TESTING OF JUTS SYSTEM AND CONSTRUCTION OF HYBRID TRAFFIC SIMULATION MODEL

David Hartman
Department of Computer Science and Engineering
University of West Bohemia
Univerzitni 22, Pilsen CZ-306 14, Czech Republic
E-mail: tazman@kiv.zcu.cz

KEYWORDS
Traffic flow models, urban traffic, hybrid simulation, cellular automaton model, head leading algorithm, JUTS system, java.

ABSTRACT

In this paper there is presented the basic design of the hybrid simulation system for traffic in urban areas. This system is based on a JUTS system used for analysis of traffic in cities which is based on a microscopic model of traffic flow. This type of traffic representation is very detailed but for larger areas consumes too much computation time. For that reason a new hybrid model is introduced. This model represents specific areas in low level of detail. The problem is to choose a suitable less detailed model that can be combined with the actual one. In this paper there is presented the testing of the actual model and the construction of the less detailed model together with its connection into the actual system in order to construct the hybrid system.

TRAFFIC FLOW SIMULATION BASIS

Traffic analysis is a very important task nowadays because of a huge amount of transportation demands arises every day. The traffic system itself and especially the urban traffic can be regarded as a complex system with many interacting elements and difficult dynamics. For a detailed description of the complex systems see (Bar-Yam 2003). Therefore the representation of such systems is very difficult and the results can be very sensitive to minor changes.

Road Traffic Model

Actually almost all existing models have their basis in a road traffic representation. For a detailed description of the road traffic models see (Gartner et al 1997; Hoogendoorn and Bovy 2000; Chowdhury et al 2000; May 1995). There exist more classifications of traffic models. In the following list there are some of them.

1. Independent variable representation
2. Representation of processes
3. Level of detail

Most of the existing models use time as an *independent variable* in a *discrete* or a *continuous* manner. In a discrete case it is also important whether the control is regarded as a *discrete time* or a *discrete event*, where the first one is just discrete approximation of the continuous time and the second one concern more in processes actions, see (Banks et al. 2000). In general the processes in simulation can be represented in *deterministic* or *stochastic* manner.

The level of detail is a very general notion. Within the traffic system modeling it can be defined as a level of representation of vehicles. The following list contains basic classification, for others see (Gartner et al 1997; Hoogendoorn and Bovy 2000; Jeanote et al 2004).

1. Microscopic Simulation Model
2. Mesoscopic Simulation Model
3. Macroscopic Simulation Model

It must be noticed that these models concern with the simulation analysis of the traffic system, because except simulation there exist many different types of analytical methods or tools mainly based on statistical description of traffic flow characteristics.

The fist noticed the *microscopic simulation model* represents reality in a most detailed way. Each vehicle is modeled by a single simulation object. These objects (same as in reality) can interact among themselves. The most important models in microscopic class are *car following models*, see (Wagner and Lubashevsky 2004; Lubashevsky et al 2003), and *cellular automaton models*, see (Schreckenberg et al 2001). On the other way a *macroscopic model* abstract away from a particular vehicle and consider the traffic in the notion of macroscopic characteristics like traffic flow, mean speed and concentration. These models are the oldest ones, see (Lighill and Whitham 1955), but they are widely used and there exist many modifications of the basic concepts, see (Philips 1979; Helbing 1996; Bradan-Ledoux 2000; Jeanote et al 2004). The mesoscopic model usually considers traffic entities in a high level of detail, but control strategies in a low level. The most important representatives of this class are gas-kinetic models, see (Prigogine and Herman 1971; Paveri and Fontana 1975; Nagatani 1996), and queuing networks models, see (Nizard 2002).

Traffic Characteristics

The important part in traffic modeling is description of the basic set of the traffic characteristics. These characteristics are able to describe actual traffic

Proceedings 20th European Conference on Modelling and Simulation
Wolfgang Borutzky, Alessandra Orsoni, Richard Zobel © ECMS, 2006
ISBN 0-9553018-0-7 / ISBN 0-9553018-1-5 (CD)

condition by a few values. This situation is very similar with thermodynamic or fluid dynamic. There also exist some variables able to describe the actual state of the system despite the fact that this state is constituted by large number of microscopic factors, see (Huang 1997). This concept is also used in traffic and many used variables also exist in fluid dynamic, see (Jost 2002).

There is a system of moving particles (vehicles) each one with its own speed and direction. If we consider only one direction of move we can define three basic characteristics:

1. Flow (vehicle per unit time)
2. Mean speed (distance per unit time)
3. Density (vehicle per unit distance)

These variables are sometimes called fundamental, because of relation among them, see below. Microscopic definition of these variables is related with their measurement, for detailed description see (Harvey et al 1995; Mimbela and Klein 2000; TGM 2001; Skszek 2001). Microscopically the flow can be defined as the number of vehicles N per total time T

$$q = N/T\ .$$

The mean speed can be regarded as the mean of the individual vehicles speeds over time or over space

$$v_t = \frac{1}{N}\sum_{i=1}^{N} v_i \ \text{ and } \ v_s = D\left(\frac{1}{N}\sum_{i=1}^{N} t_i\right)^{-1}$$

The last characteristic is density or concentration:

$$c = \frac{S_{vehicles}}{S}\ ,$$

Where the $S_{vehicles}$ means the surface of road covered by vehicles and S is the global road's surface. This is not very good equation for determination over the normal conditions. For this purpose there also exists another equation often called a *fundamental equation*

$$q = cv\ .$$

It is very important to notice that this equation is used just as an estimate of this variable and it holds only for specific somehow normal conditions (uncongested flow). To estimate it under the congested state different models used different approaches. Very important facts about these variables are mutual relations between Simplified graphs represented these relation are presented here. Each time the graphs for the real data differ in a specific shape it will be noticed. The most important and the most used relation is relation between flow and density. For two stage traffic (congested and uncongested free-flow stage) this diagram has so called *inverse lambda-shape*, see figure 1.

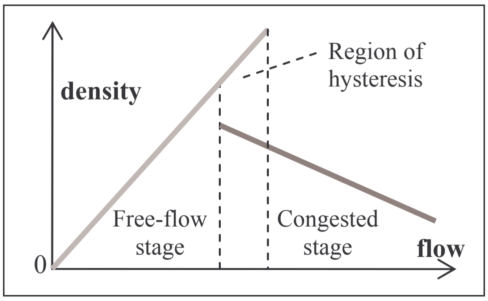

Figure 1: Flow-Density Diagram

We can see that the transition between these two stages has inner hysteresis. In the free-flow we can say that there holds the fundamental equation. For the empirical study of that hysteresis, see (Hall et al 1986). Graph from real data has not linear shape of both curves. There also exists theory about three-stage traffic that distinguishes two types of congested stage, see (Kerner 2003). This theory interprets some extreme shapes. The next diagram is flow-speed diagram, see figure 2.

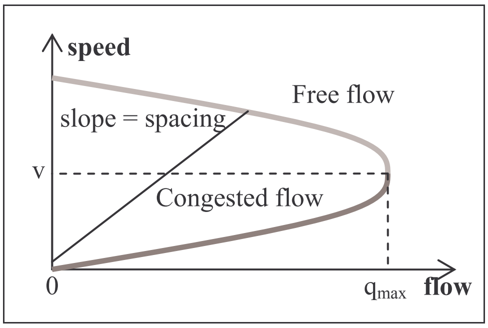

Figure 2: Flow-Speed Diagram

This equation is sometimes regarded as the main one by several authors, see example in (Gartner et al 1997) for reason that both variables can be easily measured. The last diagram is speed density diagram.

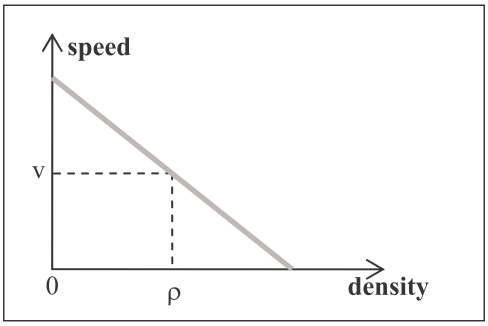

Figure 3: Density-Speed Diagram

The real shape of this diagram is more bended and for the congested stage it is even exponential like function.

DESCRIPTION OF ACTUAL MODEL

In this section the traffic simulation system JUTS is presented, see (Hartman 2004). This system has been developed from the original design of J-Sim based system, see (Hartman and Kačer 2003) and for J-Sim description see (Kačer 2002). The actual version is not dependent on J-Sim anymore and the simulation core is completely designed on java platform. For detailed information about JUTS structure, see (Hartman 2004).

Road Traffic Model

As it was mentioned the road traffic representation is the basic characteristic of traffic flow model. The model used for traffic representation according to previously presented classification is the microscopic model. More precisely it is an extension of a Nagel-Schreckenberg cellular automaton model originally presented at (Nagel and Schreckenberg 1992). The modification for more traffic lanes is presented at (Nagel et al 1998). There also exists modification of that model for the urban traffic, see (Schreckenberg et al 2001).
Basic idea of that NaSch model is a representation of a particular traffic lane with the field of cells and more traffic lanes with the cells lattice in which the vehicles as particles of this lattice are moving according to global state changes. Control of that system is therefore synchronous and it is divided in four basic steps:

1. Acceleration
2. Deceleration
3. Randomization
4. Move

In fact first four steps modify the vehicle's speed according to road situation and the last one shift the vehicle according to final value of speed. Third step is introduced to involve different driver's behavior. There also exist several modifications of that basic notion mainly stressed on more realistic representation of drivers interactions. The most significant example of these modifications is an inclusion of an anticipation step which represents driver's expectation of a road situation during the change of speed or direction of move. JUTS system is another modification used for detailed study of an urban traffic system. It includes special structure of specific traffic element and new vehicle moving concept *Leading Head Algorithm* (LHA) introduced to solve movement of long vehicles in a new urban network structure, for more detailed information see (Hartman 2004).

Structure of the Model

The structure of an existing model is a very important part of JUTS model used for detailed urban traffic representation and which also has connections with LHA. It can be in simplicity described as a collection of segments each one from the given list:

1. Road
2. Crossroad or roundabout
3. Parking or parking lane
4. Generator or terminator

All these segments have inside a special structure of cells used to store and manage vehicles during the simulation steps. In the JUTS system whole urban traffic structure can be read from XML files of simulation map (both static and dynamic data). This map is previously constructed by a special procedure of JUTS system loading raw data from geographical information system (GIS) and transform them to XML, for detailed description of data transformation see (Hartman and Herout 2005a).

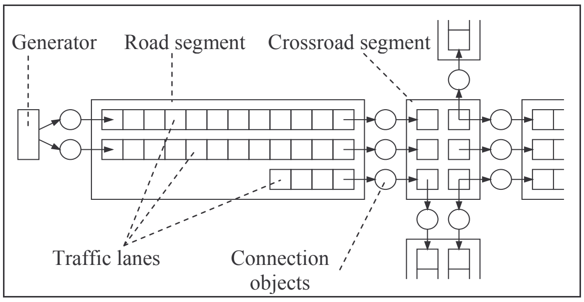

Figure 4: Structure of JUTS model

At the previous figure there is a part of the model for one crossroad and one adjacent road. Data analysis for a case study is shown at (Hartman and Herout 2005b).

Results from JUTS

In this section there are presented some basic results from JUTS testing. These results were created on simulation map for testing the basic properties of road model. Naturally there are more properties of urban model that have to be tested (like traffic waves in crossroad, etc.), but at first our new cellular automata model should fit to results of simple traffic lane.

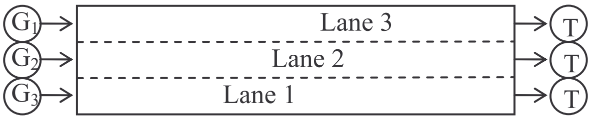

Figure 5: Basic road simulation map

Used simulation map consists of one simple multilane road with three traffic lanes and with no off or onramps joined, like in scheme on figure. The generators uses the negative exponential distribution with parameters $\lambda_1 = 0.2103$, $\lambda_2 = 0.1978$ and $\lambda_3 = 0.22$. Lane changing probabilities where determined by following matrix

$$P = (p_{ij}) = \begin{pmatrix} 0.81 & 0.1 & 0.99 \\ 0.15 & 0.75 & 0.1 \\ 0.01 & 0.21 & 0.78 \end{pmatrix},$$

where p_{ij} is probability, that a vehicle in lane i turn to traffic lane j. The first presented diagram (figure 6) is the flow-density diagram.

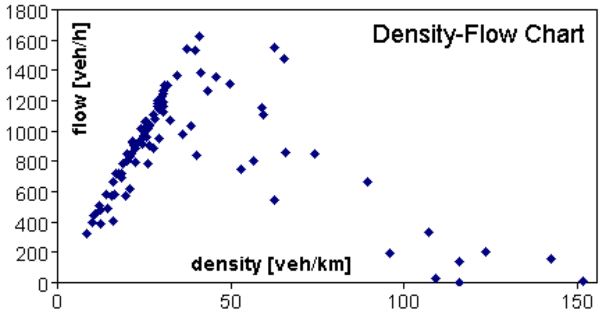

Figure 6: Density-Flow Chart

The diagram starts with the increasing part of free-flow regime and than there is decreasing trend of congested traffic this progress corresponding to the general inverse lambda form described above. Moreover the congested part corresponds to a larger surface described in the three-stage theory, see (Kerner 2003). Next diagram is the flow-speed diagram. For this case there can also be recognized two stages.

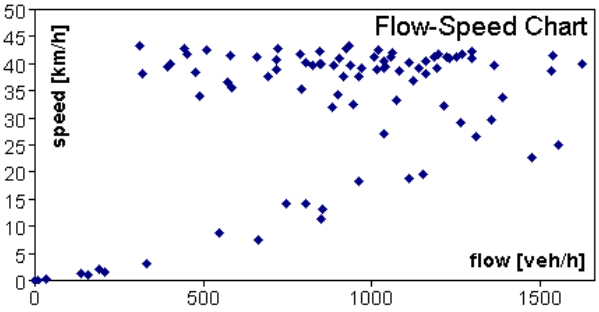

Figure 7: Flow-Speed chart

The first free-flow stage is represented by slowly decreasing trend in the upper part and the congested regime trend is moving very sharply from the joint area to zero speed and flow. The last diagram is density speed diagram (see figure 8).

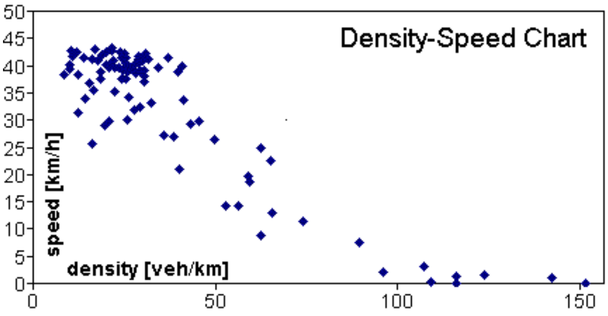

Figure 8: Density-Speed Chart

All these diagrams represent the basic testing data for head leading cellular road, which is the correct new model for road traffic representation.

MOTIVATION AND BASIC DESIGN

There is a problem with these microsimulations in such large districts and it is time consumption. The structure of JUTS system is highly suitable to construct a hybrid model that will represents different regions in a different level of detail. The whole areas can be defined in lower detail and only the specific regions of interests can be in higher detail. The most important task is to choose a suitable model in lower detail and to create a suitable hybrid model.

MODEL FOR HYBRID SIMULATION

There exist several hybrid models for traffic systems. For example a combination of mesoscopic queueing model METROPOLIS and microscopic car-following model MITSIM, see (Nizard 2002), or a combination of macroscopic second order model SIMRES and microscopic car-following model SISTRA-B+.

Our purpose is to create the hybrid model from the JUTS cellular automaton model and some macroscopic model. That model should be easily connected with the JUTS structure. For this purpose the second order model in some properties similar to METANET model, see (Braban-Ledoux 2000), is constructed.

Model of Road

The most important is to present the model of the road traffic. Here we adopt the few ideas from METANET model, see (Braban-Ledoux 2000). The macroscopic models often use set of basic equations, see (Gartner et al 1997; Chowdhury et al 2000; Hoogendoorn and Bovy 2000). Using these equations for modeling often require some adjustments. In our case the road itself is divided into several sections for which the characteristics are counted through the set of four basic equations.

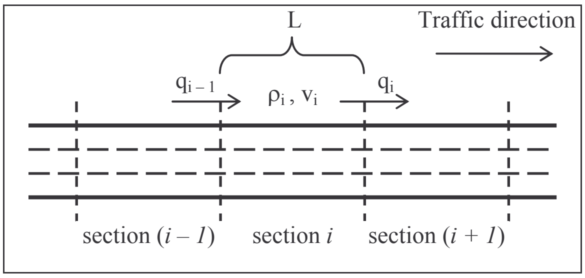

Figure 9: Structure of the road

Before showing them it should be defined some conventions. The simulation will progress in steps. The basic step will substitute time *T*. As there are more steps the variable *t* holding the actual time could represent only integer value as the multiple of *T*. For each section and each time there are defined *traffic density* $q_i(t)$, *mean speed* $v_i(t)$, *outflow* $q_i(t)$ and *inflow* $q_{i-1}(t)$ which is in the same time outflow of the previous section. For intuition about these variables, see figure 11.

The first used relation is *continuity equation* define as

$$\rho_i(t+1)=\rho_i(t)+\frac{T}{L\lambda}\left(q_{i-1}(t)-q_i(t)\right)$$

The second is *fundamental equation* described above and serves as the basic relationship.

$$q_i(k)=\rho_i(t)v_i(t)\lambda$$

The next model’s formula is a *speed update equation*.

$$v_i(t+1)=v_i(t)+\frac{T}{\tau}\left(V(\rho_i(t))-v_i(t)\right)$$
$$+\frac{T}{L}v_i(t)\left(v_{i-1}-v_i(t)\right)+\frac{\eta T}{\tau L}\frac{\rho_{i+1}(t)-\rho_i(t)}{\rho_i(t)+\kappa}$$

It consists of *relaxation term* representing drivers’ tendency to achieve a desired equilibrium speed, a *convention term* representing influence of inflow and *anticipation term* representing speed fluctuation according to drivers' experience. There τ, η, κ are parameters of the model that have to be calibrate and the function V is defined as follows.

$$V(\rho_i(t)) = v_f \, \exp\left[-\frac{1}{a} \left(\frac{\rho_i(t)}{\rho_{cr}} \right)^a \right],$$

where v_f means average free-flow speed, c_{cr} is a critical density of unstable flow and a is a parameter.

The Macro-JUTS Model

For the similarity with micro-JUTS model there are also same four segments defined (road, crossroad, generator and terminator). The road has been described above. The crossroad is modeled by a simple stochastic distribution element with probabilities of turning into present directions $p_0 ... p_m$ (indexed by j).

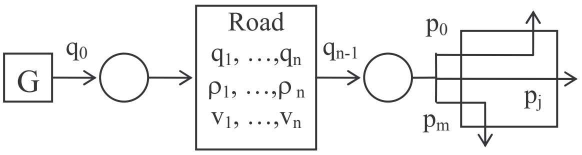

Figure 10: Crossroad model

The connection among segments are also defined by simple connection objects, however in this case these objects cannot be defined for each lane (actually no lanes exists here). These objects are used for distribution of outflow of predecessor to inflow of successor. Here the role of crossroad can be seen. It divides the outflow of specific inlane into several outflows of corresponding outlanes together with considering the actual priority lane (some directions can be temporarily forbidden – depends on crossroad structure). The same situation holds for generators and terminators. These objects are also defined in such aggregate manner. Moreover the generators are not used for generation of vehicles but for generation of inflow into a next segment. The control strategy iterates in steps with period T and calculates the state of each segment. This situation is very similar for micro-JUTS.

CONNECTION OF MODEL INTO JUTS

Everything is prepared for the hybrid model definition. There main idea of this model is to construct supersegmets containing the usual segments in specific level of detail and join them together. In such a way whole man should be constructed and afterwards the simulation will be performed on this hybrid system.

The problem is the connection of segments in different levels of detail. In general there can be two basic types of connections: in the middle of road and on the border of road and crossroad. Both types can be modeled by the connection on the border by a special connection places. The connection in the middle of road can be easily transformed to border connection, see figure 11.

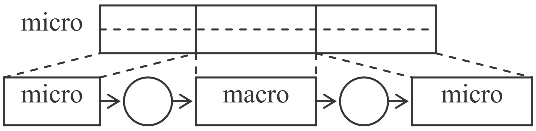

Figure 11: Different connections transformation

The design of the hybrid connection object called *convertor* depends on the direction of conversion. For the first case (micro to macro) it is easy, because it is just calculation of the macroscopic characteristics from the detailed ones, see their definition above.

For the second case (macro to micro) the problem is more difficult. There is a special new object called learning *Mμ–generator* which generates vehicles from the macroscopic characteristics using the definitions of macroscopic characteristics through microscopic variables. This process does not need to be stable for detail level switching. Therefore learning is introduced into such generator which enables it to calibrate its inner constants used for vehicles generation. The important fact for both connections is that the segments on both sides should not detect the communication with the different connection places.

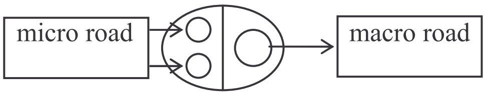

Figure 12: Hybrid connection place

The specific segment communicates with the interfaces in same manner as in its original model. The convertor collects information from segments, transforms the data into different levels of details and presents the final data in classical connection style.

CONCLUSION AND FUTURE WORK

For the existing JUTS system in a microscopic level there is a new macroscopic model defined in very similar structure. The new designed hybrid system consists of supersegments including segments in different level of detail. The connection between two segments in different levels of detail is performed on basis of pure calculation (the micro-macro direction) or with help of learning Mμ–generators. The most important future improvement is testing of those Mμ–generators and definition.

ACKNOWLEDGEMENT

The research was supported by a grant of the Grant Agency of the Czech Republic – Research of methods and tools for verification of embedded computer systems, no. 102/03/0672.

PROJECT WEB SITE

`http://www.juts.zcu.cz/` … JUTS project web site with information and references.

REFERENCES

Banks J., Carson J.S., Nelson B.L. and Nicol D.M. 2001. *Discrete-Event System Simulation*. Third Edition, Prentice Hall, Upper Saddle River, NJ.

Braban-Ledoux C. 2000. “METACOR – A Macroscopic Modelling Tool for Corridor Application to the Stockholm test site.” Final Report CRT2000:05, Center for Traffic Engineering and traffic simulation, Kungl Tekniska Högskolan.

Bar-Yam Y. 2003. *Dynamics of Complex System*. Westview Press, ISBN: 0813341213.

Chowdhury D., Santen L., Shadschneider A. 2000. “Statistical Physics of Vehicular Traffic and Some related Systems.” *Physics Report* 329, Issue 4-6, pp. 199-329, Universität Köln, Germany.

Gartner N., Messer J. C., Rathi K. A. 1997. *Traffic Flow Theory*. Research Board's Committee A3A11 and Federal Highway Administration (FHWA).

Hall F. L., Allen B. L., and Gunter M. A. 1986. “Empirical Analysis of Freeway Flow-Density Relationships.” *Transportation Research* 20A, TRB, NRC, Washington DC,pp. 197-210.

Hartman, D. 2004. “Leading Head Algorithm for Urban Traffic Model”. *Proceedings of the 16th International European Simulation Symposium ESS*, Budapest, Hungary, pp.297-302.

Hartman, D. and Herout P. 2005a. “Implementation of Head Leading algorithm in simulation of traffic in Pilsen”. *In Proceedings of the 8th International Conference ICCMS*. Oxford, England, pp. 46-51.

Hartman, D. and Herout P. 2005b. “Head Leading Algorithm and GIS Data Analysis in Simulation of Traffic in Pilsen”. *International Journal of Simulation Systems, Science and Technology*, Nottingham Trend University, ISSN:1473-8031.

Hartman, D. and Kačer, J. 2003. “JUTS – J-Sim Urban Traffic Simulator”. *Proceedings of the 2nd International Conference PPPJ*. Kilkeny, Ireland, pp.113.

Harvey B., Champion G.H., Ritchie S.M., Ruby C.D. 1995. “Accuracy of traffic monitoring equipment.” GTRI Project A-9291, FHWA and CND, ITTL, Georgia Technical Research University, Atlanta.

Helbing D. 1996. “Gas-kinetic derivation of Navier-Stokes-like traffic equations.” *Physical Rev.* E 53(3), 2266-2381.

Hoogendoorn S.P. and Bovy P.H.L. 2000. “Modelling Multiple User-Class Traffic Flow.” *Transportation Research Board* 34(2), pp. 123-146.

Huang K. 1987. *Statistical Mechanics*. John Wiley.

Jeanote K., Chandra A., Alexiandis V. and Skabardonis A. 2004. “Traffic analysis toolbox. Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools.” Final report DTFH61-01-C-00181, FHWA, Cambridge Systematics, Inc..

Jost D. 2002. “Breakdown and recorvery in traffic flow models.” Diploma thesis on Department of Computer Science and Engineering, ETH Zürich.

Kačer J. 2002. “Discrete Event Simulations with J-Sim” *Proceeding of the inaugural Conference PPPJ*, National University of Ireland, ISBN: 0-901519-87-1, pp. 13-18.

Kerner B. S. 2003. “Three-Phase Traffic Theory and Highway Capacity.” *eprint* arXiv:cond-mat/0211684.

Lighill M.H., Whitham G.B. 1955. “On kinematic waves II: A theory of traffic flow on long crowded roads.” *Proceeding of the Royal Society of London* s. A, 229, pp. 317-345.

Lubashevsky I., Wagner P. and Mahnke R. 2003. “Towards the fundamentals of car-following theory!.” *eprint* arXiv:cond-mat/0212382.

May A. D. 1995. *Traffic Flow Fundamentals*. Prentice-Hall.

Mimbela L. E. Y. and Klein L. A. 2000. “A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems.” Technical Report, Vehicle Detector Clearinghouse and FHWA. New Mexico State University.

Nagel K., Schreckenberg M. 1992. “A cellular automaton model for freeway traffic.” *J. Phys I*, France, 2:2221.

Nagel K., Wolf D.E., Wagner P., Simon P. 1998. “Two-lane traffic rules for cellular automata: A systematic approach.” Report-no LA-UR 97-4706, American Physical Society.

Nagatani T. 1996. “Gas Kinetic Approach to Two-Dimensional Traffic Flow.” *J. Phys Soc Jap* 65(10), pp. 3150-3152.

Nizard L. 2002. “Combining Microscopic and Mesoscopic Traffic Simulators.” Raport de stage d’option scientifique, Ecole Polytechnique, Paris.

Paveri-Fontana S. L. 1975. “On Boltzmann-Like Treatments for Traffic Flow: A Critical Review of Basic Model and an Alternative Proposal for Dilute Traffic Analysis.” *Transportation Research* B 9, pp. 225-235.

Philips W. F. 1979. “A Kinetic Model for Traffic Flow with Continuum Implications.” *Transportation Planning and Technology* 5, pp. 131–138.

Prigogine I. and Herman R. 1971. *Kinetic Theory of Vehicular Traffic*. Elsevier, New York.

Skszek S.L. 2001 ““State-of-the-art“ report on non-traditional traffic counting methods.” Final report n. 503, Arizona Department of Transportation and FHWA, Arizona, SPR-PL-1-(57) 503.

Schreckenberg M., Neubert L., Wahle J. 2001. “Simulation of traffic in large road networks.” *Future generation computers* 17, pp. 649-657.

TMG 2001. “Traffic Monitoring Guide.” Report FHWA-PL-01-021, Office of highway policy information, FHWA,.

Wagner P. and Lubashevsky I. 2004. “Empirical Basis for car-following theory development.” *eprint* arXiv:cond-mat/0311192.

AUTHOR BIOGRAPHIES

DAVID HARTMAN was born in Karlovy Vary Czech republic and went to the University of West Bohemia, where he studied software engineering and obtained his degree in 2003. Than he entered the PhD. studies at the Department of Computer Science at this university and worked on the simulation problems. He is a member of research group DSS (Distributed Systems, Software engineering and Simulations) and creator and one of the leading member of traffic simulation project JUTS.

E-mail: `tazman@kiv.zcu.cz`
Web: `http://www.kiv.zcu.cz/~tazman/`