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# Traffic parameter estimation on motorway networks by combination of filtering techniques

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***Abstract*—In order to perform road traffic control, it is very important to estimate the traffic parameters which can not be measured directly from sensors. In this paper, we will focus on turn fraction estimation based on a new road network representation which is used in traffic control software at the Dutch traffic management company Trinité Automatisering B.V. The common approach for the turn fraction estimation is by applying Kalman filter. However, the sensor information for motorways is not always available due to the fact that there are no physical sensors or detector failure on some parts of motorways. In this case, Kalman filter can not be applied to estimate turn fraction. A new approach by combining of Kalman filter and a low pass data filtering technology called Treiber-Helbing-filter is presented. This approach can contribute solving the problem by using Treiber-Helbing-filter to complete the missing data firstly. Then, turn fraction is able to estimate by using Kalman filter and visualize in traffic control software.**

***Index Terms*—Traffic Control, Traffic Parameters Estimation, Turn Fraction Estimation**

## I. Introduction

Traffic jams are a big problem for many countries. They cause fuel wasting, pollution, time losses, have a great impact on the economy, the environment and the quality of life. One possible solution to reduce traffic problems is to build new infrastructure. However, there are many difficulties with this approach such as high cost and lack of space. Traffic control is an attractive alternative solution to reduce traffic problems due to its relatively low cost.

Road Traffic Management is being applied in many countries for well-known purposes such as congestion prevention, augmenting efficiency by minimizing travel times, improving traffic security and driving comfort, and reducing environmental damage. Road Traffic Control (RTC) is one of the main activities within road traffic management, next to demand management, incident handling and pricing. RTC is about influencing traffic streams in order to improve traffic flow. Traffic data collection from road side equipments is essential for RTC. Traffic parameters (like turn fraction and OD matrix, ect.) which can not be measured directly are also very important for RTC. RTC can be improved if as much (accurate) as possible traffic parameters can be estimated.

In this paper, we will focus on traffic turn fraction estimation on motorway networks. The literature offers an abundance of approaches to estimate turn fraction, such as Likelihood methods [5], Bayesian estimator [10] and Kalman filter [1]. Most common approach is based on Kalman filter. We mention only a few. Simulation of turn fraction based on the unconstrained and constrained Moving Horizon Estimation (MHE) Kalman filtering is presented in [3]. Traffic state estimation based on extended Kalman filter is presented in [9]. Most studies are simulation based. However, in practice the necessary traffic information from road side equipment is not always available for the purpose of turn fraction estimation.

In this paper, we will present the approach combining Kalman filter and a data filtering technology called Treiber-Helbing-filter [6] to contribute solving the above problem for motorway. First, Treiber-Helbing-filter is used to complete the missing data on motorway. Then, Kalman filter is used to estimate turn fraction on motorway. By applying this approach to traffic control systems, turn fraction is able to estimate.

This approach is currently being implemented in a road traffic network management software which based on a new road network representation. The system was developed by the Dutch traffic management system company Trinité Automatisering B.V.

Most of the works have been made by applying new algorithms in a simulation environment. Our approach is challenging in the sense that the algorithms were implemented in a real system and try to solve traffic problems in practice.



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## II. A NEW APPROACH OF NETWORK REPRESENTATION

In order to estimate turn fraction online, a road network representation has to be defined. A well-defined road network representation can be easily applied algorithms to estimate turn fraction as well as improves traffic monitoring and control. A new road networks representation based on a distributed architecture will be presented in this section [8].

### A. System architecture

The proposed architecture in this paper is distributed. A distributed architecture improves scalability, facilitating the system to grow. The system architecture shows which elements (see table I) cooperate with each other in a high level manner, without concerns about how this interaction is done. These network elements are:

- **Origin-Destination Managers** (ODMGR) represent the relation between an origin and a destination and comprise one or more routes.
- **Routes** manages the set of routes from one origin to one destination.
- **Links** there are two types, mainlinks and accessorlinks. The mainlink is the link from the merge point to the choice point and the accessorlink is the link from the choice point to the merge point (Fig. 1).
- **Junctions** comprises the outgoing mainlinks and the incoming accessorlinks of a crossing or motorway junction. (Fig. 1). A junction is a location where traffic can change its routes, directions and sometimes even the mode of travel.
- **Control Scheme** correspond to patterns in the traffic state, such as the morning rush hours or the weekend exodus.

The representation of the relationship between control elements of the logical architecture view is shown in figure 2. Each road network element has a direct software object representation. The distributed components have to communicate with each other, as they work in cooperation. For instance, links have to communicate with other links in order to achieve a traffic state. They continuously measure the traffic state and communicate about it to other links in real-time.

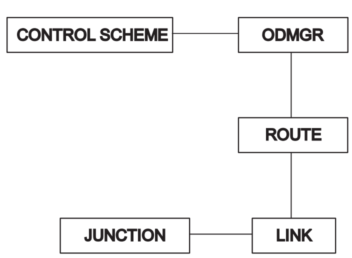



Fig. 2. Relationship between control elements

### B. Advantages of the new network representation

The new network representation consists of a set of junctions, and each one has some mainlinks and accessorlinks. Each mainlink and accessorlink only belongs to one single junction. In figure 1, it is shown that a junction consists of twelve incoming accessorlinks and four outgoing mainlinks.

There are many advantages of using the new approach to represent road networks for the purpose of turn fraction estimation. First, to be able to do turn fraction estimation at the high level–Junction level. We divided a network into two levels [7]: Junctions and Links. Junction is able to estimate turn fraction based on all the traffic information from Links.

Second, the number of accessorlinks represent the number of choices at the choice point. Thus, it is possible to express the turn fraction on the accessorlinks for different direction choices.

Last, there is only one accessorlink between two mainlinks, thus it is an 1-to-n relationship for mainlinks and accessorlinks. It avoids the n-to-n relationship and makes software data structures much simpler.

With these advantages, the new road network representation has big improvements for the purpose of turn fraction estimation. In the following section, we will introduce the common approach based on the network representation to estimate turn fraction by using Kalman filter.

## III. TURN FRACTION ESTIMATION USING KALMAN FILTER

Kalman filter is used to estimate turn fraction of motorways in the Netherlands such as the A7-A8 crossing which can be seen in figures 3. The red links are the mainlinks which are connected with two junctions. The blue links are the accessorlinks which are connected with mainlinks. If we consider the flow of the incoming mainlinks as $q_i$, the flow of the outgoing mainlinks as $y_j$ and the turn fraction of accessorlinks as $x_{ij}(0 \leq x \leq 1)$, the Junction can be modeled as the following state space model [3], [4]:

$$x_{k+1} = Ax_k + \omega_k \tag{1}$$

$$y_k = C_k x_k + \nu_k \tag{2}$$

with $x_0$ given. $\omega_k$ is the state noise vector, $\nu_k$ is the measurement noise vector, $x_k$ is the state vector. A is a constant matrix, $C_k$ is a time-variant output mapping matrix.

If the flow of the incoming and outgoing mainlinks are known, the turn fraction of accessorlinks are able to estimate by applying Kalman filter.

From above description, we know that the traffic information(flow) from all mainlinks are needed for the turn fraction estimation. However, the sensor information from mainlink for motorways is not always available due to the fact that there are no physical sensors or detector failure on mainlinks. Thus, Kalman filter can not be applied. In the following section, a low pass data filtering technology called Treiber-Helbing-filter is presented to contribute solving the above problem for motorways.

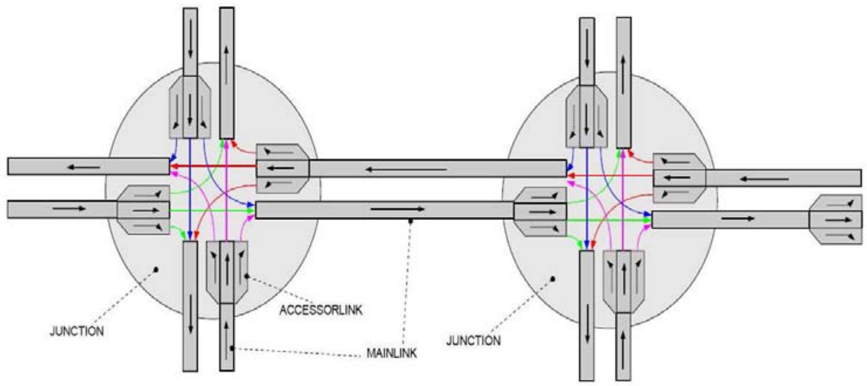



Fig. 1. Junction style

| Layer | Geographic element | Monitoring | Control |
|---|---|---|---|
| *Network* | Network<br>Route | OD-matrix<br>Route travel time | OD-Manager<br>Route Manager |
| *Link* | Link<br>merge/choice point | Remaining capacity<br>Average speed, turn fractions | Link Manager<br>Junction manager |
| *Point* | sensor/actuator position | Speed, flow, occupancy | Actuator manager |

TABLE I
SYSTEM ARCHITECTURE

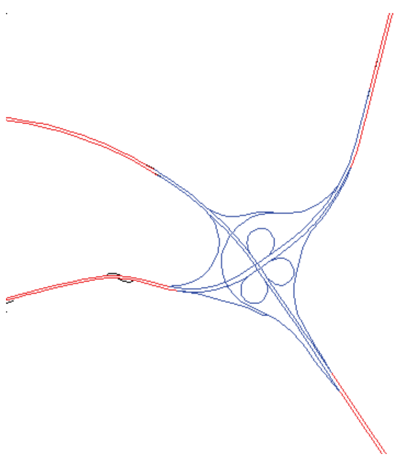
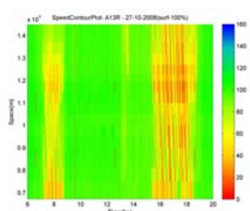


Fig. 3. A7-A8 crossing

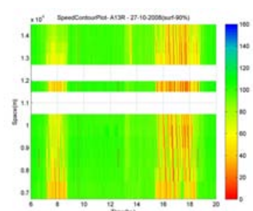
## IV. COMPLETE MISSING DATA USING TREIBER-HELBING-FILTER

The Treiber-Helbing-filter is able to supply data at points with no physical sensors or with detector failure. The Treiber-Helbing-Filter is a spatio-temporal traffic state estimator. The basic idea of Treiber-Helbing filter is to calculate each point over time and space with a linear combination of its neighbor measurement points [6].

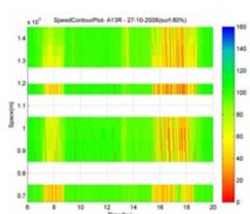
In order to test the effects of Treiber-Helbing-filter on data completion, we take one-day raw data (from 6:00 to 20:00 in one-minute pattern) from a Dutch motorway (A13) as example. The current monitoring system on the Dutch motorways consists of double inductive loops located about every 500 meters. Some test scenarios with different extent of data missing are presented in table 4.



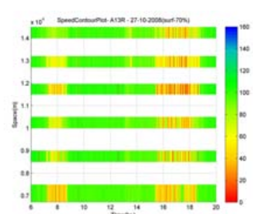
(a) 100 percent data



(b) 90 percent data



(c) 80 percent data



(d) 70 percent data

Fig. 4. Data missing

## V. RESULTS

### A. Complete Missing Data

To make a comparison between different scenarios, the filtering result derived from the overall temporal-spatial filtering based on the complete data set, is used as reference.

| Data missing level | | 90 percent | 80 percent | 70 percent |
|---|---|---|---|---|
| Speed | RMSE(km/h) | 1.3262 | 1.7342 | 1.9501 |
| Flow | RMSE(veh/h) | 94.7103 | 124.7060 | 151.1307 |
| Speed | MPE(%) | 0.3737 | 0.2864 | 0.3911 |
| Flow | MPE(%) | 0.7337 | 0.3653 | 0.5920 |
| Speed | MAPE(%) | 0.8044 | 1.2065 | 1.5875 |
| Flow | MAPE(%) | 0.9301 | 1.4881 | 2.1758 |
| Speed | SPE(%) | 3.0248 | 3.6815 | 4.1185 |
| Flow | SPE(%) | 2.3842 | 3.1907 | 3.8859 |

TABLE II
COMPARISON RESULTS FOR DATA MISSING

| Error indicator | Meaning |
|---|---|
| RMSE | The root mean of squatted error |
| MPE | The mean percentage error |
| MAPE | The mean absolute percentage error |
| SPE | The standard deviation of the percentage error |

TABLE III
THE MEANING OF DIFFERENT ERROR INDICATORS

The performance measures are used as same as presented in [2].

The speed contour plots with both raw and filtered information are shown in figure 4 and figure 5 respectively. It is different to point out the difference between the speed contour plots with data missing and the reference case. In table II, the comparison results are presented. It is found that even a further data missing to 30 percent of the detectors yields acceptable results. The meaning of the different error indicators can be seen in table III

In case of missing data, the filter turns out to be efficient to rebuilt lost data. Moreover, the relative error indicators between the filtered completed data and the filtered original data are rather small, as shown in table II.

In general, the Treiber-Helbing-filter is able to complete missing data. The completed data are acceptable in terms of the selected error indicators.

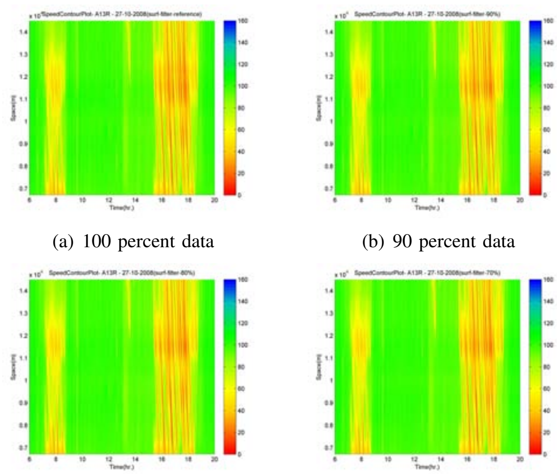
### B. Turn Fraction Visualization

Based on the complete data from Treiber-Helbing-filter, turn fraction is able to estimate by using common Kalman filter and visualize in traffic control software.

An automated image of the junction is created based on the image of links. This image and a table with turn fraction are shown in a graphical user interface. Clicking in the junction image will result in an overview from this image containing the information presented in the tables (Fig. 6).

## VI. CONCLUSION

In this paper, we present an approach to estimate turn fraction by combining Kalman filter and Treiber-Helbing-filter.



(a) 100 percent data (b) 90 percent data

(c) 80 percent data (d) 70 percent data

Fig. 5. Data filtering

| | ← | ↑ | → |
|---|---|---|---|
| Turn Fraction | | | |
| Flow | | | |

Fig. 6. Table of turn fraction

It is very important to estimate the traffic parameter for the purpose of traffic control. Kalman filter is a common approach to estimate turn fraction, however Kalman filter is not able to be applied due to the fact that the sensor information from mainlink for motorways is not always available. Treiber-Helbing-filter can contribute to solve the problem by completing missing data of mainlinks. Then, Kalman filter is able to estimate turn fraction with traffic information of all mainlinks. The approach is based on the new road network representation which is used at the Dutch traffic management company Trinité Automatisering B.V. The representation has lots of advantages for the purpose of turn fraction estimation and visualization. In general, the combination filtering techniques approach has been applied in the operational traffic control system to estimate turn fraction on motorways in case of no physical sensors or detector failure on mainlinks.

## ACKNOWLEDGMENT

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