Application and Verification of Macroscopic and Microscopic Simulation Models - Case Study for NETCELL and VISSIM on Congested Freeway

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Abstract

In order to test the capability of different simulation techniques, two computer simulation programs, NETCELL and VISSIM, are applied in a case study of congested traffic flow on freeway. It is shown that NETCELL is preferable to VISSIM for the purpose of short-time prediction and congestion warning.

Introduction

This paper presents a case study using the macroscopic simulation program NETCELL based on the Cell Transition Model (DAGANZO, 1994) and the microscopic simulation program VISSIM based on the psycho-physical car-following model (WIEDEMANN, 1974). Both simulation programs are evaluated using data collected from variable traffic sign equipment on a German freeway. The results from both simulation models are compared with the measurements as well as with each other. The aim of our study is to determine a) which simulation model (macroscopic or microscopic) is preferable for simulating congested traffic flow, b) how the simulation models can be calibrated and validated with the measurements, and c) how well do the results of both simulation models fit the measurements.

Database for the investigation

In order to enhance traffic safety and operation, variable traffic sign equipment was installed on the German freeway No. 44 (A44). Over a section of 30 km, variable traffic signs with measuring equipment were placed on 21 cross-sections. The

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freeway has two traffic lanes in both directions. A schematic layout of the variable traffic sign equipment is shown in Figure 1.

From all the 21 cross-sections, traffic data in the form of flow-speed relationship can be obtained. The data are aggregated separately for the normal and overtaking lanes in 1-minute time intervals. From the measured data fundamental diagrams (q-v-relationship) can be constructed for all cross-sections.

In the region under investigation there are three freeway interchanges (AK Werl, AK Unna Ost, and AK Dortmund/Unna), where the traffic flow rate over the cross-section abruptly increases. Such abrupt increases in the traffic flow often leads to congestion at the interchanges. The average daily traffic (ADT) flow in the investigated direction (from left to right) over the entire range is shown in Figure 2.

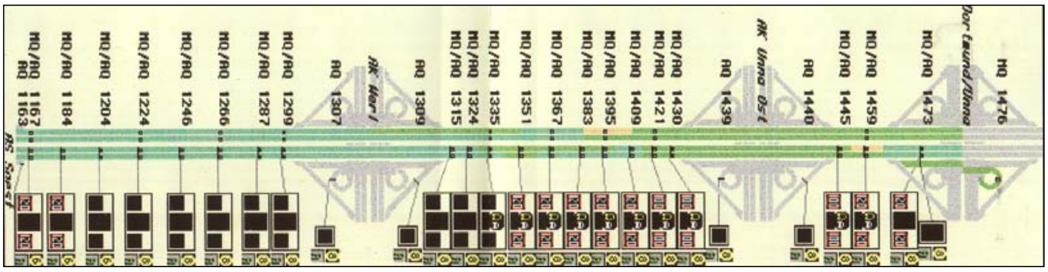


Figure 1. Schematic layout of the investigated freeway with variable traffic sign equipment

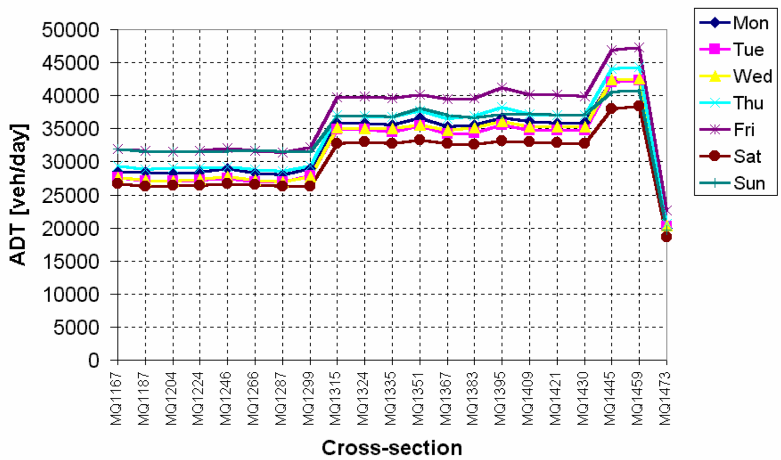


Figure 2. Average daily traffic flow of the investigated freeway

From the measured traffic data, the flow rate and the mean speed in 1-minute-intervals can be obtained. These characteristic parameters directly exhibit the state of traffic operation. As an example, the traffic congestion on Aug. 22, 1999 (Sunday) between 17:00 - 20:30 is shown in Figure **3**, part a. In this figure the mean speed is given as a function of space and time. As can be seen, the main bottleneck is in the region of the cross-section Q1445 and Q1459 where the speed level remains low for a period of 2.5 hours.

The congestion reaches the cross-section Q1421 and lasts until 19:30. A long and sustaining outlet of congestion crystallizes from 19:00. The front of the congestion outlet propagates with a constant speed of 14 km/h against the drive direction. The congestion outlet has a maximum length of 14.4 km, and it reaches the cross-section Q1315 where the congestion vanishes at 19:45.

Simulation study with NETCELL

NETCELL is a freeway network simulation program based on the cell transmission model (DAGANZO, 1994, 1994a), which captures the dynamic evolution of multicommodity traffic over a freeway network with three-legged junctions in a way that is consistent with the hydrodynamic theory of highway traffic. NETCELL is a macroscopic simulation program in which vehicle quantities are treated as continuous variables. Vehicles are advanced in a way consistent with the hydrodynamic theory of traffic flow. Unlike most existing traffic models, NETCELL preserves rigorously the first-in-first-out (FIFO) discipline for multicommodity network traffic flows. This unique feature is critical for studying freeway ramp metering and other control strategies, as well as for evaluating the performance of these strategies. The input of NETCELL consists of four parts, describing the network geometry, the routing information, incidents any, and the Origin-Destination inputs (DAGANZO et al, 1997). In addition to the traditional input parameters, NETCELL also allows a user-specified piecewise linear flow-density relationship. This feature could enhance the realism in modeling wave propagation on freeways.

The macroscopic model NETCELL is simple to calibrate because the flow-speed relationship can be used directly as predefined input. Thus, for each road section, the measured capacity and free speed are used as input parameters in the simulation model. On the other side, changing the flow-speed relationship, the simulation model can be calibrated to fit the measurements.

In order to calibrate and validate the NETCELL model with measured data, several simulation runs are conducted for different free speeds and capacities. For an initial simulation study, a capacity of 3600 veh/h and a free speed of 115 km/h over the entire range of the investigated freeway are used. The results of this simulation study is shown in Figure **3**, part b. As can be seen, compared to the real world traffic operation (Figure **3**, part a), the congestion at cross-sections Q1315 and Q1445 is well reproduced by the simulation. Using a higher capacity of 3700 veh/h and a lower free speed in the area of interchanges, the simulation gives a similar and even better fit to the measured data (Figure 3, part c).

According to the simulation (Figure3, part b), the speed level breaks down from 17:45 to 19:10 and from 20:10 to 20:30 at the interchange AK Dortmund/Unna (Q1459). In this region the average speed reduces from ca. 90 km/h to below 60 km/h. This agrees with the measured speed level. However, in contrast to the measurements, there is no clear breakdown of the speed level from 19:10 and 20:10. The simulated speed level in this area is about 60 to 90 km/h. That is much higher than the measured level, which is about 30 to 60 km/h. At the interchange AK Werl (Q1299-Q1315), a speed decrease can be observed in Figs. 3, part b and part c between 18:15 to 19:15. The speed level in this area is about 30 to 60 km/h. This again agrees with the measurements.

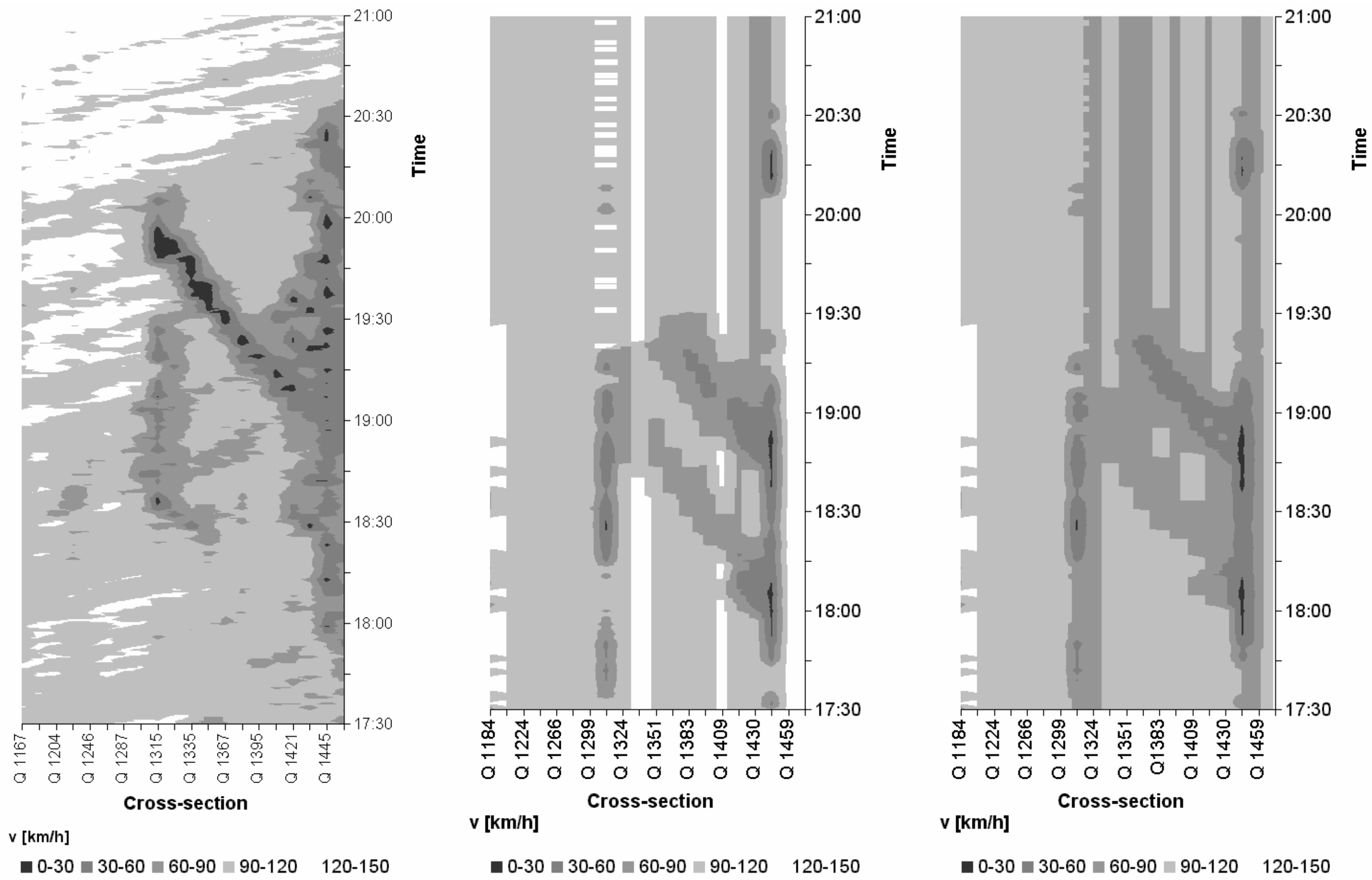
As can be seen from the simulation results, two congestions propagate backwards against the drive direction from the interchange AK Dortmund/Unna (Q1459) at about 18:00 (Congestion I) and 18:45 (Congestion II). The speed of the backward propagation is about 14 km/h. The measured speed is of the same order. However, in the simulation the congestions occur ca. 15 min earlier than that in reality. The simulated Congestion II also does not reach the interchange AK Werl (Q1299-Q1315). Furthermore, the simulated speed levels, when compared to the measurements, are much more homogeneous. The "Stop-and-Go" phenomenon is thus not sufficiently reproduced.

Despite the problems mentioned, the NETCELL model can be considered as suitable for simulating congested traffic conditions. The development of congestions can be very well reproduced. The main advantage of the NETCELL model is its high performance in the computational operation. On the other hand, "Stop-and-Go" phenomena cannot be simulated in detail.

The program NETCELL is a non-commercial product and it can be downloaded from the website of the author (DAGANZO, University of California, Berkley). For a nonprofit product, NETCELL is very user friendly and it delivers very good simulation results. It has the capability to simulate traffic flow in hyper-realtime and can thus give short-term prediction for real situations.

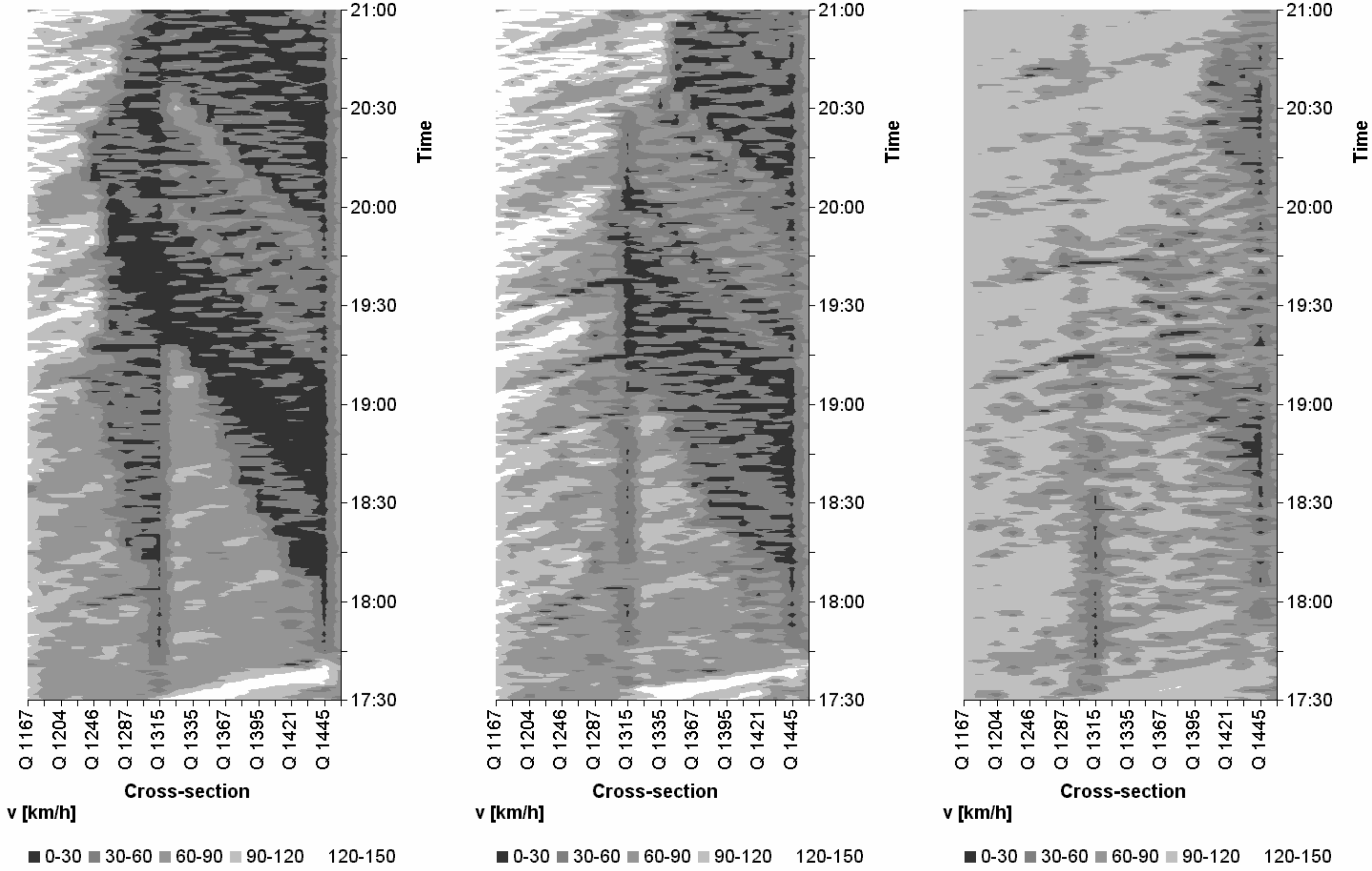
Simulation study with VISSIM

VISSIM is a fully commercial program package for microscopic simulation of traffic flow. In VISSIM vehicles are considered as individuals with certain predefined properties. Vehicles are advanced individually. This program was initially calibrated for traffic simulation in urban areas and later extended to freeway traffic. In VISSIM, the car-following model from Wiedemann (WIEDEMANN, 1974; HUBSCHNEIDER et al, 1977) is incorporated. For the simulation of freeway traffic, the system parameters of VISSIM are not very well calibrated.



a b c

Figure 3. Average speed over space and time: a) measurements, b) NETCELL, case A, and c) NETCELL, case B



a b c

Figure 4. Average speed over space and time: a) VISSIM case A, b) VISSIM case B, and c) VISSIM case C

VISSIM has 10 system parameters: CC0 through CC9, with respect to the car-following model. The default values of these system parameters are CC0=1.50, CC1=1.30, CC2=4.00, CC3=-12.00, CC4=-0.25, CC5=0.35, CC6=6.00, CC7=0.25, CC8=2.00, and CC9=1.50. The parameters CC0 through CC3 are values describing the threshold of relative distance in different predefined model cases. The parameters CC4 through CC6 are values describing the threshold of relative speed in different predefined model cases. The parameters CC7 through CC9 are values describing the threshold of different predefined model states.

It turns out that the calibration of the microscopic simulation model VISSIM is rather difficult. There are 10 microscopic parameters for the incorporated car-following model. If 5 values for each parameter are used for the calibration, there will be altogether 10^5 combinations of the parameters that can be used in the simulation. Thus it is very difficult and sometimes impossible to arrange these parameters to fit the measured flow-speed relationship. Furthermore, the parameters in VISSIM are used for the entire road net, a calibration of these parameters for each road section is impossible.

Therefore, in our case study most of the default system parameters are unchanged. Only the parameter CC1, which describes the intra-vehicle time headway in a platoon, is varied in fitting the simulation model to the measured data. Three simulation runs were conducted with CC1=1.3s (default value from VISSIM), 1.0s, and 0.5s (cf. Figure 4, part a, b, and c).

For the study case A (with CC1=1,3s), congestions at the interchanges AK Werl (Q1299-Q1315), AK Unna Ost (1430-1445), and AK Dortmund/Unna (Q1459) can be reproduced. However, these congestions cannot more recover. For the study case B (with CC1=1,0s), the congestions are reproduced. Compared to the measured data (Figure **3**, part a), the duration of the congestions is still too long. The study case C uses CC1=0.5s. That is the smallest value for this parameter. The simulated congestion is now similar to that of the measured data. For all the three study cases, the characteristic outlet of the congestion observed at 19:00 cannot be reproduced at all.

As can be seen, using the default parameters of VISSIM, it is impossible to reproduce the measured traffic condition sufficiently. The simulated capacity of the freeway is obviously too low, so that a congestion, once occurred, cannot recover again. Using a shorter intra-vehicle but unrealistic headway (e.g., 0.5s), the capacity of the freeway and thus the congestion situation can be better reproduced. However, the form of the congestion, especially the characteristic outlet of the measured congestion, cannot be reproduced.

Nevertheless, our case study shows that the microscopic model VISSIM (using the default parameters) represents the real world traffic condition in the range free flow traffic better than the macroscopic model NETCELL.

However, because of the long computation time, the program VISSIM is not suitable for simulating traffic flow in real time condition.

Conclusion

In order to test the capability of different simulation techniques, two computer models, one macroscopic and one microscopic, are validated for a special case study considering congested traffic flow on freeway

It turns out that the simple macroscopic model NETCELL can reproduce the congested traffic condition in the real world much better than the complex microscopic model VISSIM. The main advantage of the macroscopic model NETCELL is that the measured speed-flow relationship can be used directly as input parameters of the model, while the system parameters of the microscopic model VISSIM do not directly correspond to the measured speed and flow values. Therefore, it is very difficult to calibrate the VISSIM model for every geometric and traffic conditions. The case study shows that for the simulation of freeway traffic flow, a much shorter (e.g., 0.5s) than the default intra-vehicle headway must be used. The NETCELL model also consumed much less computation time than the model VISSIM, so that it is more suitable for short-time predictions.

As a consequence, the NETCELL model is more preferable to the VISSIM model for the purpose of short-time prediction, congestion warning, steering of variable traffic signs, and access control in term of traffic control systems.

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