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STEFFEN AXER, BERNHARD FRIEDRICH INSTITUTE OF TRANSPORTATION AND URBAN ENGINEERING
TECHNISCHE UNIVERSITÄT BRAUNSCHWEIG

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Steffen Axer, Bernhard Friedrich
Institute of Transportation and Urban Engineering
Technische Universität Braunschweig
38106 Braunschweig
{s.axer,friedrich}@tu-braunschweig.de

ABSTRACT

High and not adapted speed is one of the major reasons for fatal and severe accidents in road traffic. In particular rural and federal roads represent hot spots for this kind of accidents. Preventing excessive speed and thus improving traffic safety is therefore a common objective. In order to overcome the disadvantage of a conventional ex post accident analysis based on historical accident data, it is worthwhile to identify dangerous road segments and time of days ex ante and to introduce respective prevention strategies beforehand. Floating Car Data offers a promising data source to realize the objective of an ex ante identification of dangerous road segments by a statistical traffic speed analysis. This paper deals about the possibility of an identification of dangerous road sections and time of days in wide rural road networks by the help of sampled Floating Car Data (FCD). Therefore a rough overview about used data sources and application-oriented statistical measures is given. Furthermore the paper analyzes systematically the availability and representativity of traffic speed derived from FCD in comparison to the lateral radar technique. Exemplarily collected FCD are used for the development of an easy to use calibration process needed for the estimation of different speed measures with a high spatiotemporal resolution within a certain test site. The developed calibration process was tested and validated successfully on a selected test site. Based on calibrated speed measures the paper describes first concepts to optimize time and place of traffic speed enforcements by the help of FCD.

Keywords: FCD, rural roads, traffic safety, speed measures

INTRODUCTION

The improvement of road safety on rural and urban roads is one of the main objectives of police safety work. During the last decades, the total amount of road fatalities in Germany decreased substantially. To preserve this positive trend, continuous efforts are still needed for the reduction of the absolute number of accidents in road networks. High potential for the improvement of traffic safety in Germany is especially related to rural and federal roads. For example, in Germany, the total number of traffic accidents on rural and federal roads increased between the years 2010 and 2011 by approximately 5.3 % (Destatis 2012). The major reason for these mainly fatal and severe accidents is that the drivers drove too fast for the given conditions. Existing strategies for reducing accidents on road networks are usually based on a retrospective determination of accident blackspots and its statistical analysis. The scope of this paper is to extend the retrospective analysis of accident blackspots by systematically identification of dangerous road segments and times of day. Therefor the paper primarily proves the possibility of a spatial and representative determination of travel speed based on FCD. Derived travel speeds with a high temporal and spatial resolution could be used in a first approach for a spatiotemporal optimization of policy speed enforcements. The estimated travel speeds could be augmented in further researches with additional information like historical accidents and alignment specifications which allows an integrated risk estimation on road segments.

The remainder of the paper is organized as follows. The first chapter gives a brief summary of the used data sources and introduces statistical measures, which are needed for proving the representativity of FCD derived travel speeds. Furthermore, methodology and test site for the data analysis are introduced. The second chapter deals about FCD analysis. Derived FCD travel speeds of the test site will be analyzed and evaluated regarding their representativity by the help of defined statistical measures. The third chapter establishes exemplary the usage of the derived travel speeds for a spatial and temporal optimization of police speed enforcements.

CONCEPT FOR SPATIAL FCD ANALYSIS

Used data sources and data handling

The major scope of this paper is the representative estimation of travel speed with a high spatial and temporal resolution on rural and federal roads. The used data source to fulfill the estimation of travel speeds on these roads is the Floating Car Data (FCD) technology. The basic idea of observing floating cars, and therefor collecting information of the traffic, has been used since the 1950s. The principle of a FCD system uses always positioning technology like GPS (Global Positioning System) combined with data transmission technology like GSM (Global System for Mobile Communications) to transmit geo-referenced traffic information to a central data system. As the description of the FCD technology is not the main objective of this paper, it references to researches of Schäfer (2002), Kerner (2005) und Linauer (2005). In general, a FCD dataset provides several attributes, which gives information about the id, timestamp, travel speed, movement direction and the geographic coordinates of a vehicle. All of these mentioned information are used in the further FCD analysis. Besides the usage of FCD, the paper appropriates a digital road network from the open source mapping service Open Street Map. FCD and digital road network are stored in PostgreSQL database, which allows an easy and fast data analysis process.

Statistical measures for link speed analysis derived from FCD

Using the principle of FCD for the estimation of travel speeds considers generally a small sample size of the cars traveling on the observed road segment in a certain time interval. Based on the sampled FCD, it is possible to calculate several different statistical measures, which could be used to characterize the travel speed. Two of the most common and easy to interpret statistical measures are the V_{85} and V_m. The statistical value V_{85} calculates the speed that is not exceeded by 85 % of the observed vehicles. Beside this value, the V_m calculates the average trough vehicle travel speed. Both values could be calculated for a certain cross section and time interval. Especially the V_{85} establishes more sophisticated statements about the distribution of travel speeds. Both of the mentioned values are used for further speed analysis in this paper.

The most important aspect while deriving the travel speed on a certain road segment by the use of FCD is to determine the representativity of the calculated statistical measures (V_{85} and V_m). Therefore, the paper uses the approach from Vortisch (2005). Applied on the scope of this paper, Vortisch's approach compares estimated by FCD and real statistical measures in a time series. For this purpose, shape (S_{form}) and position ($S_{position}$) similarity of two time series are calculated and joined to one statistical value (S_{comb}), which describes the overall similarity. The introduced similarity measures could be calculated by the use of the following equations:

$$S_{comb} = 1 - \left(\alpha \cdot S_{form} + (1-\alpha) \cdot S_{position}\right)$$

$$S_{form} = \frac{\sum_{n=1}^{N}(x_n - \bar{X}_N)(y_n - \bar{Y}_N)}{\sqrt{\sum_{n=1}^{N}(x_n - \bar{X}_N)^2 \cdot \sum_{n=1}^{N}(y_n - \bar{Y}_N)^2}}$$

$$S_{position} = \frac{1}{N}\sum_{n=1}^{N}\frac{min(x_n, y_n)}{max(x_n, y_n)}$$

The calculation of the value (S_{comb}) needs the input of a certain value for α. Therefore, shape (S_{form}) and position ($S_{position}$) similarity are weighted with the same factor ($\alpha = 0.5$). Shape (S_{form}), position ($S_{position}$) and combined similarity (S_{comb}) are normalized between 0 and 1. The best combined similarity is reached by a value of 0.

Methodology and test site introduction

For the evaluation of the representativity and the applicability of estimating the introduced statistical speed measures with a high temporal and spatial resolution, a test site in Niedersachen (Germany) was defined. The used test site consisted of a 4880 m long rural road (Bundesstraße 4), which lies between the villages Wagenhoff in the North, and Gamsen in the South. The test track was separated into eight equidistantly road segments that were equipped with lateral radars. The northern end of the test track is influenced by a non-signalized intersection. The whole test track including the mentioned intersection has a speed limit of 100 km/h. Test selected road has as average daily traffic of 7000 vehicles per day. During an evaluation period of one month (09.06.2012 - 08.07.2012), radar data and FCD was collected on every day for 24 h. Caused by a lack of lateral radar, only the northern direction could be observed. Figure 1 depicts the eight road segments and the positions of the lateral radars.

To guarantee a precise travel speed measurement in every road segment, all lateral radars were placed in an unnoticeable box and calibrated with the help of laser speed measurement equipment. Figure 2 sketches exemplarily the setup of one single road segment. Due to the different functional principles of radar und FCD, the speed data analysis uses the assumption that the travel speed of a car derived from FCD ($V_{Local,FCD}$) is quite similar to the speed of the same car traveling along the radar cross section ($V_{Local,Radar}$) inside one road segment. This assumption holds especially for small road segment length as used in this paper (610 m).

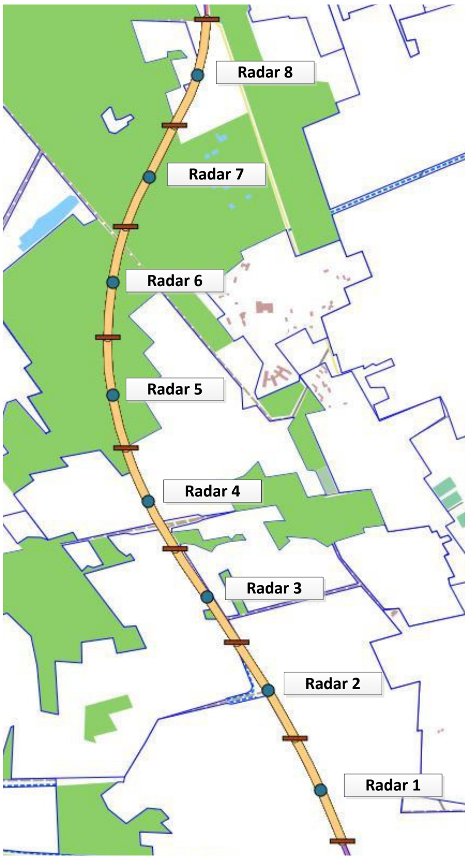

Figure 1: Test site equipped with lateral radar (blue points) and road segments (brown bars)

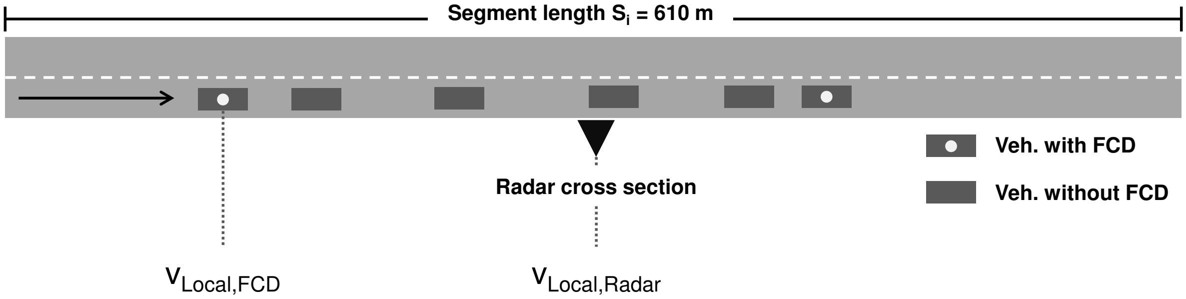

Figure 2: Comparison of travel speed derived from FCD and radar cross section

If the FCD data source is considered to be representative, the following equations hold:

$$V_{Local,FCD} \approx V_{Local,Radar}$$
$$V_{m,Local,FCD} \approx V_{m.Local,Radar}$$
$$V_{85,FCD} \approx V_{85,Radar}$$

Before evaluating the statistical measures (V_{85} and V_m) derived from FCD and radar, all collected data has to be processed. These data process consists of six basic steps.

1. Data import: Import of FCD and radar data into a relational database.

2. Coordinate transformation: Transformation of geo coordinates into a two-dimensional Cartesian coordinate system.

3. Segmentation: Separating the digital representation of the test track into equidistant road segments with a length of 610 m.

4. Map Matching: Mapping of FCD and radar data to the digital representation of the test track. Every FCD sample gets related to a road segment. Distance threshold for mapping FCD to the road segment was set to 15 m.
5. Data filtering: Datasets below a certain travel speed threshold (40 km/h) gets deleted. Filtering of cars that are traveling in the wrong movement direction. For the determination of movement direction the heading information of a FCD dataset was used.
6. Statistical travel speed analysis: Aggregation of single FCD and radar datasets into 2 h intervals. Calculation of speed measures (V_{85} and V_m).

VALIDATION OF FCD-BASED LINK SPEED

Representativity of FCD-based speed measures

After the data process, the representativity of calculated speed measures was checked for every single road segment. To keep this paper in an appropriate extent, this chapter will give a detailed analysis of representativity and availability of FCD for only one road segment. Later on, all segments will be evaluated in a short overview. Figure 3 illustrates the overall FCD distribution on all segments during the whole evaluation period. All eight segments have

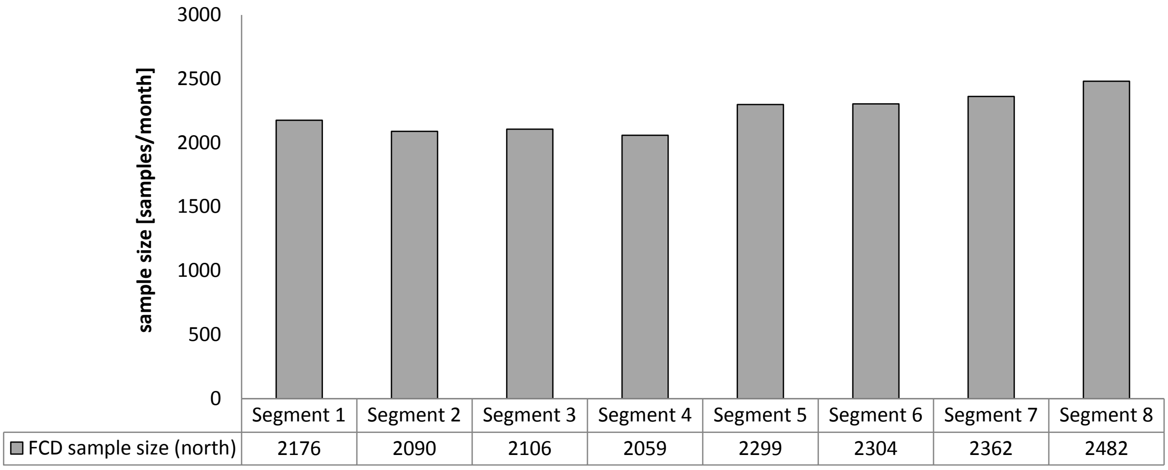

Figure 3: FCD distribution on the whole test site

nearly the same amount of sampled FCD. Due to this fact, the fifth road segment is selected and evaluated in respect to representativity and FCD availability. The analysis for the fifth road segment is divided into two cases:

- Case 1: Non HGV, HGV and unknown vehicle; 2 h interval; single days
- Case 2: Non HGV and HGV and unknown vehicle; 2 h interval; aggregation of same week days

The first case considers all collected FCD and radar data independent to the vehicle type of an FCD or radar dataset. The collected data was aggregated in 2 h time intervals, and statistical speed measures were calculated. The second case uses the same datasets, which was aggregated to identical weekdays. Therefor, the second case is based on the assumption that speed measures vary only slightly when comparing data of equal weekdays. Crucial requirement for this assumption is the consideration of the times, where the traffic situation changes heavily, compared to typical or normal traffic situations. For example, it is necessary to differentiate between holiday periods and normal periods (FGSV 2012).

Figure 5 compares the statistical speed measure (V_m) for the fifth road segment derived from FCD to the lateral radar. Furthermore, the figure illustrates the collected FCD sample size within a 2 h time interval for every single day. Obviously, the used FCD data source presents several data gaps, where no FCD could be collected within a single 2 h time interval. In 40 out of 360 2 h intervals (approx.11 %), no FCD could be sampled. Especially in the late evening up to the early morning, the used FCD data source provides only a small sample size. The average travel speed derived from FCD indicates a systematic offset compared to the radar which seems to getting slightly smaller in the observed weekends. Primary cause for this offset could be the vehicle type distribution of the FCD data source. Within the considered road segment 57 % of the FCD was generated by heavy goods vehicles (HGV) and 22 % by non HGV. 21 % of the collected FCD had an unknown vehicle type. Measured by the lateral radar the road segment was traveled in 71.67 % by non HGV and only in 28.33 % by HGV. Due to the fact that more than half of the FCD was generated by HGV, a third analysis excluding HGV vehicles in the FCD data analysis is not presented in this paper.

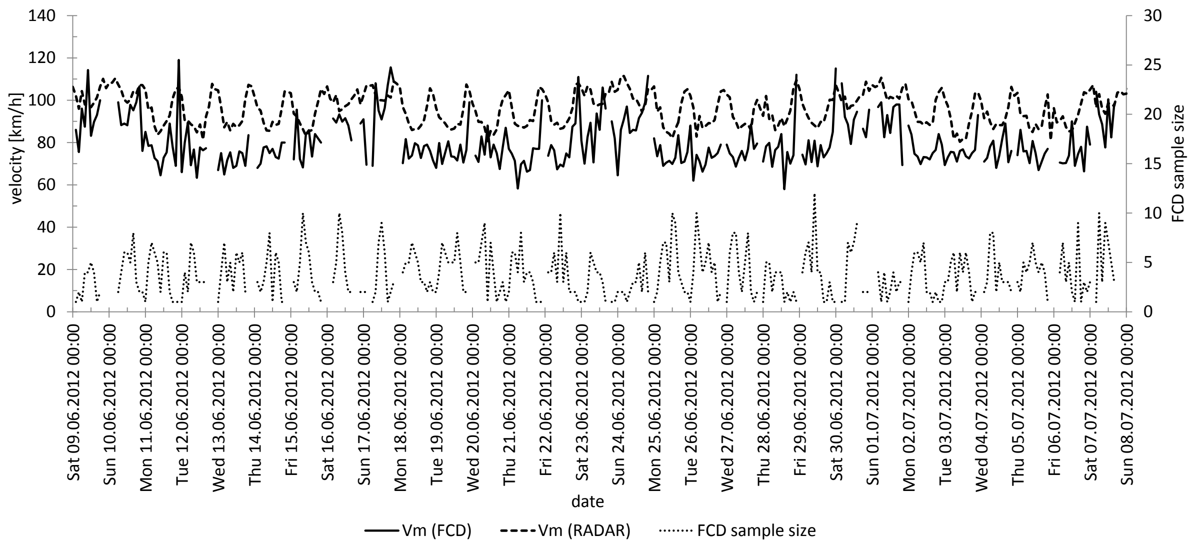

Figure 5: Case 1 - V_m (FCD) and V_m (Radar), road segment 5

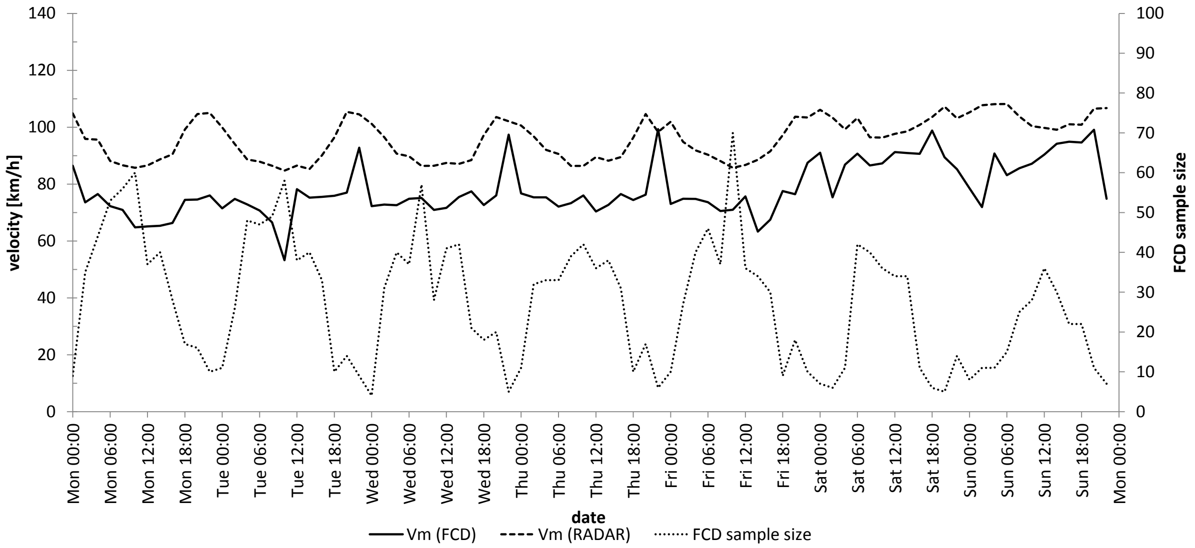

Figure 4: Case 2 - V_m (FCD) and V_m (Radar), road segment 5

Figure 4 shows the results of the second case. Based on the data aggregation process of identical weekdays, data gaps like mentioned in Figure 5 could be avoided. In return to the denser FCD data source, statements about statistical speed measures for single calendar days could no longer be realized. As already shown in Figure 5, the analysis of the second case reveals also a systematic offset which is getting smaller in the starting weekend. Table 1 shows the calculated shape, position and combined similarity between the statistical values derived from FCD and radar. The data aggregation process of identical weekdays leads to denser FCD data source. Caused by these enhanced data source, mainly the shape similarity (S_{form}) is improved, the similarity of the position only improves minimally. Because of the denser and much more representative data source, the second data analysis case is the basis for further researches in this paper.

Table 1: Statistical evaluation of FCD-Representativity (V_m and V_{85}), road segment 5

	Statistical measures					
	S_{form} [-]		$S_{position}$ [-]		S_{comb} [-]	
	V_m	V_{85}	V_m	V_{85}	V_m	V_{85}
Case 1	0,48	0,20	0,74	0,68	0,39	0,56
Case 2	0,75	0,42	0,81	0,79	0,22	0,39

Concept for improvement of data representativity

To realize further improvements in the representativity of statistical speed measures derived from FCD, the systematic offset between FCD and radar should be compensated. As mentioned before, the error is mainly related to the non-representative FCD vehicle type distribution. Caused by the high amount of vehicles with an unknown vehicle type (21%), a reliable estimation of the vehicle distribution within the FCD is hardly possible. Based on this situation, the paper introduces an easy to apply FCD calibration process which uses traffic information of single stationary traffic detectors.

Figure 6 illustrates a simple sketch of this calibration process. To adjust the statistical speed measures $V_{m,Local,FCD}$ and $V_{85,Local,FCD}$ derived from FCD in several connected road segments (i), a stationary traffic detector is firstly used to calculate their true values $V_{m,Local,Radar,I}$ and $V_{85,Local,Radar,i}$ in one single segment (i). The derived speed measures of both techniques FCD and radar are compared against each. As a result of this comparison the calibration parameter (ΔV_i) is then calculated by subtracting $V_{m,Local,Radar,i}$ from $V_{m,Local,FCD,i}$ and $V_{m,Local,Radar,i}$ from $V_{m,Local,FCD}$ respectively. The calculated calibration parameter (ΔV_i) could now be used by adding this value on the statistical speed measures derived from FCD in connected road segments. The shown calibration process implies on the one hand that vehicle type distribution within the FCD will vary only slightly on applied segments, but especially nearby big cities, freight transport centers or freeway interchanges etc. could change the vehicle type distribution heavily. On the other hand, the shown approach needs the information of several stationary traffic detectors, which should be well distributed on rural and federal roads. To check the validity of this approach, the process should be applied on larger networks in further researches.

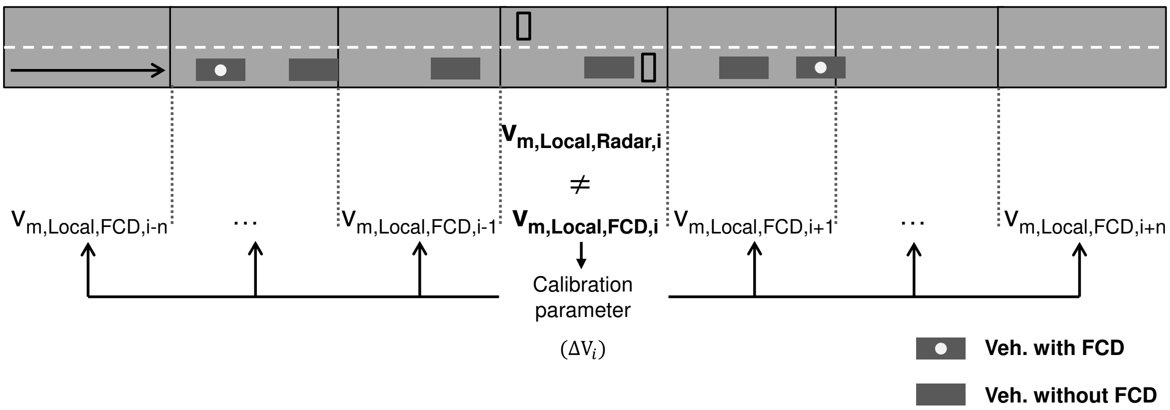

Figure 6: Principle calibration process for FCD derived statistical measures (V_m and V_{85})

Table 2: Shape, position and combined similarity after FCD calibration

	Statistical measures					
	S_{form} [-]		$S_{position}$ [-]		S_{comb} [-]	
Road segment	V_m	V_{85}	V_m	V_{85}	V_m	V_{85}
1	0,75	0,54	0,96	0,96	0,14	0,25
2	0,82	0,77	0,97	0,97	0,11	0,13
3	0,82	0,63	0,97	0,97	0,10	0,20
4	0,86	0,70	0,97	0,97	0,09	0,16
5	0,94	0,93	0,98	0,99	0,04	0,04
6	0,88	0,75	0,96	0,95	0,08	0,15
7	0,89	0,80	0,97	0,97	0,07	0,11
8	0,88	0,87	0,96	0,96	0,08	0,09

The developed concept was applied successful on the selected test site. All calibrated statistical speed measures derived from FCD were validated against lateral radar. In advance of the calibration parameter calculation, speed measures derived from FCD and radar was smoothed by the help on a first-order exponential smoothing ($\alpha = 0.5$). Smoothing the statistical values (V_{85} and V_m) was necessary to reduce high variations of the FCD-based measures, which could be seen in Figure 4. In general, data smoothing leads to a better shape similarity between FCD and radar. Afterwards, the calibration parameter (ΔV_i) was calculated within the fifth road segment in every 2 h time interval and applied to all segments of the test site. Based on this calibration process, all similarity measures comparing FCD and radar were calculated (Table 2).

As suspected, the calibrated FCD-based speed measures reach a quite good similarity compared to radar. Segments 1 to 4 show some greater deviations. On these four segments, the used calibration parameter leads to on overestimation of about maximal 10 km/h, which could be due to the slightly smaller FCD sample size within these segments. Figure 7 compares calibrated values for V_{85} and V_m, derived from FCD against the radar measurement. Basically, it can be stated that the evaluation of larger time periods (> 4 weeks) will lead to a much more representative FCD data source, which will minimize

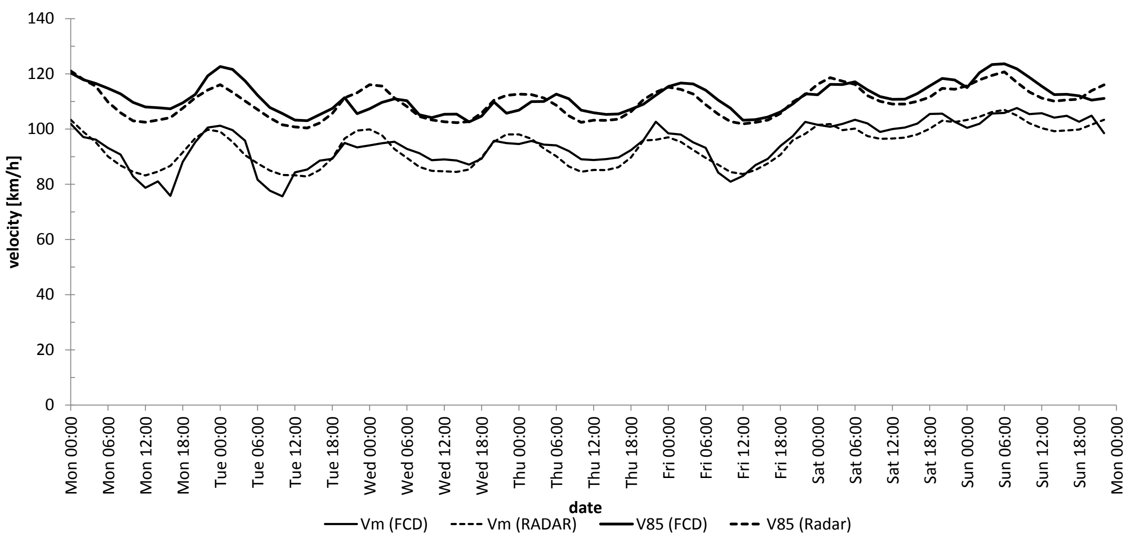

Figure 7: V_m and V_{85} based on calibrated FCD (road segment 7) in comparison to radar

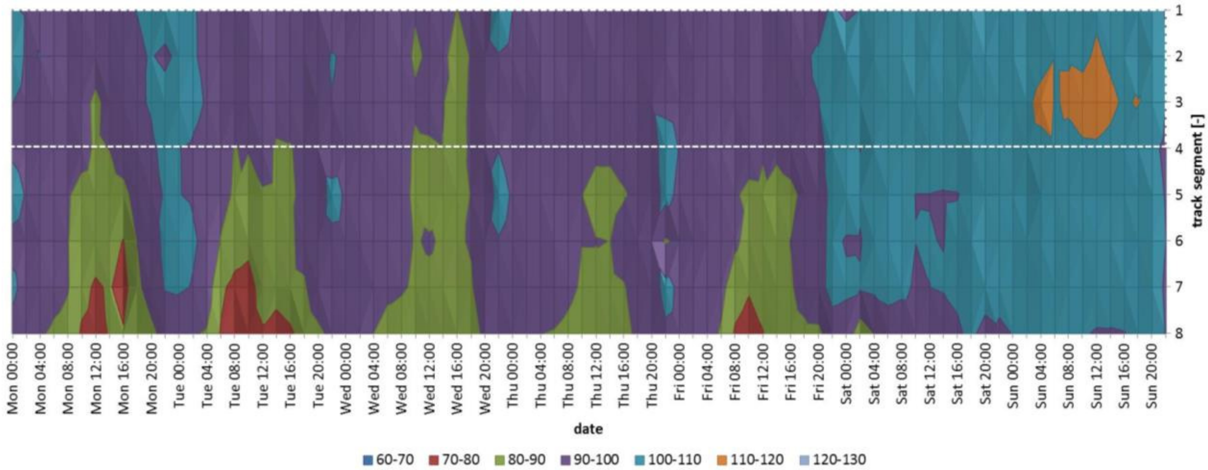

Figure 8: V_m based on calibrated FCD over all road segments (colour related to velocity)

possible deviations between both curves. In conclusion, the developed concept of data processing and the shown calibration process need to be applied and validated on a larger scale road network.

DATA APPLICATION FOR HAZARD ATLAS

Spatial and temporal optimization of police speed enforcements

The collected, processed and calibrated FCD provides statistical speed information in a very high temporal and spatial resolution. These information could be used for several approaches related to the hazard atlas introduced at the beginning of this paper. One of the first approaches could be the optimization of police speed enforcements adapted to places and times with a high speed level, which is exemplarily presented in this chapter. Figure 8 shows the average traffic speed on every single road segment over equal weekdays. The calculated speed measure V_m is correlated to the color gradation. Based on this figure, it can be stated that mainly road segments 1 to 4 reveal a higher average traffic speed compared to other segments. Especially segment 7 and 8 show low average traffic speeds in midday. Analyzing the statistical speed measure V_{85} (Figure 8) allows for the identification of time intervals with a very high speed level. In this example, speed level seems to increase in the

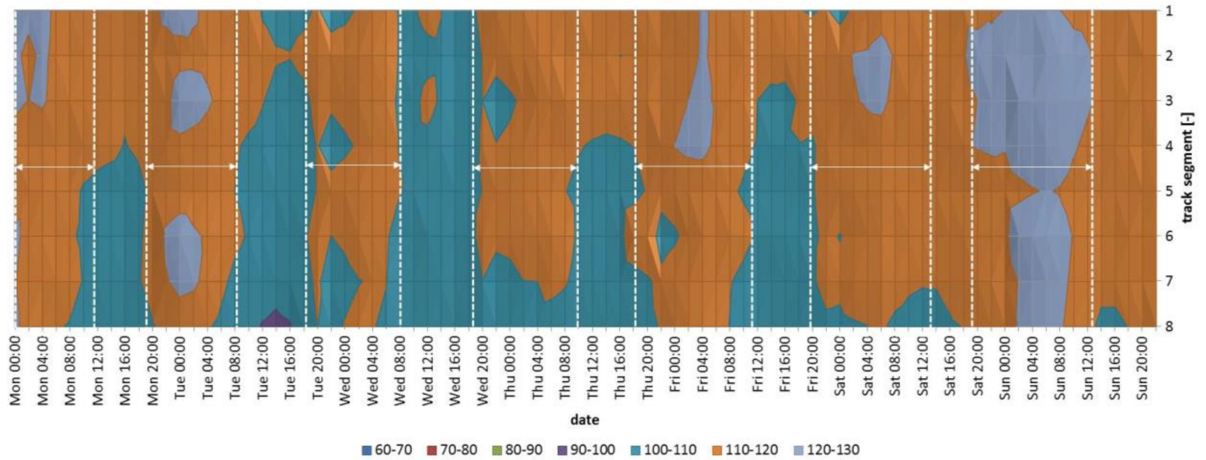

Figure 9: V_{85} based on calibrated FCD over all road segments (colour related to velocity)

beginning of the early evening (20:00). This high speed level retains up to the beginning of the rush-hour (08:00). The highest speed level on the whole test site is reached on the weekend between Sat. (20:00) to Sun. (12:00). In this time period nearly 15 % of the vehicles travel with speeds higher than 120-130 km/h.

Based on this kind of detailed statistical speed measures, an extension of alignment specifications allows for assessing risk of road segments, which, again, is the long term scope of the introduced hazard atlas.

CONCLUSION AND NEED FOR FURTHER RESEARCHES

The successfully realized statistical FCD analysis gives a good overview about the possibilities and problems for deriving statistical speed measures on rural and federal roads with a high spatiotemporal resolution based on FCD. To fulfill this aim, an easy to use FCD processing and calibration concept was developed and could be validated on the selected test site successfully. Based on all gathered statistical speed measures the paper describes first approaches for the identification of road segments, which reveal a high speed level. Further researches are necessary to prove the validity and applicability of the developed concept on greater road networks. In addition to this, a systematical data augmentation with historical accidents and alignment specifications are promising topics for further researches.

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