Event traffic forecast for metropolitan areas based on microscopic simulation

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It is shown that a traditional travel demand forecast combined with a simulation-based approach can serve as a short-term forecast for the traffic situation. The approach presented was developed and tested during the Soccer World Cup 2006 in the city of Cologne as a service for the action forces to react as fast as possible to developing aberrations. This paper discusses the merits and the short-comings of the approach.

1 Introduction

Recently, increasingly larger study areas are investigated with the help of a microscopic simulation. Starting with the TRANSIMS project [12] and the simulation of Dallas and Portland for transport system purposes, meanwhile a number of similar systems had been deployed which went into the traffic management as well [14, 15, 2, 9].

The approach presented here is going to be continued in the Delphi project at the German Aerospace Center, which aims at developing a traffic prognosis in event situations for major Germany cities.

The systems usually work by determining first the demand for travel. Based on this time-dependent demand, the dynamic user equilibrium by a simulation-based traffic assignment procedure is computed and used as the basis for the final step of correcting the simulation with on-line traffic counts. Obviously, one of the great challenges with these models is their calibration and validation, since a large number of different sub models is used, and the data used for correction are sometimes contaminated by errors.

The Soccer World Cup in Germany 2006 was a good opportunity to implement and test such a system for forecasting the traffic state in some of the cities where soccer games took place. In the German cities Berlin, Cologne, and Stuttgart, different systems had been setup with the primary objective to provide organizers and police with up-to-date traffic information and predictions.

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While the whole system consists of more parts related to the air-borne surveillance by zeppelin, helicopter and airplanes, this article will focus on the simulation used to provide the surveillance and prediction. Furthermore, this paper will concentrate on the simulation setup for Cologne, the simulation in Berlin and a data fusion process in Stuttgart followed a completely different approach.

The paper contains the following parts:

Traffic demand and online data sources A short description which sources were used in advance to create realistic event traffic situations and calculate routes and which online data sources were available.

Simulation setup How the SUMO software package[10] was used to simulate the complete city of Cologne.

Results and evaluation Comparisons between the measured and the simulated traffic data and forecasts mainly focused on traffic counts.

2 Traffic demand

In a first step, the demand for travel had to be estimated, both for the normal situation without the World Cup, and for the additional demand generated by the World Cup itself. This included not only the visitors traveling to the stadium, but also the visitors who went to public viewing places.

The second step consisted of the determination of the dynamic user equilibrium consistent with this demand, using an approach described in [4, 5]. This step has been done in advance (offline), because it is very time-consuming due to the need of computing new routes for each vehicle (about 3.5 million in this case) several times (about 20 in this case). It consists of an iterated day-to-day simulation with rerouting, which is a standard procedure to determine the simulation-based user equilibrium. Finally, the online data from the loop detectors as well as the data from the airship have been used to correct the simulation results to be in line with the measurements. Altogether 781 detectors (lane specific) from 430 sites could in principle send data, see Figure 1. However, of these only 629 were actually sending data, of which 449 provided speeds and flows, while the remaining ones provided counts only. Of course, sending data does not necessarily mean that the data are error-free; by manual inspection additional loops had been identified and excluded from the simulation, where counts had been unrealistic. Nevertheless, some hard-to-define bugs are still in the data.

The data arrived any one minute, but was averaged into five minutes intervals and summed over all lanes for each site and each direction, since the simulation model used does not have lanes.

2.1 Demand modeling

Four sources of information have been used to describe the traffic demand for the given area. A previously generated synthetic population TAPAS of the urban area of Cologne was used for the inner-city area. This data was used because it was well validated within several precursor projects and because the routes cover even smaller inner-city roads [7, 6, 8]. Traffic around the city area was extracted from the VALIDATE data set by PTV [13] which covers entire Germany. To avoid having trips double from TAPAS and VALIDATE only those data from VALIDATE

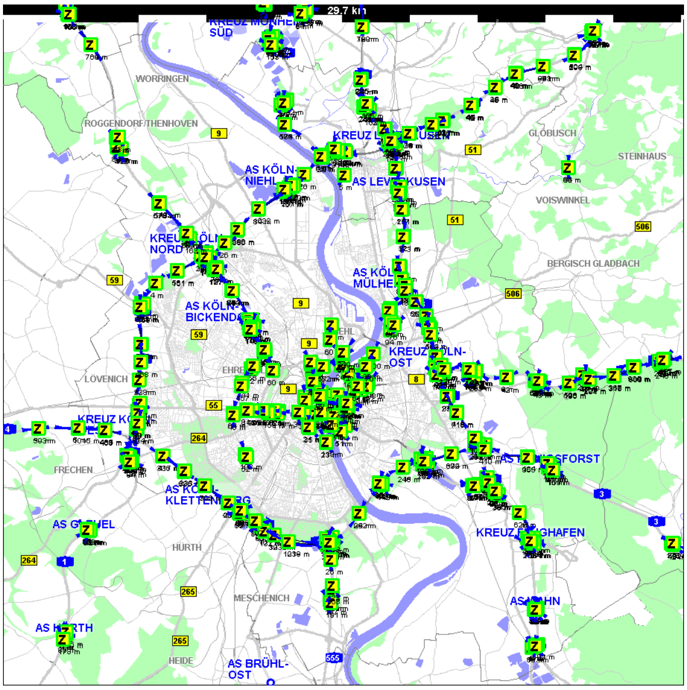

Figure 1: Overview of the simulation area with all induction loops

were used that were either entirely outside the city area, were going into the inner-city area from outside, or were leaving the inner-city area. TAPAS was used to model inner-city traffic only. Additionally, previous data from highway-detectors had been used to compute the distribution of routes over the highway network. This has been done by a statistical algorithm that constructs routes from the turn counts. While this leads to strange results when done naively, by forcing the routes to be sensible (no loops, the ratio between the length of a route and the corresponding beeline distance should be smaller than a certain number) realistic results had been achieved.

While these first three data sets are used to describe the normal workday traffic, the fourth data set was generated to resemble the expected event traffic. To indicate the arrival and the departure of these groups at the destinations, different time variation curves were built. Based on experience of other soccer games in Cologne the curves were designed in cooperation with the local police department (see an example for one day in Figure 2)

As the highway-detectors had been assumed to be the best source of information about the current state and to keep vehicle routes small, the so gained traffic demand was again manipulated and split after computing the dynamic user assignment. At first, trips were pruned as soon as the vehicle approached a highway yielding a demand that contained only those trips that do not use highways at all and those trips that approach highways. Furthermore, for all highway-off-ramps, the trips from the original demand that use them were extracted.

This means that a static microscopic set of routes for traffic outside of highways was used. All vehicles that used highways within the simulation were described using multiple trips: the first part described these vehicles way to a highway-on-ramp. At this point, a new route over the highway has been assigned to the vehicle.

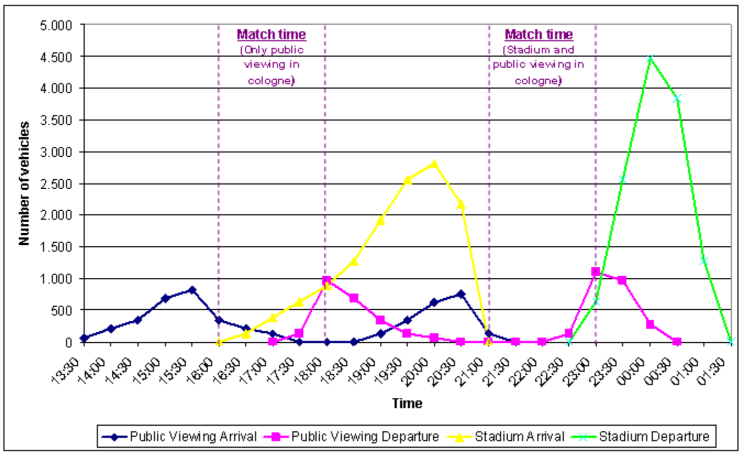

Figure 2: Estimated arrival and departure at the public viewing places and the stadium

As soon as the vehicle was reaching the end of the highway, the structures placed to the according off-ramp within the simulation were used to again change the vehicles route matching the distribution found in the routes previously generated by the dynamic user assignment.

This approach to model traffic on highways has several advantages. It reduces the memory needed by the simulation as long routes are split into the vehicle's individual route before and after the highway and a highway part that can be shared by several vehicles. Also, traffic on the simulated highways can be adapted to the values gained from reality not differing between vehicles which were inserted due to a mismatch of the simulation and the reality and those that were already on the highway. Furthermore, for each newly inserted vehicle, only its way over the highway has to be assigned at first. This reduces the amount of different routes for inserted vehicles and the simulations memory footprint.

3 Simulation setup

3.1 Software and mesoscopic model used

The software used was the open source traffic flow micro-simulation program SUMO [10, 11]. In addition to its normal car-following logic, SUMO has been extended with a so called mesoscopic traffic flow model, which is formulated as a queuing model. The idea of such a queuing model was to regard one link of the network as the atomic building block of the net, and simply put vehicles into those queues if there is enough space within it. The vehicles have to stay there for at least a minimum travel time which is given by the ratio between link length and speed of travel. When they have reached the minimum travel time, it is checked whether they can indeed proceed to the next link along their route, and it is made sure that the time δt since the last vehicle had left the link is larger than the minimum average headway, which is just the reciprocal value of the capacity constraint. For the simulation of Cologne, all long links have been divided into several queues of length 100m each (named a cell to discern it from a real link), to minimize effects which stem from links of different lengths. This is due to the fact that the constants in the equation (1) below depend to a certain degree on the length of a link. For longer links, the errors made by the queuing approximation become larger. The two constraints above (from capacity as well as from the space on the next link) can be summarized into the following set of rules which determine the minimum headway a vehicle has to obey before it is allowed to leave a cell:

$$\delta t = \begin{cases} \tau_{ff}, \text{ if } n_i < n_c \text{ and } n_{i+1} < n_c \\ \tau_{jf}, \text{ if } n_i \geq n_c \text{ and } n_{i+1} < n_c \\ \tau_{ff}, \text{ if } n_i < n_c \text{ and } n_{i+1} \geq n_c \\ \tau_{jf} n_{i+1}, \text{ if } n_i \geq n_c \text{ and } n_{i+1} \geq n_c \end{cases} \tag{1}$$

In this equation, τ_{ff}, τ_{jf}, and n_c are constants, while n_i is the number of vehicles in cell i. The constant n_c determines when a cell has to be regarded as jammed, n_c is a fraction of around 25% of the maximum numbers of vehicles that fit in a cell. The important point is the more complicated rule in the forth line of Equation (1). This makes sure, that a traffic jam spreads backwards. More simple rules unfortunately do not have this important property. A detailed description of the model can be found in [3]

3.2 Driving the simulation with online data

The online data consist of flows and (very often) speeds at the positions of the loop detectors. Additionally, the airborne sensors have measured densities and speeds on parts of the network the zeppelin was flying over. Here, the density was the most important measurement variable, the speed estimation was not reliable enough and therefore had been substituted by a simple fundamental diagram relating density and speed. During the simulation of a day, the system performed a simulation step each five minutes. During a single step the following actions have been done:

1. Collecting and saving of new data arrived so far from the sensors (induction loops on highways and within the city, airborne camera),
2. Using the data to generate input files for the simulation that resemble the traffic within the last five minutes,
3. Extrapolation of the data to predict the traffic in the next 30 minutes and building according simulation input,
4. Running the simulation and writing the current and the predicted network states (flows and speeds),
5. Post-processing of the simulation output in order to visualize it.

The first run of a day was started with an empty network. Each run was saved into a network dump which contains information about the net's state at the time until which new data were available. This dump is then read by the following simulation run in order to continue with a valid situation. This method allows starting to simulate at the current time, without the need to simulate earlier times in order to fill the simulated area.

While the simulation was fed using predefined routes/flows, the collected data was used to calibrate the simulation. When detector data were available (the first five of the simulated minutes), both the number of vehicles passing the simulated induction loops and their speeds were adapted to the values retrieved from real induction loops. During the prediction phase, where extrapolated values were used, only the predetermined flows have been used to drive the simulation.

The adaptation algorithm itself works as follows. The velocities were adapted by assigning new leaving times to those vehicles which are in a cell that belongs to a real-life induction loop as soon as the velocity measured by this induction loop changed. Additionally, the maximum velocity allowed in this cell was set to this velocity. The flows were adapted by deleting / inserting vehicles from / into the cell. Inserted vehicles got a route through the network that was taken from the set of previously computed routes. This makes sure, that the distribution of these routes should resemble at least the distribution of the routes with respect to the pre-computed dynamic user equilibrium, and, hopefully, to the distribution within the real network.

4 Evaluation and results

There are two things to be discussed:

- the quality of the reconstruction of the current state of the system and
- the quality of the prediction.

4.1 Reconstruction

Because both speeds and flows are adapted to the reality, the current situation at those street sections where detectors are located at fits well to the reality. To visualize this, Figure 3a shows a comparison of the flows retrieved from the highway induction loops and those measured within the simulation. About 40,000 different values are included in the plots, from the freeway loop detectors. Figure 3b tries to make the overall error easier to see by showing the number of error occurrences in a histogram for the flows.

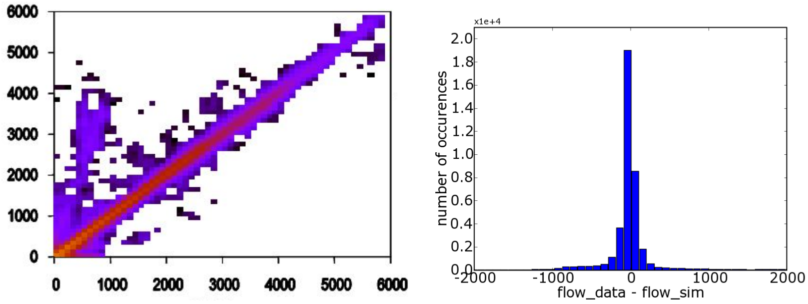

Figure 3: a) Comparison of measured and simulated flows (one point for each detector, more hits give brighter colors); b) distribution of the differences between measured and simulated flows

Since the flow was adapted on all detectors a straight diagonal line should be expected in Figure 3a, because measurement was taken at exactly the same location. The reasons why there are deviations are manifold. First of all, the simulation might not react as wished, because it may not be possible to insert a vehicle at the precise moment due to traffic jams. Furthermore the simulation somehow has to anticipate the total number of vehicles for a time interval after seeing only a few vehicles. The last reason is, that there is a delay in data transportation from the detection loops to the simulation, which means that the data at the moment of simulation (which should be identical to wall clock time) might also be an extrapolation of the last five minutes since the current dataset just did not manage it, to get into the system yet.

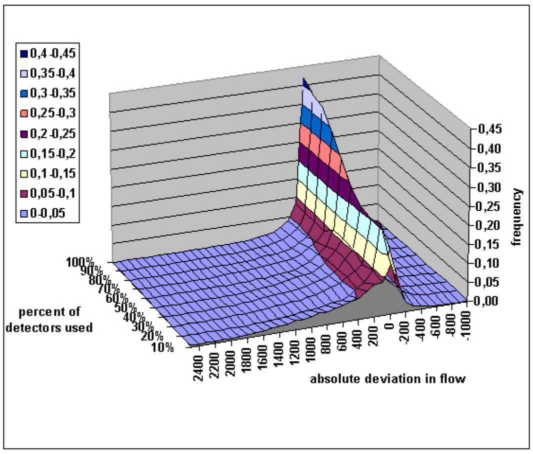

Figure 4: Frequency distribution of the absolute deviation between the simulation data (just the flows) and the measured data as function of the fraction of detector data used

Finally, it is an interesting question to investigate the deterioration of the performance of the approach described so far when detection sites are eliminated. This is shown in Figure 4 where the frequency distribution of the errors is plotted in dependence of the amount of detectors used as data input for the simulation. It can be seen that the peak in the area of minor errors decreases by using less detectors feeding the simulation from frequency of about 0.41 in case of 100% detectors used to about 0.13 in case of 10% detectors used. Furthermore, the distribution widens with decreasing the amount of detectors used. Coming more to detail Figure 5 shows the mean absolute deviation between simulation and empirical data as defined by:

$$\delta = \frac{1}{N} \sum_{i=1}^{N} \left| q_i^{\text{data}} - q_i^{\text{sim}} \right| \tag{2}$$

Figure 5 contains two curves. One taking all detectors into account for the elimination of detectors, and one where only detectors were eliminated which have no detectors in front that could insert a flow.

The results cannot be completely judged so far. Using all detectors an average error of about 190 veh/h is obtained. A difference of 200-300 veh/h as obtained by simulating with many detectors is for sure quite acceptable. A difference in flow of 500 veh/h or more as obtained by using much less detectors seems to be definitely high, but one has to regard that during this investigation also feeding induction loops were removed. The quite small error for a small number of removed detectors indicates that the traffic flow model itself is capable of catching missing inputs as soon as the flows were inserted somewhere else. This probably should be investigated by removing in-between detectors only. Still, if a feeding detector (one located at the network boundaries or at an on-ramp) is removed the network behind it is not filled within the current system setup.

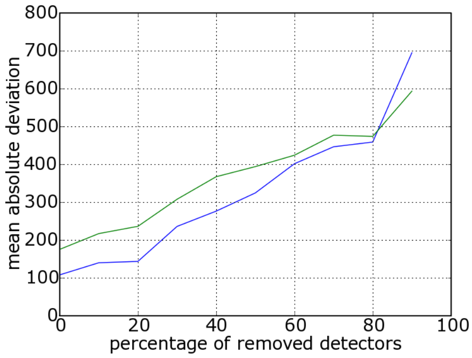

Figure 5: Development of the mean absolute deviation of flows in dependency to the percentage of removed detector inputs. Green line: including all detectors, blue line: excluding detectors with no predecessor

4.2 Forecast

In Figure 6 the forecast error is plotted for the counts. As can be seen, the error in the count forecast has increased, which can be observed by the widening of the points that scatter around the diagonal line in comparison to Figure 3a. The mean average error in flow is about 330 veh/h, which is quite more than the 190 veh/h obtained in the reconstruction case.

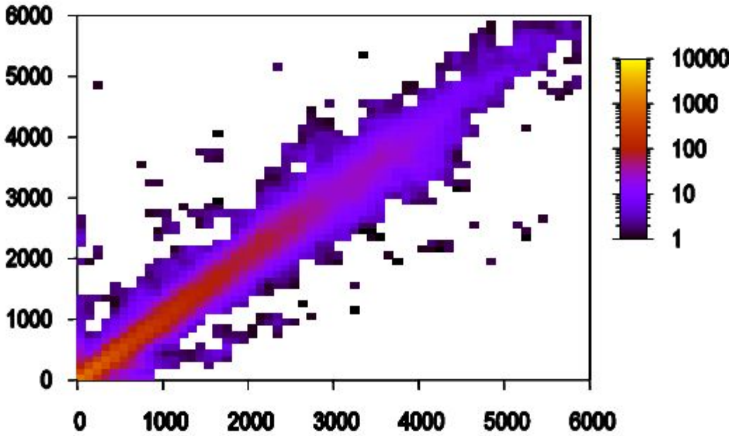

Figure 6: Comparison between predicted and measured flows. In comparison with Figure 3, it can be seen that the scatter has increased, as expected

But looking at the flow at single detectors it can be shown that the forecast is in parts acceptable as shown in Figure 7. The reconstruction gives a really good fit to the data obtained from this particular detector. The forecast in general matches the right direction except for times with high fluctuations as they are for example from about time 1100 to 1170 in this case. The time axis is in minutes, ranging from minute 800 (13:20) to minute 1400 (23:20).

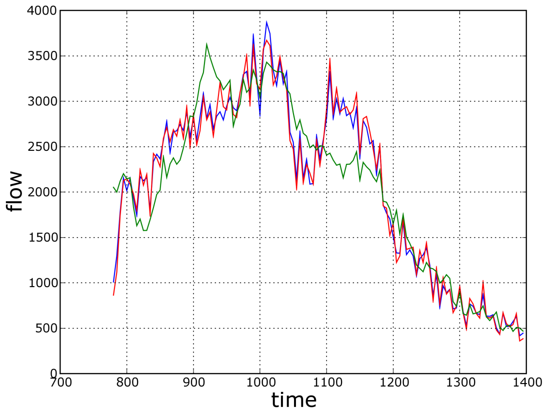

Figure 7: Traffic flows at one particular detector (red: measured flow, blue: simulated flow, green: flow predicted by the simulation 30 minutes ahead).

4.3 Ongoing work

There are a number of things which are going to be improved in this system in the context of the Delphi project. The first thing in focus is the validation of the input data coming from the detector loops. A lot of oddities in the evaluated data actually stemmed from trying to adapt the simulation to erronous detector data.

The second thing is to improve the simulation model itself. Especially for the inner city traffic it seems to be unrealistic to ignore traffic lights completely. This will change but this obviously relies on the availability of traffic light positions for the area to be simulated.

4.4 Conclusions

It has been demonstrated, that an approach based on the combination of a transport system planning with a traffic simulation can be used to provide helpful information and is able to predict a future traffic state 30 minutes into the future. The prediction error was on average about 330 veh/h, which has to be compared to the reconstruction error of about 190 veh/h. As could be expected for such a complex system consisting of several programs and a lot of empirical data, there are still a lot of glitches to be worked out.

Further improvements on the simulation setup and better results are to be obtained in the Delphi project which will be documented elsewhere.

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