TRAFFIC DATA FUSION OF VEHICLE DATA TO DETECT SPATIOTEMPORAL CONGESTED PATTERNS

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Abstract
In recent years the models ASDA and FOTO based on Kerner’s Three-Phase traffic theory have been successfully applied to the detection and reconstruction of spatiotemporal congested traffic patterns using empirical data measured with stationary inductive loop detectors. In the federal state of Hessen for more than 10 years all loop data is processed by ASDA/FOTO models. Currently, more and more Floating Car Data (FCD) or Floating Phone Data (FPD), where the individual vehicles represent moving probes, had been made available. In the paper, a practical methodology for the data fusion of FCD and ASDA/FOTO will be proposed. The ASDA/FOTO reconstructed congested pattern will be transformed into traffic state changes per minute; i.e., at any minute at any location traffic state changes will be marked. The traffic state changes for the FCD will be marked by traffic state detection method described in [1]. In the data fusion process, all traffic state changes in space and time are combined into one congested pattern. Finally, the vehicle data are fused with the ASDA/FOTO model to enhance traffic pattern reconstruction quality.

Keywords:
Vehicle data (FCD/FPD), Traffic data processing, Probe Vehicles, Kerner’s Three-Phase traffic theory, Autonomous Traffic State detection, Data fusion

OUTLINE
Instead of stationary loop detectors, probe data is becoming more and more common in order to detect and reconstruct spatiotemporal congested traffic patterns.

Features of spatiotemporal congested traffic patterns on freeways are described in [1]. Kerner’s Three-Phase traffic theory (see [1]) distinguishes between one phase of free flow (F) and two phases of congested traffic, synchronized flow (S) and wide moving jam (J). Each traffic pattern consists of a unique formation and behavior of areas in time and space...
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belonging to exactly one of these three phases. Based on speed data measured locally, each probe assigns one of these three phases to each of its positions in time and space in an autonomous way [2]. Fig. 1 illustrates the result of the ASDA/FOTO model for a typical congested pattern reconstructed based on 1km loop detector distances.

![Figure 1 - Congested pattern in ASDA/FOTO and loop data with 1km detector distances](image)

Fig. 1 illustrates the result of the ASDA/FOTO model for a typical congested pattern reconstructed based on 1km loop detector distances.

![Figure 2 - Microscopic simulation of “real measured” congested traffic pattern (Fig. 1) based on vehicle’s traffic state recognition](image)

Fig. 2 shows the result of a microscopic simulation with Kerner-Klenov traffic simulation which is very similar to the pattern in Fig. 1: the vehicles “produce” the congested traffic at the bottlenecks similarly to the ASDA/FOTO model. This is one basic prerequisite to be able to estimate how much probes are needed for a traffic data fusion.

**TRAFFIC STATES IN SPACE AND TIME**

A freeway traffic state change from one state to another is performed when the speed is above or below a specific speed threshold value for a specific time interval. Both time and speed thresholds are chosen according to microscopic traffic criteria defined in [1].

Vehicles driving through a spatio-temporal congested traffic pattern experience a number of traffic state changes. A traffic state change is represented by a unique and exact position in time and space where the traffic phase changes, e.g., from free flow to wide
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moving jam. It is experienced at any position, where a vehicle hits the upstream or downstream front of a region of a traffic phase. In contrast, a traffic phase transition is represented by the start point or the end point of a traffic phase, respectively (see Fig. 3).

Traffic state changes between the different traffic phases have impacts of different strength on the vehicle and vehicular assistance applications. Two of the most distinguishing parameters of different traffic phases from a vehicle’s perspective are the vehicle speed \( v \) and the vehicle density \( \rho \). Both parameters influence the ability of the vehicles to choose their driving speed as well as the possibility for them to overtake other vehicles and to freely choose their driving lane. Different traffic state changes have a different effect on the value of these parameters.

![Figure 3 - Qualitative explanation of traffic phase transitions and traffic state changes a vehicle experiences on its way through a spatio-temporal congested traffic pattern](image)

Traffic State Detection in Autonomous Vehicle

Instead of stationary loop detectors, probe vehicle data can be used for the detection and reconstruction of spatio-temporal congested traffic patterns. Many systems using probes transmit only aggregated travel times for pre-defined road sections [3]. Here, we are not only interested in the travel time losses caused by spatio-temporal congested traffic patterns, but also in their detailed structure (Fig. 3, [1]).

In Kerner’s three-phase traffic theory there is one phase of free flow (F) and two phases of congested traffic, synchronized flow (S) and wide moving jam (J). Each traffic pattern consists of a unique formation and behavior of regions in time and space belonging to exactly one of these three phases. One of these three phases is assigned to each of the probe positions in time and space ([1],[4],[6]). A traffic state change is performed when the chosen measured values are above or below specific thresholds in speed and time, which are chosen according to on-board traffic criteria.
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Figure 4 - State diagram for three traffic phases [4],[5],[6]

**KERNER-KLENOV MICROSCOPIC SIMULATION**

Figure 5 - Kerner-Klenov simulation output of an expanded pattern. Average vehicle speed is shown in a), average vehicle flow is shown in b), while c) shows the traffic phase of *Ground-Truth* at a given spatio-temporal position. Wide moving jams can be identified in all figures as stable structures moving upstream [7].
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For calculations and evaluation the Kerner-Klenov three-phase microscopic model was used to simulate an expanded spatio-temporal congested traffic pattern. The simulation was configured to simulate a 30km highway stretch with three lanes and three junctions containing on- and off-ramps. The incoming and outgoing flow at these three junctions leads to the realization of three bottlenecks, which have led to an F->S traffic breakdown and the formation of several regions of synchronized flow. Within the synchronized flow regions several wide moving jams emerged (Fig. 5).

**TRAFFIC DATA FUSION APPROACH**

Fig. 6 (left) shows the traffic states which take place in the ASDA/FOTO model: all upstream and downstream fronts from free to synchronized flow and to wide moving jams as well as vice versa are shown with a bullet point detected by the stationary loop data. Fig. 3 (right) gives all the state changes for 2% vehicles driving through the congested traffic pattern from Fig. 2 which experience the traffic state changes during their individual drives. In the same color up- and downstream fronts are marked.

![Figure 6 - Traffic state changes in the ASDA/FOTO model (left) and traffic state changes in the 2% vehicle data (right)](image)

In the data fusion, all traffic state changes from both sources (stationary detectors and probe vehicles) are combined: this is our data fusion approach. For the reconstruction of the congested pattern regions of both traffic phases, the algorithm is used as described in [1]. At the final stage, ASDA/FOTO models show the completed congested pattern: both loop and vehicle data have been integrated into one ASDA/FOTO model congestion reconstruction.
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Fig. 7 - Fusion of all traffic states into ASDA/FOTO model congestion reconstruction

EXAMPLE: TOMTOM PROBE VEHICLE DATA

The number of probe vehicles collecting data at TomTom reaches an equipment rate of approximately about 1% for this traffic situation. Fig. 8 a) illustrates the results after processing the TomTom probe vehicle data with the traffic state detection algorithm, while Fig. 8 b) shows the results of the phase front detection. In Fig. 8 c) consequently the overall spatial-temporal reconstructed congested pattern based on real probe vehicle data is presented.

Fig. 8 - Reconstruction based on TomTom’s probe vehicle data on 10th December, 2009 on the A5-South in Hessen, Germany [7],[8]
The following Fig. 9 presents an empirical comparison for the same traffic situation based on different measurement techniques and data processing methods. At the top the results of the ASDA and FOTO models for the measured detector data and at the bottom the congested pattern based on TomTom probe vehicle data and reconstructed with vehicle based methods. The results prove that based on an equipment rate of approximately about 1% the possible data reconstruction quality is in the order of the ASDA and FOTO models for average detector distances of about 1 km. Qualitatively, a good correlation of both congested traffic phase regions $S$ and $J$ can be identified. Between the positions 0 km and 5 km the pattern reconstructed from probe vehicle data (Fig. 9 b)) shows smaller regions of the traffic phase $S$, which do not exist in the ASDA and FOTO reconstructed pattern (Fig. 9 a)). At the location between 0-5 km the detectors are more sparse than at other sections of the freeway and the traffic phase $S$, therefore, can be detected and reconstructed less precise in the ASDA and FOTO models. Those congested regions can be identified only with probe vehicle data based reconstruction methods. Overall, in this real-world case study the processing of different raw traffic data sources with different reconstruction methods has led to comparable results [7],[8].

![Figure 9 - Traffic congestion on 10th December, 2009 at A5-South - Comparison of different reconstruction results for different empirical measurements [7],[8]](image)

**CONCLUSIONS**

- The data fusion approach allows to combine stationary detector data and probe vehicle data from moving vehicles.
- A microscopic Kerner-Klenov traffic simulation reproduces a measured empirical example processed with ASDA/FOTO models and, therefore, allows traffic state detection in simulated probe vehicles.
- Subjects of further research are the evaluation and prototyping of new vehicular assistance applications based on high quality information about traffic patterns.
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✓ Probe vehicle equipment rates of about 1-1.5 % processed with the proposed method are comparable to detectors with distances of 1-2 km processed with the existing ASDA and FOTO models.

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References