

# Visual Analytics Tool For Urban Traffic Simulation

Alberto Debiasi ,  
Federico Prandi ,  
Giuseppe Conti, Raffaele  
De Amicis  
Fondazione Graphitech  
Via alla Cascata, 56/c  
38123 Povo (TN), Italy  
{alberto.debiasi}  
{federico.prandi}  
{giuseppe.conti}  
{raffaele.deamicis}@graphitech.it

Radovan Stojanović  
University of Montenegro  
Faculty of Electrical  
Engineering  
George Washington st. bb.,  
81000 Podgorica, Montenegro  
stox@ac.me

## ABSTRACT

Nowadays is extremely important to monitor and analyze the urban environment and in particular the urban viability. The increasing availability of computational power, together with more efficient simulation algorithm allows real time modeling of even complex systems such as urban traffic. Information and simulation are at the basis of the decisional process for policy makers at global and local level. In this context, visualization tools are useful aids where the understanding of a simulated phenomenon is quite difficult. In recent years, microscopic traffic simulations have become an increasingly active field of research in transport engineering. However the main challenge of these systems is related to the high 'learning curve' and to the complex interface of the analysis tools. Often these models are used by final users that have specific competences to evaluate the phenomena and take appropriate decision. However, often these tools lack in usability and visualization makes it difficult to extract useful information. To face this problem it is important to develop a visual-analytic tool with easily readable results for users with different backgrounds, in order to catch the important information in short time.

In this paper we present a highly interactive visual analytics system that helps urban planners, decision makers and traffic analysts simulate and analyze the urban scenario related to the urban viability. The design of the interface has not been based on traditional pull-down menus, panels or buttons that can take the user outside of the frame of the task. The interaction is ensured through direct actions with the 3d context in order to make the operations intuitive and easy to perform. In this way the user is cognitively focused during the problem solving. The user can interact with the 3d environment through graphical metaphors that reduce

considerably the time needed to set the parameters for the simulation as well as the time needed to analyze the results. In this paper we focus on the design of the interface and on the visual analysis of the simulation model.

## Categories and Subject Descriptors

I.6.5 [Simulation and Modeling]: [Model Development]

## General Terms

Design, Interface

## Keywords

Urban Simulation, Urban Scenarios, Geovisualization

## 1. INTRODUCTION

The aim of this work is to develop a simulation and visualization system able to conjugate the macro and the micro level simulation model, allowing the expert user to visually setup the traffic boundary conditions and to simulate the traffic of vehicles using an agent based model. The results of the simulation will be visualized in real time into a 3D globe using a geo-visualization approach. The system described in this article simulates the traffic flows from a microscopic point of view. This means that each vehicle is an atomic entity with its characteristics. In this way the system is more realistic if compared with traffic simulators that manage groups of vehicle as atomic entities [11]. However the microscopic approach affects the complexity of the system and thus the interaction with the user.

One of the main issues of the simulation systems is related to the high 'learning curve' and to the complex interface of analysis tools, in particular if the latter are composed by simulation models such as traffic simulators. Often these models are used to evaluate the phenomena and take appropriate decision. However, typical tools lack in usability and visualization paradigm adopted makes it difficult to extract useful information. To face this problem it is important to develop a visual-analytic tool with easily readable (or in general easily understandable) results for users with different backgrounds, in order to grasp the important information in short time.

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The focus is on how to improve the interaction by using intuitive operations in order to manage a microscopic traffic simulator. In this paper we propose a simulator system for the analysis of urban traffic. The user analyzes, within a visual system, the results of a microscopic traffic simulation and should be able to redirect flows of vehicles with simple interactions and with a higher level of abstraction based on his knowledge of the real system behavior. The big challenge is to represent traffic flows with realistic behavior. In order to meet this requirement we propose an approach based on geographic information. This system bases the simulation on real geographic and census data allowing the city-manager to start their analysis starting from the real situation in the area of interest. The case study is located in the city of Trento, in Italy. The real information, provided by "Provincia Autonoma di Trento", include the location and size of buildings, the position and the capacity of the parking areas, and the structure of the road network. This knowledge allows the system to increase the level of realism of the simulation.

## 2. RELATED WORK

Many traffic simulators have been developed over the last few years. In this section we focus on a particular interface and on most important traffic simulators showing their results. SUMO [10] is an open source microscopic road traffic simulator; it uses a plugin called 'SUMO-GUI' that extends the simulator with a graphical user interface. Through a classical approach based on menus and buttons, the user can insert the parameters for the simulation. The user can also change the appearance/visualization of the simulation for the vehicles changing their color, departure and arrival position, speed, fuel consumption, number of lanes, etc. Vis-sim [3] is a tool used also for pedestrian simulations, it has a 3d interface and it represents in a realistic way specific situations such as roundabouts or crossroads. MatSim [1] is an activity-based transport modeling tool that takes, as input, real data in simple format (such as xml), it performs a simulation and visualizes the results over a 2d map, or using charts or tables for a better readability. TRANSIMS [2] is a parallel microsimulator; each vehicle is simulated in a 2d map and a 3d plot is overlapped over the map in order to represent the relative level of congestion. The higher the elevation and the more congested is the region. Paramics [4] is a traffic microsimulator that uses a car-following and lane-changing model to simulate real time vehicle movements and queuing conditions for congested networks. CORSIM [8] is a microscopic traffic simulation model with a 2d graphical space. This is similar to SUMO and it can export user-selected statistics and summary data in an Excel workbook format. VanetMobiSim [7] simulates vehicular mobility at both microscopic and macroscopic level. It can generate movement traces in different formats in order to interact with tools for mobile networks. FreeSim [14] is a microscopic and macroscopic traffic simulator, the traffic data can be generated by the user or imported as real-time data. CityMob [12] is a mobility model generator that implements different mobility models; each vehicle has a random speed within a range defined by the user. It manages semaphores and traffic density. MobiReal [9] simulates realistic mobility of human and vehicles according to their destination, route, speed and surrounding conditions such as obstacles. With MobiREAL Animator it is possible to visualize the results of

the simulation intuitively by showing node movements, connectivity states, and packet transmission. TraNS [15] is a tool that is composed by a mobility generator and by a network simulator. It can create the road networks through an automated generator or by importing shapefile maps. The results can be visualized using Google Earth.

A recent survey [13] tries to compare and evaluate the traffic simulators. The author divides these simulators in three groups; Vanet (Vehicular Ad-Hoc Network) mobility generators, Network simulators and Vanet simulators. The author uses different parameters for the comparison; in particular he defines two characteristics: "easy to use" and "easy to setup". For both measurements every tool is classified as "Easy", "Moderate" or "Hard". In the group of Vanet mobility generators only FreeSim and CityMob received an "Easy" evaluation related to the ease of setup and ease of use, and between these two tools only FreeSim supports real maps. Meanwhile in the group of Vanet Simulators only MobiReal is evaluated "easy setup" and no simulators in this group are "easy to use". Related to this group there is also a comparison between their GUI; only TraNS and GroovNet have a "good level of user friendliness".

Simplifying the interface and improving the usability of these tools can reduce the learning curve substantially. The added value of our work is the capability to simplify the complex interactions related to traffic analysis, using visualization tools which are able to translate into drawing action the complex input related to effective traffic simulation. With regard to the interface, we try to reduce the number of features and simplify the setup phase. Regarding the readability of the results (in this case related to congested areas in a town) we apply a visualization technique [16] for traffic analysis by taking into account space and time, in order to help the user detect urban congestions.

## 3. CHARACTERISTICS

A town can be, as first approximation, divided into different areas such as residential or commercial areas. In order to simplify the process of generation of the model, we have defined one assumption; we suppose that vehicles in the same geographical area have the same destinations. In the real scenario this assumption can be true in some situations: for example on Sunday afternoon traffic would move from city center to the stadium, or at 18:00 o'clock from industrial area to the city center or to residential areas. The simplified realistic scenario taken into account is the following: citizens drive from their house in order to reach an area in the city. In order to arrive at destination the driver will choose the shortest path taking into account traffic jams and avoiding temporarily closed streets, or streets with traffic accidents. When the driver arrives at the desired area he/she will search for an empty parking lot in the zone. In order to reproduce the aforementioned scenario some factors must be taken into account; 1.the geographic location of each building in the city, the number of citizens that live in each house in order to estimate the number of vehicles to be taken into account by the simulation. 2. The structure of the road network. 3. The location and the capacity of the parking lots. The simulation is based on two requirements:

1. Each vehicle must have its characteristics and it must

be simulated as an atomic entity in the system.

2. The user must be able to redirect flows of vehicles from a macro area of the city to other macro areas.

The scenario will be analyzed with two levels of abstractions; one higher level, focusing on the observation of macro-areas, is oriented to the user interaction following a topdown approach. The second, at the low level, is designed for the simulation of individual vehicle behavior.

#### 4. VEHICLE LIFE-CYCLE: LOW LEVEL ABSTRACTION

This section describes the part of the system related to the life-cycle of a vehicle: its generation, its routing choice, its behavioral state etc. This is user/engineered to simulate traffic flows from a microscopic point of view: this means that each vehicle is an atomic entity with its specific characteristics. These interactions require complex behavioral decision-making processes which can best be modeled by intelligent agent techniques. Agent technology has been a rapidly developing area of research and it has the potential to stimulate and contribute to a broad variety of scientific fields [5].

The first step is the agents generation process. In this case we called *traffic emitter* an object that generates vehicles. Each of these vehicles is considered as an entity over the road network and it will move along the graph in order to reach their destination. Each *traffic emitter* has a fixed number of vehicles that it can generate. A vehicle is removed from the system when it is located on a *traffic removal*. As the *traffic emitter* has the goal to generate vehicles, the *traffic removal* makes the opposite functionality. A vehicle has different attributes: an origin, representing its starting position, a current position and a speed. A vehicle has also a target destination, which is the destination area the vehicle is trying to reach. All vehicles have their own plans about their destinations represented by ordered collections of the route network nodes. The road network is the skeleton of the system, over this object entities are generated, moved and removed. The road network is represented as a directed weighted graph and can be composed by both one-way and two-way streets. Each segment identifies a road with a weight calculated by taking its length and its level of congestion. The level of congestion is a dynamic attribute based on the number of vehicles that are on the road at every frame.

The vehicle life-cycle is managed by following a decision diagram (see figure 1). As mentioned in the section 3, during the life-cycle each vehicle has two behaviors: initially it must reach the destination area, and then it must find for an empty parking lot. These two behaviors are identified by a state called *behavioral state* with two possible values: REACH\_THE\_AREA and FIND\_PARKING\_AREA. When the vehicle is generated, its attributes are initialized. The speed is generated randomly within a defined range, the current position is the same as the *traffic emitter*'s location, the destination area (described in section 5) is decided by the user and the *behavioral state* is REACH\_THE\_AREA. At this step, the system calculates the routing with the Dijkstra

algorithm [6]. Due to the dynamic weight of the roads, the calculated path changes during the simulation. This step should be made at every step, however, this can decrease the system performance. To avoid this issue this operation is performed just after a predefined number of steps. If the destination area is not reached, the vehicle moves to the next recommended node. Furthermore, it is possible to set up some predefined dangerous areas (such as emergency situation or closed road) that can be avoided by the routing algorithm.

If the destination area is reached, then the *behavioral state* changes to FIND\_PARKING\_AREA. The vehicle takes randomly one adjacent road that belongs to the destination area. If in the road there is a parking lot identified by a *traffic removal* then the capacity of the parking lot is decreased and the vehicle is removed from the system, otherwise the vehicle iteratively chooses another adjacent road.

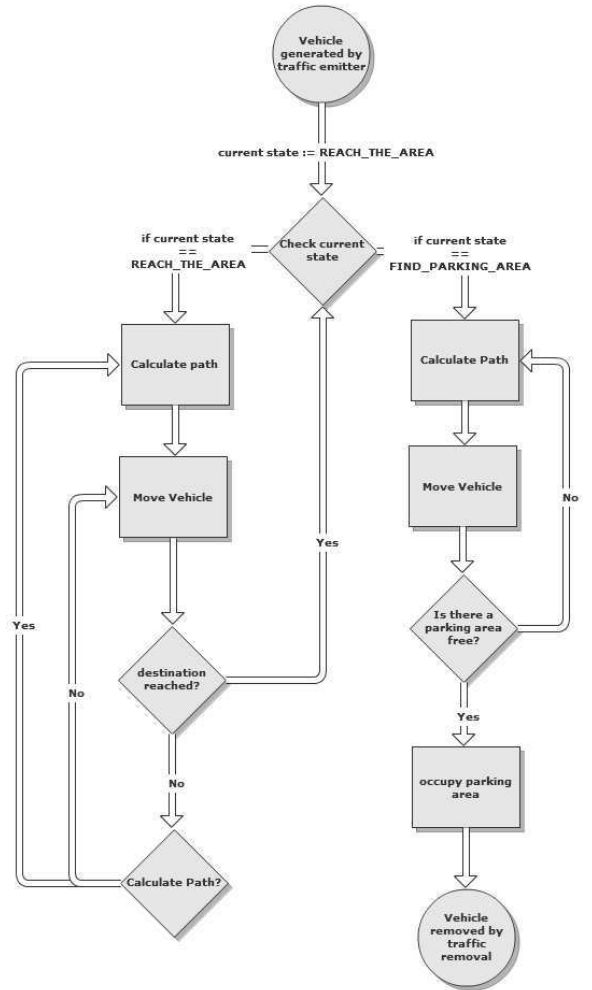


Figure 1: decision diagram describing the vehicle life-cycle in the system.

#### 5. TRAFFIC FLOW MANAGEMENT: HIGH LEVEL OF ABSTRACTION

The microscopic simulation allows a realistic description of heterogeneous traffic streams and it is necessary in order

to capture the nonlinearities of the system. However, combining space and time in a data model is a precondition to model, analyze and understand real world evolution and changing processes. At the basis of the model there is the assumption that generally drivers move from homogeneous areas of the city to other homogeneous areas at specific time ranges (i.e. from residential areas to neighbor school in the morning, from office district to house on the evening). This means that vehicles can be grouped based on the departure location. Based on these assumptions, user manages traffic flows by creating/selecting macro areas. Each of them can represent a departure area, a destination area or a dangerous area. Each departure area can be associated to more than one destination area, this means that vehicles geographically located within that area can have different destinations. The user can choose the percentage of vehicles associated to each destination area.

The process leading to the creation of macro areas is managed by the user in an intuitive way: he/she draws a polygon in the geographic location related to the macro area. For instance the user can select an area A, located in the north of Trento by drawing a polygon over that zone that represents the departure area. Then he/she selects as destination an area B, that is located in the center of Trento. Another area located near the highway will be area C, and another near the stadium, area D. The user can decide the percentage of vehicles that will start from the zone A to go to the other macro areas. Furthermore, dangerous areas can be defined by the user. Inside these areas the vehicles are not allowed. These areas can represent a traffic accident between vehicles or road works. These areas can also be the output of a particular simulator such as a fire simulator or a chemical simulator. In this case this area can be generated, for instance, from a KML file containing a geometrical feature as shown in figure 3. We use this function in order to import the result of an air pollution simulator [17] that represents a dangerous area in our simulation. This shows how the system can be used together with other simulations tools in order to create a powerful visual analytics tool for simulation, by exploiting the interoperability of the geographical information and services. For each departure area the *traffic emitters* are generated according to the location of the buildings in that area. The number of vehicles that the *traffic emitter* generates depends from the building information such as the number of inhabitants. This value is evaluated by a statistical analysis performed over the entire city. According to the percentage assigned to each link, *traffic emitters* generate vehicles for different destination areas. For each destination area the system generates *traffic removals* with the same location and dimension as the parking lots.

## 6. INTERFACE AND VISUALIZATION

The interface has been designed taking in account the interaction metaphor described within the previous paragraph in order to ensure a Human Computer Interaction (HCI) driven by the traffic manager's needs. In particular it improves the user's experience (i.e. the understanding of the crucial aspects of the urban viability) through an interactive exploration of the urban environment with intuitive operations and effective visualization. The user can detect which are the most congested roads at a given time, the situation of parking lots, the number of vehicles loaded for each

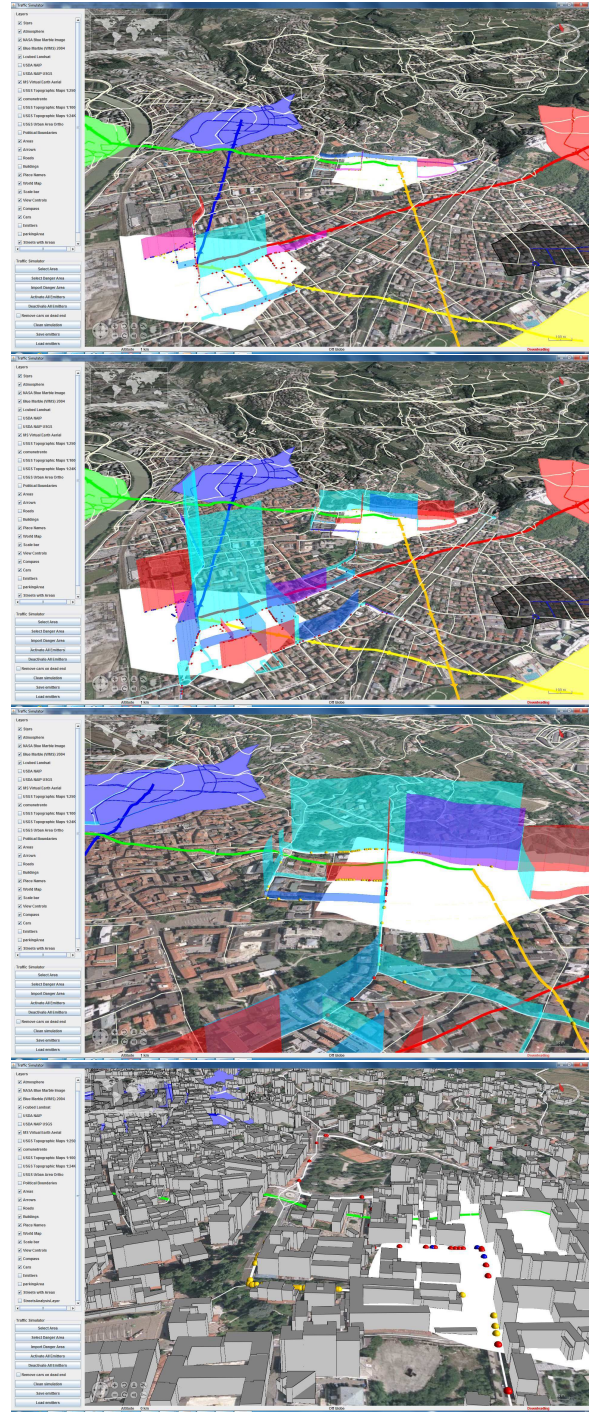


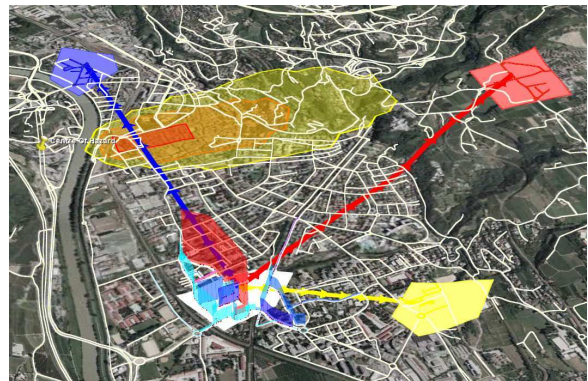
Figure 2: Screenshots of the simulation. The first three images show the same simulation at three different times. It is possible to see the different levels of congestion of the streets and which are the more congested roads. The last image shows the simulation with the buildings in 3d.

road, etc. This information is retrieved directly by observing the visual attributes of the geographical objects represented within the 3d environment. When an area is defined, a polygon with a specific color is created. Different colors are used for the departure, dangerous and destination areas. The relation between the departure area and the destination area is represented by an arrow with the same color of the destination area. The same color is used for each vehicle in order to identify its destination. In order to visualize information related to the road network (congestion, number of vehicles) a 3d visualization is used. For each road an extruded segment from the terrain is created. The elevation defines the total number of vehicles that have passed over the road. The higher the graphical component, the more vehicles have passed on that road. Furthermore each segment has a color related to the congestion of the road: the color is blue if there are no vehicles and changes according to the increasing number of vehicles to a red color that represents a road with more than a threshold value. Inside each destination area it is possible to visualize the parking lots represented by blue spheres. The size of these features changes according to the number of vehicles they contains. This characteristic can help the user to detect where there is parking zone that is more congested. The user can interactively manage the time evolution of the simulation: he/she can stop the simulation and increase/decrease the speed of the simulation. In order to increase the user experience using the real geographic context, the system allows visualization of the 3D city model including residential buildings, commercial centers and other points of interest. All these graphical components are classified by type. This way the user, by using the table of contents located on the left side of the GUI, is able to enable/disable the components according to his/her desire.

The figures 2 and 3 show few screenshots of the system during a simulation. Moving spheres identify vehicles, yellow spheres identify the *traffic emitter* and blue spheres identify *traffic removal*. Each street is colored inside the macro area. If a road does not belong to a macro area the default color is white.

The application is Java based, and it is deployed as an applet. The developed application is integrated within the NASA World Wind framework. NASA World Wind is an open-source 3D virtual globe. It provides a rich set of features for displaying and interacting with geographic data and representing a wide range of geometric objects. The source code is accessible from a comprehensive API and a SDK is available. World Wind can be used to add geographic visualization to any application and it is also cross-platform due to the code-base written in Java. High-resolution imagery, terrain and geographic information from any open-standard public or private source can be displayed on the globe. Each object is managed and rendered depending on its type, and for each entity there is a renderable layer, in this way the user can activate/deactivate the entities.

The test field selected is located in the city of Trento. It considers and uses the city road network for the base graph of the routing system. Furthermore, further useful information to model the phenomena are provided, including parking lots or 3D buildings.



**Figure 3: A screenshot of the tool with the output of the air pollution simulator that represents a danger area.**

## 7. USE CASES

In this section we describe which are the practical applications of the tool. The first use case regards the analysis of congested roads in the morning, assuming that half of the citizens from the city center drive to the industrial area. In this case the user interacts with the 3d environment (moving, zooming) and clicks on the button "select area". Then he/she draws a polygon around the city center and then he/she draws another polygon around the industrial area. After this operation a pop-up appears and the user selects the number of vehicles that will drive from/to these macro areas. The simulation starts by pressing the "activate emitter" button. The user can detect where there are congested areas along the simulation by looking at the color of the extruded lines. This use case can be extended in different ways: for instance by closing some streets, if the user wants to know what happen if there are works along a street or if there is a chemical agent released in the air. In the first scenario the user clicks on the button "select dangerous area" and draws a polygon around the roads that have to be removed from the simulation. In the second scenario the user clicks on the button "import dangerous area" and loads the kml file containing the contaminated area.

The second use case regards the analysis of parking lots around the stadium during an event on the Sunday. We assume that vehicles will drive from city center and neighborhood areas. The setup phase is not different from the previous case: the user draws a polygon that covers the city center and the neighborhoods and then draws a polygon that covers the stadium and the nearby roads and selects the number of vehicles interested. During the simulation the user can detect if there are enough parking lots, or vice-versa, if there are too many parking lots by looking at the size of the geometrical features representing these areas. These are just few examples, however other use cases could be defined within more complex situations regarding more departure areas and more danger areas.

## 8. CONCLUSION & FUTURE WORK

This paper describes a reality-based traffic flow simulator easily accessible as an applet. The system performs the simulation in a 3d web environment context. The user involved in the process analysis manages flows of vehicles with simple

commands. This application can be used for multiple purposes: it is possible to detect urban areas with traffic jams and where roads need to be changed in order to improve the viability; or to monitor the parking areas in the city.

Compared with the Vehicular Simulations described in the section 2 our system is simpler in the setup phase and it gives an easy understandable representation of the results of the simulation. The disadvantages are: the limited functionalities (as described in the section 7) and the lack of validity because of this work has not been compared to real traffic data (even though the goal of this work is not related to demonstrate the level of realism respect to other simulators).

The system is in his first development stages and several improvements can be introduced. Future improvement includes the integration of the data layer from other databases. *Traffic emitter* will have to represent not only the buildings but also the toll highways in order to extend the viability also with information about traffic outside the urban area.

The main contribution of this work is related to how the user can interact with the simulation and how the user understands the results. These two aspects belong to the perception of the user, therefore, in order to evaluate this work a questionnaire must be defined with questions about the usability of the system, the ease of setup of the simulation, the valuation of the interface and the graphical results representation.

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