# BABSIM - An object-oriented software framework for microscopic simulation of freeway traffic

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## Summary
A wide variety of behavioural models exist in microscopic traffic simulation. Commercial programms often use closed-source policies and are confined to their respective simulation platforms. Open-source approaches mainly focus on distinctive, highly specialized traffic situations. In the scope of this paper, an open-source framework for developing modular, object-oriented simulation systems is presented, capable of simultaneously accommodating different driving models and enabling the user to modify and extend the catalogue of driving behaviours. The existing driving behaviours and the computational implementation of the simulation are being described.

## 1 Introduction
The number of motorized vehicles on this planet has steadily increased to now over half a billion units, and there is no indication that this growth is likely to cease in the near future. The traffic flow on roads, especially in densely populated regions, is often on the brink of collapse, necessitating a constant expansion of road networks. Traditional design tools of traffic engineers often prove to be inadequate to meet the demands of modern road engineering. For the analysis of complex, interacting traffic junctions, traffic simulation has been established as a legitimate alternative to conventional planning methods.

Numerous commercial simulation packages have been developed in recent years, that are now competing against another in a relatively small customer market segment. As a result of this competition, the underlying simulation algorithms are often subject to non-disclosure policies, thus effectively preventing the use, analysis and advancement of their traffic models for educational, scientific or commercial uses. Though there is a considerable number of known microscopic driving behaviours for individual vehicles, only a few simulation programs are implementing more than one behaviour, thus disallowing the use of alternative driving models. By virtue of the simulation package BABSIM (BundesAutobahn SIMulator, Federal Highway Simulator), a new framework encompassing several driving behaviours has been developed that lacks the previous limitations.

## 2 Traffic Simulation
Traffic simulation models are often distinguished into four classes, according to their level of simulation detail. Most common are macroscopic models where traffic flow is emulated as a stream of particles subjected to the laws of fluid dynamics. Also often used are microscopic models that focus on individual vehicles and their driving behaviour. While macroscopic models use less computational resources and, therefore, allow the simulation of large road networks, the results are often less accurate compared to microscopic simulation. In many cases, individual road segments or junctions cannot be recreated. By contrast, mesoscopic models try to bridge the gap between macroscopic and microscopic simulation using individual vehicles that are being actuated by macroscopic control variables. Sub-microscopic models provide the highest level of detail, but they are computationally expensive and take a lot of time to be calibrated, and are, therefore, most often used for single vehicle simulation in the automobile industry.

Microscopic traffic models try to represent real world traffic flow by emulating individual vehicles, the attributes of their drivers as well as their driving behaviours. The simulation is usually carried out by means of discrete time-steps, in a continuous space environment. At each time-step, the vehicle measures the distance to its interacting cars, and, from this information, uses its driving behaviour to decide whether to accelerate or decelerate. Also, for each vehicle one has to chose whether to lanes are to be changed in order to reach a targeted on-/offramp or to overtake a slower preceding vehicle. In this context, several established driving and lane change behaviours are known in traffic research.

# 3 Behavioural Models implemented in BABSIM

The following common simulation strategies have been included into BABSIM. In the implementation phase, our goal has been to leave the underlying algorithms as untouched as possible, and to adapt them only when model changes or obsolete traffic assumptions force alterations.[1]

## 3.1 Driving Behaviours

In this paper, the term driving behaviour describes all vehicle movements in axial direction, i.e. accelerating oder decelerating along a current road lane. All models described in the following consider only the vehicle in front of a car. In addition, all model realizations try to accurately emulate realistic acceleration rates.

### 3.1.1 Driving behaviour KINEMATIC

The kinematic model uses a very elementary kinematic equation to calculate the maximum degree of acceleration/deceleration that a vehicle must exert to prevent a collision with the preceding vehicle. At each time-step, the new deceleration rate $a_{n+1}$ must be high enough to prevent a collision for a predefined time interval (called time-to-collision, $t_c$), and adjust the current following distance *Dx* to attain a targeted optimal following distance (called *dx*). The velocity is being clipped so that it remains in the interval of $[0..v_{max}]$.

$$a_{n+1} = a_n + (Dx - dx) \cdot \frac{2}{t_c^{\,2}} + dv \cdot \frac{2}{t_c} \qquad (1)$$

As the model relies on only two parameters, the calibration effort is rather small – but the simulation obviously does not attain high levels of reality, either. Due to its limitations, the kinematic model is of little significance in modern traffic simulation and not recommended for road dimensioning tasks. It has been included, however, for educational purposes.

### 3.1.2 Driving behaviour WIEDEMANN

Wiedemann's model, also known as the psycho-physical model and based on works of Michaels (1963), has now been in use for over 30 years. It is still deemed to provide quite accurate simulation results, and several commercial simulation packages, like Paramics and VISSIM, are quite successful in using this model. Wiedemann's concept was to define a driver's perception threshold, that, if exceeded by a visual stimulus (e.g. an approaching vehicle), triggers a behavioural reaction. The reaction is dependent on the relation between the car and the preceeding vehicle. Several regions of interaction are defined (Approaching, Following, Emergency and Uninfluenced). Each driver-vehicle unit (DVU) is provided with an individual set of attributes that define his driving behaviour, e.g. his alertness, reaction time, need for safety or willingness to accelerate. The advantage of the psycho-physical model lies in its high level of realism. Furthermore, it is proven and shows a reasonable robustness.

### 3.1.3 Driving behaviour BANDO

In 1995, Bando et al. introduced the Optimal Velocity Model (OVM), a velocity-density-model that belongs to the group of deterministic driving models and relates a vehicle's target velocity to the macroscopic traffic density. Bando introduced an optimal velocity such that every vehicle tries to follow the relation

$$a_{n+1} = \alpha\left(v_{opt}(dx) - v_n\right) \tag{2}$$

where:

$a_{n+1}$ = acceleration for the next time-step,
$\alpha$ = sensitivity factor (inverse of the driver's reaction time),
$v_{opt}$ = optimal velocity function
$dx$ = distance headway to preceding car
$v_n$ = current vehicle velocity

Bando's team proposed a monotonically increasing optimal velocity function with an upper bound of $v_{max}$. Thus

$$v_{opt}(dx) = \frac{v_{max}}{2}\left(tanh\left(0.086 \cdot (dx - 25)\right) + 0.913\right) \leq v_{max} \tag{3}$$

Since that time, several modified optimal velocity functions have been developed, e.g. using different functions for the acceleration and deceleration cases (Asymmetric Optimal Velocity Functions) or differentiating between a vehicle's free-speed (uncongested traffic flow) and the speed-at-capacity (congested traffic) with a four-parameter-equation (Van Aerde, 1995). The original Bando version as well as the Van Aerde modification have been included into BABSIM as well.

### 3.1.4 Driving behaviour GAZIS

The so called car following theory, based on the works of Gazis, Herman and Rothery (1961), attempts to emulate the vehicle behaviour by determining the car following distance by considering a driver's reaction time to certain stimuli (speed difference to preceding car, velocity and headway)

$$a_{n+1} = \alpha_0 \cdot \frac{v_{n+1}^{\ m}}{dx^l} \cdot dv \tag{4}$$

where:

$a_{n+1}$ = acceleration after a fixed reaction time T
$\alpha_0$ = sensitivity factor
$m, l$ = calibration parameters
$dv$ = velocity difference to preceding vehicle

For German highways, values for the parameters $m$ and $l$ have been established in the study by Hoefs (1972) for different situations (falling back or closing in on the car in front, with or without brake lights). But, due to the steady increase of traffic on European roads, a recalibration of the model parameters has been performed during the development of BABSIM, resulting in a new parameter set for more realistic simulation results.

## 3.2 Lane Change Behaviours

Lane Change Behaviours describe the strategy for lateral transitions of a vehicle from one road lane to an adjacent one. In contrast to the car following behaviours described above, where only the preceeding and following vehicles have to be taken into account, a lane change requires a far more complex interaction between the car and all its neighbouring vehicles. Each vehicle has to decide whether it wants to change lanes, whether such a change would be safe, and whether the security of other cars would be affected in the process. Furthermore, vehicles have to assist other cars that try to change lanes, which complicated the decision finding process even more.

### 3.2.1 Lane Change Behaviour SPARMANN

Based on the work of Wiedemann Sparmann has developed a lane change algorithm for two-lane highway traffic. Taking into account all six potential interaction partners (i.e. each vehicle in the front and back on the current lane as well as its two neighbours), a vehicle might develop the desire to change lanes by using a variation of Wiedemann's regions of relation. Once the need for a lane change has been established, the vehicle checks whether such a transition would endanger either him or its interaction partner. If the safety of all vehicles can be ensured, the lane change behaviour initiates the change process, and the vehicle is set on the neighouring driving lane.

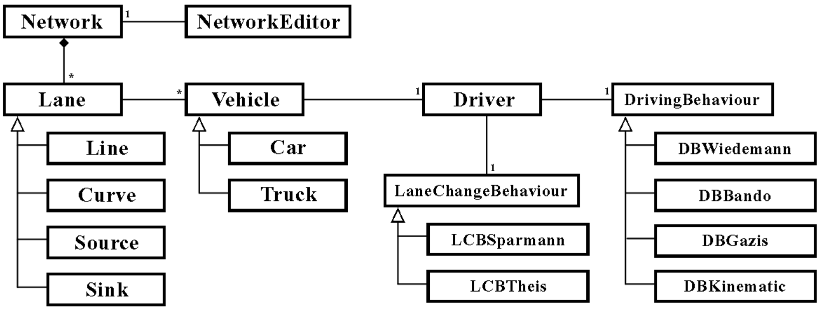
One disadvantage of Sparmann's model is the lack of a more anticipatory strategic approach. Only the neighbouring vehicles are being considered, ignoring the need to assist other vehicles that might change lanes. As a consequence, a cooperative interaction, especially in the proximity of highway junctions, can not be represented. For a better emulation of on-ramp and off-ramp behaviour, therefore, Theis has created an improved model.

### 3.2.2 Lane Change Behaviour THEIS

Theis added a strategic component to Sparmann's model: If a vehicle is trying to reach a certain lane, it has to ask conflicting vehicles for their assistance. Vice verso, the assisting vehicle has to decide whether to accelerate or to fall back to create a gap for the changing vehicle, or to change lanes by itself to make room. Theis differentiates between on-ramp and off-ramp behaviour. "Classic" Sparmann behaviour is used when no strategic interaction planning is necessary.

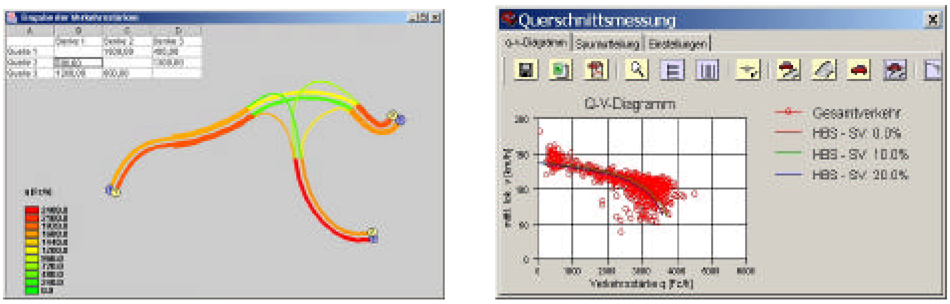
# 4 Implementation notes

As the simulation system was targeted to run on different operating systems, an object-oriented approach has been taken, using Sun Microsystems programming language Java for the implementation. In the first step of the design phase the real world traffic elements and their interactions have been identified, classified and modelled. Based on this analysis, all ingredients of a traffic modelled could be incorporated into common class structure. On this basis, complex highway networks can be emulated by associatively linking different traffic lanes. Vehicles are being generated by sources, placed onto the lane and steered by the chosen driving and lane change behaviour, until the vehicles reaches a sink and are being removed from the simulation. For evaluation of simulation runs, measuring points can be inserted into the existing road network at any time, responsible for locally registering current traffic conditions and gathering data for generation of distance/time-diagrams as well as velocity/density-diagrams. The simulation is time step-oriented, with time steps adjustable from 0.1 to 1.0 seconds.




Class diagram of the main simulation classes (overview)

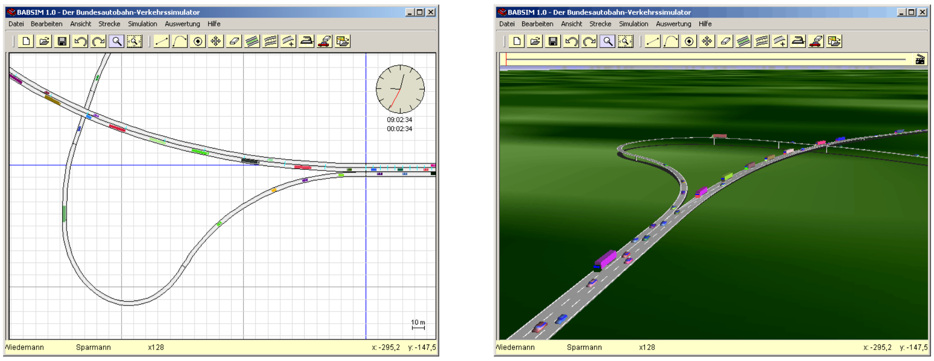
Each vehicle is characterized by numerous attributes describing the driving state of the vehicle as well as the inherent properties of vehicle and driver. All attributes required by the respective driving behaviours can be provided. Each driver-vehicle-unit is randomly assigned to its own route of preference, which is generated using a shortest path algorithm. Simulation settings, such as traffic volumes, truck rate, upward gradients and speed limits, allow for a differentiated emulation of real traffic situations.




Input of traffic volumes (left) and resulting q-v-diagram (right)

Early on in the development phase, it could be realized that usability of the simulation environment is of vital importance. Therefore a user interface has been created that is both intuitively accessible and comprehensive. The graphical user interface (GUI) relies on the familiar GUIs of current CAD-applications and offers a wide variety of tools to establish complex road networks in a short time. The result of the development process is the so-called NetworkEditor, which simultaneously acts as a construction tool and simulation environment. The connection between the data model and visualisation is basically accomplished by means of the model-view-controller (mvc) design pattern, resulting in a strict separation of data model classes, visualization classes of the editor, and controller classes for user interaction.

The NetworkEditor also allows for maps or satellite views of existing roads which may be used as a template for the simulated road network. Single or multiple lane roads can easily be created and connected via on-ramps or off-ramps, forming complex highway junctions with arbitrary traffic densities for each route. To further verify the plausibility of the simulation, a three-dimensional view has been integrated into the editor, enabling the user to check the vehicle behaviour from any given point of view.



The NetworkEditor in 2D and 3D view

## 5 Calibration and Testing

For a recalibration of the model parameters a series of measuring runs have been carried out, gathering specific data on vehicle velocities, accelerations and following distances according to different traffic situation. During the test runs, the measuring vehicle was driven by different drivers on about 800 kilometres of German highway. All measuring runs were recorded on video to capture following and lane change processes. Using the obtained data sets, optimization runs have been performed using BABSIM, to define appropriate parameter sets for all driving behaviours.


Rangefinder (left), Velocimeter (center) and video view (right) of the measuring car

The essential advantage of traffic simulation is the possibility to simulate a wide variety of scenarios on the computer that are possibly not directly representented within the German highway manual (Handbuch für Straßenwesen, HBS). The results of the simulation, however, can be verified with real-life measurements on existing roads. During the calibration phase of our project, it has been examined what the effects of a ban on truck overtaking would be on a six-kilometre stretch of two-lane highway for different traffic densities. The simulation results fit the empirical measuments, proving the applicability of the simulation to new traffic dimensioning tasks.

| | q = 1.500 vehicles/h | q = 2.500 verhicles/h |
|---|---|---|
| average speed (simulated, overtaking) | 122,4 km/h | 108,8 km/h |
| average speed (simulated, no overtaking) | 125,0 km/h | 112,9 km/h |
| Speed difference (simulated) | + 2,6 km/h | + 4,1 km/h |
| Speed difference (empirical) | + 2,9 km/h | + 4,4 km/h |

Example: The effect of banning trucks from overtaking in simulation and reality

## 6 Conclusions

A short overview of traditional traffic simulation strategies has been given. Also, it has been demonstrated that these strategies can be integrated into a unified simulation system. An object-oriented approach of modeling complex traffic networks has been presented. Furthermore, its implementation in Java, using an intuitive graphical user interface, has been illustrated. BABSIM has evolved into a complex, but easy to use open-source alternative to commercial traffic simulation systems that can be used for scientific research and road design tasks as well.

## 7 Endnotes

1) For a closer look on the described behavioural models and their implementation, please refer to the BABSIM research report (Brilon, Hartmann 2004).

## 8 References


Brilon, W. and Hartmann, D. (2004) *Fortentwicklung und Bereitstellung eines bundeseinheitlichen Simulationsmodells für Bundesautobahnen.* Research project FE01/157/2001/IRB for the Bundesanstalt für Straßenwesen (Federal Highway Research Institute, Germany), in cooperation with the Ruhr-University Bochum. Germany.

Wiedemann, R. (1974) *Simulation des Straßenverkehrsflusses.* PhD-thesis. University of Karlsruhe. Germany.

Theis, C. (1997) *Modellierung des Fahrverhaltens an Autobahnanschlußstellen*. PhD-thesis. University of Karlsruhe. Germany.

Bando, M., Hasebe, H., Nakayama A., Shibata, A. and Sugiyama, Y. (1995) *Dynamical Model of Traffic Congestion and Numerical Simulation.* Physical Review E 51.

Gazis, D.C., Herman, R. and Rothery, R.W. (1961) *Non-linear Follow-the-Leader Models of Traffic Flow.* Operations Research 9, No.4

Hoefs, D.H. (1972) *Untersuchung des Fahrverhaltens in Fahrzeugkolonnen.* Straßenbau und Straßenverkehrstechnik 140.

Sparmann, U. (1978) *Spurwechselvorgänge auf zweispurigen BAB-Richtungsfahrbahnen.* Straßenbau und Straßenverkehrstechnik 263.

Van Aerde, M. and Rakha, H. (1995). *Multivariate calibration of single regime speed-flow-density relationships*. Proceedings of the Vehicle Navigation and Information Systems (VNIS) Conference. Seattle. Washington.