# Lecture Notes for „Applicated Jamology" – part of the First Forum of Math-for-Industry Consortium 2008 in Tokyo

By Tobias Kretz

Introduction: Jam from Something – World Population Development

It has recently been shown [1] that drivers' behaviour inevitably leads to the formation of jams in density regions, where in principle jams could be avoided. However, this being a fascinating result, one must not forget that the typical rush hour jam is caused by the enormous numbers of participants in traffic. Those numbers typically gather in large cities – the more, the larger a city is – or at certain times on highways. Therefore, let's take a look at the past, current and projected future numbers of people living in cities.

Today the United Nations very closely monitor these numbers [2], they are well known beginning at the year 1950 and a lot of effort is put into predicting the development until 2050. All numbers prior to 1950 contain uncertainties that grow the further one looks back into the past.
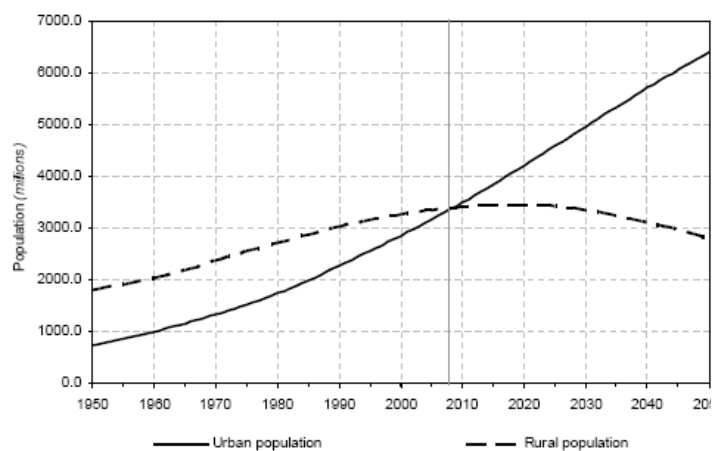
Source: [2]

The number of people living in cities increases by two factors: first the world population is still growing rapidly – from 2.5 billion people in 1950 over 6.6 billion people in 2007 to probably 9.2 billion people in 2050. The second factor is the migration of rural population to the cities. While in 1950 only 30% of the world population lived in urban areas, 2007 was the year, when more people lived in cities than in rural areas. By 2050 the UN estimates that it will be 70% of all the world population living in cities.

In ancient times (year 1 AD) only 300 million people populated the earth. As by 1800 the ratio of the urban population was 3%, one can estimate that in 1 AD far less than 9 million people lived in cities. But even in 45 BC Julius Caesar and the senate of Rome had to release a law that no wagon was allowed to enter the urbem by daylight [3], as they had seen no other chance to get the chaotic traffic conditions under control.

	1 AD	1950 AD	2007 AD	2050 AD
World Pop.	~ 300 m	2500 m	6600 m	9200 m
Ratio in Cities	< 3%	30%	50%	70%
Pop. in Cities	< 9 m	740 m	3300 m	**6400 m**

So as a matter of fact the number of cities as well as their size will increase, or to put it in a more general way: for an arbitrary number between 100,000 and 10,000,000 the number of settlements with a population exceeding that size will increase at least until 2050. The product of the two trends mentioned above yields that the urban population will double in the next 50 years. In result, it is to be concluded that – except for regions like Europe and Japan, where the development is ahead by decades and has settled to a more or less static state – the construction of the urban face of the

world has only just begun. But now, it is developing rapidly, rising the need for research in jamology as well as efficient and powerful planning tools. It is not only the city and it's arterials for vehicle traffic that need to be built, but also the places within, where people move regularly or gather only occasionally for mass events – a phenomenon that just as well has and will increase in frequency and size. And finally, the area occupied by cities will not increase in the same way the city population increases. Instead ever larger buildings will be constructed. Buildings for which emergency evacuation plans need to be created. A task that – for such complex structures – needs to be assisted by efficient and powerful computational tools.

VISSIM

What is VISSIM?

VISSIM is a multi-modal microscopic traffic simulation software manufactured by PTV in Karlsruhe, Germany. "Multi-modal" means that many different means of transport (individual transport by vehicles and motorcycles or bicycles, but also pedestrians and public transport by bus or tram) can be simulated. "Microscopic" refers to the fact that all entities and their interactions are modelled individually. VISSIM is an acronym of "Verkehr in Städten – SIMulation", its development has been started in 1992. The model that controls the vehicles is based on the model proposed by Prof. Wiedemann in 1974 [4].

Basics of the Wiedemann Model

The Wiedemann model is a psycho-physical driver-vehicle model that calculates the reaction of a driver on the basic variables "speed difference to leading vehicle" and "distance to leading vehicle" under consideration of physical restrictions like maximum breaking ability, but also imperfect human recognition.
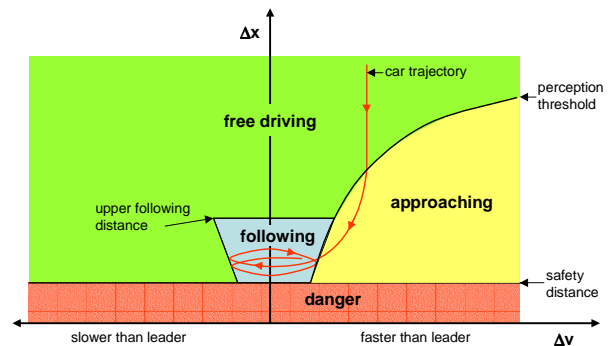
### Speed Limits and the Jam from "Nothing"

An application of the Wiedemann model on the borderline of theory and application is an investigation of the emergence of jams from "nothing" in absence and presence of speed limits. "Nothing" is set in quotation marks here, as the study investigates the influence of a truck overtaking another one on a two-lane highway. The result of the Wiedemann model is that with speed limit the overreaction of the following drivers is restricted in a number of situations in a way that no jam occurs, while with speed limit it does.

A truck overtaking another one in a VISSIM simulation.

Pedestrians: the Social Force Model

The pedestrians in VISSIM are controlled using the Social Force Model introduced in 1992 by Helbing et al. [5][6][7][8][9][10]. Its basic structure resembles Newtonian mechanics in that it is formulated using forces that act between a pedestrian and his destination, a pedestrian and his fellow pedestrians as well as a pedestrian and nearby walls or obstacles.
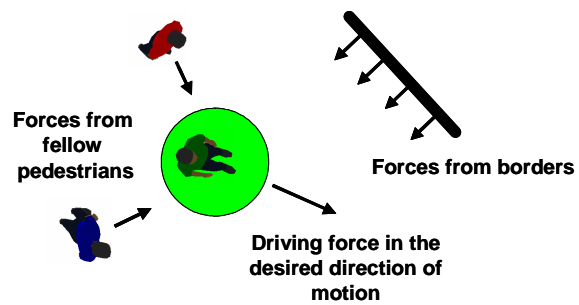
Pedestrian Dynamics at Bottlenecks

As an example for a detailed research – empirically and simulated – on the dynamics of pedestrians the flow of pedestrians through bottlenecks of different widths will now be examined.

It has been a discussion lasting almost all the 20th century [11][12][13][18], if there is a step function for the flow in dependence of the width of a bottleneck, or if it is a linear dependence. Recently some experiments indicate that the situation is more complex at smaller bottleneck widths [14][15][16] and that there is a linear dependence at wider bottlenecks (above 1.5 meter) [13][15][16][17].


Empirical Results

A whole set of experimental results of recent years show that – of all simple functions – it is the linear function that describes best the dependency of the flux from the width of the bottleneck. So the specific flux (flux over width of bottleneck) should be either constant or have a pole at some minimum width and then decrease monotonically. However, two experiments reveal a minimum of the specific flux around a width of 70 cm [14][15]. One experiment even had an increase of the evacuation time (a decrease of the flow), when the width was increased from 60 to 70 cm [14].

The reason – or at least a part of the reason - for this is that at a width of 70 cm two pedestrians sometimes only in the very last moment realize that they cannot pass simultaneously and therefore have to communicate again to set a sequence. As these experiments were done in a relaxed mood, it is hard to say, what would happen, if a crowd really rushes toward a 70 cm bottleneck, but it might well be that a width of 70 cm would be particularly dangerous in so far as pedestrians might "arch" and therefore get stuck [16].
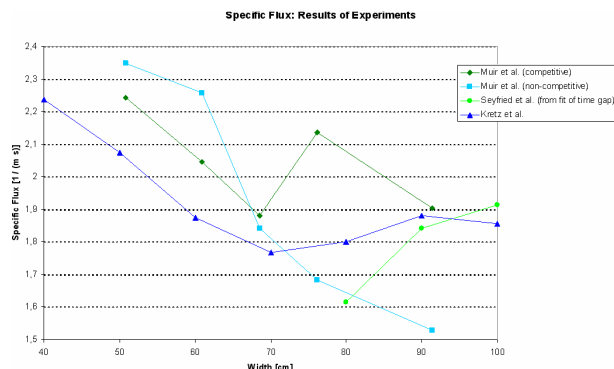
## Results of Simulations using the Social Force Model built in VISSIM

Interestingly simulations with VISSIM resulted in a minimum at a width of 60 cm, and that for a variety of model parameters. It needs further investigations to fix the reason for this, as it is obvious that the cause of reality – an effect from perception and psychology – cannot hold for the model, as the model does not include psychology or misperceptions. Still, no matter, what the reason is, one here has the case that accidentally by some "trick" the model has a detail correct that to model intentionally would probably have been very difficult [16].
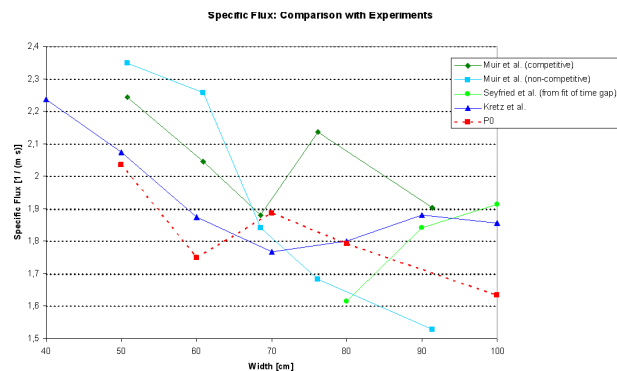
Large Scale Pedestrian Simulations: The F.A.S.T. Model

The Social Force Model is in its formulation continuous in space and time. For implementation on a computer, discretizations have to be introduced, which still are comparatively fine (for example there is a time step of 0.05 seconds). In effect this leads to considerable computational effort, once a simulation scenario has 10,000 or even many times 10,000 pedestrians.

To overcome this problem, there is a class of cellular automata related models [19][20][21][22][23][24], which are discrete in space and time already in their formulation. The discretization is always chosen as large as possible, but such that the model is still fully microscopic. The F.A.S.T. model (Floorfield and Agent based Simulation Model) has a discretization of 40 x 40 cm² and 1 second per time step. A cell (i.e. a node on the lattice) can be occupied by at maximum one pedestrian. Each pedestrian has an individual speed given in cells per time step (v = 1 would equal 0.4 m/s). The faster a pedestrian is, the more cells he can reach within a time step. At the beginning of each time step a pedestrian assigns a selection probability to each of the cells, he is able to reach. Cells with obstacles and cells occupied by other pedestrians have probability 0. Then a cell is chosen as destination for this time step according to these probabilities. Finally all pedestrians try to reach their destination cells, but may fail due to other pedestrians crossing their path [25][26][27][28].
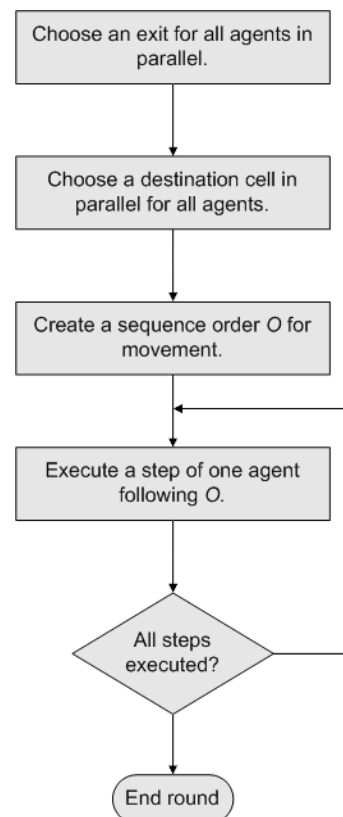
VISUM

What is VISUM?

VISUM is a software system for macroscopic, multi-modal transportation planning, travel demand modelling and network data management. VISUM is used on all continents for metropolitan, regional, state-wide and national planning applications.

VISUM is used to build conventional four-step models for regional and state-wide planning while also serving as an analysis and data management tool for traffic engineers and transportation planners. Its detailed public transportation service planning capability includes a very elaborate data model for routes and schedules [29].
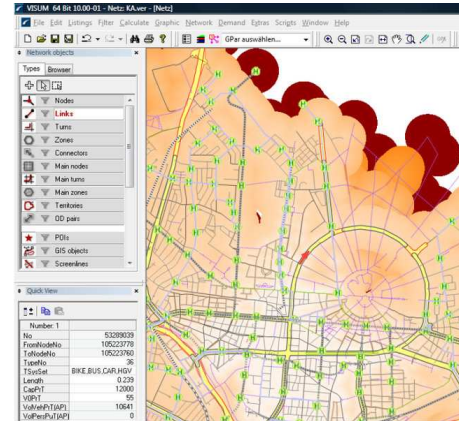
An example: the Dubai Bus Master Plan

The metropolitan area of Dubai is one of the fastest growing ones all over the world. Dubai has just recently started to install a public transport system with integrated metro. Some of the special demands of the task of planning such a system are:

- Due to the special climatic conditions no bus station shall be further away than 300 meters from any private or public building
- Due to the rapid growth the future layout of the city has to be considered at any step of the planning process. The extension of the transportation system has to be planned right from the beginning.

This was solved by introducing the metro that will form the backbone of the future public transport system and a high level system of direct express bus services, complementing the metro system. A feeder bus system will connect local service areas with the higher level bus and metro system. Thus, a clearly separated network hierarchy has been established with different bus product types. Smooth passenger transport is assured by full integration of all network elements.

Dubai's public transport system as planned for 2009. (The metro is shown as a red line and will start its service in 2009)

Plans for Dubai's metro by 2020.

Conclusions

The history of traffic jams nowadays counts almost 2100 years. But until today only half of the path is gone in the sense that in another 40 years twice as many people than today will live in a way that will make them part of jams and crowds very frequently. Both, the science to guide this process as well as the software tools to plan its details exist. Though, the enormous challenges of the years to come demand rapid development in both fields. At least the most ambitious calculations are and will remain at the edge of the computation power of affordable hardware. And some nations fail to educate traffic engineers capable to use the complex planning and simulation software tools fast enough, where "fast enough" relates to the growth rate of their cities. So, jamology quickly has to spread to universities everywhere on the globe to enable people to contribute to the construction of cities worth living in.

Literature

[1] Y. Sugiyama, M. Fukui, M. Kikuchi, K. Hasebe, A. Nakayama, K. Nishinari, S. Tadaki, and S. Yukawa. Traffic jams without bottlenecks—experimental evidence for the physical mechanism of the formation of a jam. *New J. Phys*. 10 (2008) 033001.

[2] Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2006 Revision* and *World Urbanization Prospects: The 2007 Revision*, http://esa.un.org/unup, Wednesday, August 20, 2008.

[3] G. I. Caesar. *Lex Iulia Municipalis* aka *Tabula Heracleensis*. 45 BC.
   a. The passage says: *Quae viae in urbem Romam sunt erunt intra ea loca ubi continenti habitabitur nequis in ieis vieis post Kalendas Ianuarias primas plostrum interdiu post solem ortum neve ante horam X diei ducito agito nisi quod aedium sacrarum deorum immortalium caussa aedificandarum operisve publice faciumdei causa advehei portari oportebit aut quod ex urbe ex ve ieis loceis earum rerum quae publice demoliendae locatae erunt publice ex portarei oportebit et quarum rerum caussa plostra hac lege certeis hominibus certeis de causeis agere ducere licebit.*

[4] R. Wiedemann. Simulation des Straßenverkehrsflusses. *Schriftenreihe des IfV*, 8, 1974. Institut für Verkehrswesen. Universität Karlsruhe. (in German).

[5] D. Helbing and P. Molnar. Social force model for pedestrian dynamics. *Phys. Rev. E*, 51:4282–4286, 1995.

[6] D. Helbing, I. Farkas, and T. Vicsek. Simulating dynamical features of escape panic. *Nature*, 407:487–490, 2000.

[7] D. Helbing, I.J. Farkas, P. Molnar, and T. Vicsek. Simulation of Pedestrian Crowds in Normal and Evacuation Situations. In Schreckenberg and Sharma editors. *Pedestrian and Evacuation Dynamics*. (PED01), Proceedings, Duisburg, GER, 2002, Springer-Verlag Berlin Heidelberg.

[8] T. Werner and D. Helbing. The Social Force Pedestrian Model Applied to Real Life Scenarios. In E. Galea editor. *Pedestrian and Evacuation Dynamics: 2nd International Conference*. (PED03), Proceedings, Old Royal Naval College, University of Greenwich, London, UK, 2003, CMS Press.

[9] A. Johansson, D. Helbing, and P.K. Shukla. Specification of the Social Force Pedestrian Model by Evolutionary Adjustment to Video Tracking Data. *Advances in Complex Systems* 10(4):271–288, 2007.

[10] PTV – Planung Transport Verkehr AG. *VISSIM 5.1 User Manual*, 2008.

[11] D. Dieckmann. *Die Feuersicherheit in Theatern*. Jung (München), 1911. (in German).

[12] H. Fischer. *Über die Leistungsfähigkeit von Türen, Gängen und Treppen bei ruhigem, dichtem Verkehr*. Dissertation, Technische Hochschule Dresden, 1933. (in German).

[13] T. Rupprecht. Untersuchung zur Erfassung der Basisdaten von Personenströmen. Master's thesis, Bergische Universität Wuppertal, FB D - Abt. Sicherheitstechnik, 2005. (in German). Some results were published in English in [17].

[14] H.C. Muir, D.M. Bottomley, and C. Marrison. Effects of Motivation and Cabin Configuration on Emergency Aircraft Evacuation Behavior and Rates of Egress. *Intern. J. Aviat. Psych.*, 6:57–77, 1996.

[15] T. Kretz, A. Grünebohm, and M. Schreckenberg. Experimental study of pedestrian flow through a bottleneck. *Journal of Statistical Mechanics: Theory and Experiment*, P10014, October 2006.

[16] T. Kretz, S. Hengst, and P. Vortisch. Pedestrian Flow at Bottlenecks - Validation and Calibration of VISSIM's Social Force Model of Pedestrian Traffic and its Empirical Foundations. In M. Sarvi, editor, *International Symposium of Transport Simulation 2008*. (ISTS08), Proceedings, Gold Coast, AUS, 2008. (to be published), arXiv:0805.1788.

[17] A. Seyfried, T. Rupprecht, O. Passon, B. Steffen, W. Klingsch, and M. Boltes. New insights into pedestrian flow through bottlenecks. *ArXiv Physics e-prints*, 2007.

[18] A. Schadschneider, W. Klingsch, H. Klüpfel, T. Kretz, C. Rogsch, and A. Seyfried. Evacuation Dynamics: Empirical Results, Modeling and Applications. In R.A. Meyers, editor, *Encyclopedia of Complexity and System Science*. Springer, Berlin Heidelberg New York, 2009. (to be published in April 2009). arXiv:0802.1620.

[19] V.J. Blue and J.L. Adler. Cellular Automata Microsimulation of Bi-Directional Pedestrian Flows. TRR, TRB, 1678:135--141, 2000.

[20] K. Nishinari, A. Kirchner, A. Namazi, and A. Schadschneider. *Extended floor field CA model for evacuation dynamics*. IEICE Trans. Inf. & Syst., E87-D:726–732, 2004.

[21] H. Klüpfel. A Cellular Automaton Model for Crowd Movement and Egress Simulation. PhD thesis, Universität Duisburg-Essen, 2003.

[22] A. Schadschneider. *Cellular Automaton Approach to Pedestrian Dynamics – Theory*. Pages 75-85 in N. Waldau, P. Gattermann, H. Knoflacher, M. Schreckenberg, editors *Pedestrian and Evacuation Dynamics '05*. (PED05), Proceedings, Vienna, AUT, 2006, Springer, Heidelberg.

[23] C. Burstedde, K. Klauck, A. Schadschneider, and J. Zittarz. *Simulation of Pedestrian Dynamics Using a 2-dimensional Cellular Automaton*. Physica A, 295:507, 2001.

[24] A. Kirchner, K. Nishinari, and A. Schadschneider. *Friction Effects and Clogging in a Cellular Automaton Model for Pedestrian Dynamics*. Phys. Rev. E, 67(056122), 2003.

[25] T. Kretz. *Pedestrian Traffic – Simulation and Experiments*. PhD thesis, Universität Duisburg-Essen, 2007.

[26] T. Kretz and M. Schreckenberg. F.A.S.T. – Floor field- and Agent-based Simulation Tool. In E. Chung and A.-G. Dumont, editors, *International Symposium of Transport Simulation 2006*. (ISTS06), Proceedings, Lausanne, CH, 2008, EPFL Press. (to be published), arXiv:physics/0609097.

[27] T. Kretz and M. Schreckenberg. The F.A.S.T.-Model. In S. El Yacoubi, B. Chopard, and S. Bandini, editors, *Cellular Automata – 7ᵗʰ International Conference on Cellular Automata for Research and Industry*. (ACRI2006), Proceedings, pages 712-715, Perpignan, FRA, 2006, Springer-Verlag Berlin Heidelberg.

[28] T. Kretz, C. Bönisch, and P. Vortisch. Comparison of Various Methods for the Calculation of the Distance Potential Field. In C. Rogsch et al. editors, *Pedestrian and Evacuation Dynamics '08.* (PED08), Proceedings, Wuppertal, GER, 2008, Springer, Heidelberg. (to be published), arXiv:0804.3868.

[29] PTV – Planung Transport Verkehr AG. *VISUM 10.0 User Manual*, 2007.

Online Resources

PTV AG

- **PTV**: http://www.ptv.de/
- **PTV Japan**: http://www.ptv-vision.jp/
- **VISSIM**: http://www.vissim.de/
- **Traffic Library**: http://www.english.ptv.de/cgi-bin/traffic/traf_library.pl

Initiatives

- **Ped-net**: http://www.ped-net.de/
- **Rimea**: http://www.rimea.de/
- **Evacmod**: http://www.evacmod.net/

Conferences

- **ACRI**: http://acri2008.ynu.ac.jp/ Cellular Automata for Research and Industry conference (including a "crowds and cellular automata" workshop)
  - o The next ACRI conference will be held in Yokohama in September 2008.
- **Walk21**: http://www.walk21.com/
  - o The next Walk21 conference will be held in Barcelona in October 2008.
- **ITS World Congress**: http://www.itsworldcongress.com/
  - o The next ITS World Congress will be held in New York in November 2008.
- **TGF**: http://www.th.u-psud.fr/TGF07/ Traffic and Granular Flow conference
  - o The next TGF conference will be held in Shanghai in 2009.
- **PED**: http://www.ped2008.com/ Pedestrian and Evacuation Dynamics conference
  - o The next PED conference will be held in Washington in spring 2010.
- **Intertraffic**: http://www.amsterdam.intertraffic.com/
  - o The next Intertraffic conference will be held in Amsterdam in March 2010.
- **ISTS**: http://civil.eng.monash.edu.au/conferences/ists08 International Symposium on Transport Simulation
  - o The next ISTS conference will be held in 2010.