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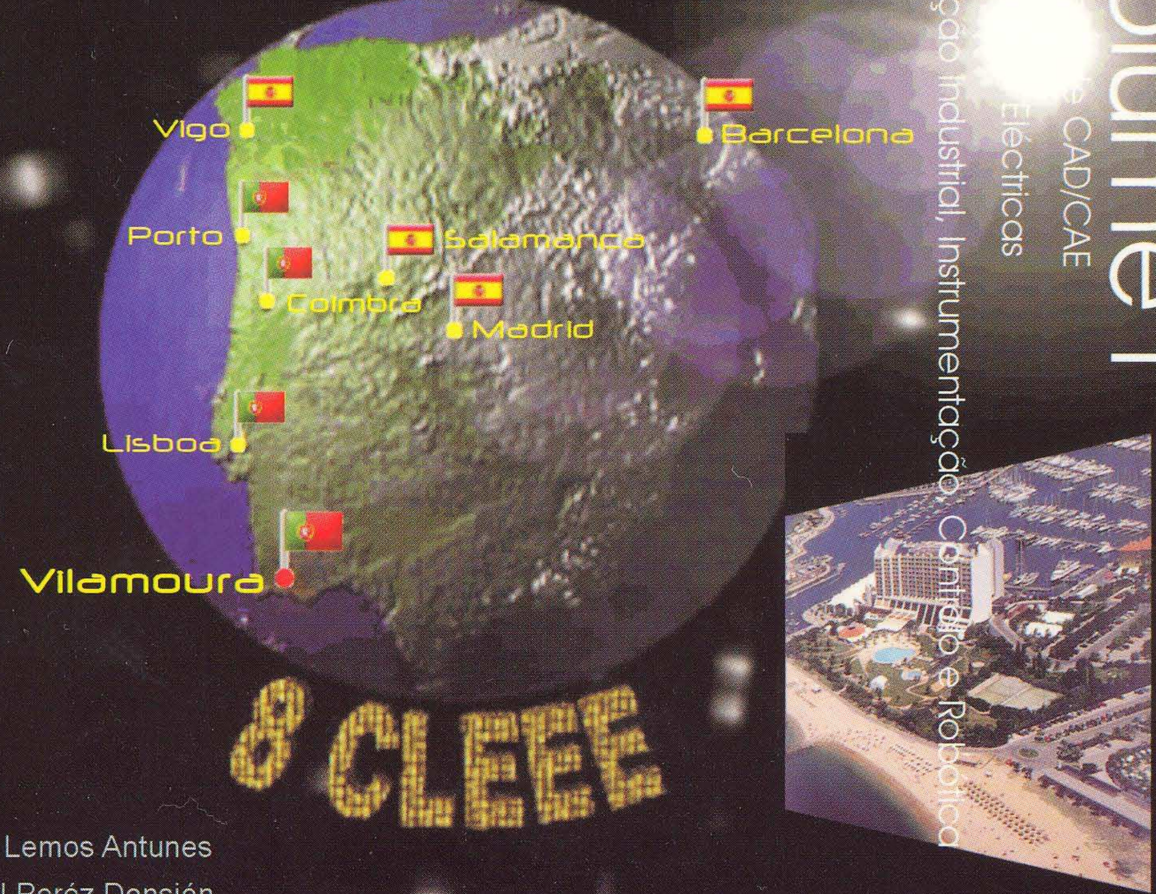

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Simulation and Modelling of Intelligent Transportation Systems

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Abstract

This paper discusses the problem of modelling and simulation of traffic systems, and presents the traffic simulator SITS (Simulator of Intelligent Transportation Systems). The SITS is based on a microscopic simulation approach considering different types of vehicles, drivers and roads. A dynamical analysis of several traffic phenomena is then addressed.

Index Terms: Intelligent transportation systems, Simulation and modelling.

1. Introduction

Nowadays we have a saturation of the transportation infrastructures due to the growing number of vehicles over the last five decades. This situation affects substantially our lives particularly in the urban areas, while people needs, more and more, to move rapidly between different places. The results are traffic congestion, accidents, transportation delays and larger vehicle pollution emissions. The difficulties concerned with this subject motivated the research community to center their attention in the area of ITS (Intelligent Transportation Systems).

ITS depend on results from research activities spread over many different areas such as electronics, control, communications, sensing, robotics, signal processing and information systems. This multidisciplinary nature increases the problem's complexity because it requires knowledge transfer and cooperation among different research areas.

Presently ITS is a global phenomenon, attracting worldwide interest from transportation professionals, automotive industry and political decision makers. ITS applies advanced communication, information and electronics technology to solve transportation problems such as, traffic congestion, safety, transport efficiency and environmental conservation [1]. Therefore, we can say that the purpose of ITS is to take advantage of the appropriate technologies to create "more intelligent" roads, vehicles and users [2].

Computer simulation has become a common tool in the evaluation and development of ITS [3, 4]. The advantages of this tool are obvious. The simulation models can satisfy a wide range of requirements, such as: evaluating of alternative treatments, testing new designs, training personal and analyzing safety aspects [5].

Bearing these facts in mind, this paper is organized as follows. Section 2 describes briefly the microsimulation model SITS. Section 3 presents simulation results related with the dynamic behaviour of a traffic system. Finally, section 4 presents some conclusions and outlines the perspectives towards future research.

2. The SITS Simulation Package

SITS is a software tool based on a microscopic simulation approach, which reproduces real traffic conditions in an urban or non-urban network. The program provides a detailed modelling of the traffic network, distinguishing between different types of vehicles and drivers and considering a wide range of network geometries.

SITS models each vehicle as a separate entity in the network according to the state diagram showing in figure 1. Therefore, are defined five states {1-aceleration, 2-breaking, 3-cruise speed, 4-stopped, 5-collision} that represent the possible vehicle states in a traffic systems.

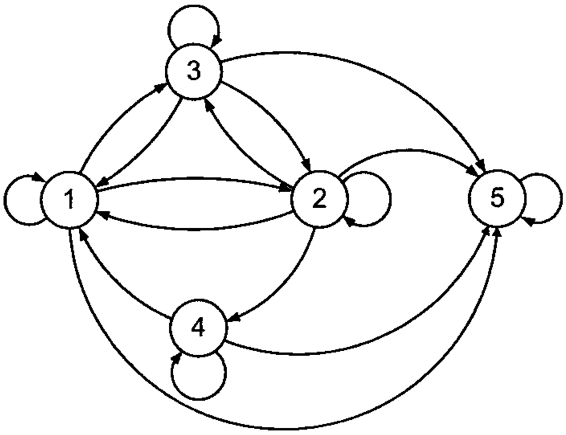

Figure 1 – SITS state diagram

In this modelling structure, so called State-Oriented Modelling (SOM), every single vehicle in the network has one possible state for each sampling period. The transition between each state depends on the driver behaviour model and its surrounding environment. Some transitions are not possible; for instance, it is not possible to move from state 4 (stopped) to state 2 (breaking), although it is possible to move from state 2 to state 4.

At this stage of development the SITS considers different types of driver behaviour model, namely car following (where drivers follow their leaders and try to match their speed), free flow (where each driver tries to attain its own desired speed) and lane changing logic. Furthermore, SITS allows also the analysis of signal control devices and different road geometries considering road junctions and access ramps.

The simulation model adopted in the SITS is a stochastic one. Some of the processes include random variables such as, individual vehicle speed and input flow. These values are generated randomly according to a pre-defined amplitude interval.

The main types of input data to the simulator are the network description, the drivers and vehicles specifications and the traffic conditions. The output of SITS consists not only in a continuously animated graphical representation of the traffic network but also the data gathered by the detectors, originating different types of printouts.

SITS tracks the movements of individual vehicles to a resolution of 10^{-2} sec and uses five different colours to represent the individual vehicle states; namely, stopped (red), acceleration (green), breaking (yellow), cruise speed (blue) and collision (black), as represented on figure 2.

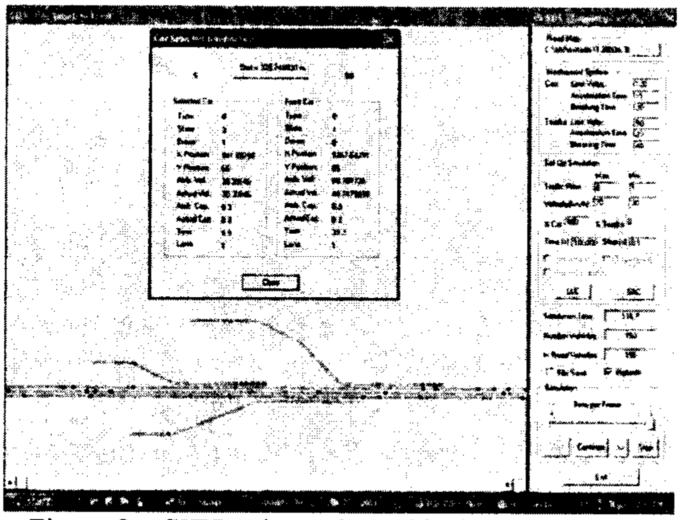

Figure 2 – SITS animated graphical representation

3. Simulation Results and Dynamical Analysis

In the dynamic analysis are applied tools of systems theory and automatic control. In this line of thought, a set of simulation experiments were developed in order to estimate the influence of the vehicle speed $v(x,t)$, the road length (l) and the total number of lanes (k) in the traffic flow $\phi(x,t)$ at the road coordinate x and time t. In fact, traffic flow is a non-linear and time variant system but, in the sequel, it is shown that the Fourier Transform can be used to analyse the system dynamics.

In a first set of experiments it is considered a one-lane road with a length $l = 1000$ m. Across the road are placed $m = 21$ sensors equally spaced. Therefore, sensor 1 (S_1) is placed at the beginning of the road (*i.e.*, at $x = 0$) and the last sensor (S_{21}) at the end (*i.e.*, at $x = l$).

In order to analyse the results of the Transfer Function (*TF*) between two sensors it is considered a one-lane (*i.e.*, $k = 1$) road with a traffic flow at the beginning of the road in the range $\phi_1(t) \in [1, 8]$ vehicles s^{1} and a vehicle speed in the range $v_1(t) \in [30, 70]$ km h^{1}. These values are generated according to a uniform probability distribution function.

Figure 3 shows the Polar plot of the *TF* $G^{1}_{21,1}(s) = \Phi_{21}(s)/\Phi_1(s)$ between the traffic flow at sensors S_{21} and S_1 on the one-lane, where $\Phi_i(s) = \mathcal{F}\{\phi_i(t)\}$ $(i = 1, 21)$. It can be observed that the result is distinct from those usual in systems theory revealing a large variability. Moreover due to the stochastic nature of the phenomena involved different experiments, using the same input range parameters, result in different *TF*s.

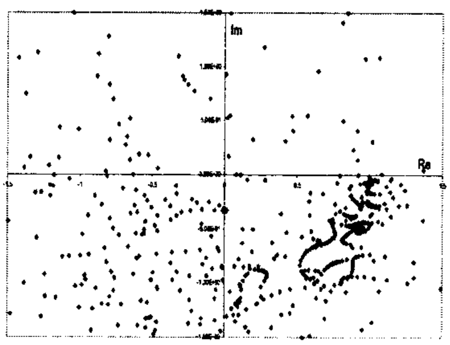

Figure 3 – Polar plot of *TF* $G^{1}_{21,1}(s)$ for one experiment with $\phi_1(t) \in [1, 8]$ vehicles s^{-1} and $v_1(t) \in [30, 70]$ km h^{-1}.

This phenomenon makes the analysis complex and experience demonstrates that efficient tools capable of rendering clear results are still lacking. Moreover, classical models are adapted to 'deterministic' tasks, and are not well adapted to the 'random' operation that occurs in systems with a non-structured and changing environment.

In order to overcome the problems, alternative concepts are required. Statistics is a mathematical tool well adapted to handle a large volume of data but not capable of dealing with time-dependent relations. Therefore, to surpass the limitations of statistics, it is adapted a new method [6], that takes advantage of the Fourier transform by embedding both tools.

In this line of thought, the first stage of the new modelling formalism starts by comprising a set of input variables that are free to change independently (*ivs*) and a set of output variables that depend on the previous ones (*ovs*). In a traffic system the *ivs* and *ovs* are defined as $\phi^k(x_i,t)$ and $\phi^k(x_j,t)$, that is the traffic flows at positions x_i and x_j respectively, for lane k ($k = 1,2,3\ldots$).

The second stage of the formalism consists on embedding the statistical analysis into the Fourier transform through the algorithm:

i) A statistical sample is obtained by carrying out a large number (n) of experiments having appropriate time/space evolutions. All the *ivs* and *ovs* are calculated and sampled in the time domain.

ii) The Fourier transform is computed for each of the *ivs* and *ovs*.

iii) Statistical indices are calculated for the Fourier spectra obtained in *ii)*.

iv) The values of the statistical indices calculated in *iii)* (for all the variables and for each frequency) are collected on a 'composite' frequency response entitled Statistical Transfer Function *(STF)* of each *TF*.

The previous procedure may be repeated for different numerical parameters (*e.g.*, traffic flow, vehicle speed, road geometry) and the partial conclusions integrated in a broader paradigm.

To illustrate the proposed modelling concept, was repeated the previous simulation for a sample of $n = 2000$ and it was observed the existence of a convergence of the *STF*, $T^1_{21,1}(s)$, as show in Fig. 4

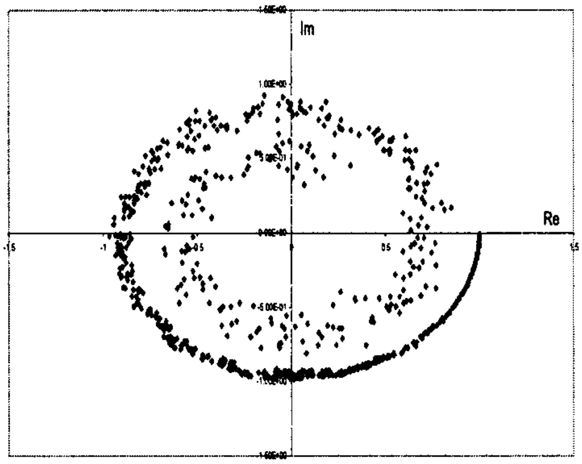

Figure 4 – The *STF* $T^1_{21,1}(s)$ for $n = 2000$ experiments with $\phi_1(t) \in [1, 8]$ vehicles s^{-1} and $v_1(t) \in [30, 70]$ km h^{-1}.

Based on this result we can approximate numerically the *STF* to a second order system with time delay yielding the approximate expression:

$$T_{21,1}^{1}(s) = \frac{e^{-\tau s}}{\left(\frac{s}{p}+1\right)^{2}} \quad (1)$$

where $\tau = 95.0$ sec and $p = 0.095$.

Further experiments and analysis are being carried out in order to identify the variation of $T(s)$ with the vehicle flow and speed.
In a second set of different experiments it is analysed the interference between vehicles. It can be observed that, the vehicles interfere with others in the same lane because they have different speeds. This results in a diminishing in the speed of the faster vehicle if the one preceding it is a slower one. The analysis of the traffic flow along the road, can be quantified through the entropy $H(x) = \frac{1}{N}\sum_i f_i \ln(f_i)$, where $f_i = n_i/N$, $N = 2048$ is the total number of vehicles used in the simulation and n_i is the absolute frequency.
The entropy decreases along the road because the faster vehicles have to diminish their speeds to match the speed of the slower vehicles.
A third set of simulations analyses the entropy variation for different ranges of vehicle speed. Figure 5 shows the results for an average vehicle speed of v_{av} =50 km h^{-1} in the ranges $v_1(t) \in [20, 80]$, $v_1(t) \in [30, 70]$, $v_1(t) \in [40, 60]$, $v_1(t) \in [45, 55]$ and $v_1(t) \in [48, 52]$ km h^{-1}.

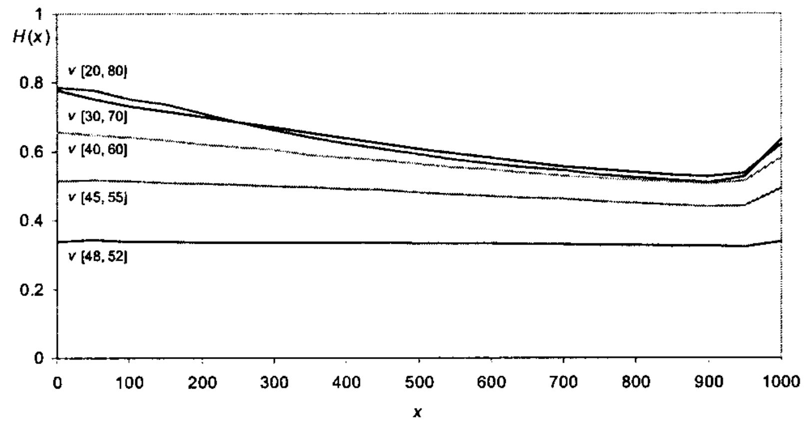

Figure 5 – Entropy $H(x)$ of the traffic velocity *vs.* the position x for a one-lane road with length l= 1000 m and average vehicle speed of v_{av}= 50 km h^{-1} with $\phi_1(t) \in [1, 8]$ vehicles s^{-1}

It can be observed that, for small ranges, the entropy remains almost constant and the transients are difficult to detect. This is justified by the fact that the vehicles have a small difference of speeds that originates a minimal interference among the vehicles. Also relevant are the rise of the output transient and the convergence of entropy, for larger velocity ranges.
In a last set of experiments it is compared the variation of entropy for roads with one and three lanes. As shown in figure 6, at the beginning of the road the entropy has almost the same value for both cases. For distances $x > 500$ m the entropy for the one-lane road decrease more than for three-lanes case. This happens because for a road with three-lanes it is applied a lane change scheme that results in diminishing the influence of the vehicles with lower speed on the traffic flow. For the same reason, in a three-lanes road, the entropy of the right lane is lower than the entropy of the left lane.

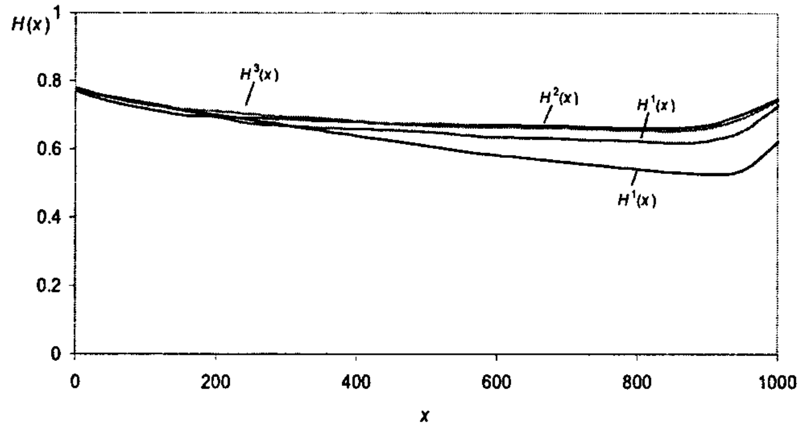

Figure 6 – Entropy $H(x)$ of the traffic velocity *vs.* the position x for one-lane and three-lanes roads with length $l = 1000$ m and $v_1(t) \in [30, 70]$ km h^{-1} and $\phi_1(t) \in [1, 8]$ vehicles s^{-1}

4. Conclusions

In this paper was described a software tool based on a microscopic simulation approach, to reproduce real traffic conditions in an urban or non-urban network. At this stage of development the SITS considers two types of driver behaviour model, namely car following and free flow. On the next stage of development we will include better driver behaviour models and lane changing logic. Another important improvement is the inclusion of aspects such as, road junctions, ramp-metering devices and signal control devices.

Several experiments were carried out in order to analyse the dynamics of traffic systems. The results of using classic system theory tools point out that it is possible to develop traffic systems, including the knowledge gathered with automatic control algorithms.

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