A model for new data - Using air borne traffic flow measurement for traffic forecast

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INTRODUCTION

In the last few years a system for real time air borne traffic flow measurement was developed. During the Soccer World Cup which took place in Germany, three different air borne systems for traffic flow measurement have been set-up to provide organizers and police the current traffic situation and a short term forecast. The systems are called "Air borne Traffic Analyzer - ANTAR" (hardware) and "Traffic Finder" (software). In the cities of Stuttgart, Cologne and Berlin complex systems were installed consisting of automated image analysis and sensors on different air borne platforms like airship, helicopter, or airplane. The systems provide data like measured density, traffic flow, or the field of trajectories of all detected vehicles. Within the demonstration project SOCCER (traffic information and traffic forecast) in two cities simulations for forecast of the traffic state were developed: a microscopic model in Berlin and a queuing model in Cologne. Both models are based on the common parameters (I) average of density and (II) average of speed. The air borne traffic flow measurement approach is able to generate much more interesting traffic variables.
This paper will show the overall system which was set-up in Stuttgart based on a helicopter of the police of Baden-Württemberg as an introduction for a new model idea using the more sophisticated data an air borne system can provide. It shows the air borne sensors, the automated picture computing for traffic flow measurement and the data fusion for current traffic information and forecast.
The model presented here in the second part of the paper differs from ordinary continuum models, which calculate the flow from cell to cell, in the sense that it uses traffic patterns to classify the actual traffic state and estimates future states according to the actual state and the road's characteristics ahead. The model aims to simulate the formation of traffic clusters, flow and density for short term forecast. In this paragraph the structure and methodology of the simulation model are explained briefly.

SYSTEM FOR AIR BORNE TRAFFIC FLOW MEASUREMENT

During the project SOCCER for each of the three cities Cologne, Berlin and Stuttgart another type of aircraft was in use. In Berlin a small air plane type Cessna, in Cologne an airship called "Zeppelin NT", and in Stuttgart the sensor system were adapted at a police helicopter (MD 902) of the local government of Baden-Württemberg. In the ongoing project is one task to have a look at the advantages and disadvantages of different aircrafts in the practice of air borne traffic data collection.
The advantages of the helicopter are the following:

- highly manoeuvrable
- hovering over special points of interest
- low flying platform
- low vibrations

In addition to these advantages this special type of helicopter has very low noise emissions.
In comparison to the helicopter the airship Zeppelin NT (used in Cologne) has the advantage of a very long endurance (up to ten hours). The Zeppelin has also low noise emission it might be less than the helicopter. The disadvantages are the high operating costs and the liability to strong wind situations. Because of the special shape of an airship it is possible to make public relations by branding the cover.
The operating costs of the aircraft (it was used in Berlin) are the cheapest in comparison to the helicopter or the airship. The airplane goes very fast over long straight streets, but it is not possible to observe one point (like an intersection) for a longer period of time.
It depends of the geometry of the area, of the ownership of the aircraft, and of the observing assignment which kind of advantages strikes the others.

SENSOR SYSTEM

Using different aircrafts makes a special adaptation of the sensor system for each aircraft necessary. Therefore in the project three different sensor systems for air borne traffic flow measurement were build up. Just two key modules were the same in all three systems: the digital camera and the inertial measurement unit. In the case of the IMU the systems are from the same company but with two different product specifications (POS-AV 410 and POS-AV 510). GPS-antennas, differential GPS-receivers, wireless data downlink, or camera mounted.
One of the systems was described in detail in Ruhé et al. 2006 and Ernst et al. 2003. The system includes data fusion with data from other sources like inductive loops and vehicle probes, it includes also the graphical online presentation of the current traffic situation and the short term forecast (30 min).

THE MODEL

Why is there a need for a new model when the system is already up and running? The queuing model (used in cologne) and the microscopic (used in Berlin), both have two (in this context important) disadvantages: To set up an online simulation based on such models it connotes an important assignment of man power and a lot of information. For instance it is necessary to know the origin to destination matrix and information about routes or the proportion of individual traffic on the over all volume. The project SOCCER at least has shown that the approach of air borne traffic data collection is useful for the traffic management of big events. But before this approach becomes to an attendance an easy set up has to be possible. The second disadvantage is the fact that the models can not deal with measured densities or with a vehicle trajectory field.

In the third city of the project SOCCER a very simple model was used to display the current traffic situation based on measured traffic parameters (also average of density and average of speed). All parameters from all kind of sensors (loops, vehicle probes and helicopter) were stored in one database. A simple model was developed and implemented as a sql-script to use current or historical parameters to show the current traffic situation. In a similar way also a short term forecast was possible. Based on this database approach a new smarter model was looked for.

To go one step ahead in modelling in the past an approach was searched: In Treiterer et al. 1970 an air borne approach for traffic flow measurement was developed. In several pictures cars were identified and its trajectories constructed the result is shown in Figure 1. This approach (the very first was done by Johnson in 1927) was used as baseline in several papers (see for example Kim 2002).

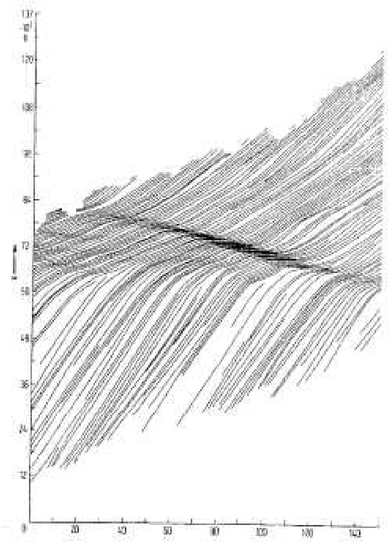

Figure 1: Diagram with vehicle trajectories done by Treiterer 1971.

Because the costs of operating a helicopter or another aircraft are very high the endurance of a flight has to be used as effective as possible. In the case of wide aerial traffic data collection the aircraft has to be very fast, that long street sections can be analysed for traffic information. Therefore the helicopter of the police of Stuttgart which is still in use flies with the operating speed of 150 km/h over ground. Figure 2 shows the trajectories of each cars measured by ANTAR. The comparison of these figures shows that the trajectories of the new approach are much shorter, but the different traffic patterns are visible too.

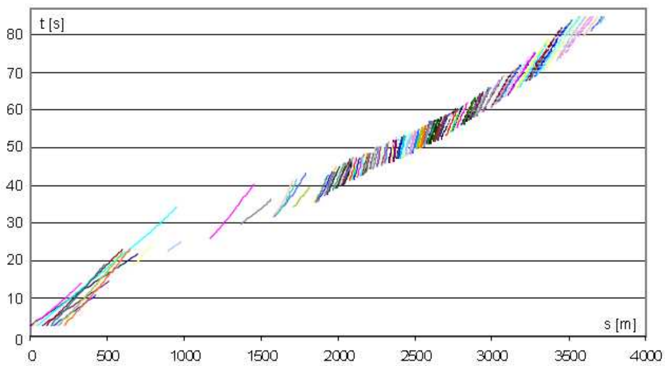

Figure 2: Diagram with vehicle trajectories done by Hipp.

The model is based on the assumption that there is a defined number of possible traffic states and that all other traffic behavior is to be seen as a transition between two states occurring only for short time. Road characteristics are represented in this model by dividing the surveyed road section into small segments of the length of 50 meters. Assuming that road characteristics do not change over short segments, also the traffic state stays constant on each segment. The simulation calculates from one segment to the next using the knowledge of the predecessor's traffic state and the current road characteristics to estimate the current traffic state. As shock waves propagate upstream the simulation is updated and additional boundary conditions are set for possible traffic states.
In the following the model's three pillars – traffic states, road parameters and shock wave propagation – are explained in detail.
Traffic states are defined if two values of the tuple (speed v, flow q, density k), fall into a certain area. In Figure 3 the states are shown a diagram of flow q and density k. How these patterns were empirically derived and later computed is not topic of this paper and can be read in detail in KIM, 2002. The work of Kim was based on the work of Treiterer too.

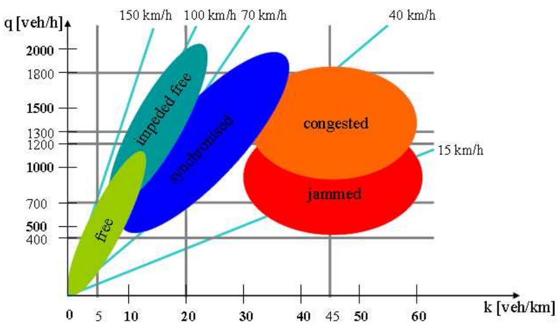

Figure 3: Diagram with traffic states done by Kim based on the trajectories by Treiderer.

For detection of a observed traffic state the average speed, flow and density are calculated from the vehicle trajectories for each road segment starting at the upstream end. This gives a profound knowledge of the initial traffic state on which the estimation of the following road segments' state will be estimated.
The impact of road characteristics such as speed limits, slip roads, exits, slopes, bends, tunnels, bridges or bottle necks in general on traffic flow is difficult to measure. As there is no clear degree of impact and the variables, named above, have so-called blurred values, fuzzy logic becomes a helpful theory to calculate the road parameters for each segment on the basis of vague variables.
For simplification, road characteristics are described by only two variables average_speed ***av*** and number_of_lanes **nl** which are given for each link by digital vector map of streets. For each variable two things are relevant. First, how much the value of a variable changes at the end of a link, i.e. **Δav**, **Δnl** and second, where the change of value takes place in relation to the position of each road segment, i.e. **ΔS(av)** and **ΔS(nl)**. Next, a membership function for each of the four input variables **Δav**, **ΔS(av)**, **Δnl**, **ΔS(nl)** is defined, the so-called fuzzy sets. The fuzzy logic determines two road parameters $\mathbf{v_f}$ and $\mathbf{k_f}$. With these a third road parameter

$$\mathbf{q_f = k_f * v_f} \qquad \mathbf{(1)}$$

is calculated. As a result the traffic state of the current road segment can be estimated by factorizing the aggregated speed v, flow q and density k of the predecessor's traffic state as follows:

$$\mathbf{v_{new} = v_{old} * v_f} \qquad \mathbf{(2)}$$

$$\mathbf{k_{new} = k_{old} * k_f} \qquad \mathbf{(3)}$$

$$\mathbf{q_{new} = q_{old} * q_f} \qquad \mathbf{(4)}$$

where

- $\mathbf{v_f}$, $\mathbf{k_f}$, $\mathbf{q_f}$ are road parameters for current road segment,
- $\mathbf{v_{old}}$, $\mathbf{k_{old}}$, $\mathbf{q_{old}}$ are aggregated speed, density, flow of the predecessor road segment,
- $\mathbf{v_{new}}$, $\mathbf{k_{new}}$, $\mathbf{q_{new}}$ are estimated average speed, density, flow of the current road segment.

A schematically overview of the calculation by fuzzy logic is shown in Figure 4 below for the parameter $\mathbf{v_f}$.
The fuzzyfication determines the logical value, e.g. $\boldsymbol{\mu_{\tilde{A}i}(\Delta av^*)}$, of each elementary logical statement e.g. **Δav=neglow** for every given value of the two input variables **Δav** and **ΔS(av)**. The inference step evaluates the

fuzzy rules according to the results of the fuzzyfication using a max-operator. At last defuzzyfication transforms the output result back to sharp values for the road parameters using the mean-of-maxima method.
The propagation of shock waves is the most challenging element in this model as it shows dynamic behavior. Shock waves form if traffic fields with significantly different flow and density characteristics encounter. In the case of a forming congestion the shock wave propagates upstream from segment ***j*** to segment ***i*** with following shock wave speed

$$\boldsymbol{v_{ij}} = \frac{q_i - q_j}{k_i - k_j} \qquad \textbf{(5)}$$

where

- $\mathbf{q_i}$, $\mathbf{k_i}$ are the flow and density of the encountering traffic field **i**,
- $\mathbf{q_j}$, $\mathbf{k_j}$ are the flow and density of the encountered traffic field **j**.

According to the shock wave speed a critical time frame is stored for each road segment upstream of the source of congestion modelling the time interval in which the shock wave reaches a road segment. This time frame is used as additional boundary condition for the second simulation run. If the estimated endpoint of a trajectory happens to be in the critical time frame the average speed, calculated as described above, is altered to a temporary speed $\mathbf{v_{apr}}$ which models the approach of a vehicle on to congestion ahead. If, however, the start point of a trajectory happens to be in the critical time frame the average speed is altered to the average speed of the congestion $\mathbf{v_{con}}$ modelling thereby a vehicle following congestion. The propagation of congestion, and so the setting of boundary conditions being the critical time frames, ends if there is a break-off time gap in the flow of traffic. Looking at the last segment upstream to which the continuous congestion propagated – the end segment - the break-off is defined as the time gap twice the length of the critical time frame. If no vehicles pass this road segment during the break-off the congestion is not propagated any further upstream and all boundary conditions are reset. This definition is reasonable due to the maximum deviation of time in calculating the upstream propagation of congestion.
Downstream propagation is not modelled here as these effects tend to dissolve very quickly.

SIMULATION

The simulation process starts by matching links in NAVTEQ coordinates with the vehicles coordinates to define the vehicle position in road coordinates. In a second step, of road parameters are calculated once for all segments of the surveyed road. Detecting traffic states, starting at the first road segment upstream, gives the starting point for estimating future states later on. For the initial state the average speed, flow and density are calculated from the given trajectories and extrapolated to the end of each road segment. After estimating the future state in the next road segment, according to equations (3) – (5), a new average speed according to Kim's (Kim, Y., 2002) diagram is set. In the model single vehicle trajectories react differently to the change in average speed modeling different characters of drivers. This is represented by following equation with respect to the variance of each traffic state

$$\boldsymbol{v_{i,n}} = \frac{\sigma_n * \left(v_{i,n-1}\bar{v}_{n-1}\right) + v_n}{\sigma_{n-1}} \qquad \textbf{(6)}$$

where

- $\mathbf{v_{i,j}}$ is speed of the vehicle **i** in road segment **n**,
- $\mathbf{v_{n-1}}$ is average speed of traffic state in predecessor road segment **n-1**,
- $\boldsymbol{\sigma_n}$ is variance of speed in traffic state on road segment ***n***.

Simulating shock wave propagation needs to include feedback of congestion propagation. This is done by inserting an iteration loop. While the calculation is processing through the road segments critical traffic patterns such as synchronized flow or congestion may be estimated. In this case the shock wave speed is calculated as stated in equation 6 and saved for the next iteration loop. The calculation proceeds with next road segment downstream until the end of the surveyed road. Then the second iteration loop starts with additional boundary conditions and the estimated traffic states are updated according to shock waves critical time intervals explained above.

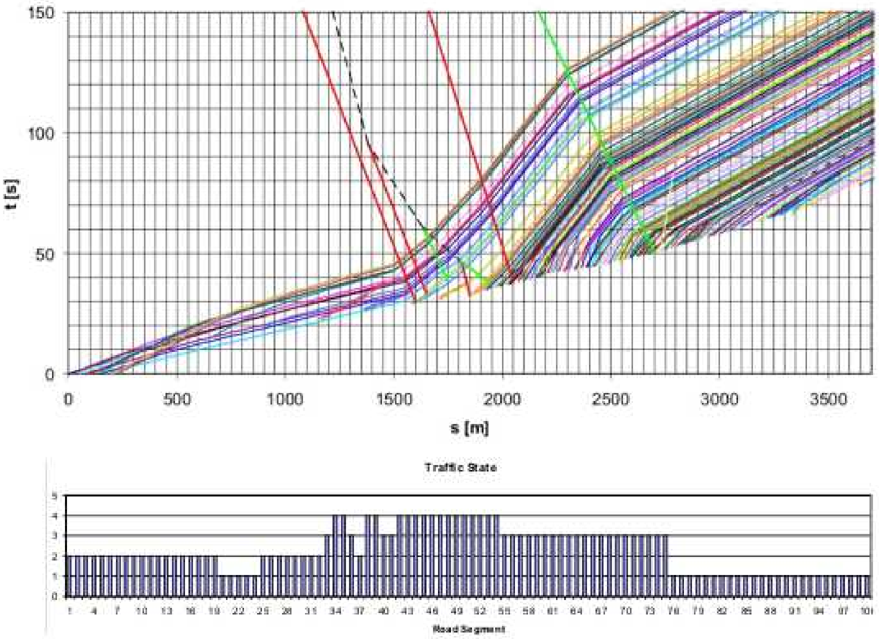

Figure 4: Extended trajectories and corresponding traffic states.

As a first result from the Soccer World Cup figure 4 shows the extension of the trajectories and the corresponding traffic states (for the measured situation). After the extension of the trajectories the congestion wave goes back to upstream by approximately 19 km/h what is a reasonable value.

The model will to be validated on more real data. A campaign just for improving the model is in preparation. The idea is to fly over the same track several times and show the coherences by using the model. Therefore it is possible that parameters and fuzzy sets given in this paper have to be slightly adjusted. For example the very rough changeover between two traffic states should be smoothed out.

CONCLUSIONS

During the World Soccer Championship 2006 the system for real time air borne traffic flow measurement with its modules Air Borne Traffic Analyzer – ANTAR (hardware) and Traffic Finder (software) were installed in three different cities of Germany. The systems were used in cooperation with the organisations responsible for the security of the games. It was demonstrated that this approach is usable for traffic forecast in a surrounding of common ITS hardware and software. The traffic parameters average of speed and average of density were merged with parameters like travel time and number of cars.

On occasion of the described big events area wide propagating of traffic disturbances and incidents were observed which require an area wide detection technique. The air borne technique turns out to be very appropriate for these requirements. But since the detection is more or less instantaneous as the short segments of the derived vehicle trajectories show a merging with other data sources is necessary to get a complete picture of the traffic situation.

Beyond the common parameters the effort was done to describe the traffic flow on the base of the trajectories directly. The considered air borne detection is very successful because the high precision localization of the camera pictures using the differential GPS positioned platform enables online traffic data evaluation. Together with the underlined sequence of traffic states free flow - impeded free flow – synchronized flow – congested flow – stopped or jammed flow by using membership mapping with the help of fuzzy set theory a concise traffic report is feasible allowing online traffic control and short term traffic forecast. The very first results show that this new kind of traffic flow data contains a lot of important information. In the near future some analysis has to be done to find the best fitting approach for these new data.

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