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TRILHA PRINCIPAL

A review about multimodal traffic simulation techniques

Daniel Marques Gomes de Morais, *Graduate Student in Information Systems, USP*,
Luciano Antonio Digiampietri, *Professor at the Information Systems Department, USP*

***Abstract*—One of the current challenges in urban planning concerns the urban transportation involving multi-mode transportation. One of the ways to evaluate different situations in order to make decisions of how, when and where to invest is using multimodal traffic simulation. This paper presents a review about multi-modal traffic simulation, identifying the state of art and directions for future work.**

***Keywords*—Traffic simulation, multimodal simulation, public transportation, Smart cities, Public Transportation Simulation.**

I. Introduction

GIVEN the continuous propulation growth in big cities and the impact caused by the growing number of vehicles, it becomes necessary to create an adequate urban plan in order to minimize travel time and increase the quality of life of the whole population.

The growing number of private vehicles, besides its known environmental impacts, makes it hard to travel inside urban centres, especially in the so called “peak hours”. Besides, what would take minutes in ideal conditions ends up taking, in extreme cases, several hours in stressful conditions, both in the case of the overcrowded public transportation and in the traffic jam at the roads used for individual transportation vehicles.

Seeking the highest possible flux in all conditions, it is important for the figures of power that are responsible for planning transportation systems and roads to have adequate tools to help them at this task. Hence, this paper intends to present a review about the works done on multimodal transportation simulation systems. We intend to clear the following issues on this topic:

- What are the most recent works on simulation involving more than onde transportation method;
- What are the simulation methods used in those works;
- What are the proposed evolution proposed by the authors of those papers;
- What are the main research opportunities on the field.

The review in this article is part of a research project called “simulation of urban traffic conditions using multiple modals”, in which we intend to develop a urban travel multimodal combined simulation model, fed with statistical information of point of origin and destination in urban centers and data on decision factors that make the user select one model above others. Hence, it will be possible for the transportation system planner to simulate the cause and effect relationships among modals. This will allow for the perfection of the transportation systems distribution identifying the work conditions in which there will be the maximum flux in a given scenation. Hence, the main goal of this research project is to help perfect urban traffic planning.

This paper is organized as follows. Section II presents a brief context on the issue, in order to give the readers information on the main types of simulation in this area. Section III describes the methodology we uses to extract and analyze articles. Section IV contains the analysis of the chosen articles, presenting general considerations and going deeper in some aspects of their content that we considered most interesting for the scope of this work. Section V contains a brief description of the main tools used for transport simulation. Finally, the Section VI presents some final considerations on the analysis performed and also some possible paths tho be explored in future works.

Corresponding author: Luciano Digiampietri, *digiampietri@usp.br*

II. Contextualization

BEFORE describing the methodoloy and analysis of the articles we research in this review process, it is important to present some concepts related to the traffic simulation classification that we will mention in this paper.

Multimodal transport simulation is the one that involves more than one way of transportation or travel. This simulation can involve several motorized transportation methods (public and private) as well as non-motorized mechanisms, such as by foot and by bycicle.

According to Barceló [2], we can classify vehicle traffic simulation in three types : microscopic, macroscopic and mesoscopic.

Microscopic simulation is “based on the description of the movement of each individual vehicle in the traffic flow ” [2], in which each relevant aspect and behavior of a specific vehicle must be considered: acceleration, desacceleration, lane changes, and many others, depending on context.

On the other hand, macroscopic simulatio is base on the “flow theory of continuous flow, whose goal is the description of the evolution in space and time of variables that are characteristic of macroscopic flows: volume, speed and density" [2]. That is, differently from the microscopic simulation that uses the individual as its basis, macroscopic simulation consider the mass of vehicles as something unique and its behavior is the study object. Its origin comes straight from fluid mechanics.

Finally, mesoscopic simulation "is the simplification that intends to capture the essential points of the dynamic, while demanding less data and hence is computationally more efficient than microscopic models" [2]. This model tries to put together some aspects of microscopic simulation with others from the macroscopic ones in order to better represent the dynamic behavior.

These three models are not only restricted to vehicles: it is possible to understand them as valid also for other forms of displacement, such as, pedestrians. This can also be seen by the use of this terminology in the papers we are goind to analyze.

III. Metodology

IN order to identify the articles related with the state of art in this area, we performed a review process which had as basis an exploratory research performed before in order the authors to get familiarized with the main terms and concepts of this field of study. From this exploration we identifies the keywords relative to the concepts related to the questions we posed and its variations in the context, which are presented in Table I. PLease notice that the terms mentioned were used together, in order to contextualize the most generic terms in our goal.

In order to select the sources, two points were used as main criteria:availability of the whole articles and relationships to the main conferences and journals in this field. Data sources that index articles from third parties were not consider, because of the noise in the communication (articles whose text we cannot read in ints entirety, for instance, do not allow for the correct interpretation of their results, having their meaning restricted to the interpretation of the intervening third party). Hence, the following sources were adopted:

- ACM: ACM Digital Library
- IEEE: IEEExplore
- Springer: Springer Link
- Elsevier: SciVerse Scopus

Notice that these are also the most respected sources in the scientific community, habing among its publications most of those journals that are classified in the higher sets of quality assessment processes such as QUALIS.

For each of the data sources we created a search key from the set of keywords we described before. Not necessarily all terms would be present given that, in some cases, the search became too restrictive. For instance, several articles selected do not contain in their title or abstract the expression *Intelligent Transportation Systems*.

Table II presents the keys used for each source and the search option used. We also added a filter in order to obtain only the articles published in the last five years, allowing to identify the current state of the art of th research in the field.

Given that some terms are used in more than one domain, such as *traffic* and *simulation*, we added some negative conditions in the search keys, in order to eliminate results that would not be interesting for our research. For example, the words traffic and simulation are widely used in works on data transmission optimization on communication networks. In order to avoid papers on data traffic, we excluded works that contained the keywords *broadband* and *wireless*.

After finding and sownload the articles according to the search keys presented, we filtered (selected) the articles based on the contents of the abstract of each one of them, taking into account four inclusion and four exclusion criteria. In order to be accepted the article need to fit at least one inclusion criteria and fit none of the exclusion ones. There are the criteria:

- Inclusion 1: Papers that present intelligent transportation systems that implement multimodal simulation;
- Inclusion 2: Papers that present a panorama on works on intelligent transportation systems that incluve simulation implementation;
- Inclusion 3: Papers that present intelligent transportation systems that in spite of involving a single component includes the simulation of another component (such as pedestrians) even if only to study the effect of this second component on the first;
- Inclusion 4: Works that present the implementation of simulation for other types of urban displacement that are not vehicles (for instance, pedestrian, or focused on public transportation);
- Exclusion 1: Papers that present Trabalhos que apresentem intelligent transportation systems but implement simulation only of vehicles;
- Exclusion 2: Papers on intelligent transportation systems involved on other methods of transportation that are not urban (ferries for river transposition connecting two points of a city, for instance, do not fit this restriction);
- Exclusion 3: Papers that do not implement simulattion of traffic or flows or that do not implement simulation of urban transportation;
- Exclusion 4: Papers whose contents are not entirely available.

The selected articles were fully read and we analyzed the relevant points of each one of them, identifying the type of simulation, its goal, the transportation methods analyzed and how each one is treated in the implemented system and the future works suggested by the authors. From these data, we performed the following analysis.

IV. Conduction

FROM the four sources selected we found 143 papers that fit the selection criteria, distributed according to the graph in Figure 1.

At IEEExplore we selected 13 articles based on abstract analysis given their fitness to the inclusion and exclusion

Keywords	Variations
Intelligent Transportation Systems	ITS
Multimodal	Mixed
Urban Planning	Planning
Traffic Simulation	Simulation
Public Transportation	-
Pedestrian	-

TABLE I
Set of keywords and its respective variations

Source	Search key	Filtering conditions
ACM Digital Library	"Abstract":"Traffic" AND "Abstract":"Simulation" AND ("Abstract":"Pedestrian*" OR "Abstract":"public transportation" OR "Abstract":"Multimodal") NOT "Abstract":"Network" NOT "broadband" NOT "Wireless"	Advanced search, scanning only the field *abstract*.
IEEExplore	"Abstract":"Traffic" AND "Abstract":"Simulation" AND ("Abstract":"Pedestrian*" OR "Abstract":"public transportation" OR "Abstract":"Multimodal") NOT "Abstract":"Network*" NOT "Abstract":"air*" NOT "broadband" NOT "Wireless"	Advanced search, with the filter "*Metadata only*" active.
Springer Link	"Abstract":"Traffic" AND "Abstract":"Simulation" AND "Abstract":"Pedestrian*" OR "Abstract":"public transportation" OR "Abstract":"Multimodal") NOT "Abstract":"Network*" NOT "Abstract":"air*" NOT "broadband" NOT "Wireless"	Advanced search, with the filter "*Metadata only*" active.
SciVerse Scopus	ABS(traffic) AND ABS(simulation) AND (ABS(pedestrian) OR ABS(multimodal) OR ABS("Public Transportation")) AND NOT ABS(wireless) AND NOT ABS(broadband) AND NOT ABS(network) AND NOTABS(automation)	Advanced search, restricting to publication and conferences from the relevant fields: Computer Science, Civil Engineering, Traffic and Urban Planning and similar areas.

TABLE II
Search keys and conditions that were specifically configured for each data source. Different keys were used in order to guarantee that the relevant works were found and to avoid many irrelevant works to be selected.

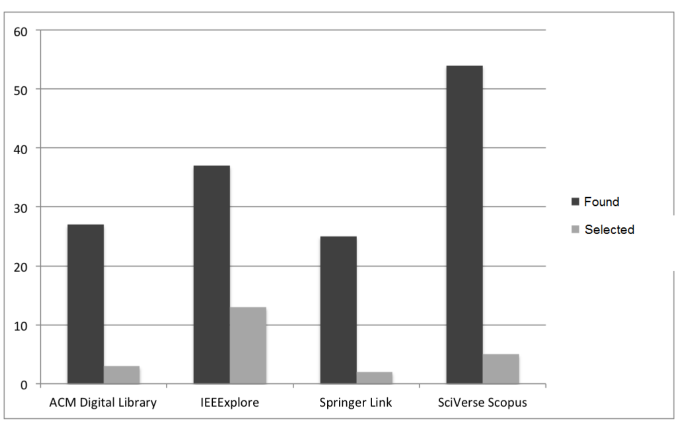

Fig. 1. Distribution of papers by source, found and selected. The sum exceeds the total number of papers found because some papers are present in more than one source.

criteria. In this base there was a single article that was published in two different journals and hence it appeared twice at our search.

At ACM Digital Library, we selected three articles, and one of them was also at the IEEExplore data base. In this source there were also five articles that seemed to fit according to their abstract, but were not fully available for download, what excluded them from the analysis.

At Springer Link we found 25 papers, five of which were excluded for not being fully available for download and two were selected because of the criteria stated above.

Finally, at SciVerse Scopus we found 54 papers, of which five were selected and from the others, six were not fully available for download and one was already present at the IEEExplore selected list.

The articles selected were classified according to the type of simulation they performed: microscopic, mesoscopic, macroscopic or no fit, this last one used to classify simulations that have characteristics that do not fit any of the presented models, in spite of representing components of traffic systems. The distribution of articles by type of simulation is presented in the graph at Figure 2.

Among the papers we can see a great concentration in

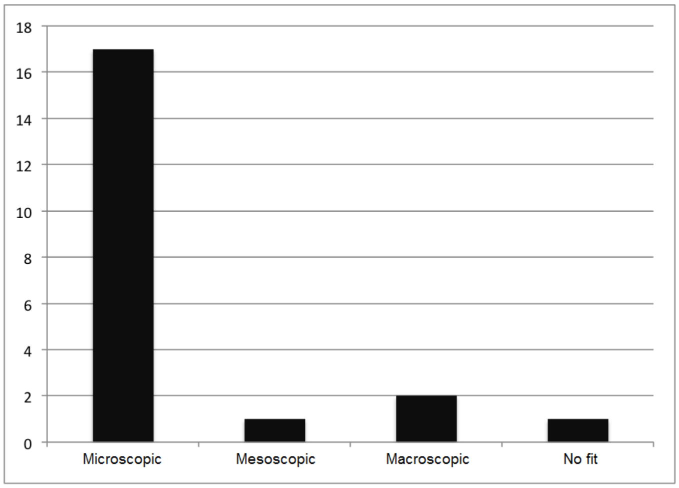

Fig. 2. Distribution of papers by the kind of simulation performed.

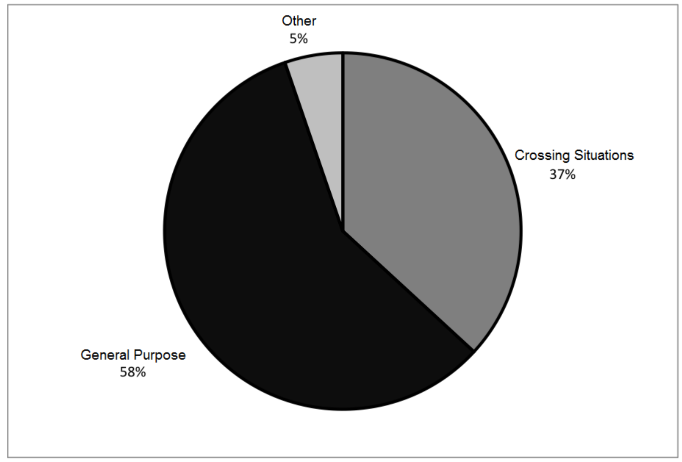

Fig. 4. Distribution of articles according to the simulation goal

the are of microscopic simulation, there being a single work on mesoscopic models and only two macroscopic ones, and out of these, one of them used two models, as we will see in the papers analysis we perform later. One of the results was classified as no fit because de papers presented did not have the goal of simulation traffic density but the optimization of a transportation network using for that a simulation of the displacement and the behavior of the agents.

The prevalence of the microscopic simulations was expected given that his is the type of work that represents each vehicle and person individually and therefore allows the detailed simulation of real traffic conditions.

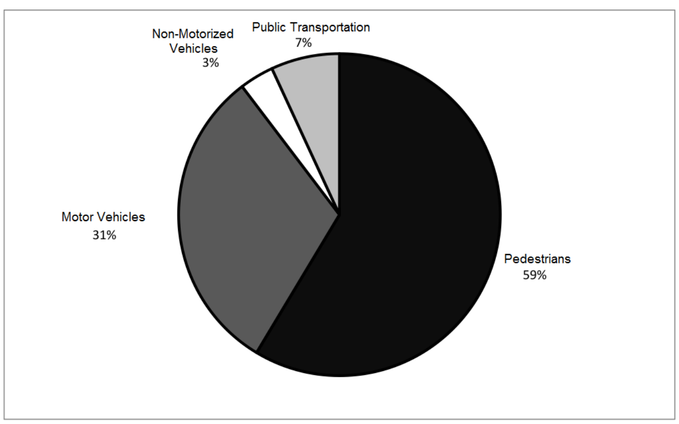

Fig. 3. Distribution of articles according to the transportation method approached

The distribution of papers according to the forecast transportation methods can be seen in Figure 3. In spite of most of the works involving traffic simulations concentrate on motor vehicles, when we involve more that one method, the majority of the second main component is the pedestrian.

Considering the displacement simulation models, most of the papers study are of general purpose or a combination between pedestrians and vehicles (typically at crossing situations), as we can see in Figure 4. On the issue of simulation object, one of the papers is included in the "others" category, which includes papers that are not necessarily applied to traffic simulation.

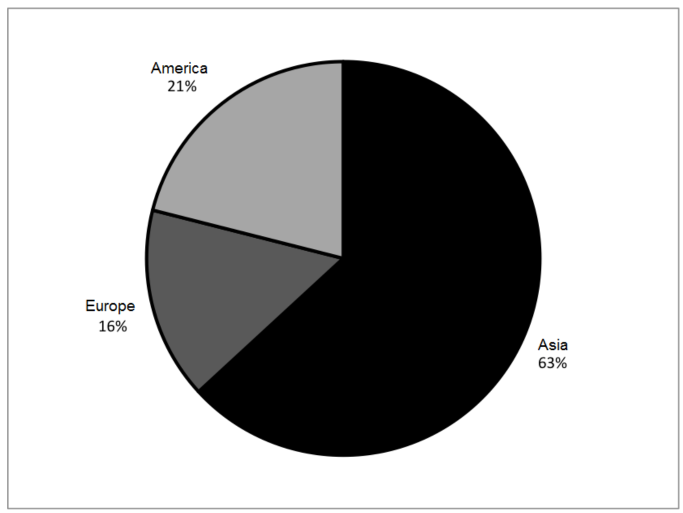

Fig. 5. Geographic distribution of the papers

Our attention is called by the geographic distribution of the institutions where the authors work (Figure 5). There is a massive presence of asian institutions, more specifically chinese, among the articles we analyzed. We can imagime that this presence is due manily to demographic conditions and to the growth both economic and scientific of a few countries in that region. These factors have taken to a big increase in the number of vehicles in circulation without the necessary increase in infrastructure and safety, resulting in a high number of accidents, as pointed out as justification of several of the analyzed papers.

When there is pedestrian presence in the papers, the main methods chosen to simulate their behavior are:celular automata, such as in [3, 8, 10, 14, 19], agents (microscopic simulation), such as in [11, 12, 18, 21], or using a tool specific for microscopic simulations, *VISSIM*[1], from the PTV software company[2], such as in [4, 15–17], which do not specify how the set the tool parameters for their simulations.

Some papers have different simulation proposals. In [22] a model based on hidrodynaics is presented for crowd simulation is presented, that is, a macroscopic model. The paper [9] uses a model that, in spite of being based on agents, has some abstractions that are characteristic of macroscopic simulations, resulting in a mesoscopic model, the single one found in this research.

For vehicle simulation, the most used model is car following or some variation [8, 19]. The car following model is characterized by a ordinal differential equation that describes completely the position and speed dynamics of each vehicle, as well as its speed and distance to the next vehicle or any obstacle.

In some cases the vehicle role is secondary in the simulation. Hence the authors decided to simplify their representation (in general, limiting their behavior in variations in accelation or space occupation in the environment), as can be seen in [14].

Two articles proposed improvements in the transitions of cellular automata models [3, 19]. The first one presents a set of predefines rules for vehicle bidimensional displacement, and the second proposed a more complex approach, involving probabilistic variables for decision making of the direction to follow, forecasting that themodel answers not only to change of direction situations (bidimensional displacement), as well as changes in unidimensional displacement. On the other hand, the articles [8, 10, 14] use the automata model with no variations to implement simulations in their respective scenarios.

Four papers use the agents model [11, 12, 18, 21] to simulate th pedestrian decision model when choosing the best path. Out of those, three papers [11, 18, 21] show simulations that try to fully understand the pedestrian displacement model, while the paper [12] is concerned solely with the decision on the fastest route, estimated time and possible obstacles. In all those works, in spite of the creation of specific simulation environments, the author mention that those models can be used in different environment types, what seems likely given their description.

Fuzzy logic is used when considering the decision process in the studies conducted in [6, 7, 16]. The first one uses fuzzy variables to control the decision taking process by an intelligent semaphre, in order to make the wait smaller, both to pedestrian and vehicles. The other two simulate the decision making process and path planning by a cyclist to cross a street, based on the analysis of existing obstacles, speed, possible paths and colision risks.

In the paper [1] the authors propose a macroscopic simulation model for pedestrians, which is built on a microscopic model, intending to fill the void of models to treat crowd behavior, as mentioned by the authors.

Finally, the paper [13] presents the planning and simulation of using collective taxis (cabs that are used by more than one passenger with different destinations). In this paper no specific method concerning vehicle traffic was used, but a model using a graph was present, in order to represent a sector of Paris and the displacement of cabs through this graph, accepting or rejecting passengers according to a defined decision process.

In most papers analyzed, the most relevant factor is the constant mention to the lack of available data on the analyzed situations, what decreases the effectiveness of the simulation and proposed models validation. In those papers, the authors mention as next steps the gathering of empirical data in order to perform a more extensive validation of their models [3, 21]. Only the paper [7] explains in detail how the model validation was performed, using collected emipirical data, while some papers even mention the need to validate their model in future works but, in general, the qestion of model validity is not mentioned.

Concerning suggestions of future works, most papers propose refining the developped models [3, 7, 10, 20] or the validation of their work through gathering data and empirical research [1, 3, 17, 20, 21]. The remaining papers do not propose any guidance in this direction but, as mentioned before, it is palpable the lacking of validation of the presented models. No matter how difficult it is to validate those models with real data, this validation is of the utmost improtance to assure the quality of the work as well as to indicate the viability of the solution in real situations.

V. Traffic Simulation Tools

During this review we identified some tools for traffic simulation. In this section these tools are briefly presented with the characteristics obtained directly from the sites of their developpers or responsible companies. It is not in the scope of this work to test each one of those tools.

Given the different characteristics of each of those tools, we chose to descirve them using a brief text instead of using a comparative table. Most functionalities are related to simulation evaluation (traffic jam, average speed of the vehicles, etc) and not only of the simulation tool per se. Following we present the tools in alphabetical order. Detailed analysis and compariosns on traffic simulation tools can be found in [5, 23].

Aimsun[3] is a tool that allows for modelling and microscopic, macroscopic and mesoscopic simulation. Among its main characteristics is efficieny, for allowing real time models that include more than 10,000 intersections and 5,000 km of roads in a personal computer using multinucleus architecture; presence of two models two simulate driver behavior: dynamic user equilibrium and stochastic model of route decision (integrated to the car following

[1] http://www.ptvamerica.com/software/ptv-vision/vissim/

[2] http://www.ptvamerica.com

[3] http://www.aimsun.com/wp/?page_id=21

and lane-changing models); and simulation of the interaction of pedestrians and vehicles (having the ability to simulated more than 30.000 pedestrians). Some of its main applications, according to the responsible company are: simulation and analysis of using reversible roads and reserved roads in specific time tables, change of semaphore timing, impact analysis of new roads, public transportation evaluation and security analysis and traffic forecast during major events.

PARAMICS[4] allows dynamic modelling of roads (for instance, resersible roads and road exclusive to buses in specific timetables), as well as public trnasportation (routes and schedules of transportation services, including modelling bus stops and passengers entering and leaving the buses). It allows the description of different classes of vehicles with type, journey purpose and dynamics. Each vehicle has as attribute (configured by the user) to describe his agressiveness or caution in the decision process. The decision to change or keep the lane (by the driver) is based on the distance necessary for the next manouever. Collaborative driving during traffig jams is also modelled. As to the decision on the route, the tool allows an ample variation from all cars taking the same route as well as all cars using dynamic routes (based on stochastic methods). The choice of dynamic routes also takes into account the current state of traffic jam verified by the driver. Concerning functionalities for simulation analysis we can highlight the following: comparative analysis of different models or simulated situations, average speed quantification, pollutant emissions, dealys and events, saturation analysis and alternative route analysis..

SUMO[5] is an open source tool for simulation using microscopic model It is highly efficient being capable of simulating in a personal computer 10,000 roads with 100,00 vehicles; modelling different types of vehicles; different algorithms for route determination; modelling parallel views allowing the dynamic change of road direction and personalized behavior for each semaphore.

VISSIM[6] is a simulator developped by the company PTV[7] that uses the microscopic model. Its main functionalities are: change of lane considering three criteria (minimum benefit needed to change lane, minimum speed necessary for the manouever and timespent), besides modelling cooperative behavior (when a driver avoid risk situations during lane change) and non cooperative; variable time to park the car according to the type and size of parking spot; smooth acceleration and desacceleration when distancing or approaching obstacles; projected routes considering the current traffic situation and the traffic forecast for the next instants. Besides this tool, PTV also has a pedestrian simulator (*VISWALK*[8]) that can be used together with the traffic simulator.

[4]http://www.sias.com/ng/spcurrentrelease/spcurrentrelease.htm
[5]http://sumo.sourceforge.net
[6]http://www.ptvamerica.com/software/ptv-vision/vissim
[7]http://www.ptvamerica.com
[8]http://www.ptvamerica.com/software/ptv-vision/viswalk

VI. Conclusions

THIS paper presented a review on the state of the art of urban traffic multimodal simulation. Given the analyzed articles, we can see a high volume of papers involving microscopic simulations of crossing and semaphores what shows a concern of the authors with efficiency and optimization of the time in those situations, as well as an attempt to identify and reduce accident conditions at those points.

It also evident from those article the solid position of the cellular automata models for pedestrian behavior simulation as well as the position of the car following model to simulate vehicle behavior, as well as the constant use of the VISSIM tool for simulations.

Something that draws the attention is the small presence of duly validated models, which is evident by th elack of empirical information collected for the proposed scenarios as well as the technical and operational difficulties for that activity, given the huge amount of work involved ,what makes us question the efficiency of the governments to gather this information and consequently use it for planning, what may be the goal of future research.

Finally, another point that deserves attention in this review is the lack of mention to public transportation systems, with the exception of an alternative method proposed and one work tha tstudies the user decision process, that is, as an auxiliary method (without the simulation of the method per se), as well as the absence of studies that involve more than one transportation method with a global view on efficieny and cause and effect relationships, being these data an indication of points to be explored in future works. This theme in particular is extremely important when thinking about smart cities and has been so far the object o flittle work.

As futur ework, we intend to extend one of the traffic simulation tools in order to allow for the analysis of the impact caused by changes in public transportant on rails on the traffic of big cities.

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Daniel Marques Gomes de Morais is a graduate on Information System from the School of Arts, Sciences and Humanities from University of São Paulo (EACH / USP - 2009). Nowadays he is a graduate student (masters level) at the same institution and is an Specialist on Technological Development at the Foundation for Administrative Development of the State of São Paulo(FUNDAP).

Luciano Antonio Digiampietri (corresponding author) is a graduate on Computer Science from the State University of Campinas (2002) and a PhD graduate on Computer Science from the State University of Campinas (2007). Since April, 2008 he is a researcher professor at the Information Systems course at the the School of Arts, Sciences and Humanities from University of São Paulo (EACH-USP) and since 2010 he is a tenured professor at the Masters Degree Course on Information Systems at USP. He has experience in the Computer Science field, with emphasis on Computational Biology, Databases and Artificial Intelligence, working mainly on the following issues: scientific workflow, bioinformatics, data provenance, services automatic compositions, algorithms and experiments trackability.
E-mail: *digiampietri@usp.br*.