# An Integrated Environment for Urban Traffic Flow Simulation Using Cellular Automata

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**Abstract**

Simulation of large traffic networks is becoming an essential tool for traffic studies as the number of vehicles increases continuously and traffic conditions deteriorate, both for vehicles and pedestrians. This paper discusses the development of a visual environment for micro-simulation of vehicle traffic flow in road networks and highways, employing cellular automata. The integrated tool targets at non-expert users who wish to study urban traffic and not smulationists, thus we focus on parameterization capabilities and visualization features. The environment copes with expandability and parameterization of both the road networks and the simulation rules. Our goal is to facilitate the construction of hierarhical modular traffic models, provide the ability to experiment with alternative simulation rulesets and offer efficient viualization, which accomodates monitoring traffic conditions and exporting useful conclusions.

## 1. INTRODUCTION

Currently, the simulation of traffic flow in urban networks is becoming an important factor not only in transportation studies, but in environmental and safety studies as well [4-6, 13]. A variety of models for traffic flow has been developed by scientists from several areas, each coping with the problem from a different perspective. In many cases, corresponding simulation tools employing these models have been implemented. However, as changes in vehicle technology occur, new road network structures appear and pedestrian and driver behaviour alters over time, the simulation models for traffic flow of the past may have to be adjusted to reflect real world conditions more accurately. Such adjustments would also serve the exploration of traffic flow on a localized basis, where classical single-lane models might not be accurate enough. Furthermore, most traffic management projects require simulation study before realization, in order to be cost-effective. Therefore, great interest lies in the development of expandable simulation tools that should be capable of encapsulating the complexity of contemporary urban complex environments, while at the same time should be fully paremeterizable in order to easily adapt to real world changes.

A research in literature shows that so far, there is a variety of tools, such as TRANSIMS [7], which facilitate the parametric definition of road network models. However, model expandability and parametric composition is not provided, while simulation rules are embedded within the model and cannot be modified.

In this paper an integrated environment incorporating cellular automata is proposed, accomodating the definition and study of hierarhical, modular, parameterizable models, and facilitates the modeller’s intervention not only to road network models but to simulation rules as well. In addition, the environment aims at a high degree of integration by including visualization features. These features include efficient visualization of simulation results, and comparison with empirical results in charts. Moreover, an important aspect of the environment is the real-time visualization of certain traffic measures, which facilitates monitoring of traffic conditions in urban networks and detecting specific conditions such as congestion. Such features are also exploited in safety studies, where efforts to locate the most appropriate places for pedestrian crossings take place. The environment is developed on two different platforms which cooperate, in particular

MATLAB for the simulation modules and Java for the visualization modules.

The rest of the paper is organised as follows: Section 2 reviews the Cellular Automaton Model, Section 3 presents the features of our environment, as well as validation issues, and Section 4 discusses future work and goals.

## 2. THE CELLULAR AUTOMATA MODEL

The proposed approach was based on the cellular automaton model for freeway traffic proposed by Kai Nagel and Michael Schreckenberg [1,2]. The model is defined by a vector which is comprised of sites, also known as *cells*. The size of each cell is usually set to 7.5 m. Each cell may either be empty, or occupied by a vehicle. In the original model, all vehicles are of the same size and have integer velocities between zero and $u_{max}$, which is a parameter of the model. An ordinary, realistic value for $u_{max}$ is 5. Update of the vehicle position involves three rules, which, at each time step, determine the velocity of the vehicle. These rules are the following:

- *Acceleration*: if the velocity of the vehicle has not reached the maximum velocity $u_{max}$, it is increased by 1.
- *Slowing down*: if the gap between a vehicle and its preceding vehicle, counted in cells, is less than the velocity of the vehicle, the velocity is descreased to gap-1.
- *Randomization*: With a probability pdec, the velocity of a vehicle is decreased by 1.

The above rules are executed and velocity is calculated for each vehicle present in the system. Eventually, the position of each vehicle is updated according to this velocity. In order for the results to correspond to real-life measurements, each time step is considered to be 1 sec.

In order to demonstrate the effect of the above rules to the velocity of the vehicles, the following example is presented, involving a road comprised of twelve cells. The first, the fourth and the last cell are occupied by vehicles with velocities 2, 5 and 3, respectively. The pdec for this example is set to 0.33, therefore, an average of 1 out of 3 vehicles will be forced to reduce its velocity. Applying the rules will result in the first vehicle increasing its velocity by 1 but then decreasing it again because of the small gap of only two cells between the first and the second vehicle. The second vehicle has already reached $u_{max}$ therefore it will not further increase its velocity. In case randomization requires this vehicle to decelerare, its velocity will be reduced to 4. Finally, the third vehicle has a velocity that allows it to leave the system. The updates in the vehicle positions will take place, simulation time will advance and the next simulation step will begin by applying again the same rules.

The most important measures in the model are traffic flow and traffic density, which, on a single lane, are computed from the local measurement data. The traffic flow is defined as the number of vehicles per time unit and is calculated as follows:

$$q_j(x,t) = \frac{\Delta N_j(x,t)}{\Delta t}$$

The mean traffic density is defined as the number of vehicles per length unit and can be calculated approximately from the traffic flow and the mean velocity:

$$\rho_j(x,t) = \frac{\Delta N_j(x,t)}{\Delta x_j} \approx \frac{\Delta N_j(x,t)}{\Delta t \cdot v_j(x,t)} = \frac{q_j(x,t)}{v_j(x,t)}$$

The approach Δxj ≈ Δt · vj (x, t) is valid only if all detected vehicles are moving with approximately the same velocity during the time interval Δt.

## 3. INTEGRATED SIMULATION ENVIRONMENT

The proposed tool aims at providing enhanced visualization and parameterization capabilities for modeling and simulating urban traffic. The cellular automata model, described in the previous section, is frequently used for modeling traffic flow. Evidently, experts in this field would appreciate an efficient and easy to use visual interface for conducting simulation experiments. The proposed simulation environment aims at providing such a visual interface, and accomodating the expandability and parameterization of road network models and alternative simulation rules. Scalability of the road networks is not an issue, as road networks can be arbitrarily large and new parts can be progressively added, at any time, to the existing road networks.

Simulation result exploitation and comparison features are supported through a distinct module, while monitoring of traffic conditions in each separate part of the road network in real time is also provided. Among the other elements of road networks available for monitoring, there are traffic lights and pedestrian crossings, which are of great significance when it comes to pedestrian safety studies.

The modular architecture of the environment is illustrated in Fig. 1. Most of the modules were implemented in MATLAB, while for the visualization modules, Java was considered more appropriate.

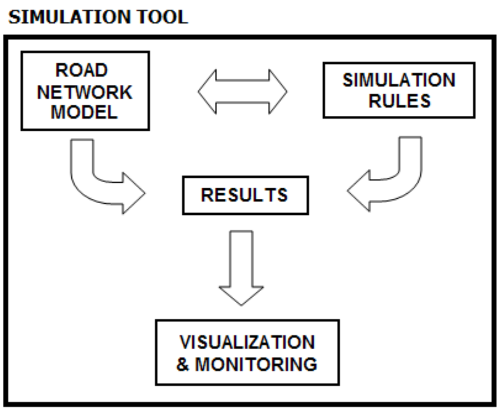


**Figure 1.** Integrated environment architecture.

The simulation environment facilitates:

- Parametric definition of road network models.
- Easy modification and expansion of existing road network models.
- Adaptive ruleset that can easily be altered.
- Parametric simulation.
- Visualization of simulation results in charts and comparison with empirical data.
- Real-time visualization of simulation measures and traffic conditions in road network.

### 3.1. Parametric road network definition

The conceptual model of the road network, as designed in the proposed system, consists of roads and junctions. Each road is divided into lanes and parts, and each part into cells. Junctions may be simple, in which case regular traffic laws indicate priority of vehicles, or may have traffic lights which concern vehicles, pedestrians or both, in which case their indications are taken into account. Moreover, the system has entry and exit points, where vehicles enter and leave the system and statistics are gathered. As far as properties of the road parts are concerned, each part has a predefined capacity, which indicates the number of cells, and a deceleration factor, which indicates how often the vehicles slow down in this part of the road in a probabilistic way. The deceleration factor accounts for unpredictable events that may cause a vehicle to slow down, such as unexpected pedestrian behaviour. To demonstrate the model, a simple road network is presented as an example in Fig. 2.

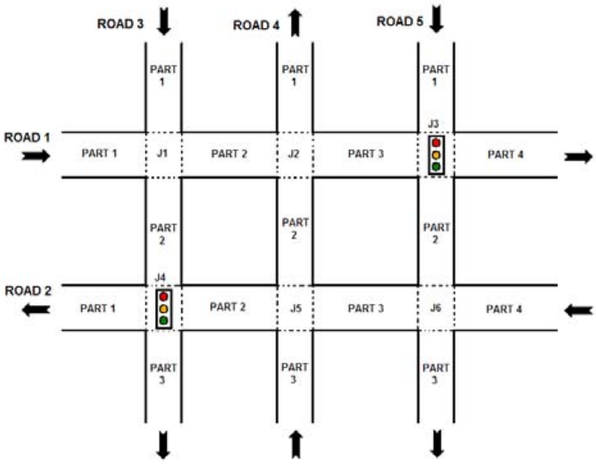


**Figure 2.** An example road network with entry and exit points marked and its representation in terms of cellular automata.

Each vehicle is represented as a separate entity which has its own parameters, such as velocity. These parameters are used in combination with the simulation rules and other safety parameters of the system, in order to produce the updates to the position of the vehicle. Vehicles are inserted in the system at entry points, according to a predefined arrival rate given by the user in advance as a parameter of each entry point. While they are in the system, they can occupy exactly one cell at any given time, as they are all considered to be of the same size. Finally, they leave the system at exit points, affecting the appropriate statistic measures.

The implementation of the aforementioned model in MATLAB involves a combination of arrays and other variables. The structural information of the road network is provided either through user interaction or formatted text files.

The network consists of five single-lane roads and junctions between them, two of which have traffic lights. The direction of the roads as well as the entry and exit points of the network are also marked. The network is divided into roads, parts and junctions as indicated.

A partial example demostrating the insertion of information for the first part of Road 1 to MATLAB follows (Fig. 3):

```
How many roads are there in the network?  5

How many parts do you have in road 1?  4

Is part/lane 1 an input point for the network?
(no=0 / yes=1):  1

Enter interarrival time (lambda):  1.5

Enter part/lane 1 capacity?  50

Which part/lane is on the right of part/lane 1
(0 for no part/lane):  0

Which part/lane is on the left of part/lane 1
(0 for no part/lane):  0

What is the type of the intersection at the end
of this part/lane?
(roundabout=0,  traffic  light=1,  dead  end=2,
other lane=3, network end=4):  3

What  is  the  id  of  the  intersection  at  the
beginning of this part/lane?  0

What is the id of the intersection at the end
of this part/lane?  1
```

**Figure 3.** Example of road data input through user interaction.

The information provided to the system includes the interarrival time for this part, since it is an entry point for the system, the capacity of the road part, its direction, its neighbouring lanes, if any, and the junctions at the beginning and end of the road part. Traffic light information is provided in a similar way. The same procedure has to be followed once for every part and every traffic light in the system. Then, it can be saved and modified at a later time, used to run a traffic simulation with the simulation rules embodied in the system, or used with a different set of simulation rules.

It should be noted that the road network model is saved as a simple text file in order to be easily expanded and modified. An example of such a file for the above data input follows (Fig. 4):

```
1      1   1 1.50  50   0   0 E   1   0   1
1      2   0 0.00  50   0   0 E   4   1   2
2      1   1 2.10  35   0   0 S   1   3   1
2      2   0 0.00  40   0   0 S   4   1   4
```

**Figure 4.** Example formatted file for road network data storage.

For example, if the modeller wishes to add a crosswalk in part 3 of road 2, this part can be splitted into two parts, and the new information can substitute the old data in the text file, without any further changes. Likewise, new roads or road parts can be added to the network by appending new data to the text file.

### 3.2. Simulation

Each step of the simulation consists of three sub-steps:

- Importing the vehicles
- Updating vehicle positions
- Advancing the simulation time

The above steps comprise different sub-modules of the simulation module. Therefore, each one is independent from the other, thus enabling the modeller to experiment with different sets of simulation rules.

The implemented model in the proposed system is the original one by Nagel and Schreckenberg. The same simulation rules and conventions for cell length and maximum speed are followed. At each time step, the rules that determine the velocity of each vehicle are acceleration, slowing down and randomization, and in the end the position of the vehicle is updated according to this velocity. Randomization probability, referred to as pdec, is introduced in the system as a parameter of each road part, therefore each part may have a different probability.

The above rules are encoded as a module in the system and executed consecutively. As long as a vehicle stays in the same part of the road, updating its position is a trivial task. However, attention must be paid to take the appropriate actions when a vehicle approaches the end of the road part it is moving in, and its velocity enables it to leave this road part. Priority in junctions and traffic light indications must be taken into account. Moreover, there is the possibility that the vehicle has reached a network exit point, therefore statistics must be updated.

### 3.3. Visualization

At the end of each simulation step, measures of interest for each road part and for the network in general are calculated and exported to a formatted text file for further utilization. Some of these measures, such as vehicle density, enable monitoring and exporting conclusions about traffic conditions in road parts. Therefore, some kind of real-time visualization is considered necessary in order to accomodate the study of critical properties of urban traffic, both for vehicles and pedestrians. This is achieved through another module which provides visualization of the road network along with real-time visualization of appropriate measures. The road network is presented as a map, preserving the spatial properties of road parts, such as direction and capacity, which makes the interface familiar to the users, while the measure values are depicted using indicative colours, with each colour representing a range of values. This level of abstraction, facilitated by the use of intervals instead of specific values, enables the identification of congestions and other abnormal traffic conditions at a glance, even for inexperienced users. Apart from real-time monitoring of traffic conditions and detecting temporary abnormalities, the visualization can also serve as long-term monitoring of traffic behaviour over a period of days or weeks. In this case, decision making can be facilitated as far as traffic lights and pedestrian crossings are concerned.

The visualization module was not implemented in MATLAB, but instead the Java platform was preferred. This choice is justified by the graphical and interface capabilities of Java, the expandability of the language, as well as the ability to export applications on the web in the form of applets or web services. An example of the interface in presented in Fig. 5. The road network represented includes the roads approximate to Harokopio University in Athens, and the measure of interest here is vehicle density per road part. In this example only three intervals were used, and the colours representing them are green, yellow and red. As the simulation evolves, new values of the measures are calculated in each simulation step, therefore the colours in each road part change.

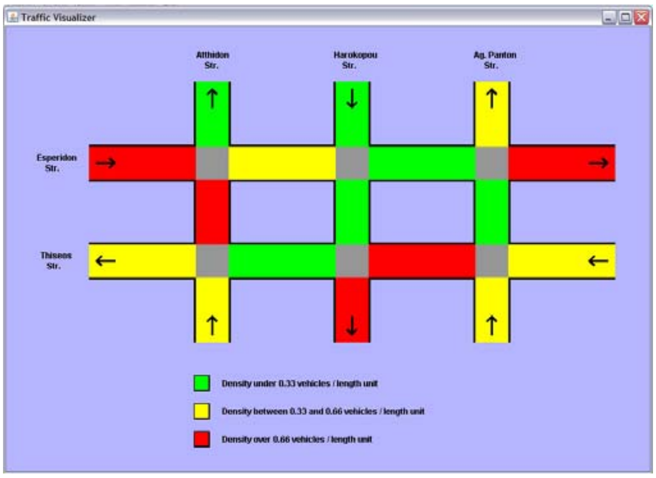


**Figure 5.** Real-time visualization of vehicle density in an indicative road network.

### 3.4. Validation and results

In order to facilitate validation, the tool offers the ability to compare simulation results to empirical results using charts. However, a series of steps has to precede comparison: First of all, road networks have to be modelled and simulated with the simulation ruleset of choice. The default ruleset is the one by Nagel and Schreckenberg, which accomodates simple urban traffic in the original cellular automata model. However, as the simulation rules comprise a different module, they can easily be altered without affecting the rest of the tool. In addition, numerical results have to be produced during simulation in order to be compared to empirical results, and empirical results themselves must be gathered and inserted in the system.

The example results in Fig. 6 concern the simulation of a simple network that consists of one road with two parts. Simulation was performed for different values of the probability factor pdec, which serves randomization purposes and shows how often vehicle velocity is decreased, and the chart presented concerns the value 0.2. The measure of interest in this example is the number of vehicles that went through the network in each simulation step.

Taking into account the results from the simulation of simple models and their proximity to empirical results, the reliability of the proposed tool was established. Thus, further experimentation with more complex traffic models and different simulation rulesets can be explored.

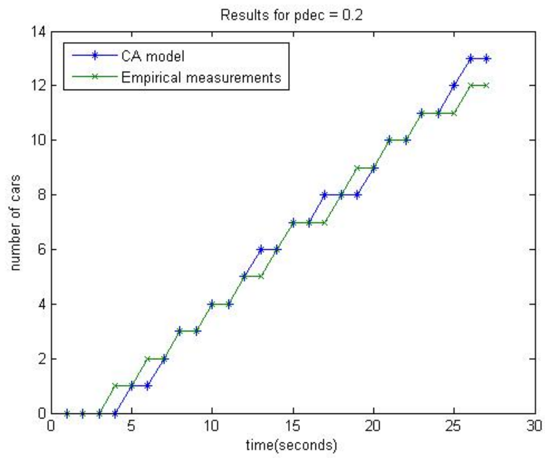


**Figure 6.** Comparison of simulation and empirical results.

## 4. CONCLUSION AND FUTURE WORK

The proposed tool accomodates the definition and experimentation of hierarhical modular models and simulation rules in an independent fashion, along with efficient visualization of results and real-time visualization of certain traffic measures. We are currently working on a case study of an autonomous inner city network in downtown Athens, in order to demonstrate the use of the tool in more complex urban environments and with altered, localized simulation rules, which ensure accuracy.

The next steps include the ability to incorporate other types of metrics in the system, such as environmental ones, and incorporate these metrics in the visualization module. Moreover, the possibility of combination of vehicle and pedestrian traffic in a single simulation tool is explored. This necessitates pairing simulation rules from both fields [12], therefore extensions to the modules of the tool are required. This combination is estimated to lead to more complete conclusions as far as safety studies are concerned.

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## References

[1] von Neumann, J. 1966, *The Theory of self reproducing automata*. Edited by A. Burks, Univ. of Illinois Press, Urbana

[2] Nagel K and Schreckenberg M. 1992, "A cellular automaton model for freeway traffic". J. Physique I 2 2221

[3] Knospe W., Santen L., Schadschneider A. and Schreckenberg M. 2001, "Single-vehicle data of highway traffic:microscopic description of traffic phases". Phys. Rev. E at press

[4] 58th Traffic and Safety Conference, May 9-11,2007, Columbia, Missouri. *Available online via http://muconf.missouri.edu/traffic/index.html [accessed April 19, 2007]*.

[5] Ontario Traffic Conference, Ontario. *Available online via http://www.otc.org/otcweb2 [accessed April 19, 2007]*.

[6] European Transport Safety Council. *Avalable online via http://www.etsc.be/home.php [accessed April 19,2007]*.

[7] TRANSIMS, *The TRansportation ANalysis and SIMulation System project*. Los Alamos National Laboratory.

[8] Simon P. M. and Nagel K. 1998, "Simplified cellular automaton model for city traffic". Phys. Rev. E 58, 1286 – 1295

[9] Fouladvand M. E., Shaebani M. R., Sadjadi Z., 2004, "Intelligent controlling simulation of traffic flow in a small city network". Journal of the Physical Society of Japan, vol. 73, no11, pp. 3209-3214.

[10] Ping-Hua H., Ling-Jiang K., Mu-Ren, L. 2002 "A study of a main-road cellular automata traffic flow model". Chinese Physics Beijing Journal, VOL 11; PART 7, pages 678-683.

[11] Barlovic R., Esser J., Froese K., Knospe W., Neubert L., Schreckenberg M., Wahle J., 2001, "A cellular automaton traffic flow model for online simulation of traffic". Parallel Computing, Volume 27 , Issue 5, Special issue on cellular automata: from modeling to applications, Pages: 719 – 735.

[12] Blue, V.J., Embrechts, M.J., Adler, J.L. 1997, "Cellular automata modeling of pedestrian movements". IEEE International Conference on Systems, Man, and Cybernetics 1997, 12-15 Oct 1997 Page(s):2320 – 2323 vol.3

[13] Environmental Impact of Transportation Conference. *Available online via http://www.planeta.com/ecotravel/tour/transportation.html [accessed August 3, 2007]*