Integrated Modeling of Transport Demand, Route Choice, Traffic Flow and Traffic Emissions

Authors:

Martin Fellendorf , PTV AG,
Stumpfstr. 1, D-76131 Karlsruhe, Germany
phone ++49/721/9651/302, email martin.fellendorf@ptv.de

Peter Vortisch, PTV AG,
Stumpfstr. 1, D-76131 Karlsruhe, Germany
phone ++49/721/9651/305, email peter.vortisch@ptv.de

Abstract:

This paper presents a simulation model developed by PTV AG and the Group Research Department of the Volkswagen AG. Four separate models are integrated in one software suite to cover traffic demand, route choice, traffic flow and pollutant emissions. The traffic demand model follows a behavior-oriented, disaggregated approach. It computes the set of trip chains performed during one day in the analysis area. The dynamic route choice is calculated by an iterated simulation of the entire day. Each individual vehicle travels through the road network using the microscopic traffic flow model of VISSIM. Fuel consumption and exhaust gas emissions of all vehicles in the network are determined based on dynamic engine maps. In addition, the model is capable of considering additional emissions during the warm-up phase of the engine as well as evaporation emissions during parking. Typical applications of this simulation software extend from traffic- and air quality-oriented assessment of isolated intersections up to optimizing the entire road network of cities. The completely microscopic approach across all parts of the model allows the representation of a broad variety of traffic control measures.

Keywords:

traffic flow simulation, traffic demand modeling, traffic emissions, route choice, dynamic assignment

1 INTRODUCTION

Modeling traffic-induced emissions and the resulting air quality is gaining increasing importance in urban areas. The entire sequence starting with the mobility of the inhabitants up to the air quality can be simulated by a number of models: Disaggregated traffic demand models describe the daily trip pattern of individual persons. Microscopic route choice and traffic flow models can be viewed as a model of motorists choice of path from origin to destination. Emission models calculate the exhaust gas amount arising from the traffic flow of the motorized traffic, from which the resulting air quality is then determined with a dispersion calculation.

It is state of the art to use such models separately of each other. Typically the results of one model are used as input for the next model. Two problems arise in this case: First information losses due to aggregation occur in the transition between the models, and secondly, feedback across several models during state changes is impossible. In the presented simulation software on the other hand, traffic demand, route choice, traffic flow, vehicle emissions and air quality are simulated over an entire day on the same microscopic model level (*1*). In order to calculate the vehicle emissions the integration of these models leads to an important advantage supported by data of the thermal state of the engine and the catalytic converter on the base of the trip chain. Thus the cold start and warm-up induced extra emissions of all vehicles in the network can be calculated more accurately than would be possible by the lump sum addition of cold start supplements.

The simulation software is based on four models for traffic demand, route choice, traffic flow, and emissions. As a fifth model, a dispersion model can be coupled to assess air quality. The route choice model and the traffic flow model require the same input data with extensive iteration loops between both (Figure 1).

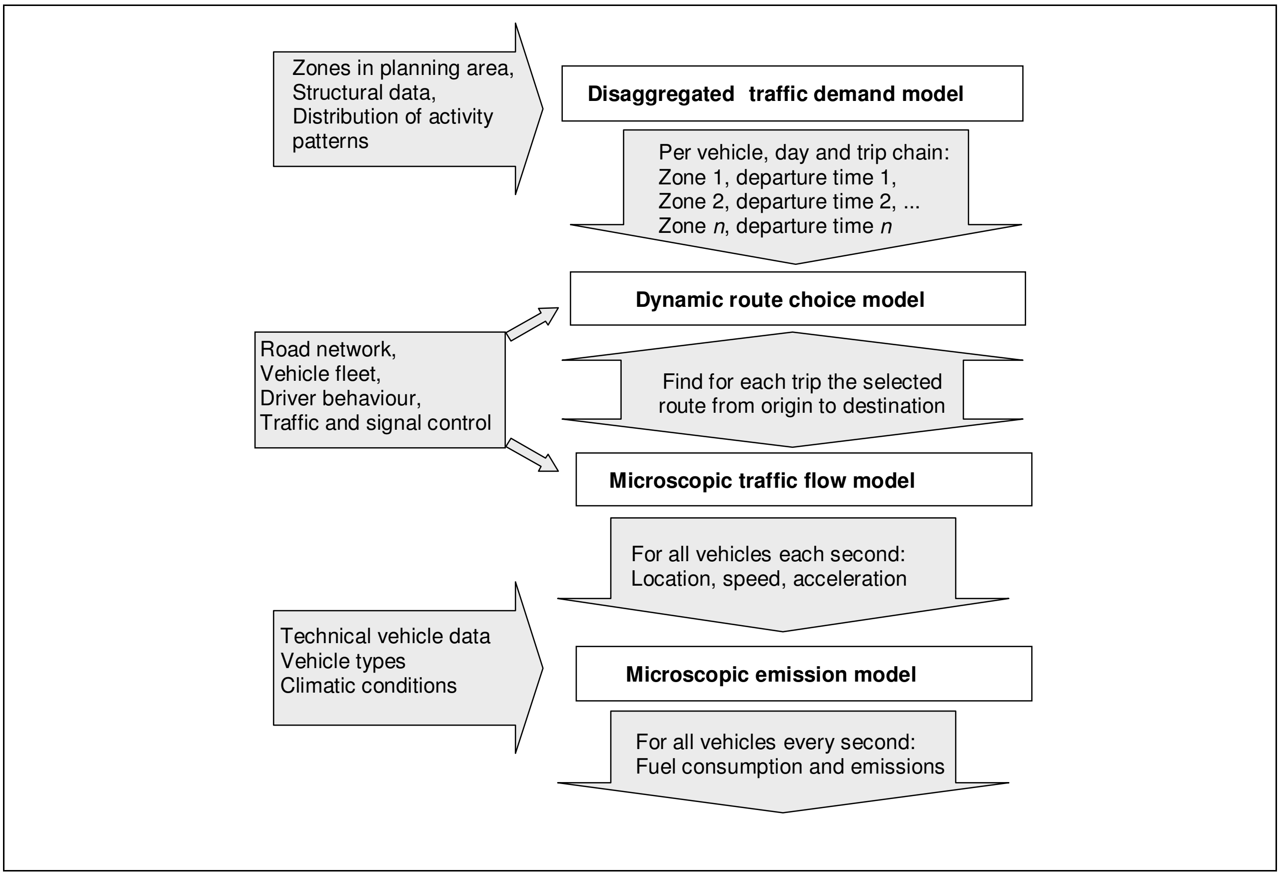
2 DISAGGREGATED TRAFFIC DEMAND MODEL

An adapted version of the VISEM model (*2*) calculates the traffic demand. The demand model uses a disaggregated and behavior-oriented approach. The population is classified into behaviorally homogeneous groups and their typical activity patterns are modeled.

The demand model includes :

- Traffic generation (from where (origin) are requests for zonal change?),
- Traffic distribution (what are the destinations of these requests for a trip?),
- Mode choice (what mode like car, bus, bike or foot is taken?).

Figure 1: Data flow between the individual models within the simulation software



The study area is divided into zones characterized by demographic data, traffic infrastructure and behavior data. From these data the model computes the series of location changes performed by the inhabitants of the zone. In each zone the population is classified into so-called behaviorally homogeneous groups with the assumption of characteristic mobility behavior. This mobility behavior is represented by a distribution of typical activity chains (e.g. living – working – shopping – living).

The traffic distribution model calculates the directed traffic demand. The traffic proceeding from each zone is distributed over the suitable set of destinations. For each trip, being a result of the activity chains of each group, a mode to travel has to be chosen. Since we are concerned about traffic induced pollution, we will follow up only car traffic.

The result of the traffic demand calculation is the entire set of individual trip chains which take place within one day in the study area. One trip chain passed onto the following dynamic route choice model contains all single trips of one vehicle during this day with the information about departure time and destination zone which is important for the emission model.

3 DYNAMIC ROUTE CHOICE MODEL

The volumes computed by the traffic demand model must be assigned to the road network. In our model the assignment is done dynamically over time by an iterated application of the microscopic traffic flow model (see Section 4). One step of iteration comprises the simulation of the traffic over a period of 24 hours. Traffic flow is calculated in time steps of one second; resulting values like traffic volumes, travel times etc. are aggregated to intervals of typically 5 to 15 minutes.

Typically, routes for the simulated vehicles are supplied as input for most microscopic traffic flow models. The presented simulation model, however, is designed to model the route choice behavior of drivers as a reaction on changes in traffic situations. The result of the transport demand model are trip chains for each person. They must be translated to suitable microscopic structures within the traffic flow model. Trips start and end at a zone. A zone is an idealized spatial area. To represent the physical origin and destination points of the trips, car parks are used. Each zone has one or more car parks, and a car park may belong to more than one zone. Each car park is connected to the modeled road network. Originating and terminating traffic of a zone is distributed to several car parks according to their capacity.

A set of links on the modeled road network between the starting and the ending car park is called a route. Every driver chooses a specific route at the departure time. These route choice decisions of all drivers add up to a dynamic assignment of the given transport demand, thus determining the traffic volumes on the road network. Travel times in the network are affected by these traffic volumes. The volumes and travel times are not constant during the simulation period, and therefore the fastest routes will not always be the same. However, drivers – at least today – do not have pre-trip information about the actual travel times in the network. They have empirical knowledge about several routes and the travel times using these routes during the day. In our model, we represent this empirical information by using travel time measurements from preceding simulation runs for route choice decision, instead of using the current data at departure time.

Based on this travel time information, the fastest route between car parks is computed in each iteration. However, not all vehicles will drive on this route, but all routes between the two car parks which were already found in the preceding iterations will be used. All vehicles with the same origin-destination pair will be distributed on the set of suitable routes according to Kirchhoff´s law known from electrical physics:

$$P(route_j) = \frac{tt_j^{-\alpha}}{\sum_{k=1}^{n} tt_k^{-\alpha}} \qquad j = 1..n$$

Here, n denotes the number of routes for a given origin-destination-relation, and tt_j is the travel time on route j. For the exponent α values between 3 and 4 have been used.

For a given simulation scenario a new set of travel times is assessed during each iteration. During the iterations a growing archive of routes is constructed. This archive contains every route that has qualified as a fastest route in at least one iteration. Since no travel times are available in the first simulation run, the initial route search is based on minimum link length. The principle of iterated simulations is illustrated in Figure 2, the algorithm is described in more detail in figure 4. Instead of using travel time as cost function for the link, a generalized cost function can be used.

Figure 2: Principle of dynamic assignment by iterated simulation

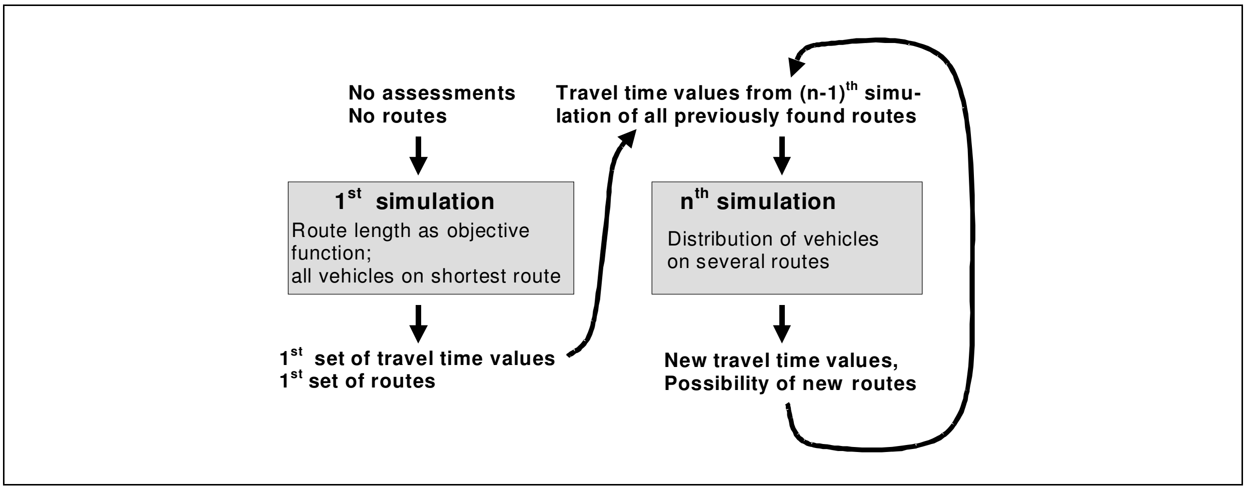
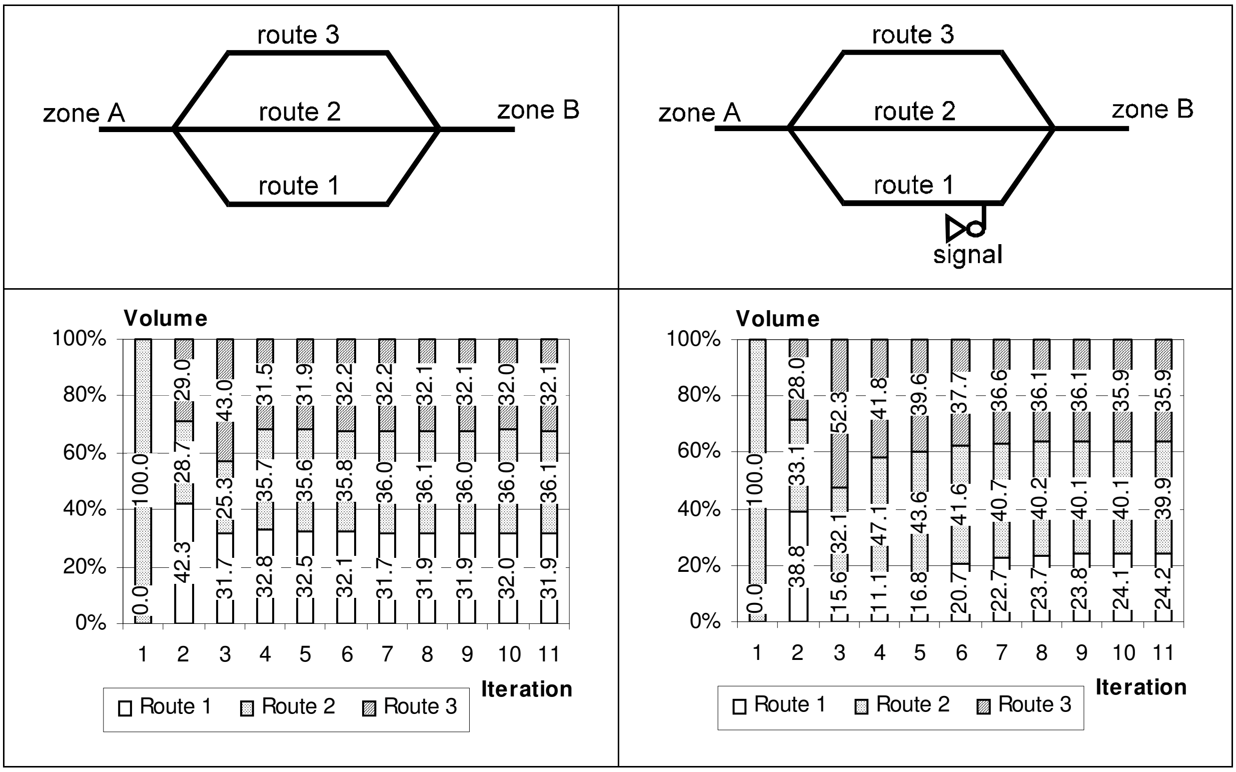


Figure 3: Example: Distribution of traffic on 3 routes



The procedure described above requires that traffic volumes and travel times on the links converge in the course of the iterations. The number of iterations until convergence depends on the size of the network and the traffic load. Up to now, there is no formal proof of convergence.

Figure 3 shows an example of the dynamic assignment in two different situations. Traffic demand is set to 2000 vehicles that want move from zone A to zone B. There are three possible routes, one of them, route 2, is significantly shorter, route 1 and 3 have about the same length. Initially, all routes have the same capacity, so that travel time correlates to the length of the routes (left set of figures). Then a traffic signal is added on route 1 to induce a capacity restraint (right set of figures). The diagrams below the network sketch show the distribution of the total volume to the three routes during the first 11 iterated simulations. In both cases, the first iteration assigns all trips to the shortest route. The following iterations distribute the traffic on all routes, reaching a stable situation after 7 or 8 iterations. In the case without traffic signal, routes 1 and 3 are loaded with nearly the same volume, whereas with signal, a significant portion is shifted away from route 1.

Figure 4: Algorithm for dynamic assignment by iterated simulation

```
For all time intervals:

    For all links: Set cost function of link
        If first iteration:     cost = length of link
        Else:                   cost = smoothed travel time from preceding iteration

    For all origin-destination-pairs:
        Compute shortest path with respect to link ratings
        Add shortest path to the set of known paths for this od-pair

    For all origin-destination-pairs:
        Compute rating of all known paths as sum of ratings of the contained links
        Set path choice probabilities according to Kirchhoff-formula

    Simulate traffic flow during current time interval and measure dwell time of all vehicles on all links

    For all links: Compute new smoothed travel time

        Compute current travel time:
            If  link never used in all iterations:          1 second
            Else If  link not used in current iteration:    old smoothed travel time
            Else:  maximum of:
                -   Longest dwell time of all vehicles present on the link at end of time interval
                -   Mean value of dwell times of all vehicles leaving the link during time interval

         Set as new smoothed travel time:
             If old smoothed travel time was 1 second:current travel time
             Else:       $(1-\alpha) \cdot$ old smoothed travel time + $\alpha \cdot$ current travel time
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4 MICROSCOPIC TRAFFIC FLOW MODEL

The traffic flow on the road network of the study area is simulated with a further development of VISSIM (*3*), which models driver-vehicle-units. The driving behavior is simulated in discrete time steps. A time step of one second is used for calculation over all models in the simulation software. However, to increase the modeling accuracy, a higher temporal resolution can be used for the traffic flow model. The simulation of car following is complemented by the modeling of special driving maneuvers for typical situations in urban traffic, e.g. stopping at traffic signals or lane changing caused by turning movements. The driving behavior was subject to special calibration with regard to the characteristics relevant for the emission calculation.

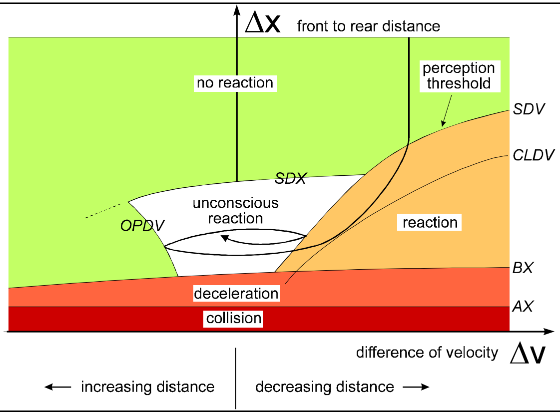
The traffic infrastructure is modeled in detail: Number of lanes, lane markings and geometry are superimposed on scaled layout maps. Traffic regulations like priority rules, speed restrictions and signal control are simulated realistically. Since signal control is the most important measure for urban traffic management schemes various types of vehicle actuated signal control are available to extend or shorten green times depending on traffic demand. For public transport, stops are created on the road network as well as timetable information for buses and trams. Public transport priority at signalized junctions can also be modeled within the framework of traffic actuated signal control. The modeling of pedestrians is also possible, but only as far as they influence traffic signals or force vehicles to wait while they are crossing the street.

The traffic flow model was extended in order to manage different vehicle classes with respect to the needs of the microscopic emission model. Such a vehicle class comprises vehicles with similar emission characteristics, e.g. same type of engine, exhaust gas cleaning concept etc. The vehicle classes can be defined by the user. The vehicle fleet used in the simulation can be combined from these classes to meet the local characteristics. These vehicle classes can also be used to restrict parts of the road network for selected vehicle types, e.g. busses or taxis. For assessment of the simulated traffic, several kinds of measurements are possible, ranging from cross-section measurements to a complete protocol of all movements during the simulation. These measurements can also be restricted to certain vehicle classes.

The traffic flow model used is a discrete, stochastic, time step based microscopic model, with driver-vehicle-units (DVU) as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The model is based on the continuous work of Wiedemann, (*4, 5*).

As a faster vehicle approaches a slower vehicle on a single lane it has to decelerate. The action point of conscious reaction depends on the speed difference, distance and driver depended behavior. Figure 5 indicates the oscillating process of this approach.

Figure 5: Car-following model of WIEDEMANN, Thresholds and one vehicle trajectory



The thresholds of figure 5 are explained in an abbreviated form. Driver specific perception abilities and individual risk behavior is modeled by adding random values to each of the parameters as shown for AX.

AX: Desired distance between the fronts of two successive vehicles in a standing queue.
$AX := VehL + MinGap + RND1 \cdot AXMult$ with RND1 normally distributed N(0.5, 0.15)

ABX: Desired minimum following distance which is a function of AX, a safety delta distance BX and the speed
$ABX := AX + BX \cdot \sqrt{v}$

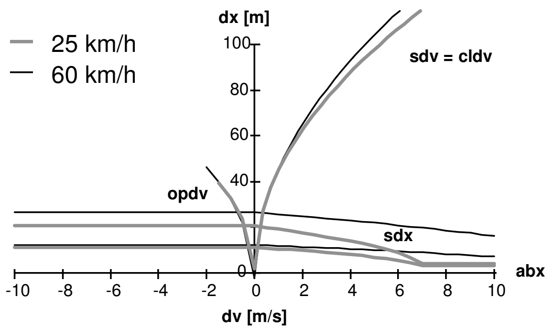
SDV: Action point where a driver consciously observes that he approaches a slower car in front. SDV increases with increasing speed differences ($\sqrt{\Delta v}$). In the original work of Wiedemann an additional threshold CLDV (closing delta velocity) is applied to model additional deceleration by usage of the brakes with a larger variation than SDV.

OPDV: Action point where the following driver notices that he is slower than the leading vehicle and starts to accelerate again. The variation of OPDV is larger than the variation of OPDV.

SDX: Perception threshold to model the maximum following distance which is about 1.5 - 2.5 times ABX.

A following driver reacts to a leading vehicle on up to a certain distance which is about 150 m. The minimum acceleration and deceleration rate is set to be 0.2 m/s². Maximum rates of acceleration depend on technical features of vehicles which are usually lower for trucks than the personal desire of its driver. The model includes a rule for exceeding the maximum deceleration rate in case of emergency. This happens if ABX is exceeded. The values of the thresholds depend on the present speed of the vehicle. Figure 6 denotes the values for two different speeds to display a current set of values.

Figure 6: Car-following thresholds used in urban situations as a function of the speed



In case of multi-lane roads a hierarchical set of rules is used to model lane changes. A driver has a desire to change lane if he has to drive slower than his desired speed due to a slow leading vehicle or in case of an upcoming junction with a special turning lane. Then the driver checks whether he improves his present situation by changing lanes. Last he checks whether he can change without generating a dangerous situation. In case of multi-lane approaches towards intersections this method will lead to evenly used lanes unless routing information forces vehicles to keep lanes.

5 MICROSCOPIC EMISSION MODEL

As a result of the traffic flow model the position, speed and acceleration of every vehicle is known for every second. Its emission characteristics are described by the defined vehicle type. This data allow for a computation of the instantaneous fuel consumption and pollutant emission of the vehicles based on exhaust gas emission maps. The necessary data base of engine maps is provided by the TUEV Rheinland and was produced during a comprehensive research project (*6*) sponsored by the German Umweltbundesamt (Federal Environmental Agency).

Engine maps contain the rate of pollutant emission for several components like hydrocarbons or carbon monoxide depending on the instantaneous values of speed and acceleration. However, the values in the map are measured at the engine’s operating temperature. The emissions are significantly higher during the warm-up phase at the beginning of a trip, since the cold engine consumes more fuel and the catalytic converter does not reach its full conversion rate.

The Group Research of Volkswagen AG developed a model to represent the effects of additional emissions in warming-up conditions based on two thermodynamic submodels for the engine and the catalytic converter (*7*). The vehicle model in the traffic flow simulation is extended to cover also the temperature of the engine and the catalytic converter, so that these values are known in every second. A functional dependency was derived to describe the modified emission behaviour during warm-up conditions. Since the trip chains of the vehicles are known from the transport demand model, it is possible to model emissions with high resolution in time and space during all phases of the trips, including evaporation emissions during parking. The results of the described emission model are used as input for a microscale dispersion model. This dispersion model is not part of the newly developed software package, instead the well known model MISKAM is used.

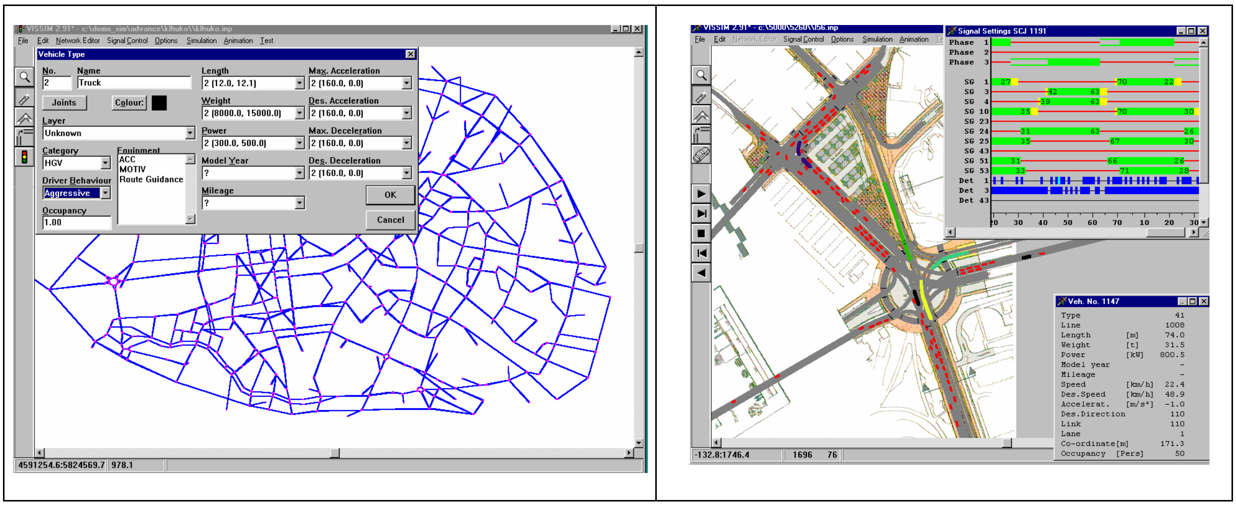
6 APPLICATIONS

Typical applications of the integrated model are innerurban road networks. The model requires a training phase for computation of routes and travel times during a day by iterated simulations. Once such a model of a city is prepared and calibrated, it can always be updated to reflect the ongoing changes in the road network and in city structures. It can be used for development and planning of traffic control measures, and assessment of effects takes into account not only traffic engineering parameters like level of service but also emission level.

Besides the modeling of larger networks also more local studies can be performed, e.g. a comparison of two signal control methods for a complex junction. For studies of this kind, the model of traffic demand is not used. Instead, the user provides an origin-destination-matrix for the modeled network to the traffic flow model. If the emission model is used within such a study, a starting temperature for engine and catalytic converter must be supplied for the newly generated vehicles.

Due to the microscopic modeling of traffic flow the impacts of traffic control measures can be analyzed on a very detailed level. This is of special interest for the evaluation of network-wide transport telematic applications that operate on the level of single vehicles. The presented simulation system allows not only to investigate local improvements but also to study the effects on the overall road network.

Figure 7: Example of urban network model (left) and of a signalized junction (right)



Vehicle Type

No.: 2
Name: Truck
Layer: Unknown
Category: HGV
Driver Behaviour: Aggressive
Occupancy: 1.00
Equipment: ACC, MOTIV, Route Guidance
Length: 2 (12.0, 12.1)
Weight: 2 (8000.0, 15000.0)
Power: 2 (300.0, 500.0)
Model Year: ?
Mileage: ?
Max. Acceleration: 2 (160.0, 0.0)
Des. Acceleration: 2 (160.0, 0.0)
Max. Deceleration: 2 (160.0, 0.0)
Des. Deceleration: 2 (160.0, 0.0)

Veh. No. 1147

```
Type                        41
Line                      1008
Length         [m]        74.0
Weight         [t]        31.5
Power          [kW]      800.5
Model year                   -
Mileage                      -
Speed          [km/h]     22.4
Des.Speed      [km/h]     48.9
Accelerat.     [m/s²]     -1.0
Des.Direction              110
Link                       110
Lane                         1
Co-ordinate[m]           171.3
Occupancy   [Pers]          50
```

7 CONCLUSIONS

Various initiatives have been started lately to model road traffic in detail to optimize traffic flow, since the traffic situations have to be improved without constructing new road infrastructure. Since the traffic flow model of VISSIM is showing a great level of detail it is focused on the simulation on the operational level. Other projects like TRANSIMS (*8*) are emphasizing the regional planning point of view. Out of practical reasons our model is not aimed to handle large areas due to calibration effort, data requirements and computational burden. However it has proven to be a valuable tool to reflect dynamic changes in a variety of urban traffic situations. Additionally the model can handle the cold start emission calculation realistically based on trip chaining of each person and vehicle.

8 ACKNOWLEDGEMENT

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