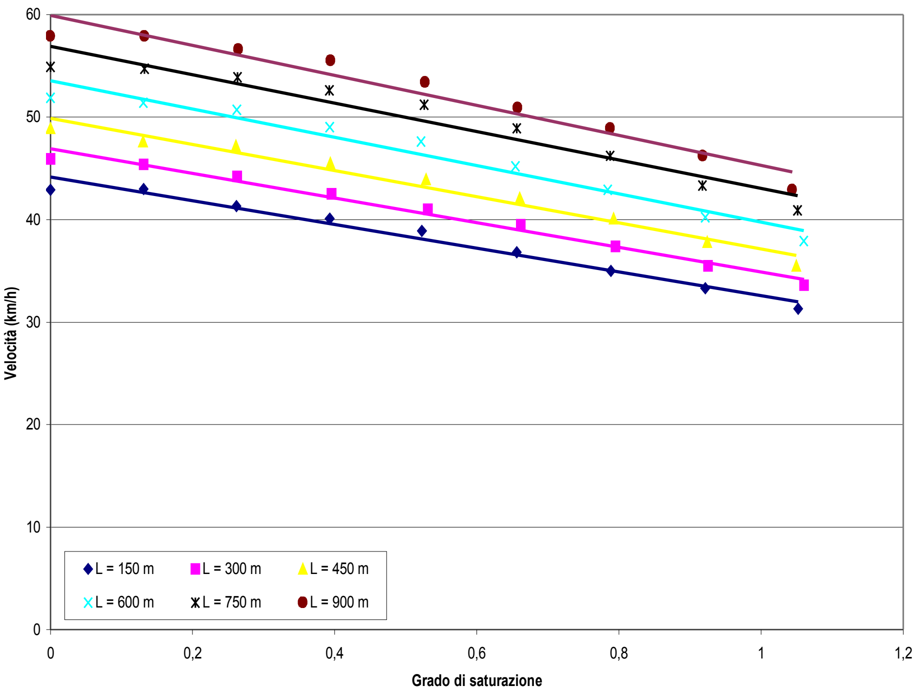

Fig.3.a - AIMSUN: speed-saturation degree profile for roads with two lanes

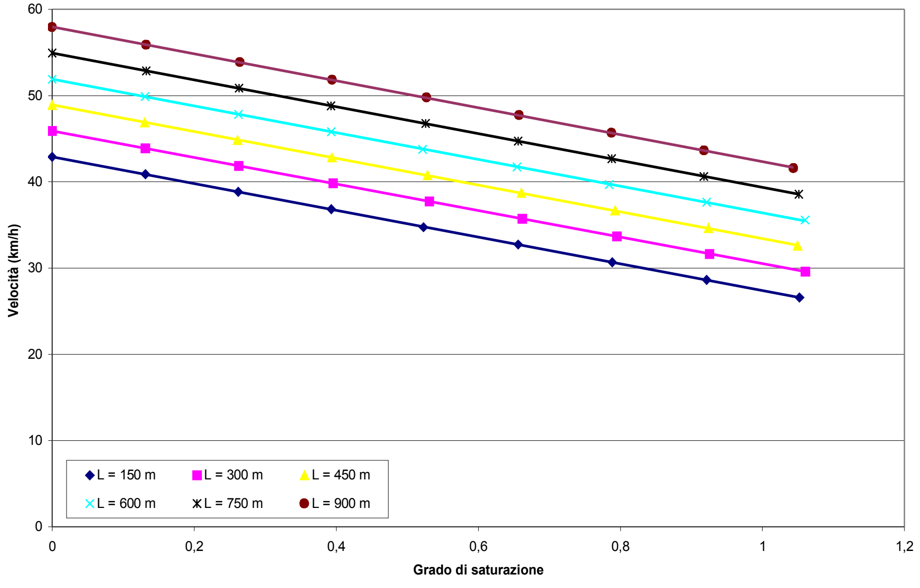

Fig.3.b - Experimental model: speed-saturation degree profile for roads with two lanes

The speed increases with the augmentation of the saturation degree. The speed level is higher when the length of the link is higher. This seems coherent with the experimental approach but the diminution is lower; moreover it appears a tendency of the curves for saturation conditions that does not appear in the experimental curves. This is true both for the one lane roads and the two lanes roads.

The microsimulation model does not reproduce correctly the vehicular flow when the saturation degree is near to or higher than one. In this case, the plot speed – saturation degree would have a "bell" curve that does not appear from the output data. The Gipps model, used as car-following law in the microsimulation model, does not allow to easily reproduce the real traffic conditions for high vehicular flow.

4.3. Obtained results with ARCHISIM

In ARCHISIM the input parameters concern the behavioural characteristics of the drivers, for example the desired speed, desired time headway, accepted jerk, rate of infraction of the road rules, etc. In this model, the concept of capacity is not explicit; the approach adopted by the model supposes that the decrease of the service level is mainly related to the drivers behaviour.

Figures 4.a and 5.a show the trends for flow and speed obtained by the simulations with ARCHISIM, for roads respectively with one and two lanes. It is possible to observe, in this case, a basic congruence with the experimental results: speed decreases when the saturation degree increases, there are speed levels differentiated in function of the links length. Moreover, in opposite with the results of AIMSUN, when the saturation degree increases, ARCHISIM shows a divergent trend of the curves. The entity of the speed reduction is higher when the saturation degree is higher. Another element, compared with AIMSUN, is the greater dispersion of the data with respect with the interpolating curves.

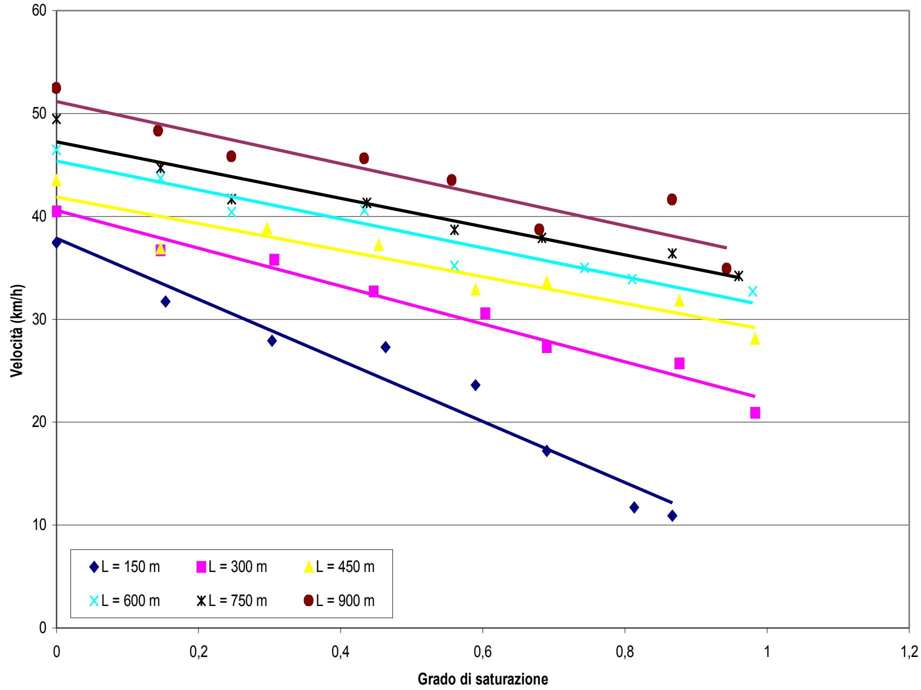

Fig.4.a - ARCHISIM: speed-saturation degree profile for roads with one lane

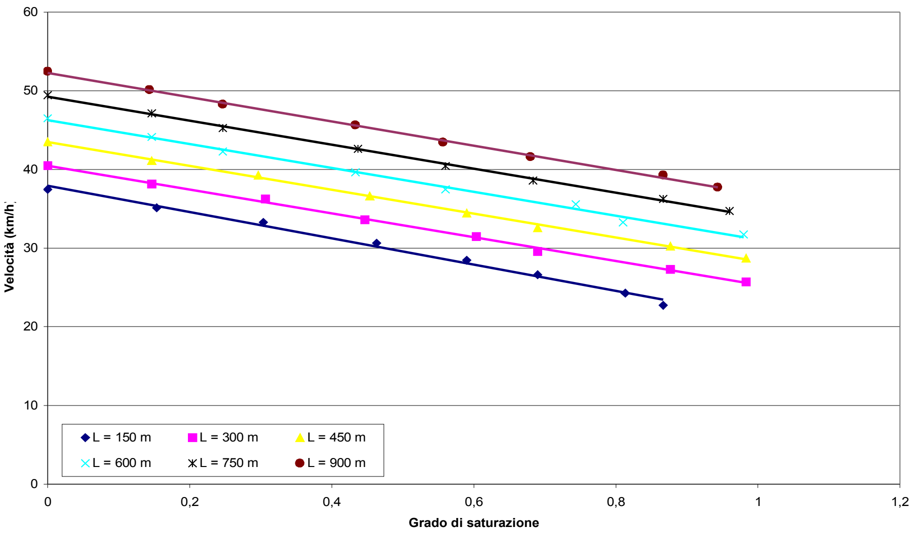

Fig.4.b – Experimental model: speed-saturation degree profile for roads with one lane

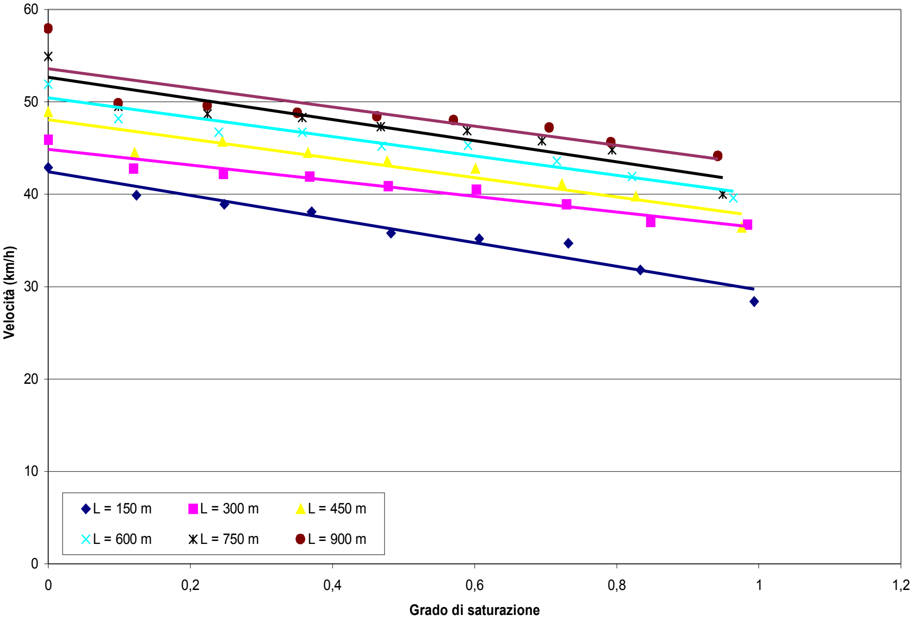

Fig.5.a - ARCHISIM: speed-saturation degree profile for roads with two lanes

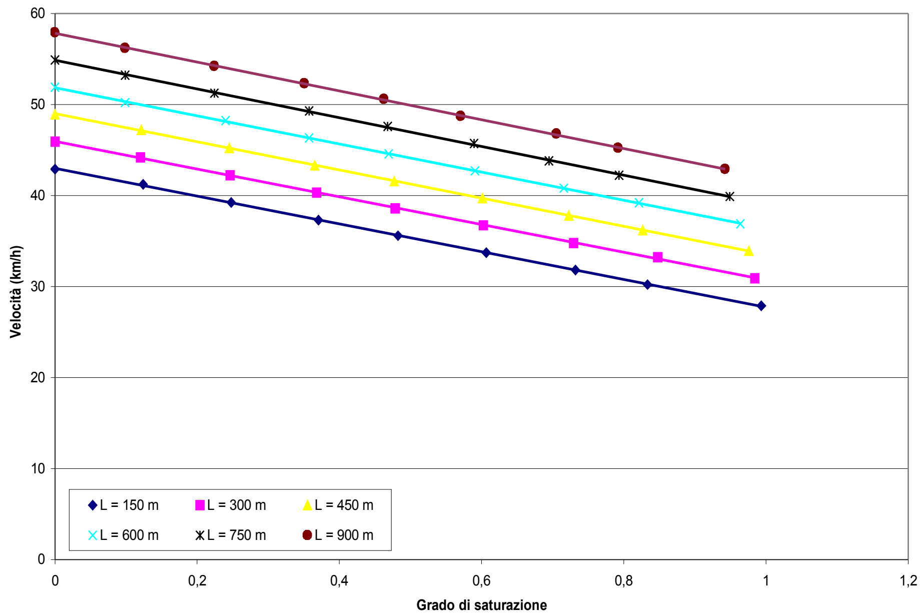

Fig.5.b – Experimental model: speed-saturation degree profile for roads with two lanes

Compared with the experimental model, for links with one lane when the length of the links increases there is a lower deviance from the curves. For shorter links, with ARCHISIM the effect of the links length is higher when flows are higher.

For links with two lanes, the same deviance between the curves appears. In this case, the fastest vehicles have the possibility to overtake those slowest, maintaining sufficiently high the mean speed of the flow. This factor also influences the mean speed of the longest links; in this case, the mean speed obtained are a little higher than those of the theoretical model.

5. Conclusions and perspectives for the research

The travel time of a vehicle on a road link is one of the main parameters intervening in the formulation of the cost functions. The assessment of the running time appears very important, and different formulations have been proposed in the literature. The Gattuso-Meduri model for the assessment of the running time has been recently realized to take into account the length of the considered road link.

The aim of this note was to verify if in the microsimulation traffic models then exists a relation between the running speed on the section and its length. Two microsimulation models (AIMSUN and ARCHISIM), differenting the adopted approach, have been chosen. In fact, AIMSUN is a “classic” model based on mathematical relations regulating the vehicle motion in function of the leader; the vehicle speed is regulated by a car-following model. ARCHISIM, on the contrary, is based on the analyses, from the virtual vehicle, of the traffic situation in which it is immersed; the vehicle can be considered “intelligent” and its behaviour depends on the one of the other vehicles and from the environment. This kind of models are called “behavioural”.

The realized analyses consisted with simulation, with both the models, of an increasing of traffic flow (from low values of flow to values overtaking the hypothetic theoretical capacity) on sections with increasing length, both with one and two lanes. Then it was possible to verify if the trend of the curves speed-flow obtained by the simulations was similar to the one obtained with the Gattuso-Meduri model. The theoretical-experimental model shows that the running speed increases when the section length increases.

The results obtained with AIMSUN reflect only partially the indications of the theoretical model. As expected, the mean flow speed on a link decreases when the flow increases. This tendency is realistic only for values of flow lower than the theoretical capacity of the link; over the capacity, it would be a decrease of service level. With AIMSUN, instead, it is not possible to obtain the congestion phenomenon; the car-following model used in the software seems to be too much “deterministic”. Moreover, with the chosen values of standard deviation of the desired speed, it is not possible to obtain the same speed trend obtained with the theoretical model; there is, on the contrary, an higher mean speed of the flow.

With ARCHISIM the expected congestion phenomena are reproduced. The speed values obtained are similar to those obtained using the model. This tendency is more important on the longer links, when there is only one lane. For links with two lanes, a good fit between curves of theoretical model and microsimulation model also appears on the shorter links; furthermore there are higher differences when the length of the links increases.

It is evident that a better calibration of the microsimulation models would be necessary, in order for them both to “follow” the trend of the theoretical model and reproduce the saturation situations that appear for vehicular flow higher than the infrastructure capacity.

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