Modeling of Freeway Traffic

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Summary

An integrated modeling of freeway traffic is developed, whose implementation in an uniform computer–aided simulation model facilitate comparative evaluation and systematic coupling of several traffic simulations, traffic controls, traffic measurements and traffic scenarios. The integrated modeling of freeway traffic is a basic mapping of freeway networks, control methods, measurements and different simulations of traffic flow.

Commonly, the simulation of traffic flow bases on microscopic, macroscopic or mesoscopic traffic modeling. A microscopic modeling featuring descriptive rules is developed. A macroscopic modeling consisting of Navier–Stokes–like equations is considered. An integration of the microscopic modeling in any macroscopic modeling leads to a novel rule–based mesoscopic modeling. The three different modelings are numerically approximated by different numerical methods. In particular, the finite element method can successfully be applied to the macroscopic modeling.

The simulation programs evolved from implementations of numerical approximations of the three modelings are verified for usefulness in perturbation analysis and comparison of simulation results with detector data. Both the microscopic and the macroscopic simulation are able to reproduce typical traffic phenomena like traffic jams or stop–and–go waves. Choosing a suitable velocity–distance–relation the mesoscopic simulation proves a consistent link between microscopic and macroscopic simulations. The velocity–distance–relation respectively the velocity–density–relation are the decisive parameters of the shown simulations. Due to changes of these parameters, the simulation reacts very sensitively.

1 Freeway Traffic

Freeway traffic characterizes translocations of people or goods via vehicles in a freeway network. The behavior of vehicles and their interactions in a freeway network forms a traffic flow. The traffic flow should be interferenced by traffic control methods like static or variable traffic signs. The realization of an efficient traffic control system requires data obtained by traffic measurements.

An integrated modeling of freeway traffic has to consider the components traffic flow in the freeway network, traffic control and traffic measurement as well as the dependencies and influences between these components (see figure 1). Furthermore the modeling should be integrated in the simulation of traffic flow, traffic control and traffic measurement to be used for short–term forecasts.

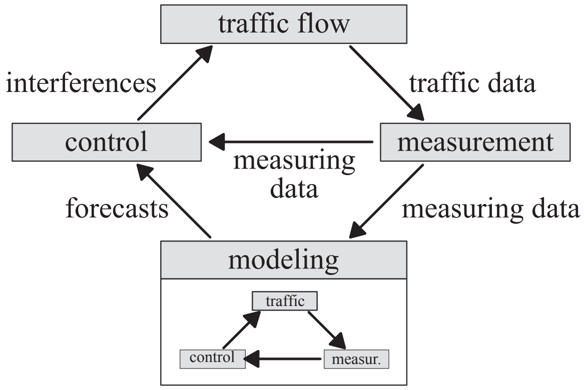

Figure 1: Dependencies and influences between traffic flow , traffic control, traffic measurement and traffic modeling

1.1 Freeway Network

A freeway network is the basis for freeway traffic. It is characterized by its network structure. In order to model this structure, it is advisable to decompose the network in small uncomplex sections. The sections and their correlations are mapped as nodes and edges in directed or bipartite graphs (Pahl and Damrath 2002). The geometry of a section is modeled by a cell. The geometry of a freeway network is a graph of cells called cellcomplex (Milbradt 2001).

Different traffic problems need different detailed modelings of the freeway network. For example, finding an optimal route through the network requires a shortest path algorithm (Rose 1996) in a less detailed graph of the network. Whereas a simulation of traffic flow demands a very detailed graph of the network.

In order to consider different traffic problems a hierarchical system of freeway networks with different levels of detail is modeled. In this modeling a freeway network consists of seversal freeways, a freeway consists of to contrariwise directed carriageways and a carriageway consists of parallel lanes. A freeway network is decomposed in freeway sections by cross sections of the freeway completely. The structure of a cellcomplex with two different kinds of sections, like interchanges and freeways between this interchanges, is a bipartite graph (see figure 2). A freeway section is decomposed in carriageway sections, a carriageway section is decomposed in segments and cross sections and a segment or a cross section is decomposed in segment lanes or cross section lanes.

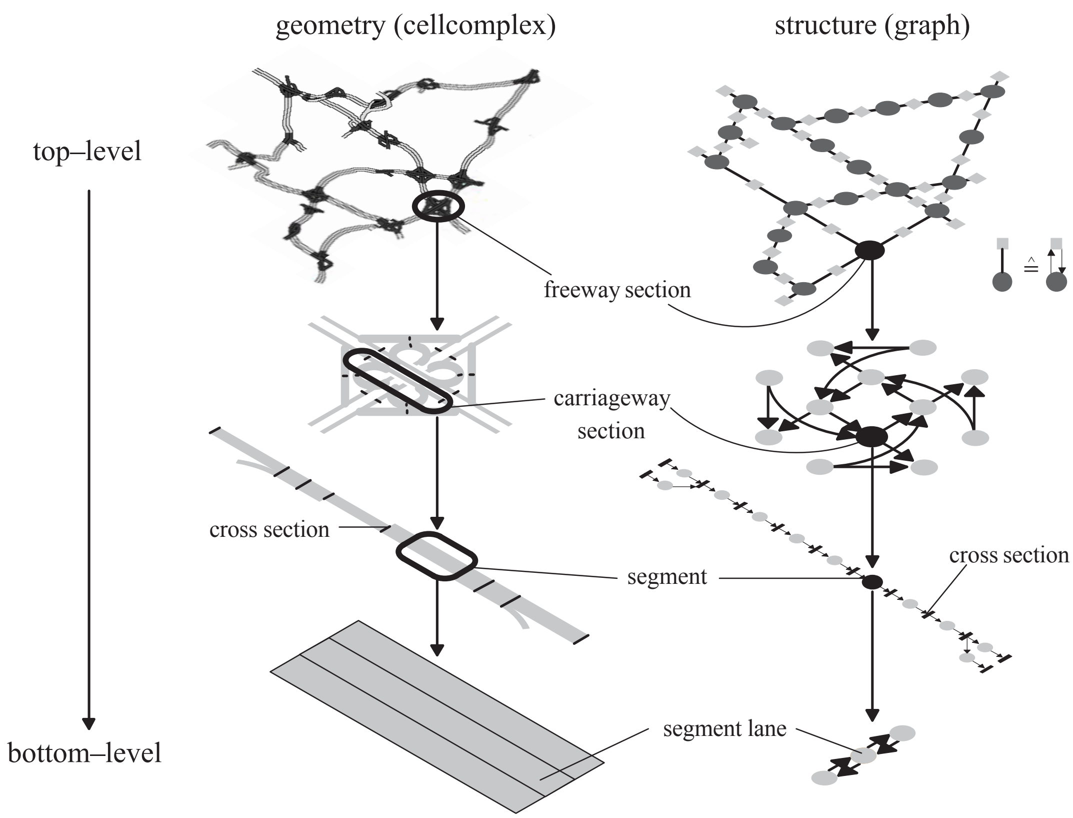

Figure 2: Hierarchical system of a freeway network with different levels of detail

Essential for this hierarchical system is the consistence of structure, geometry and physics between different levels of detail. Each subcellcomplex or rather each subgraph on a level is unequivocally mapped to one cell respectively one node on the next higher level. The geometrical and structural consistence is guaranteed. The physics of the freeway network as well as the physics of traffic flow, traffic control methods and traffic measurements in the network must also be consistent between the different levels and between adjacent sections in a network of the same level.

1.2 Traffic Control

Traffic control has to be considered by operational traffic methods in an integrated modeling of freeway traffic. In principal, two different kinds of traffic methods exists. Firstly there are static methods like traffic signs or long term road works. Secondly there are dynamic methods like alternating direction signs or light–signal systems. Methods interference traffic flow on a carriageway either at a position, for instance by a direction sign, or in a range, for instance by a speed limit (see figure 3). With the decomposition of a freeway network, shown in figure 2, a method at a position is modeled as a component at a cross section lane. This cross section based component allows modifications of downstream traffic flow behavior. A method in a range of a carriageway is modeled as a component at a segment lane. This segment lane based component acts as a resistance for the traffic flow.

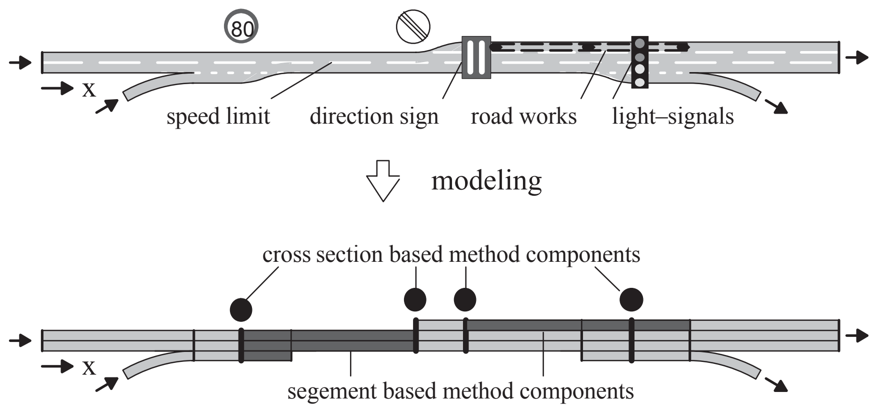

Figure 3: Modeling of traffic control measures on a carriageway section

1.3 Traffic Measurement

Traffic measurements are used to collect data of the traffic flow on a carriageway section. The traffic data allow statements about spatial and temporal processes of traffic state values on the section. Normally traffic measurements are either momentary measurements or local measurements.

A momentary measurement leads to a spatial distribution of vehicles on a segment of the carriageway at a particular time. The proportion of the counted vehicles to the segment length is a characteristic value for traffic density. Two short–delayed momentary measurements allow the determination of the relevant mean velocity. One possible momentary measurement is a photo of the segment. A momentary measurement is modeled by several components at the segment lanes of the shown decomposition of a freeway network.

A local measurement leads to a temporal distribution of vehicles at a cross section of the carriageway during a time interval. The proportion of the counted vehicles to the time interval is a characteristic value for traffic volume. Two near–displaced local measurements allow the determination of the relevant mean velocity. Possible instruments for a local measurement are detectors like radars or induction loops. A local measurement is modeled by several components at the cross section lanes of the shown decomposition of a freeway network.

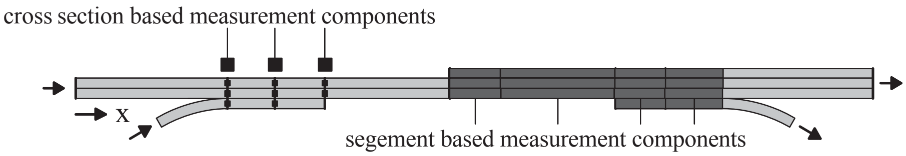

Figure 4: Modeling of traffic measurements on a carriageway section

1.4 Traffic Flow

Traffic flow is determined by the movements and interactions of the vehicles on a carriageway in one direction. It is discribed in a space–time diagram (see figure 5). The diagram plots the positions of all vehicles on a carriageway section at each time in a particular time interval. A motion curve for every vehicle in the traffic flow occurs. The curve discribes the vehicle motion on the section in the time interval. The gradient at each point of the motion curve is equivalent to the velocity of the accordant vehicle.

There are some essential characteristics to discribe traffic flow: Traffic density characterizes vehicles in a section at a time. Traffic volume characterizes vehicles at a position in a time interval. Mean velocity is the average of all vehicle velocities in a traffic flow. Definitions of this characteristics depends on various control regions. A spatial density ρ_s and mean velocity v_s is defined in a spatial control region (see figure 5a) at position x at time t with a length Δx as follows:

$$\rho_s := \frac{n_s(x, \Delta x, t)}{\Delta x} \qquad v_s := \frac{1}{n_s}\sum_{a=1}^{n_s} v_a(x, \Delta x, t) \tag{1}$$

A traffic volume is not definable in a spatial control region. A temporal volume q_t and mean velocity v_t is defined in a temporal control region (see figure 5b) at position x at time t with a time length Δt as follows:

$$q_t := \frac{n_t(x, t, \Delta t)}{\Delta t} \qquad v_t := \frac{1}{n_t}\sum_{a=1}^{n_t} v_a(x, t, \Delta t) \tag{2}$$

A traffic density is not definable in a temporal control region. A spatiotemporal density ρ_{st}, volume q_{st} and mean velocity v_{st} is defined in a spatiotemporal control region (see figure 5c) at position x at time t with a length Δx and a time length Δt as follows:

$$\rho_{st} := \sum_{a=1}^{n_{st}} \Delta t_a / (\Delta t\, \Delta x) \qquad q_{st} := \sum_{a=1}^{n_{st}} \Delta x_a / (\Delta t\, \Delta x) \qquad v_{st} := \frac{\rho_{st}}{q_{st}} \tag{3}$$

Coherences of characteristics are only allowed in the same control region. The well known flux relation is only valid for density, volume and mean velocity in a spatiotemporal control region:

$$q_{st} = \rho_{st} \cdot v_{st} \tag{4}$$

The values of a momentary measurement are equal to the characteristics of a spatial control region. The values of a local measurement are equal to the characteristics of a temporal control region. The flux relation (4) is neither applicable for momentary nor local measurement data. Presently, a traffic data measurement in a spatiotemporal control region is not available.

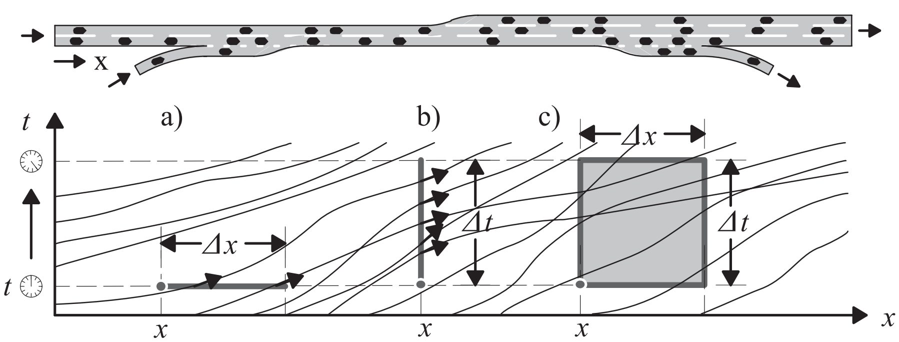

Figure 5: Spatial, temporal and spatiotemporal control region in a space–time diagram

Traffic flow in a freeway network is mapped by various modelings. Microscopic modelings discribe each vehicle individually. Macroscopic modelings treat the traffic flow like a continuous fluid flow. Mesoscopic modelings are links between microscopic and macroscopic modelings.

2 Microscopic Modeling

Microscopic modeling maps traffic flow as a set of individual vehicles. Each vehicle is identifiable and is modeled. The behavior of a vehicle depends on its own drive and on influences of its environment. The basic microscopic modeling is the so–called Follow–the–Leader modeling, in which the motion of a vehicle a depends on the distance and the velocity diffence to a leading vehicle b (e.g. Gazis, Herman and Rothery 1961).

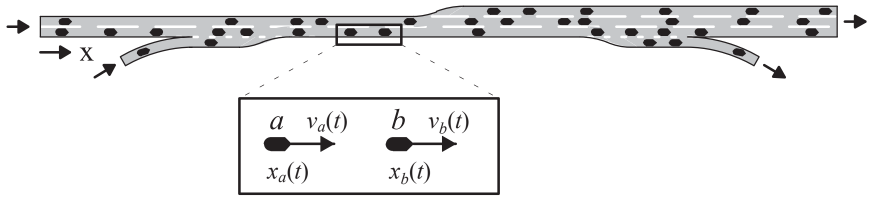

Figure 6: Microscopic modeling of traffic flow as a set of individual interacting vehicles

The behavior of vehicle a will be modeled by two conditional equations. The first conditional equation is the temporal derivation of its position $x_a(t)$ at time t. This is equal to its velocity $v_a(t)$:

$$\frac{dx_a(t)}{dt} = v_a(t) \tag{5}$$

The second conditional equation for vehicle a is the temporal derivation of its velocity $v_a(t)$ at time t. This is equal to its acceleration $a_a(t)$:

$$\frac{\mathrm{dv_a(t)}}{\mathrm{dt}} = \mathrm{a_a(t)} \tag{6}$$

Microscopic modelings differ in varying mappings of the acceleration. In this case a rule–based modeling of the acceleration is developed:

$$\begin{aligned} a_a(t) = \; & \frac{v_a^0 - v_a(t)}{\tau_a^0} \cdot \left(1 - \Xi\left(v_a^0 - V_a^s(\Delta x_a)\right)\right) \\ + \; & \frac{V_a^s(\Delta x_a) - v_a(t)}{\tau_a^s} \cdot \Xi\left(v_a^0 - V_a^s(\Delta x_a)\right) \qquad , \; \Xi(X) = \begin{cases} 0 \text{ if } X \geq 0 \\ 1 \text{ if } X < 0 \end{cases} \\ - \; & \gamma \frac{\Delta v_a^2}{\Delta x_a - l_b} \cdot \Xi(-\Delta v_a) \cdot \Xi(v_a(t) - V_a^s(\Delta x_a)) \end{aligned} \tag{7}$$

There are Heaviside functions $\Xi(X)$ in equation (7), working like an if–statement in a computer language, to manage the use of each rule in a line of equation (7):

- **Rule 1 (desired velocity)** arranges the behavior of the vehicle a without any outside influences. Vehicle a adapts its velocity $v_a(t)$ to its desired velocity v_a^0 with a relaxation time τ_a^0.
- **Rule 2 (safe distance)** arranges the behavior of vehicle a behind a leading vehicle b. Vehicle a try to keep a safe distance to the leading vehicle b. This means, that vehicle a adapts its velocity $v_a(t)$ to a velocity V_a^s depending on the distance $\Delta x_a(t) = x_b(t) - x_a(t)$ between the vehicles. The velocity–distance–relation V_a^s is a strictly monotonic increasing curve, which runs from $V_a^s(0) = 0$ to $V_a^s(\Delta x_a > \textit{safe distance}) = v_a^0$. The velocity–distance–relation V_a^s can hardly be determined, because different vehicles and different drivers differ extremely in their behavior.
- **Rule 3 (braking)** arranges the behavior of vehicle a when the safe distance to the leading vehicle b cannot be adhered and vehicle a has to slam on the brakes. According to the kinetic laws the required braking is directly proportional to the square of the velocity difference $\Delta v_a(t) = v_b(t) - v_a(t)$ and indirectly proportional to the distance $\Delta x_a(t)$ between the vehicles.

The rule–based modeling is plain and may be modified and updated easily at any time. For example, the sharply form of the Heaviside function $\Xi(X)$ can the replaced with a softer form like a fuzzy–function. Or the rules in equation (7) can upgraded with additional rules for multi–lane traffic.

The modeling of a multi–lane traffic is illustrated in the following figure with a vehicle *a* on lane *1* and several vehicles, which are leading or following this vehicle on lane *0*, lane *1* or lane *2*.

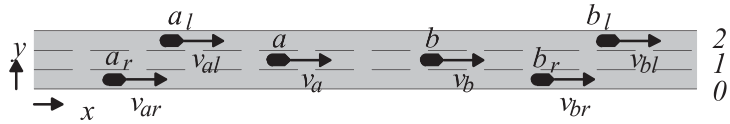

Figure 7: Microscopic modeling of multi–lane traffic flow

Vehicle a on lane $y_a(t)$ at time t changes the lanes with $\Delta y_a(t)$ during the time interval dt:

$$y_a(t + dt) = y_a(t) + \Delta y_a(t) \;\; mit \;\; \Delta y_a(t) \in \{-1, 0, 1\} \tag{8}$$

The lanes changing Δy_a consists of a rule for overtaking to the left–hand lane Δy_a^+ and a rule for pass back to the right–hand lane Δy_a^-:

$$\Delta y_a = \Delta y_a^+ - \left(1 - \Delta y_a^+\right) \cdot \Delta y_a^- \tag{9}$$

$$\Delta y_a^+ = \Xi\left(v_a^0 - V_a^s(x_b - x_a)\right) \cdot \Xi\left(V_a^s(x_{bl} - x_a) - v_a\right) \cdot \Xi\left(V_{al}^s(x_a - x_{al}) - v_{al}\right)$$

$$\Delta y_a^- = \Xi\left(V_a^s(x_{br} - x_a) - v_a\right) \cdot \Xi(V_{ar}^s(x_a - x_{ar}) - v_{ar})$$

3 Macroscopic Modeling

Macroscopic modeling maps traffic flow as a continuous unity of “fluidized” vehicles. No vehicle in the traffic flow is identifiable. The traffic flow is characterized by macroscopic state values like density, volume and mean velocity, which is associated with each other by the flux relation. Following this approach a traffic flow is treated as a continuous fluid flow in fluid dynamics (first publications by Lighthill and Whitham 1955).

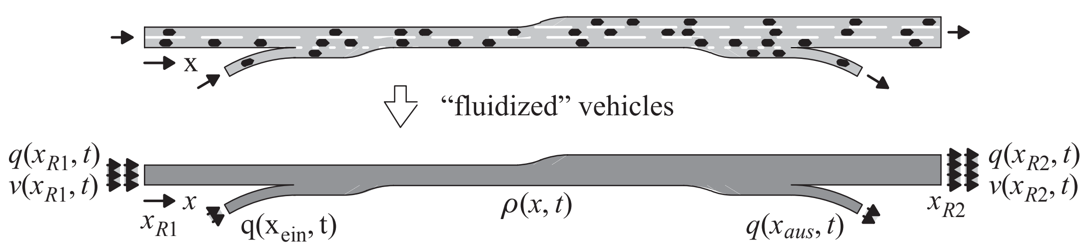

Figure 8: Macroscopic modelings of traffic flow as a continuous unity of “fluidized” vehicles

The behavior of state values in a continuous traffic flow is modeled by two conditional equations. The first conditional equation is the well–known equation of continuity, which assures the conservation of mass or rather the number of vehicles in a one–dimensional space:

$$\frac{\partial \rho(x,t)}{\partial t} + \frac{\partial q(x,t)}{\partial x} = 0 \tag{10}$$

The second conditional equation is an equation of motion with a derivation of the mean velocity:

$$\frac{\partial v(x,t)}{\partial t} + v(x,t)\frac{\partial v(x,t)}{\partial x} = a(x,t) \tag{11}$$

Macroscopic modelings differ in varying mappings of the acceleration in equation (11). One alternative is to transfer the shallow water equation for fluid flow to a Navier–Stokes–like equation for traffic flow (Kühne 1991):

$$a(x,t) = \frac{V(\rho) - v(x,t)}{\tau} - \frac{1}{\rho(x,t)}\frac{\partial p(x,t)}{\partial x} + \frac{\mu}{\rho(x,t)}\frac{\partial^2 v(x,t)}{\partial x^2} \tag{12}$$

The first term on the right side of equation (12) is an adaptation term. It models the adaption of the mean velocity $v(x,t)$ to a mean velocity $V(\rho)$ with a relaxation time τ. The velocity–density–relation $V(\rho)$ is the well–known fundamental diagram of traffic flow. It is a strictly monotonic decreasing curve, which runs from $V(0) = v^0$ to $V(\rho(x,t) > \rho_{\max}) = 0$, whereas $\rho_{\max}$ is the density in a standing traffic jam. $V(\rho)$ is only defined for a homogeneous and stationary traffic flow. This means all vehicles drive equidistant with the same velocity. Such a hypothetical traffic flow cannot be measured in a freeway network.

The second term is a so–called pressure term modeling influences of a local pressure $p(x,t) = c^2 \cdot \rho(x,t)$ with a propagation velocity c. The third term is a viscosity term weighted with a dynamic viscosity μ.

4 Mesoscopic Modeling

Mesoscopic traffic modeling is a consistent link between microscopic and macroscopic modelings. The link is reached by a transition from a microscopic to a macroscopic modeling. The usual transition with the theory of stochastic processes (Helbing 1999) is very extensive. Thus a mesoscopic modeling is developed from the plain rule–based microscopic modeling in chapter 2.

Mesoscopic modeling bases on a distance–density relation establishing a link between the distance of two sequenced vehicles in a microscopic modeling and the density in a macroscopic modeling. If a vehicle a is at time t at the position x, then the leading vehicle b is at position $x+s$.

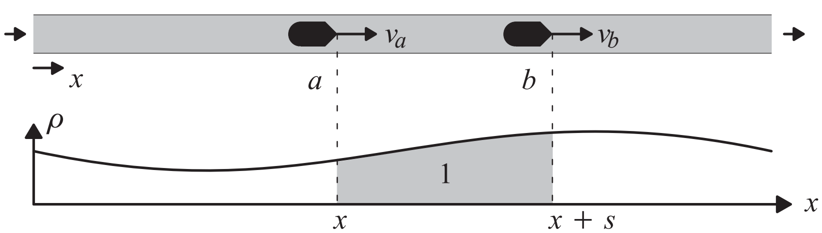

Figure 9: Distance–density relation as a basis of a mesoscopic modeling

A macroscopic modeling discribes the number of vehicles by traffic density. The number of vehicles between the positions x and $x+s$ is exactly one, hence the density between x and $x+s$ is exactly one. The distance between two vehicles is modeled by an integral of density from x to $x+s$:

$$\int_0^s \rho(x + \xi, t)\, d\xi = 1 \qquad \rho \geq 0 \qquad s \geq 0 \tag{13}$$

The conditional equations of the mesoscopic modeling contain the distance–density relation (13), the equation of continuity (10) and an equation of motion (11). According to the equation (7) the acceleration $a(x,t)$ is composed by three terms:

$$\begin{aligned} a(x,t) \;=\; & \frac{v^0 - v(x)}{\tau} && \cdot \big(1 - \Xi\big(v_0 - V^s(s)\big)\big) \\ + \; & \frac{V^s(s) - v(x)}{\tau} && \cdot \Xi\big(v^0 - V^s(s)\big) \\ - \; & \gamma \frac{(v(x+s) - v(x))^2}{s - l} && \cdot \Xi\big(v(x) - v(x+s)\big) \cdot \Xi\big(v(x) - V^s(s)\big) \end{aligned} \tag{14}$$

The first term is the rule of driving with desired velocity. The second term is the rule of keeping a safe distance to a leading vehicle. The third term is the rule of braking behind a leading vehicle. Futher information to this mesoscopic modeling, particularly to its consistence and an update for multi–lane traffic, can be extract from (Rose 2003).

5 Numerical Realization

The modelings in chapters 2, 3 and 4 consist of continuous conditional equations. These nonlinear partial differential equations cannot be solved analytically. They have to be solved numerically. There are several numerical methods to convert the continuous equations in discrete equations. The implementation of these discrete equations leads to simulations allowing comparative calculations and forecast calculations. The numerical methods are for instance finite volume methods, finite difference methods, finite element methods or cellular automatons. Exemplary, a finite element method will be applied to the macroscopic modeling in chapter 3 and a finite difference method will be applied to the mesoscopic modeling in chapter 4.

5.1 Finite Element Method for the macroscopic modeling

In the finite element method the progression of the unknown state values will be approximated by simple functions, which have to approximate the real progression as much as possible (e.g. Zienkiewicz and Taylor 2000). For the macroscopic modeling of traffic flow on a carriaggeway section, the approximation functions should be piecewise limited on the segments.

The conditional equations of the macroscopic modeling are the equation of continuity (10) and the Navier–Stokes–like equation of motion (11) with (12). This system of nonlinear partial differential equations is written in a matrix notation:

$$\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{A}\,\frac{\partial \boldsymbol{u}}{\partial x} - \boldsymbol{B}\,\frac{\partial^2 \boldsymbol{u}}{\partial x^2} = \boldsymbol{f} \tag{15}$$

$$\boldsymbol{u}(x,t) = \begin{bmatrix} \rho(x,t) \\ v(x,t) \end{bmatrix} \quad \boldsymbol{A} = \begin{bmatrix} v & \rho \\ c^2/\rho & v \end{bmatrix} \quad \boldsymbol{B} = \begin{bmatrix} 0 & 0 \\ 0 & \mu/\rho \end{bmatrix} \quad \boldsymbol{f} = \begin{bmatrix} 0 \\ \frac{1}{\tau}\,(V(\rho) - v) \end{bmatrix}$$

First, the infinite space of solution will be approximated in a finite space, which is spaned by N linear shape functions $\phi_i(x)$. The numerical solution $\tilde{\boldsymbol{u}}(x,t)$ is discribed as a linear combination of the shape functions $\phi_i(x)$ and the discrete state vectors $\boldsymbol{c}_i(t)$:

$$\boldsymbol{u}(x,t) \rightarrow \tilde{\boldsymbol{u}}(x,t) = \sum_{i=1}^{N} \boldsymbol{c}_i(t)\,\phi_i(x) \qquad \boldsymbol{c}_i(t) = \begin{bmatrix} \rho_i(t) \\ v_i(t) \end{bmatrix} \tag{16}$$

Inserting the numerical solution $\tilde{\boldsymbol{u}}(x,t)$ in the matrix notion (15) leads to a defect $\boldsymbol{d}(\tilde{\boldsymbol{u}})$:

$$\boldsymbol{d}(\tilde{\boldsymbol{u}}) = \sum_{i=1}^{N} \phi_i(x)\,\frac{\partial \boldsymbol{c}_i(t)}{\partial t} + \sum_{i=1}^{N} \boldsymbol{A}\,\frac{\partial \phi_i(x)}{\partial x}\boldsymbol{c}_i(t) - \sum_{i=1}^{N} \boldsymbol{B}\,\frac{\partial^2 \phi_i(x)}{\partial x^2}\,\boldsymbol{c}_i(t) - \boldsymbol{f} \tag{17}$$

The target of the numerical methods is to minimize this defect, for instance with an Upwind–Petrov–Galerkin method:

$$\int_0^L \left(\boldsymbol{I}\,\phi_j(x) + \alpha \boldsymbol{A}\frac{\partial \phi_j(x)}{\partial x} \right) \boldsymbol{d}(\tilde{\boldsymbol{u}})\,dx = 0 \tag{18}$$

The Upwind–Petrov–Galerkin method (18) is an upgrading of the well–known standardised Galerkin method. The solution of the Galerkin method tends to oscillate. The Upwind–Petrov–Galerkin method damps this oscillations with a damping term weighted with an upwind–coefficient α.

An analytical or numerical integration of the equations (18) leads to a global system of equations, whose solution follows either by creation of the inverse $\boldsymbol{M}^{-1}$ or by the usage of a solver. The finite element method for the macroscopic traffic modeling, particularly a proposal for an appropriate upwind–coefficient α, is expatiated in (Rose 2003).

The results of the finite element method for the Navier–Stoke–like traffic flow modeling are nearly the same as the results of a finite difference method by (Kerner, Konhäuser and Schilke 1996).

5.2 Finite Difference Method for the mesoscopic modeling

In the finite difference method the progression of the unknown state values will determined for values at discrete points on a grid. Differential quotients between adjacent grid points will be replaced with difference quotients. In the mesoscopic modeling of traffic flow on a carriaggeway section, the grid points are the cross sections. The conditional equations are the distance–density relation (13), the equations (10), (11) and (14). The numerical solution of (13) is a piecewise linear integration over each segment of the considered carriageway.

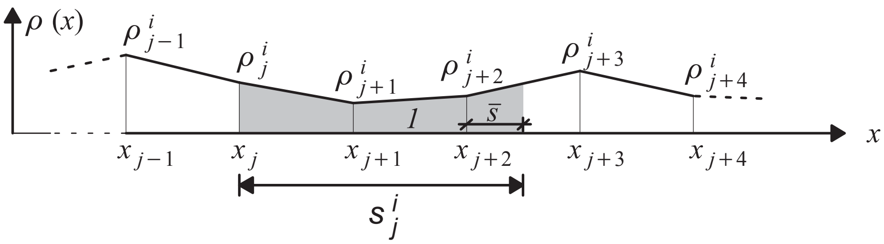

Figure 10: Integral of the density from x_j to $x_j + s_j^i$ on the discrete carrigaeway section

Replacing the differential quotients with difference quotients leads to the following equations:

$$\frac{\partial \rho_j^i}{\partial t} + v_j^i \frac{\rho_j^i - \rho_{j-1}^i}{\Delta x} = -\rho_j^i \frac{v_{j+1}^i - v_j^i}{\Delta x} \tag{19}$$

$$\begin{aligned} \frac{\partial v_j^i}{\partial t} + v_j^i \frac{\partial v_j^i}{\partial x} &= \frac{V^s(s_j^i) - v_j^i}{\tau} - \gamma \frac{s_j^{i\,2}}{s_j^i - l} \left(\frac{\partial v_j^i}{\partial x} \right)^2 \\ &\quad \cdot \Xi \left[- s_j^i \left(\frac{\partial v_j^i}{\partial x} + \frac{\Delta x}{2} \frac{\partial^2 v_j^i}{\partial x^2} \right) \right] \cdot \Xi \left(v_j^i - V^s(s_j^i) \right) \\ &\quad + \frac{\Delta x}{2} \left\{ v_j^i - \gamma \frac{s_j^{i\,2}}{s_j^i - l} \frac{\partial v_j^i}{\partial x} B \right\} \frac{\partial^2 v_j^i}{\partial x^2} + O\left(\Delta x^2\right) \end{aligned} \tag{20}$$

These equations are calculated implicit or explicit in every step of a time–step–method like the Runge–Kutta method or Fehlberg method. The numeric stability of an explicit time–step–method is guaranteed by fulfilling the Courant criterion at every cross section in every time step.

6 Computer Simulations

An implementation of the numerical realization of a traffic flow modeling leads to a computer simulation of traffic flow. The Simulation assists a traffic engineer with the analysis of traffic situations in a freeway network and the development of traffic control methods. The correctness and the qualification of a traffic flow simulation for a concret traffic problem will be determined with a pertubation analysis and a comparison of simulation results and measurement results.

6.1 Perturbation Analysis

The perturbation analysis is a comparative study of effects by a small perturbation to an undisturbed taffic state. At various densities, an initially homogeneous traffic flow on an annulus carriageway will be disturbed with either no perturbation, a local perturbation (for instance by a short braking of one vehicle) or a global perturbation (for instance by a natural fluctuations in the traffic flow). Several simulations with the microscopic modeling, the macroscopic modeling and the mesoscopic modeling are almost showing quantitative nearly the same results with similar parameters.

Without a perturbation, the homogeneous traffic flow in all simulations doesn't change. At this initial state, the computer simulations are correct. An initially local perturbation in a micorscopic simulation with a few vehicles on the ring disappears after a short time. Successive increasing of the vehicle number in the initial state produces traffic jams, stop–and–go waves and wide jams.

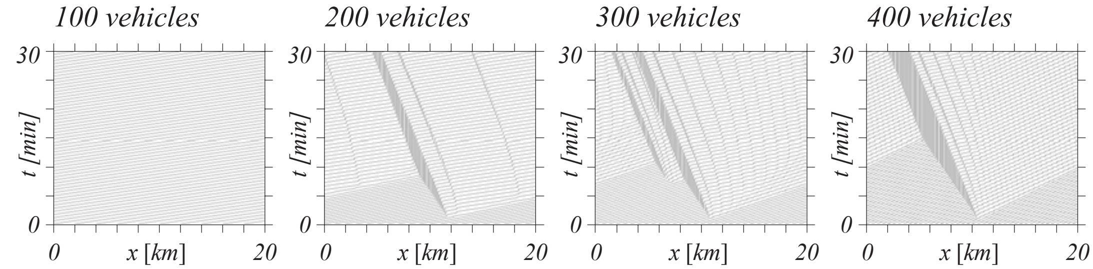

Figure 11: Motion curves of the microscopic traffic flow simulation in chapter 2

A local perturbation in a macorscopic traffic flow simulation with a low initial density disappears after a short time. Successive increasing of the initial density produces traffic jams, stop–and–go waves and wide traffic jams like in the micoscopic traffic flow simulations.

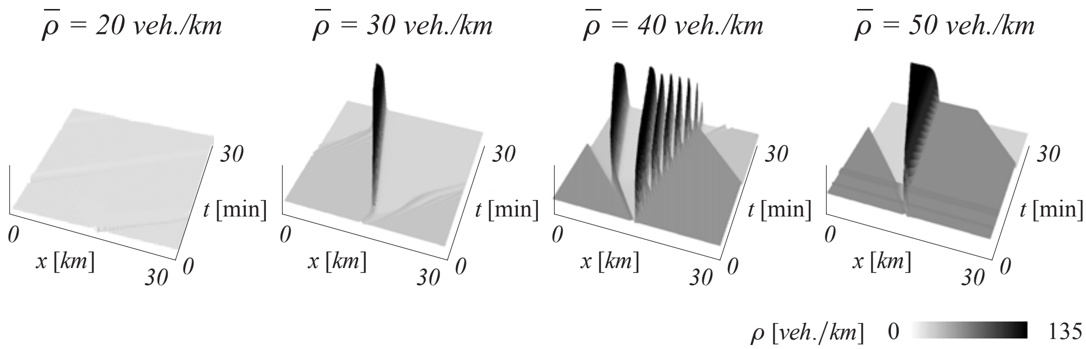

Figure 12: Density progressions of the macroscopic traffic flow simulation in chapter 3

The same results for a local perturbation occurs in a mesoscopic traffic flow simulation. A global perturbation in all three traffic flow simulations produces similar traffic phenomena (see figure 13). Only the formation of the phenomena takes a little bit longer.

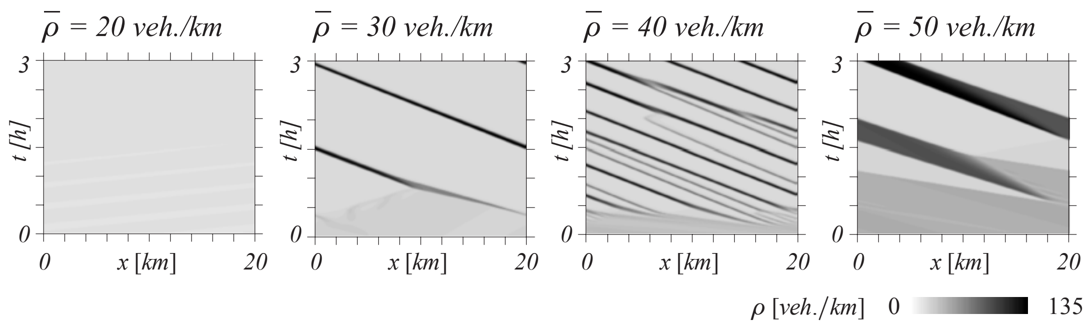

Figure 13: Density progressions of the mesoscopic traffic flow simulation in chapter 4

All simulations of the three modelings with nearly the same parameters leads to similar typical traffic phenomena. At this, the most important parameter is the velocity–distance relation respectively the velocity–density relation. The other parameters influence only the appearance of the traffic phenomena. The character of the fundamental diagram decides the appearance of a traffic phenomen. Furthermore the mesoscopic simulations turn out to be the link between the microscopic simulations tending towards many small oscillations in the calculated traffic flow and the macroscopic simulations tends towards a smooth progression of traffic flow.

6.2 Comparison of Simulation Results and Measurement Results

The comparison of simulation results and measurement data gives information about the ability of the modeling to reproduce measuring traffic phenomena. A qualified traffic region for the comparison is a carriageway section of the german freeway A5 near Frankfurt am Main. The 1–minute data allow the identification of several traffic phenomena. They will be compared with results of corresponding macroscopic and mesoscopic simulations on the basis of two traffic scenarios.

The first traffic scenario is dealing with the formation and the release of a stationary traffic jam (see figure 14). Both the macroscopic simulations and the mesoscopic simulations are able to reproduce the measurement data. At this, the quality of the measurement data didn't allow a determination of the quality of the simulation results.

A5 near Frankfurt am Main, kilometer 485 – 472.4, 1:00 am – 4:00 am, Januar 27th, 2001

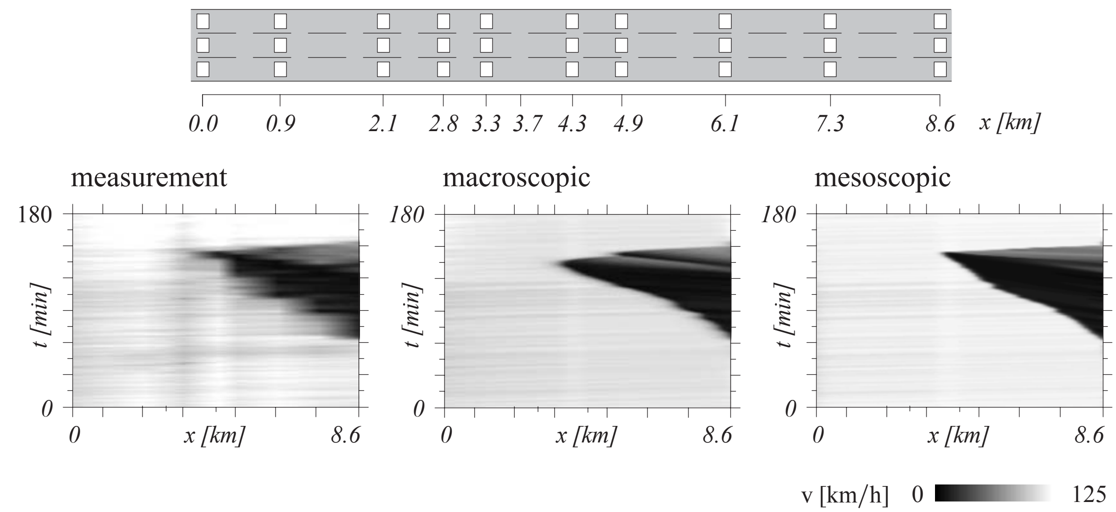

Figure 14: Traffic scenario 1: formation and release of a stationary traffic jam

The second traffic scenario is dealing with a moving traffic jam (see figure 15). Both the macroscopic simulations and the mesoscopic simulations are able reproduce the measurement data. The quality of the simulation results is hardly determinable again.

A5 near Frankfurt am Main, kilometer 488 – 481.7, 4:25 am – 4:40 am, Januar 16th, 2001

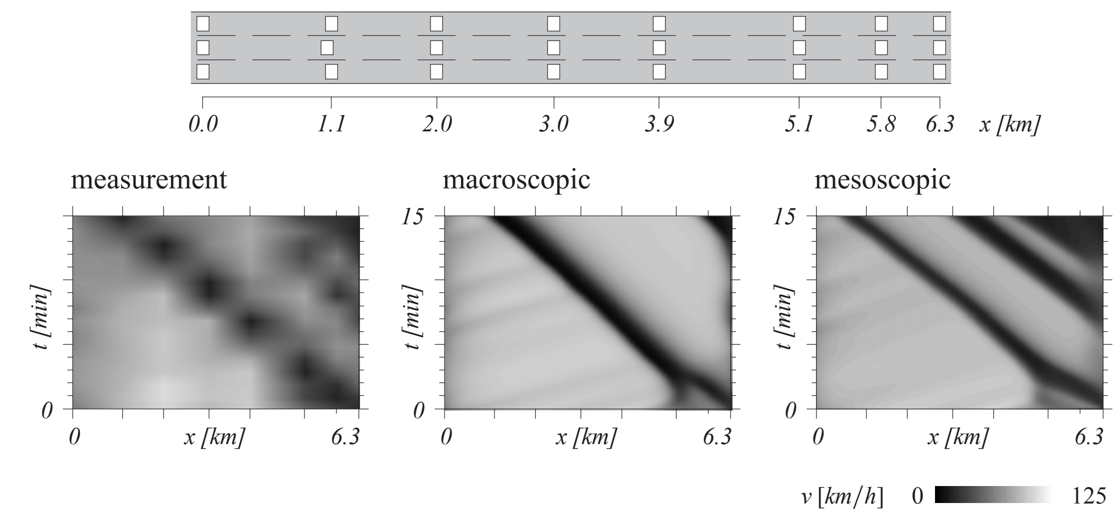

Figure 15: Traffic scenario 2: moving traffic jam

All traffic flow simulations of the scenarios react very sensitive to changes of the model parameters. The qualified parameters of a simulation for one traffic scenario are not transferable to the same simulation for another scenario or to another simulation for the same scenario. The fundamental diagram is also the most important parameter for the comparison between simulation results and measurement data. It decides the appearance of traffic phenomena. The investigations have shown that data editing of the measured data for traffic jam situations on the basis of conventional methods is inadequate, that parameters of the simulation methods from the traffic measurements cannot be determined systematically and methods for traffic control must also be allowed for the simulation.

7 Endnotes

Essential fundamentals for a design of a program system are developed that allows an integrative framework for a comparative assessment and a systematic coupling of the traffic measurements, traffic management strategies and traffic simulations. The modeling components of the freeway network, traffic measurement, traffic control and traffic flow have to be integrated in the program system. With this system a systematic and comparative analysis of dynamic forecasts is possible.

The fundamentals allow the computational realization of a freeway network with heterogeneous modeled traffic flow. Different carriageway sections with different microscopic, macroscopic or mesoscopic modeling of traffic flow is developed and combined to one freeway network. Thus the transition from one section to an adjacent section has to be mapped consistently.

A simulation of traffic flow requires a qualified determination of the model parameter, especially the fundamental diagram as the driving force of traffic flow. There are no methods zu determinate this parameter except theoretic assessable scopes and experience values. A systematic analysis of the qualitative influences of the model parameter in reproducible reference scenarios is required to determine this parameters from measured traffic data.

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