AN OPEN-SOURCE BASED GIS AND SIMULATION SOFTWARE: A CASE STUDY FOR CONTINGENCY PLANNING IN MICROREGIONS

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ABSTRACT

Traffic analysis by means of discrete event simulation is being more and more used to find good solutions to traffic problems. A geographic information system (GIS) is a software application which can process and analyze spatial data. Integrating a simulation tool and GIS gives more flexibility to deal with the spatial data consumed and generated by simulations. The main goal of this work is to present a traffic simulator developed in Java and integrated to a GIS tool. A case study conducted in Belo Horizonte, Brazil, is shown, along with the analysis of a contingency plan to a street interdiction situation. Some contingency situations in the given region were tested in simulation to find alternate solutions to the problem. Statistical results are presented to assure the adequability of the approach and the useful features it can provide the traffic operation personnel.

1. INTRODUCTION

Currently, vehicle traffic in big cities is a major problem faced by public agencies. Time spent in traffic, excessive fuel consumption and the stress generated to the drivers and passengers are serious consequences that can be mitigated with a good traffic planning. One of the actions towards a better traffic would be to expand the road network in order to relieve the areas of greatest flow. However, this action is limited to the availability of financial and physical resources that, in most cases, are scarce. On the other hand, it is possible to optimize the road network characteristics in order to improve vehicular traffic. This can be done by programming traffic lights, changing the tracks' direction and making preventive decisions for already planned interruptions, among other actions. Among many tools that support the work of the Traffic Engineer, the simulation technique appears to be very important, allowing to identify solutions to the numerous traffic problems (PORTUGAL, 2005).

A traffic simulator is a tool that is characterized by the ability to reproduce, in a computer, the real situations that occur in city traffic, generating information that will support the decision-making. As shown by Poyares, cited by Portugal (2005, p. 105), the simulation allows to analyze various situations and to anticipate positive and negative impacts generated by a chosen particular alternative. Besides, it allows for simulating situations that are difficult or unlikely to be encountered in practice.

Geographic Information Systems (GIS) have been increasingly used in the transport area as a source of information. The ability to model, process and analyze spatial data, in addition to the increasing availability of geo-referenced maps, makes them suitable for dealing with the information necessary for traffic simulation. The work of Pinto et al. (1998) can be cited as an example of use of GIS as a platform for data management for transport models.

Among the various kinds of information used by simulators as data sources, the network model can be highlighted. It represents the road network using a set of arcs and nodes that form the network. Each arc represents a segment of the road and each node, a crossing or endpoint. Figure 1 shows an example of such a network. Network models allow existing attributes to be linked to the geometries. These attributes can describe the characteristics of a particular passage, as the number of lanes, the average vehicle flow, names of the streets and so on.

Figure 1: Network model of the transport system of Sete de Setembro Square (BH, Brazil)

The simulator used in this article is being developed by the Geoprocessing and Intelligent Systems Project at the Federal Center for Technological Education of Minas Gerais State (CEFET-MG). This project was initiated by Viana Junior (2004), who proposed the use of *fuzzy* logic as a technique for intelligent path planning. Then, Silva (2006) continued this work by integrating the solution proposed by Viana Junior (2004) to an open-source GIS tool called *OpenJump*. Subsequently, Saliba Neto (2009) developed the simulator presented in this article using the same architecture proposed by Silva (2006). The aim of this paper is to present this simulator through a case study in the hyper-center region of Belo Horizonte, Brazil, analyzing alternatives to the interdiction of a street.

In the next section, a theoretical review on Geographic Information Systems is made. Section 3 presents computer simulation and traffic concepts. Section 4 presents the *GISSIM* simulator. In Section 5, the simulator is utilized in a case study and some analysis are depicted. The last section presents the final considerations.

2. GEOPROCESSING AND GEOGRAPHIC INFORMATION SYSTEMS

According to CASANOVA et al. (2005), Geoprocessing is an interdisciplinary technology that allows the convergence of different disciplines for the study of urban and environmental phenomena. Broadly, Geoprocessing relates to the processing of data from a geographic area. For this processing, it is used data with a spatial nature, such as geographical coordinates, and also those that somehow can be georeferenced, that is, linked to other data that can be found in the earth's surface. The spatial data can be called cartographic data, which are the graphical representation of the studied entities' location and geometry. The alphanumeric data are usually stored in tables and contain information describing the existing entities. Figure 2 illustrates the difference between cartographic and alphanumeric data.

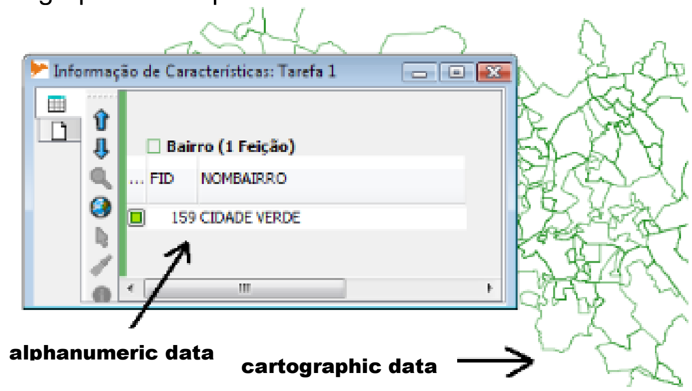

Figure 2: Comparison between cartographic and alphanumeric data

Lewis (1990) considers a geographic information system as a computer database management system which is used to capture, store, retrieve, analyze and visualize spatial data.

To House and Queiroz (2000), the term Geographic Information Systems (GIS) is applied to systems that perform the computational analysis of spatial data and retrieve information based not just on their alphanumeric characteristics, but also based on its spatial location. To make this possible, data geometry and attributes in a GIS must be georeferenced, that is, allocated in the earth's surface and represented in a cartographic projection.

Geographic Information Systems have been increasingly used in the transportation field. In this specific sector, these systems are known as GIS-T (GIS for Transportation). According to Rose (2001), the scope of GIS-T is wide both in planning and in transportation operations. Among the various applications of GIS in transportation, one can cite the geometric design of roads, traffic monitoring and control, transport supply and demand, accident prediction, route optimization, monitoring and controlling road operations.

In the area of traffic engineering, Thieman (2008) used a GIS-T to analyze accidents in avenues, when the system was utilized to visualize streets that were congested due to accidents. In Wu et al. (2001), a GIS-T was used as a decision support system for analyzing the choice of routes in congested traffic networks.

In this work, a GIS platform was used and extended, the *OpenJump,* a free and open source software written in Java programming language. *OpenJump* has in extensibility one of its main features, which allows for the addition of new modules, providing flexibility to the resulting GIS applications.

3. COMPUTER SIMULATION

The behavior of a physical system can be studied through simulation models. According to Owen et al. (1996), a model consists of presentation, representation, or idealization of selected aspects of the structure, behavior and other characteristics of a process or system from the real world. As Lieberman and Rathy (1997) put it, simulation is a powerful tool for analyzing a wide variety of dynamic problems that would be difficult to solve by other means. These problems are characterized as complex due to the large number of simultaneous interactions between various components and entities involved. These interactions generally cannot be adequately described in a logical or mathematical way. However, the behavior of each entity and/or the interactions of a limited number of elements can be understood, thus allowing for a logical and mathematical representation with an acceptable confidence.

In the definition by Miyagi (2004), simulation is seen as an "imitation" of an operation or procedure from the real world. It involves the generation of an "artificial history" to a system for the analysis of its operational characteristics. Once developed and validated, this simulation model can be used in the investigation of a wide variety of questions about the system. In some cases, this model is based on mathematical formulations. However, mathematical models of very complex problems tend to be too difficult to be developed and used. In these cases, simulation techniques are used to reproduce the behavior of the system at a certain time interval. In most cases, the model is implemented in a computer. As a result, the term "simulation" is synonymous to "computer simulation". Although simulation can be done manually, the time spent to perform the large amount of required calculations make this approach unfeasible in practice.

3.1. Traffic Simulation

The increasing expansion of the vehicles fleet in big cities has been causing serious traffic problems, requiring a greater planning and control from the agencies that regulate city traffic. The use of traffic simulation has proven to be a very important tool in the analysis and prevention of traffic related problems, especially in the cities. It allows quantifying the effects of many changes in the system before they are effectively implemented. According to Bazzan & Klügl (2007), the control of traffic flow has as main objectives providing an orderly movement of traffic, increasing the traffic capacity at the intersections, reducing accident rates, stopping the main traffic in benefit of the secondary traffic and, possibly, synchronizing the traffic lights in order to allow for a continuous traffic movement at a certain speed.

The best-known simulators are developed in other countries and do not always consider some specific characteristics of the traffic at Brazilian cities. Also, these tools often do not meet the financial reality of most traffic regulators from our country, i.e., purchasing of such tools do not fit their annual budgets.

Traffic simulation models are generally classified according to the aggregation level to the physical system under investigation (KRAJZEWICZ et al., 2002, Lieberman and RATHI, 1997, Wang and Prévédourou, 1996).

3.1.1. Macroscopic

In this approach, traffic is treated with a low level of detail. It is represented as a single entity, ignoring the individuality of the vehicles. The relationship between flow, speed and density describes the operation of the system. The models are less flexible, with fewer details, but in return they require less computational effort. As a result, they are well suited for modeling large networks.

3.1.2. Microscopic

Microscopic models are characterized by a high level of detail. Both vehicles and other entities of the system can be represented individually. The movement of vehicles occurs both along and across the lanes. Due to the high level of detail and the large number of interactions between entities, this approach requires a great computational effort and a complex, difficult and time consuming calibration process.

3.1.3. Mesoscopic

Here, the models have an intermediate level of detail. It is a mixed approach that represents some entities in the aggregated form and others with some level of detail. They are usually used in traffic light networks.

3.1.4. Sub-microscopic

Also known as nanoscopic, it considers the individual vehicles, such as the microscopic classification. However, it has a greater level of detail, considering, for instance, the rotation of the vehicle's engine. This allows for more detailed calculations such as, for example, the emissions of pollutants produced by vehicles. Figure 3 illustrates the different levels of aggregation.

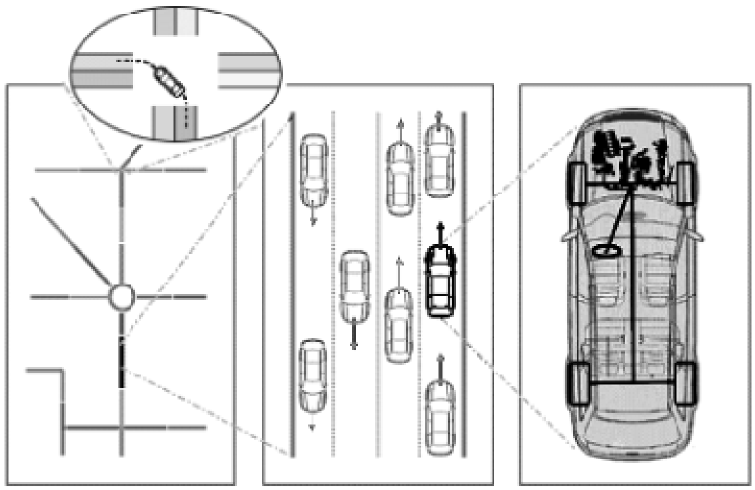

Figure 3: Classes of Simulation
(from left to right: macroscopic, microscopic, sub-microscopic; in the circle: mesoscopic).
Source: KRAJZEWICZ et al., 2002

Traffic simulators, especially the microscopic ones, are characterized by requiring a large amount of input data such as, for instance, about the road network from the region to be studied. Assuming that it is increasingly common the use of Geographic Information Systems by municipalities as a tool for urban planning, it is plausible to use such tools as a data source for the simulators, making it possible to reutilize the spatial information of the road network, such as roads and location of traffic lights, among others. The simulator used in this article is classified as microscopic because it is able to deal individually with various system entities like vehicles, individual lanes and semaphores.

3.2. State-of-art

Traffic simulation is a recurrent study area in the specialized literature. Panwai and Dia (2005) presented a comparative study on the behavior of car-following models. These models represent one of the most important processes in microscopic simulations, for defining the interaction between adjacent vehicles in the same road. The authors selected three of the most used traffic simulation tools (AIMSUN, VISSIM and PARAMICS) and made a comparative evaluation of the implemented car-following models. A comparison was made between the behavior of the evaluated car-following models and the results collected by an instrumented vehicle in the field. This work is notable for comparing car-following models used by commercial tools, helping in the process of choosing and validating the model to be implemented.

Bazzan & Klügl (2007) describe new trends in transport and traffic engineering and in intelligent transportation systems (ITS). The introduction of new techniques related to ITS and Advanced Traveler Information Systems (ATIS), which can disseminate various information to the system users, such as alternative routes and blocked roads, made the traditional simulation tools evolve in order to reproduce the driver's behavior. In microscopic simulation, specifically, one can cite the use of agent-based simulation (ABS). In this type of simulation, it is possible to model the decision-making process of the driver or any other agent of the system. This work also lists some challenges to be overcome by researchers from the field of intelligent transport systems. The use of automated highways is one of them. In this type of road, vehicle control is completely automated, as acceleration, deceleration and lane change actions.

Pinto et al. (1998) discussed the use of a GIS for the construction of a transport network topology to be used in the mesoscopic simulator SATURN. According to the authors, the use of this tool has provided simplicity in assembling the network and significant time saving. This work highlights the importance of using GIS as a reference database for the cities' road systems, allowing for a systematic information maintenance process. Furthermore, the authors cite some of the problems that must be overcome during the process of integrating a GIS and a traffic simulator.

Claramunt et al. (2000) proposed the creation of a framework for real-time integration, analysis and visualization of urban traffic data with GIS. This type of integration is suitable for the analysis of data generated by a simulator or a real-time traffic monitoring system. This work highlights the importance of the spatial analysis of traffic data, complementing the commonly used outputs, such as graphs and charts.

Gonçalves (2003) presents a conceptual way to implement the behavior of intelligent agents in a spatial context using GIS, multi-agent systems and discrete event simulation. In this approach, the spatial components are classified as passive (no dynamic behavior) and active (spatial agents).

4. THE *GISSIM* SIMULATOR

The simulator used in this work, called *GISSIM,* is based on the microscopic approach because it deals individually with each vehicle and other existing entities. Each vehicle internally maintains all the features of interest to the system by means of an alphanumeric database. The movement along the roads is governed by car-following laws, and the vehicles' behaviors at intersections is more detailed and complex.

The main sources of information for the simulator are the city cartographic databases, which often have a lot of data about city roads and streets. It is natural that such information comprehends the entire length of the city. However, due to its microscopic character, the simulation area must be restricted to a small study region. Figure 4 shows the detail of a road network selected for simulation.

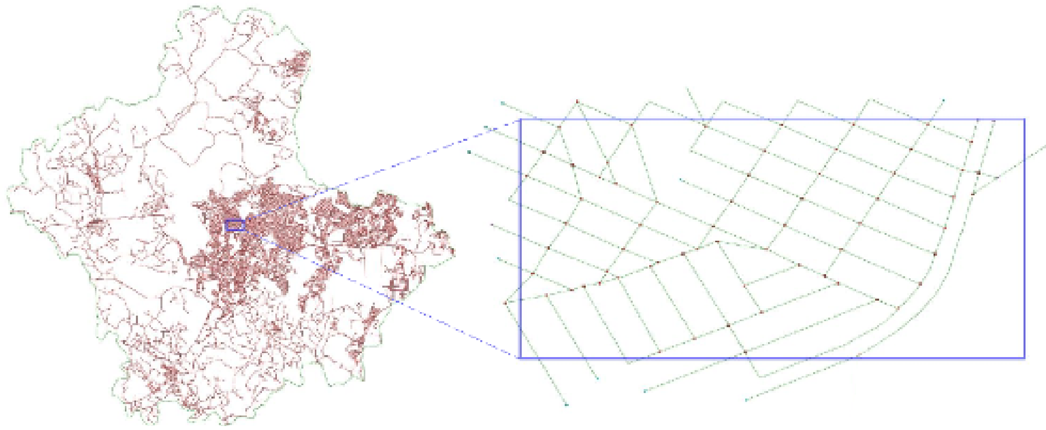

Figure 4: Detail of the simulation area.

Usually the street addresses cartographic databases are split at intersections, that is, a path is composed of several parts. This feature allows the map data to be loaded into a data structure called graph, which is composed by edges (sections) and nodes (crossings). The generated graph structure is of the directed type, in which the directions of the edges are defined according to the direction of the geometries vectorization. The directions of the graph's edges correspond to the direction of vehicle movement along the road network. Besides these features, *GISSIM* allows for the storage of other information about the traffic network, for instance, if a street flow is bidirectional. The nodes of the graph represent intersections and points of vehicle input / output from the network.

In the input nodes to the network, the values of VPH (vehicles per hour) are provided. From this information the gap between the vehicles can be calculated. As for the vehicle flow distribution per intersection, it is defined in a file in XML format.

One of the main models used in traffic simulation is the one based on vehicle movement, or *car-following.* The motion model is applied when calculating the vehicles speed. This calculation is done, basically, depending on the actual distance from the vehicle to an obstacle immediately in front of it. One obstacle may be a vehicle or a crossing, if the vehicle doesn't have the right of way. In this study, the linear car-following model was implemented, known for its simplicity and yet close relationship to actual traffic behavior. In this linear model, the vehicle tries to move at maximum allowed speed, if there is no obstacle in front. The vehicle speed is increased to a constant acceleration to the limit imposed by the roads maximum speed. If the vehicle reaches a certain distance from an obstacle, it slows down proportionally to this distance. If a minimum distance is reached, the vehicle must completely stop.

The rules of gap acceptance, on the other hand, are applied in priority crossings. This rule is applied whenever a vehicle is stopped at an intersection and needs to move. The simulation model applied in this article's simulator does not allow car crashes, so the time spent by a vehicle crossing an intersection must be compatible with the available time gap.

The gap calculation is based on the time spent by vehicles entering the intersection, which is calculated in accordance with the speed of each vehicle and the distance between their front bumper and the junction. The gap is accepted when the minimum time of vehicles arrival is greater than or equal to a predefined parameter of gap acceptance.

An important feature of the simulator utilized in this article is the use of instrumented vehicles. An instrumented vehicle has all the features of a common vehicle, except for the ability to follow a predefined fixed path. In common vehicles, the path is set during the simulation, according to the system information about the traffic volume at the intersections. The function of this type of vehicle is to gather information about fixed travels and general statistics from the simulation.

5. CASE STUDY

This section shows the use of the *GISSIM* simulator through a case study conducted in the region known as hypercenter in the city of Belo Horizonte, Brazil.

The site selected for the case study was Tamoios Street, located near two of the main avenues of Belo Horizonte, Amazonas and Afonso Pena. The case study is based on a possible interdiction in this street on the section between Rio de Janeiro Street and Afonso Pena Avenue. Two alternatives were considered. The first one (Alternative 1) would be the natural choice, without any intervention in the roads directions. In this alternative, from the point of origin, the vehicle should turn right at Rio de Janeiro Street, climb up till the corner with Goitacazes Street, turn left on Espírito Santo Street and continue in this road until reaching the destination point, located at the crossing between Avenida Afonso Pena and Espírito Santo Street. Figure 5 shows this alternative.

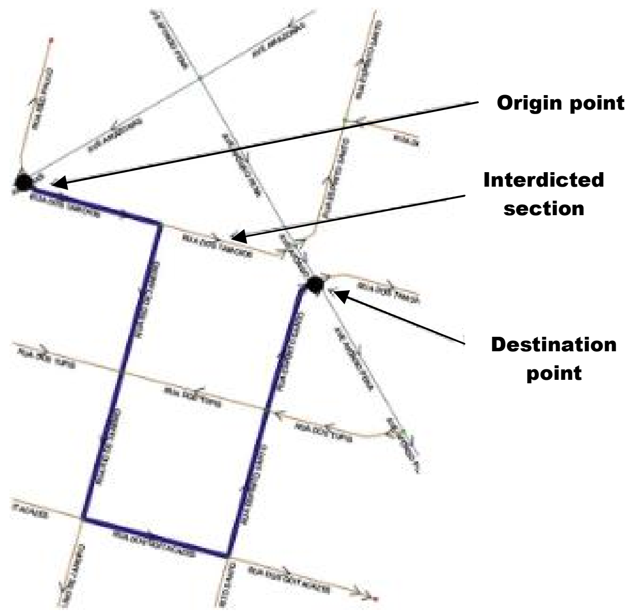

Figure 5: Detail of alternative 1

In the second alternative (alternative 2), it was suggested the reversal of Tupi Street's direction in the section located between Rio de Janeiro Street and Afonso Pena Avenue. Figure 6 details this alternative.

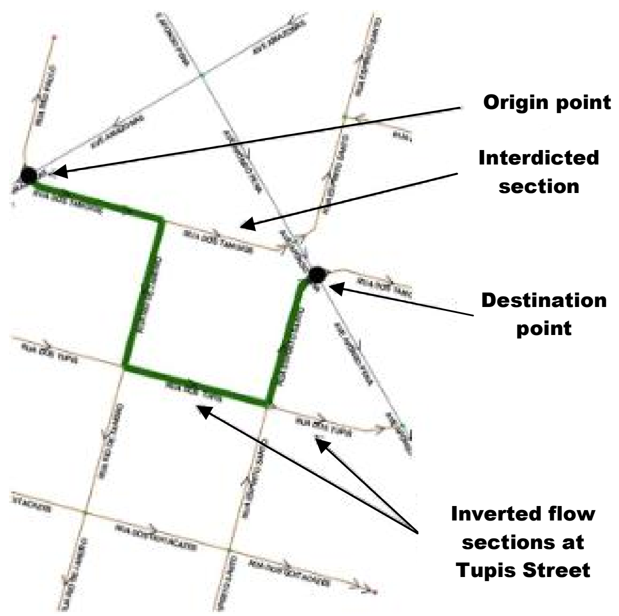

Figure 6: Detail of alternative 2

To collect travel times, some simulations were made for each alternative. Travelling time was collected by an instrumented vehicle that had the alternatives 1 and 2 as predefined routes. Then, the arithmetic means and standard deviations were calculated.

The distances of the original and alternative routes are, respectively, of 829 and 547 meters. Table 1 shows averaged results obtained in the simulation.

Table 1: Results of simulation

	Original Route		Alternative Route	
Simulation Number	Time (seconds)	Average speed (km / h)	Time (seconds)	Average Speed (km / h)
1)	294	10.15	114	17.27
2)	264	11.30	124	15.88
3)	296	10.08	102	19.31
Arithmetic Mean	284.67	10.51	113.33	17.49
Standard Deviation	17.93	0.69	11.02	1.72

Analyzing the results of the simulation, it is possible to notice that the adoption of the proposed alternative route indicates a significant gain in travel time. The total length of this alternative route also explains the benefit observed in the simulation.

6. FINAL CONSIDERATIONS

The utilization of traffic simulation software is increasing a lot around the world. The use of these tools is becoming more and more widespread and, especially in Brazil, there are numerous studies that apply traffic simulators in the search for solutions to many problems. With the spread of the use of simulators, it is sought a decrease in the use of subjectivity in the traffic management decision-making process. However, the high cost of commercial simulators can be an impediment to the utilization of these tools on a larger scale.

This paper presented a traffic simulator for microregions that is open-source and integrated to a GIS. We conducted a case study in the hypercenter region in the city of Belo Horizonte, analyzing the possible alternatives to a street interdiction. The results, obtained by the use of this simulator, suggested that the alternative proposal is feasible and more desirable than the natural solution, which does not alter any driving direction in the region. The average transit time gains using the alternative route, through Tupis Street, is of 51% compared to the use of the natural route, through Goitacazes Steet.

It is important to highlight that the simulator has important limitations, for example, a limited amount of lanes per road and no signal light intersections. These limitations are due to the current stage of the tool, which has still much to evolve with the development of future works.

REFERENCES

Bazzan, Ana L. C.; Klügl, Franziska. (2007) - Sistemas Inteligentes de Transporte e Tráfego: uma Abordagem de Tecnologia da Informação. *Annals of Jornadas de Atualização em Informática*, Rio de Janeiro, v. 1. p. 2296-2337.

Casanova, M.A.; Davis, C.; Vinhas, L.; Queiroz, G.R.; Câmara, G. (2005) - *Banco de Dados Geográficos*, São Paulo. MundoGEO.

Claramunt, C.; Jiang, B.; Bargiela, A. (2000) - *A new framework for the integration, analysis and visualization of urban traffic data within geographic information systems.* Transportation Research Part C 8 p. 167-184.

Gonçalves, Antônio. (2003) - *Multi-Agentes para Simulação em Sistemas de Informação Geográfica*. Master Thesis, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, Lisboa.

Krajzewicz, Daniel; Hertkorn, Georg; Wagner, Peter. (2002) - An Example of Microscopic Car Models Validation using the open source traffic simulation SUMO. *Proceedings 14th European Simulation Symposium*. Dresden, Germany.

Lieberman, E. e Rathi, A. K. (1997) - *Traffic Simulation. The revised monograph on traffic flow theory*. EUA: Federal Highway Administration.

Miyagi, P.E. (2004) - *Introdução a simulação discreta*. USP, Sao Paulo-SP.

Owen, B.; Brock, G.; Mastbrook, P.; Pavlik, R.; Rao, S.; Stallard, C.;Sunkari, Z.; Zhang, Y. (1996) - *A compendium of Traffic Model Validation Documentation and Recommendations: Phase I, Tasks A-H.* USA: Department of Transportation. Available on: <http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/3892.pdf > Acessed in 15 jan. 2008.

Panwai, Sakda e Dia, Hussein. (2005) - *Comparative Evaluation of Microscopic Car-Following Behavior*. IEEE Transactions on Intelligent Transportation Systems, vol. 6, no. 3.

Pinto, A. B. ; Cybis, H. B. B. ; Araújo, D. R. C. ; Lindau, L. A. (1998) - *Utilização de um sistema de informação geográfica como plataforma para aplicação do modelo SATURN*. LASTRA – Laboratório de Sistemas de Transportes, UFRGS, Porto Alegre.

Portugal, Licinio da Silva (2005) - *Simulação de tráfego: conceitos e técnicas de modelagem*. Rio de Janeiro: Interciencia.

Saliba Neto, Tuffi (2009) - *Desenvolvimento de um SIG de código aberto para simulação microscópica de tráfego urbano.* Master Thesis – CEFET-MG, Belo Horizonte-MG.

Silva, Gabriel da (2006) - *Modelagem e Implementação de uma ferramenta inteligente e de código aberto para inserção automática de inferência fuzzy em SIG convencionais.* Master Thesis – CEFET-MG, Belo Horizonte-MG.

Viana Júnior, Gentil (2004) - *Um Sistema de Informação Geográfico inteligente para escolha de trajetos: uso do modelo de rede e da lógica fuzzy*. Master Thesis – CEFET-MG, Belo Horizonte-MG.

Wang, Yuhao e Prevedouros, Panos D. (1996) - *Synopsis of Traffic Simulation Models*. Compendium of Papers from the Transportation Research Board Annual Meeting. Washington D.C.