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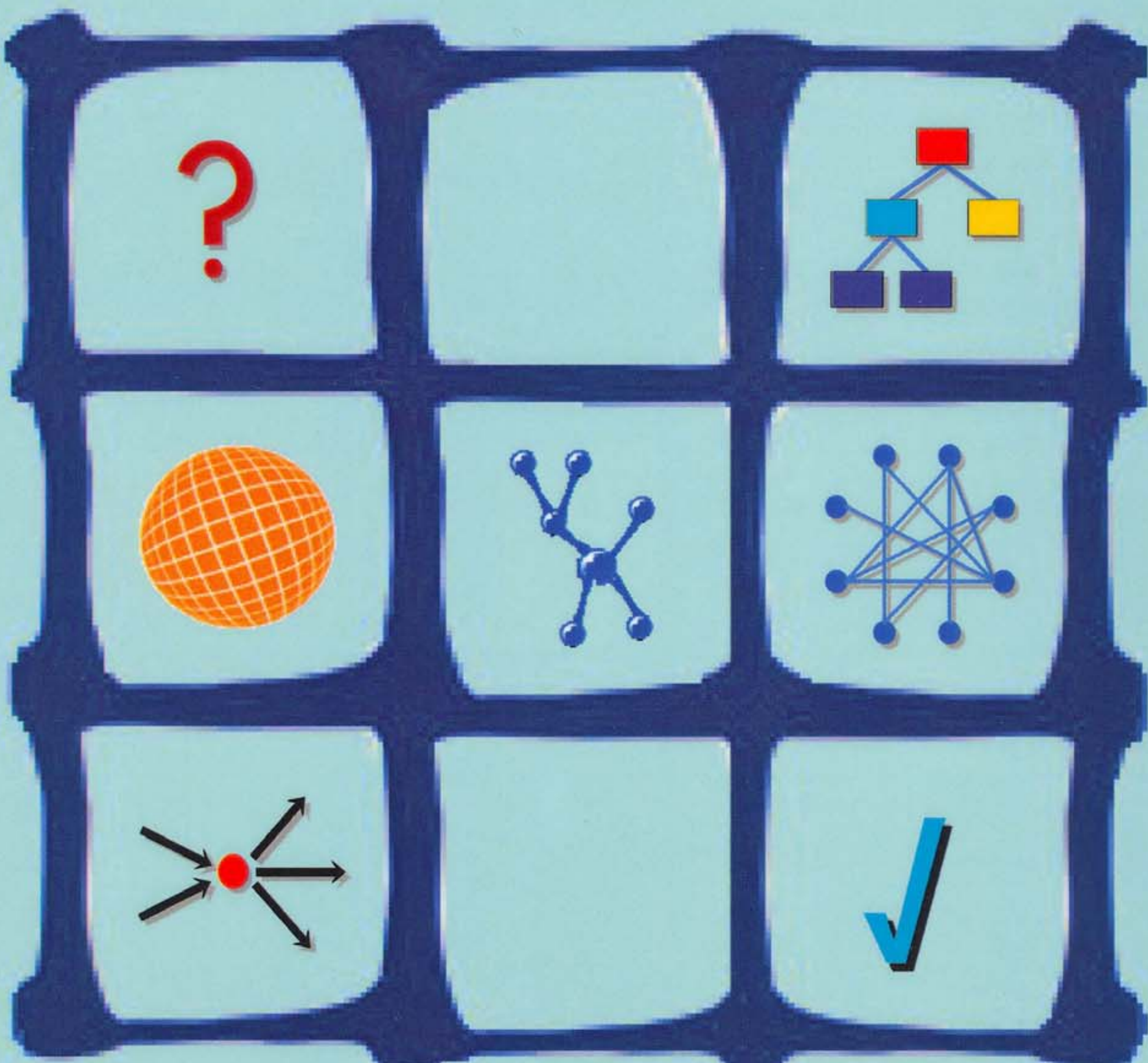

# A SIMULATOR OF INTELLIGENT TRANSPORTATION SYSTEMS

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**Abstract – This paper presents the most recent developments of the Simulator of Intelligent Transportation Systems (SITS). The SITS is based on a microscopic simulation approach to reproduce 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 net-work geometries. In order to analyse the quality of the microscopic traffic simulator SITS a benchmark test is per-formed.**

***Keywords: Simulation, modelling, Traffic System.***

## I. INTRODUCTION

The difficulties concerned with the saturation of the transportation infrastructures, due to the growing number of vehicles over the last five decades, motivated the research community to focus their attention in the area of ITS (Intelligent Transportation Systems). This research studies the technologies and the scientific aspects with the purpose of developing new systems capable of solving some of the most relevant problems, such as traffic congestion, accidents, transportation delays and large vehicle pollution emissions. ITS depend on results from research activities spread over many different areas such as electronics, control, communications, sensing, robotics and information systems. This multidisciplinary nature increases the problem's complexity because it requires knowledge transfer and cooperation among different research areas [1]-[3].

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

The traffic simulation models can be classified according to various criteria, namely, the scale of independent variables, the representation of the processes and levels of detail [4]. Presently, most traffic system simulation applications are microscopic in nature and based on the simulation of vehicle-vehicle interactions [5].

The main modelling components of a microscopic traffic simulation model are: an accurate representation of the road network geometry, a detailed modelling of individual vehicles behaviour and an explicit reproduction of traffic control plans. The recent evolution of the microscopic simulators has taken advantages of the state-of-the-art in the development of object-oriented simulators and graphical user interfaces.

Bearing these facts in mind, this paper is organized as follows. Section 2 discusses the state-of-the-art of model-ling and simulation of ITS. Section 3 describes the new developments of the microsimulation model SITS. Finally, section 4 presents some conclusions and outlines the perspectives towards future research.

## II. MODELLING AND SIMULATION OF ITS

Some authors define simulation as a dynamic representation of some part of the real world achieved by building a model and moving it through time [6]. A model of a sys-tem is an abstraction and an approximation to the actual one and should simplify the analysis of the system under investigation. The purpose of modelling is to help the analysis, design, control or understanding of a system without actually having to build the system [7]. We can say that modelling is a support tool for simulation.

The first research work on this subject was published in 1955 at the University of California, by D.L. Gerlough under the title "Simulation of freeway traffic on a general-purpose discrete variable computer" [8]. The car-following analysis based on GM models, is one of the oldest and most well known cases of the use of simulation in theoretical research. In these models, the movement of each vehicle in the platoon under analysis is governed by a differential equation [9]. After almost 40 years from the first trials, car-following is still under active analysis, being one of the basic questions of traffic flow theory [10]. In the recent years simulation models have been developed to support the analysis in almost all the areas of ITS namely in Advanced Traveller Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS).

In this section we give an overall view of the development of simulation models in road traffic planning and research, which is considered as the most prevalent in the transportation community. However, it should be noted that there are other simulation models available for use in aviation, railroad and maritime transportation [11].

The traffic simulation models can be classified according to various criteria, namely, the scale of independent variables, the representation of the processes and levels of detail [12].

The scale of independent variables can be related to one or all the independent variables associated with traffic, that is, actual position/velocity, desired position/velocity and time. However, since almost all traffic simulation models describe dynamic systems, where the time is al-ways the fundamental independent variable, the time-scale classification is the most natural. There can be distinguished two time scales, continuous and discrete. The continuous model describes the way the traffic system's change versus time, as a response to continuous stimuli. On the other hand, the discrete model considers that the state changes occur discontinuously at discrete time instants over the time.

The representation of the process can be done through deterministic or stochastic models. In the former all the entities represented in the model are defined by exact relationships (mathematical, statistical or logical). The stochastic models incorporate processes, which include random variables, or probability functions.

The classification according to the level of detail with which the traffic system is represented by the model can be divided in Microscopic, Mesoscopic and Macroscopic. The Microscopic simulation model describes both, the space-time behaviour of the system's entities (i.e. vehicles and drivers) as well as their interactions at a high level of detail (individually). The Mesoscopic model represents most entities at a high level of detail, but describes their activities and interaction at a lower level of detail. The Macroscopic model represents entities and describes their activities and interactions at a low level of detail. These models describe traffic at a high level of aggregation as a flow without distinguishing its constituent parts.

In Table 1 it can be observed some of the most relevant traffic simulation models, developed during the last forty years. They are classified according to the criteria de-scribed in the previous paragraph.

**Table 1 -** Traffic Simulation Models

| Detail Level | Model Name | Continuous /Discrete | Deter./ Stoch. |
|---|---|---|---|
| Micro | INTEGRATION | D | D |
| | NETSIM | D | S |
| | CORSIM | D | S |
| | TRANSIMS | D | S |
| | Cellular Automaton | D | S |
| Meso | DYNASMART | D | D |
| | Multilane Gas-Kinetic | C | D |
| | Improved Gas-Kinetic | C | D |
| Macro | FREFLO | D | D |
| | Helbing Type Models | C | D |
| | Cell Transmission | D | D |

Presently, most traffic system simulation applications are microscopic in nature and based on the simulation of vehicle-vehicle interactions. One of the few areas where macroscopic simulation has also been in use is the traffic flow analysis.

In macroscopic flow models the traffic stream is represented in an aggregated manner using some characteristics such as, flow-rate, density and velocity. Individual vehicle manoeuvres, like lane changes are usually not explicitly represented. Most of the well known macroscopic applications in this area originate from the late 60s or the early 70s. One example of macroscopic simulation of highway traffic is the cell-transmission model. In a cell-transmission scheme one partitions a highway into small sections (cells) and keeps track of the cell contents (number of vehicles) as time passes. The record is updated at closely spaced instants (clock ticks) by calculating the number of vehicles that cross the boundary separating each pair of adjoining cells during the corresponding clock interval. This average flow is the result of a comparison between the maximum number of vehicles that can be "sent" by the cell directly upstream of the boundary and those that can be "received" by the downstream cell [13]. A macroscopic model of mixed-lane freeway traffic is an example of Helbing type models. This model is derived from a gas-kinetic level of description, including effects of vehicular space requirements and velocity correlations between successive vehicles [14].

A mesoscopic model does not distinguish (nor traces) individual vehicles, but specifies the behaviour of individuals in probabilistic terms. Some mesoscopic models are derived in analogy to gas-kinetic theory. With a gas-kinetic model one can describe velocity distributions at specific locations and time instants. The dynamics of these distributions are generally governed by some processes that characterize the individual driver's behaviour (e.g. acceleration, interaction between vehicles, lane-changing) [15]. Multi-lane gas kinetic model and improved gas-kinetic model have a similar approach, although the former explicitly consider lane-changing. DYNASMART is a traffic simulation model designed as a research tool for the study of ATIS/ATMS scenarios at the network level, including the evaluation of strategies for providing traveller information, traffic control measures and rules for route assignment. DYNASMART is a mesoscopic model, which uses macroscopic flow models and simultaneously captures the movements of individual vehicles. Seven different driver (or behaviour) classes can be specified as a function of vehicle type, information availability and network restrictions. These classes allow modelling of user behaviour in response to ATIS information [16]. The model can simulate traffic signals, ramp meters and incidents. DYNASMART calculates optimal travel paths based on the simulated travel times and simulates the movements and routing decisions by individual drivers equipped with in-vehicle information systems [17].

Microscopic traffic simulators are simulation tools that emulate realistically the flow of vehicles on a road net-work. Micro-simulation is used for evaluation prior to, or in parallel with, on-street operation. The main modelling components of a microscopic traffic simulation model are: an accurate representation of the road network geometry, a detailed modelling of individual vehicles behaviour and an explicit reproduction of traffic control plans [18]. With these components it is possible to deal with ITS systems, like adaptive traffic control systems, automatic incident detection systems, dynamic vehicle guidance systems and advanced traffic management systems. The recent evolution of the microscopic simulators has taken advantages of the state-of-the-art in the development of object-oriented simulators and graphical user interfaces [19]. Also, the adaptation to traffic modelling requirements of the new trends in software design and the available tools to support it, was an important factor for the evolution of the microscopic simulators. A proper achievement of the basic requirements of a microscopic simulator implies building models as close to the reality as possible. There is a con-siderable number of developed microscopic simulation models. The SMARTEST project identified 58 of these models of which 32 are listed on Table 2 [20].

**Table 2 -** Types of models

| Urban | Motorway | Combined | Other |
|---|---|---|---|
| CASIMIR | AUTOBAHN | AIMSUN2 | ANATOLL |
| DRACULA | FREEVU | CORSIM | PHAROS |
| HUTSIM | FRESIM | FLEXSYT II | SHIVA |
| MICSTRAN | MIXIC | INTEGRATION | SIMDAC |
| NEMIS | SISTM | MELROSE | |
| NETSIM | | MICROSIM | |
| PADSIM | | MITSIM | |
| SIGSIM | | PARAMICS | |
| SIMNET | | PLANSIM-T | |
| SITRA-B+ | | TRANSIMS | |
| SITRAS | | VISSIM | |
| THOREAU | | | |

The main purpose of micro-simulation models is, from the model designers point of view, to quantify the benefits of ITS, primarily ATIS and ATMS. All the listed models classified as urban, motorway and combined types, address such objectives. The type "other" models have been de-signed with specific objectives like modelling of the tactical level of driving and testing of intelligent vehicle algorithms. They provide a detailed roadway environment for a simulated robot-driving vehicle, to evaluate the safety and comfort conditions of a line of cars on a single lane or to simulate strategies. In the sequel we give an overview of some of the micro simulation tools listed on the table 2.

SMARTEST is one simulation modelling project that covers the different areas of ATMS. It is applied to road transport European scheme tests and is the result of European Union research project. This project uses mathematical simulation modelling for dynamic traffic management problems. AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-urban Networks) is one of the SMARTEST's software tool based on a microscopic simulation approach, which reproduces real traffic conditions in an urban network. It provides a detailed modelling of the traffic network, distinguishing between different types of vehicles and drivers, modelling incidents and conflicting manoeuvres. The main types of input data to the simulator are the network description, the traffic signal control plans and the traffic conditions. The outputs consist in an animated graphical representation of the traffic network, printouts of statistical data and the data gathered by the simulated detectors.

The CORSIM traffic simulation program is a microscopic stochastic model of urban and motorway traffic operations. It combines a simulation model of urban traffic (NETSIM), and a simulation model of motorway traffic (FRESIM). Because it microscopic nature, CORSIM models each vehicle as a separate entity in the network. The behaviour of each one is represented in the model by the interaction with its surrounding environment, including traffic control and network geometry. CORSIM also models some active traffic control systems, which have influence on the behaviour of vehicles, like intersection controllers and ramp-metering devices [21].

INTEGRATION is a simulation model, completely microscopic, that tracks the lateral and the longitudinal movements of individual vehicles to the resolution of a decisecond. The algorithm for the car following is a kinematics model that calculates the individual vehicle speeds based on the macroscopic parameters of jam density, speed at capacity and free-flow speed. INTEGRATION also al-lows the demonstration of the dispersion of a platoon as it traverses the link, through the continuous variation of the density of traffic along a link. It uses up to five different driver/vehicle types to represent distinct routing behaviour or access privileges to real-time traffic conditions. Assessment of the effectiveness of route guidance systems, impacts of ramp metering on signal control strategies and the modelling of incidents are included in the model features and capabilities.

TRANSIMS (Transportation Analysis and SIMulation System) models are used to create a virtual metropolitan region by the complete representation of the region's individuals, their activities, and the transportation infrastructure. The trips are planned to satisfy the activity patterns. After that, TRANSIMS simulates the movement of individuals across the transportation network, including their use of vehicles on a second-by-second basis. So a virtual world of travellers is created, which mimics the travelling and driving behaviour of real people in the region. TRANSIMS attempts to capture every interaction considered important between travel subsystems, like the individual's activity plans and congestion on the transportation system. The TRANSIMS allow the creation of an integrated regional transportation systems environment, through the employment of advanced computational and analytical techniques. The models "simple car-following" and "lane changing logic" are based on cellular automaton technique. This technique is based on a discrete approach where the road and street network is build from elements that can accommodate only one vehicle at a time unit. In this cellular automaton approach the vehicles move by jumping from the actual element to a new one according to rules describing the driver behaviour while maintaining the basic laws of physics present in vehicle movements [22].

*A. Driver steering behaviour, traffic safety and nanosimulation*

An important issue is the modelling and simulation of the driver steering behaviour. Due to the development of vehicles incorporating new technological devices, a deeper knowledge about the interaction between the vehicle and the driver becomes of great usefulness for the vehicle design. Some projects are undergoing focusing on this particular aspect. One of these projects consists on the development of a driver's model, representing his real behaviour, based on issues like surveillance and steering expertise. For example, the model considers the driver's control actions tacking into account the point where he fixes his attention. In fact, traffic safety simulation related questions have been quite a hard problem for simulation. Usually, in simulation programs, the drivers are programmed to avoid collisions, so they do not exist. Al-though some trials for analysis of conflict situations have been made [23], a general approach to this problem is still missing. Traffic safety simulation is sometimes classified as nanosimulation, belonging to the field of human centred simulation where the perception-reaction system of drivers and all its characteristics are described.

## III. THE SITS SIMULATION PACKAGE

SITS is a software tool based on a microscopic simulation approach, which reproduces real traffic conditions. The program provides a detailed modelling of the traffic net-work, distinguishing between different types of vehicles and drivers and considering a wide range of network geometries. SITS uses a flexible structure that allows the integration of simulation facilities for any of the ITS related areas. This new simulation package is an object-oriented implementation written in C++.

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 overall model structure is represented on Figure 1 [24].

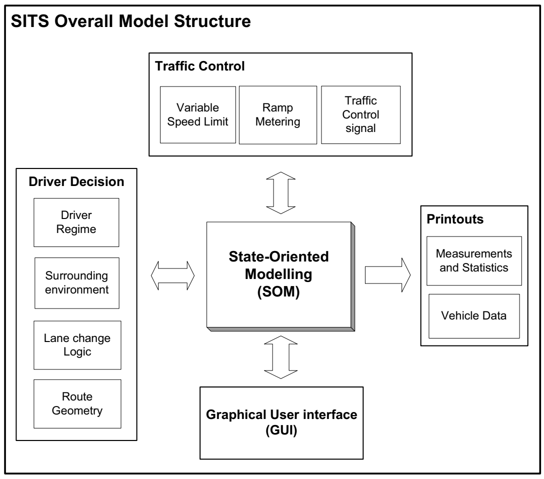


**Figure 1 -** SITS overall Model Structure

In this structure, a nuclear module, State-Oriented Modelling, interacts with the Traffic Control and Driver Decision modules. 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.

*A. State-Oriented Modelling*

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

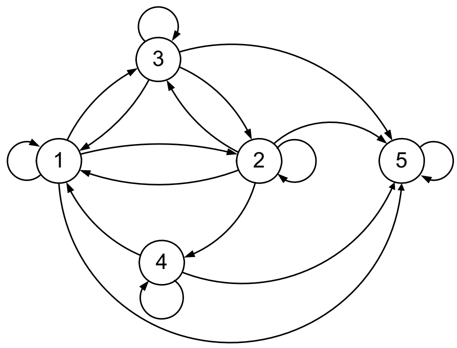


**Figure 2 -** SITS state diagram: 1-aceleration, 2-braking, 3-cruise speed, 4-stopped, 5-collision

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 (braking), although it is possible to move from state #2 to state #4.

Included on the most important elements of SITS are the network components, travel demand, and driving decisions. Network components include the road network geometry, vehicles and the traffic control. To each driver is assigned a set of attributes that describe the drivers behaviour, including desired speed, and his profile (e.g., from conservative to aggressive). Likewise, vehicles have their own specifications, including size and acceleration capabilities. Travel demand is simulated using origin destination matrices given as an input to the model.

*B. Driver Decision*

At this stage of development the SITS implements different types of driver behaviour models, namely car following, free flow and lane changing logic. SITS considers each vehicle in the network to be in one of two driver regimes: free flow and car-following [25].

The free flow regime prevails when there is either (i) no lead vehicle in front of the subject vehicle or (ii) the leading vehicle is sufficiently far ahead that it does not influence the subject vehicles behaviour. In the free flow case the driver travels at his desired maximum speed.

Car-following regime dictates acceleration/deceleration decisions when a leading vehicle is near enough to the subject vehicle in order to maintain a safe following distance.

*1) Perception-Driver Model*

Accelerations and decelerations are simulated using the Perception-Driver Model (PDM). According with the PDM, the driver decides to decelerate/accelerate depending on two factors: the difference between the distance to the leading vehicle and the critical distance, and his active state. The critical distance $d_{c,n}$ is defined as follows:

$$d_{c,n} = d_{sb,n} + d_{f,n} + L_{n+1} \qquad (1)$$

where: $d_{sb,n}$ is the safety braking distance for the vehicle $n$, given by equation (2), $d_{f,n}$ is the following distance for the vehicle $n$, given by equation (5) and $L_{n+1}$ is the length of the leading vehicle.

Figure 3 shows a schema of the critical distance for the $n^{th}$ vehicle (assuming that the traffic conditions for both vehicles remain constant between time instants $t_0$ to $t_1$).

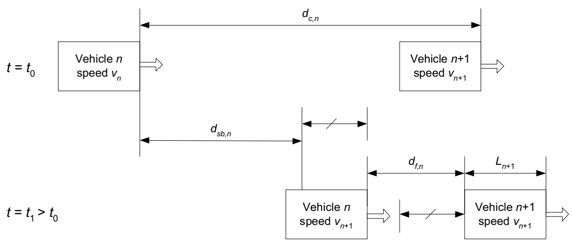


**Figure 3 -** Critical distance schema

The safety braking distance $d_{sb,n}$ is given by:

$$d_{sb,n} = -\frac{\left(v_{n+1} - v_n\right)^2}{2\left(a'_n - s_{n+1}\right)} \qquad (2)$$

where: $v_n$ is the current speed of vehicle $n$, $v_{n+1}$ is the current speed of leading vehicle $n$+1, $a'_n$ is the deceleration of vehicle $n$ given by equation (3) and $s_{n+1}$ is the deceleration/acceleration of the leading vehicle $n$+1, given by equation (3) or (4) depending on his current state.

The driver reduces the speed by applying a deceleration $a'_n$. The model relates the vehicle performances with the driver characteristics.

$$a'_n = a'_{\max,c}\ \gamma_d \qquad (3)$$

where: $a'_{\max,c}$ is the maximum deceleration for a vehicle of type $c$ and $\gamma_d$ is a parameter for driver type $d$ ($0.1 < \gamma_d < 1.0$).

The value of $\gamma_d$ can be changed at any time in order to prevent a collision. This parameter defines the driver profile (*e.g.*, from conservative $\gamma_d = 0.1$ up to aggressive $\gamma_d = 1.0$).

The value of the deceleration/acceleration $s_{n+1}$ depends on the state of the leading vehicle. If the vehicle is in state #2 then $s_{n+1}$ is given by equation (3); otherwise if it is in state #1, $s_{n+1}$ is given by equation (4). Therefore, $s_{n+1} = 0$ only when the vehicle is in one of the other states.

$$s_{n+1} = a_{\max,c}\ \gamma_d \qquad (4)$$

where: $a_{\max,c}$ is the maximum acceleration for a vehicle of type $c$.

The following distance $d_{f,n}$ depends on the speed of vehicle $n$ and the associated driver profile, yielding:

$$d_{f,n} = v_n^2\ \gamma_d \qquad (5)$$

*2) Lane Changing Model*

The lane changing model in SITS uses a methodology that tries to mimic a driver behaviour when producing a lane change. This methodology was implemented in three steps: (*i*) decision to consider a lane change; (*ii*) selection of a desired lane; (*iii*) execution of the desired lane change if the gap distances are acceptable. A driver produces a lane change maneuver in order to increase speed, to overtake a slower vehicle or to avoid the lane connected to a ramp. After selecting a lane, the driver examines the lead $g_b$ and lag $g_a$ gaps in the target lane in order to determine if the desired change can be executed, as shown in Figure 4.

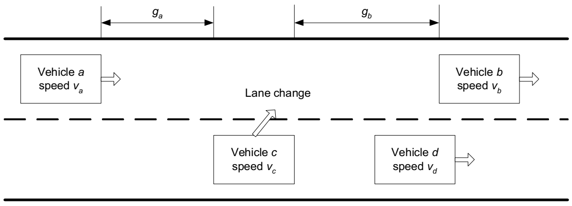


**Figure 4 -** Lead $g_b$ and lag $g_a$ gaps for a lane change manoeuvre of vehicle $n$

If $g_a$ and $g_b$ are higher than the critical distances between vehicle $a$ and $c$, and $c$ and $b$, respectively, then the desired lane change is executed in a single simulation sampling interval $\Delta t$.

### C. Graphical User Interface

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 $\Delta t = 10^{-2}$ 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 5.

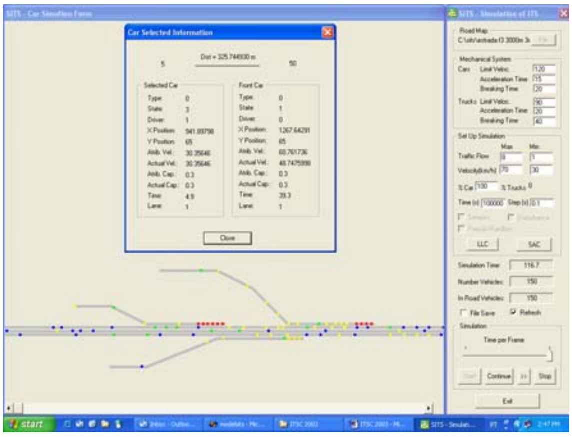

**Figure 5 -** SITS animated graphical representation

## IV. MODEL CALIBRATION AND TESTING

The research group of Robert Bosh GmbH developed in 1998 a benchmark to analyze the quality of microscopic simulators by checking their ability to reproduce a macroscopic behaviour [26]. More recently, this benchmark was also used to evaluate the performance of the AIMSUN simulator [27].

In [26] the authors test the macroscopic behaviour of a microscopic model by simulating the traffic on a cyclic one lane road with a length of $l$ = 1000 m. A fixed number $N$ of identical vehicles (4.5 m length) is set with a initial speed of $v$ = 0 km/h, at randomly positions, having a limit free flow speed of $v$ = 54 km/h. After elapsing the starting transient the steady-state traffic behaviour is recorded (the exact passing time and the speed value of each vehicle) at one measurement point during a period of 2 hours. The benchmark procedure consists on varying the number $N$ of vehicles to accomplish different traffic densities $Q$ and the corresponding traffic flow $\phi(Q)$.

Having this benchmark in mind, Figure 6 plots the traffic flow $\phi$ *versus* its density $Q$ for the empirical (macroscopic), the SITS and the AIMSUN [27] simulators.

The output of SITS is clearly in accordance with the expected results. Moreover we have a maximum traffic flow of about 1800-2000 vehicles/km, which is known as a realistic value for long periods of measurement time.

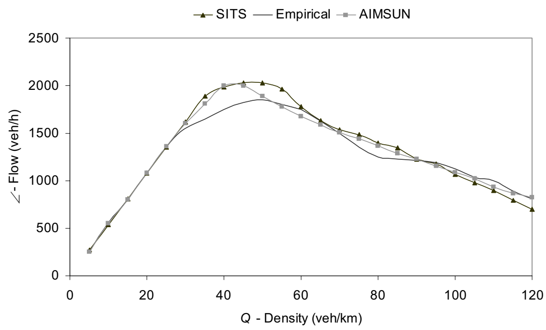


**Figure 6 -** Empirical (macroscopic) versus SITS and AIMSUN simulated flow density curves

## V. CONCLUSIONS

In this paper, we described a software tool based on a microscopic simulation approach, to reproduce real traffic conditions in an urban or nonurban network. At this stage of development the SITS considers different types of driver behaviour model, namely car following, free flow and lane changing logic.

On the next stage of development we will include better driver behaviour models and traffic safety models. Another important improvement is the inclusion of aspects such as, ramp-metering and signal control devices.

In order to analyze the quality of the microscopic traffic simulator SITS a benchmark test was performed. The output of SITS is clearly in accordance with the expected results.

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