Evaluation of driven speed on German motorways without speed limits

- a new approach -

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Abstract

The introduction of a general speed limit on German motorways is currently heavily discussed. This paper analyses a Floating Car Data (FCD) set from April 2017 generated on German motorways without speed limits. The data set is compared to average speeds measured at automatic traffic counting points. Therefore, the validity of the reported speed in the present FCD data set is analysed by comparision to the reported speed at continuous counting stations. The results show that the average driven speed on motorways in metropolitan areas is lower than on long distance highways and motorways in rural areas. The frequency scales offer insights into expected effects of a general speed limit. Recommended speed (130 kph) is rarely exceeded during a trip but a large number of trips can be observed where maximum speed is higher than 130 kph on short parts of a motorway route.

1 Delimination of the investigation topic

The introduction of a general speed limit of 130 kph on German motorways has been frequently discussed. As mandatory climate protection targets for transport sector were introduced by the *German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety*[1] in October 2019, this discussion actually received great public attention. Prescribing the transport sector must reduce its Greenhouse Gas (GHG)-emissions by 40 - 42 % until 2030, the discussion turns out to be very emotional in Germany because it is one of a few countries whithout any general speed limit. In addition to the postulated effects such as traffic safety, GHG-emission savings up to 14 % are predicted.[2] Whereas approximately 70 % of motorways did not have any speed limit in Germany in 2015, dynamic speed limits count for approx. 6 % of total lentgh of motorway network. Accordingly, approx 25 % of the federal motorways have speed limits.[3]

This article examines the average driven speed on German motorway segments without speed limits. Comparable evaluations have already been carried out by *TomTom* on behalf of *ZEIT Online*.[4] These results will be reproduced, compared and evaluated in order to provide a technical basis for further discussions of general speed limits on German motorways.

2 Methodology

2.1 Research object

The Chair for Freight Transport Planning and Transport Logistics at Wuppertal University has access to historical Floating Car Data (FCD)[5] (here in after these data are called FCD_{BUW}) covering Europe and

[1] Cf. [Bundesregierung Deutschland, 2019].
[2] Based on speed distribution of 2016 and mileage of 2018 on German motorways. Saving depends on speed limit and is between 5 % (130 kph) and 14 % (100 kph). Cf. [Lange, M., 2020].
[3] Cf. [Kollmus, B. et al., 2017].
[4] Cf. [Biermann, K. et al., 2019].
[5] FCD provided by the ADAC.

is engaged in several research projects based on FCD data sets from Germany and neighboured European countries. The data sets allow to reconstruct the trajectories of cars and trucks in an anonymized form.

These FCD_{BUW} are generated from position data transmitted by navigation and fleet-software. Each position point contains information about the exact time, the currently driven speed as well as the direction and a unique vehicle ID that assignes individual measuring points to exactly one vehicle.

FCD_{BUW} used for speed analysis only contain passenger cars. Similar studies were carried out by the authors with truck-generated FCD. Before starting the analysis all data points were assigned to a motorway section and only FCD_{BUW} of motorway sections without speed limits were extracted. The FCD_{BUW} reporting year (2017) and state of the network model are the same. Due to low impact of weather conditions and vacation traffic April 2017[6] is chosen for the analysis. FCD_{BUW} being influenced by construction sites with temporary speed limits are not removed from the data set, as there was no exact information available about position and duration of constrution sites in April 2017. The network elements are cut into edges with a maximum length of 100 m. In total this network includes 185.799 edges[7]. The map matching indentifies 629.252 vehicles on this network in April 2017. This analysis focusses on the following two perspectives on the data:

1. Driving speed on the 100 meter network edges (average, percentiles).
   a) The **average speed** is the harmonic mean of the reported speed of all vehicles which generate data on an edge (maximum length 100 m) of motorways without speed limit. Generally, each vehicle is only represented once on an edge. If more than one data point per vehicle exists, the average speed of these points is considered.
   b) **Percentiles** are generated from car-related speed reports, similar to the harmonic mean. Example: For the upper 10 % percentile all reported speed measurements are sorted in ascending order and then the speed is taken that is not exceeded by 90 % of the cars on the edge.
2. Reported maximum speed and average speed of the individual vehicles identified on network edges without speed limit.
   a) **Maximum reported driven speed of a vehicle** on all motorways without speed limit for the whole day. For this purpose, all reported data points of a vehicle are chosen, if this vehicle is detected at least once on an edge without speed limit. Out of this data set the highest reporting speed of each vehicle is chosen.
   b) **Average of reported driven speed of a vehicle** on all motorways without speed limit for the whole day. For this purpose, all reported data points of a vehicle are chosen, if this vehicle is detected on an edge without speed limit. Out of this data set the average speed for each vehicle is calculated.

2.2 Validation of FCD reported speed

Reported speed at continuous counting stations are compared to FCD_{BUW} based speed in order to ensure that speeds generated with FCD_{BUW} forms a valid sample and represents real driven speed. In 2016, the *German Federal Highway Research Institute* (*BASt*) published an analysis for driven speed on German motorways. For this purpose, speed data recorded by continuous counting stations[8] were analyzed. The comparision with FCD_{BUW} based speed distribution on edges close[9] to these continuous counting stations (**Figure 1a**) only shows small differences. Especially in lower speed classes (1 - 70 kph) the amount of FCD_{BUW} data points is higher. On the one hand this can be explained by inaccurately reported positions of the continuous counting stations in the available database[10]. A counting station position near an exit or entry lane will measure lots of accelerating and breaking vehicles and therefore lead to higher shares of slow vehicles. Assuming the real position of the continuous counting stations is located between exit and entry, the differences in the lower speed classes could be explained. In a few

[6] April is choosen to reduce the influence of weather condition and vacation. In addition the impact of congestion in April is low due to the congestion analysis of the ADAC e. V. (cf. [ADAC e.V., 2018, p. 7]).

[7] Cutting the network into edges that are no longer than 100 m can result in very short edges. In the context of the network matching of the FCD_{BUW}, it can therefore happen that individual short edges exist on which no FCD_{BUW} data are machted.

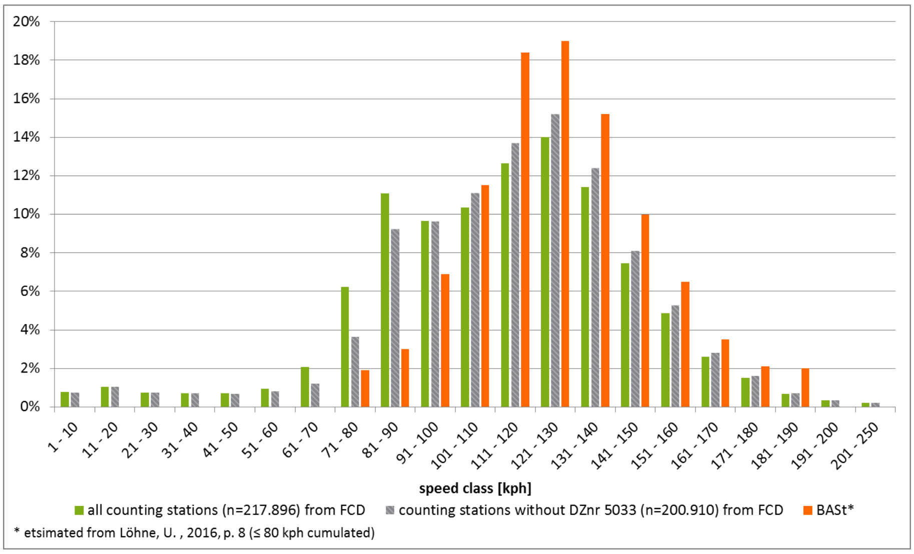
[8] Cf. [Löhe, U., 2016, p. 8].

[9] FCD_{BUW} are generated in intervals. Therefore they cannot be taken at a defined single point, in contrast to continuous counting stations. Instead FCD_{BUW} are taken from a 100 m edge on which the counting station is located.

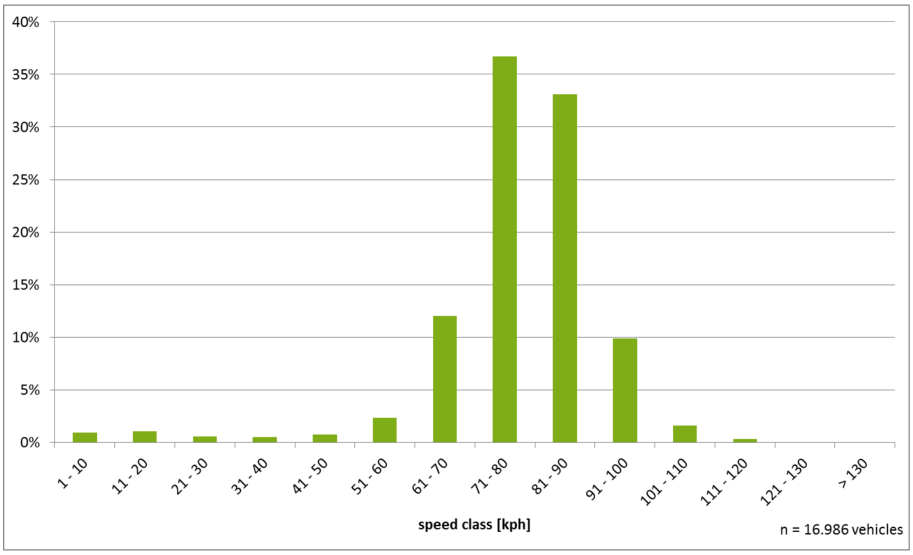
[10] Database of continuous counting stations can be downloaded at `https://www.bast.de/BASt_2017/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/Aktuell/zaehl_aktuell_node.html`. Retrieved on 2 March 2020.

cases FCD_{BUW} are assigned wrongly to the main edge although they in fact are located on a parallel running entry lane. On the other hand the FCD_{BUW} data set shows lower speeds than *BASt* analysis on some edges without any exit or entry lane nearby. This difference is probably effected by construction sites which could not be eleminated in FCD_{BUW} data set yet.

Because of the above mentioned effects, the distribution generated from FCD_{BUW} shows a significant difference in the speed classes 71 - 90 kph. This difference can be eliminated by identifying the construction sites. For example **Figure 1b** shows a continuous counting station on motorway A3, which was under construction in April 2017.[11] This counting station is passed by about 17.000 vehicles (according to FCD_{BUW}) which are about 10 % of all counted vehicles in April 2017, which were detected on the above mentioned continuous counting stations.



(a) Distribution of reported speed at continuous counting stations, with and without counting station No. 5033 (A3 near Leverkusen)[12]



(b) Distribution of reported speed on motorway A3 near conting station No. 5033 (A3 near Leverkusen) during influence of construction site

Figure 1: Distribution of reported FCD_{BUW} speed in April 2017

[11] Information about road construction on motorway A3 can be found in `https://www.strassen.nrw.de/de/projekte/a3/sanierung-zwischen-opladen-und-hilden.html`. Retrieved on 2 March 2020.

[12] The FCD_{BUW} based speed at the continuous counting stations reported in [Löhe, U., 2016] are used the evaluation.

Due to missing information about road construction in 2017, it was not possible to eliminate all edges which were under construction in Germany in April 2017. As a result, edges which were under construction might have a lower speed within the results than in reality.

The above mentioned validation process shows, that FCD_{BUW} can be used for speed related evaluations. Nevertheless, it must be considered, that there are still some inaccuracies in the FCD_{BUW} because of a lack of information like missing databases about construction sites. For further analyses the FCD_{BUW} have to be merged with external event information about detours, construction sites, weather etc. to enlarge the significance of the results.

3 Results

3.1 Speed aggregates on edges

The average speed on German motorways without speed limits can be divided into two major groups of motorways: Motorways inside of metropolitan areas and those in rural areas. The density of the network is probably an indicator for the average speed. About 75 % of all edges have an average speed of 130 kph or lower. Only some motorways connecting major cities and predominantly passing rural areas (e. g. Ulm – Munich, Berlin – Rostock) show a higher average speed than 130 kph (see **Figure 2**). On these motorways long distance cummuters dominate the normal daily traffic and they obviously choose higher speed.

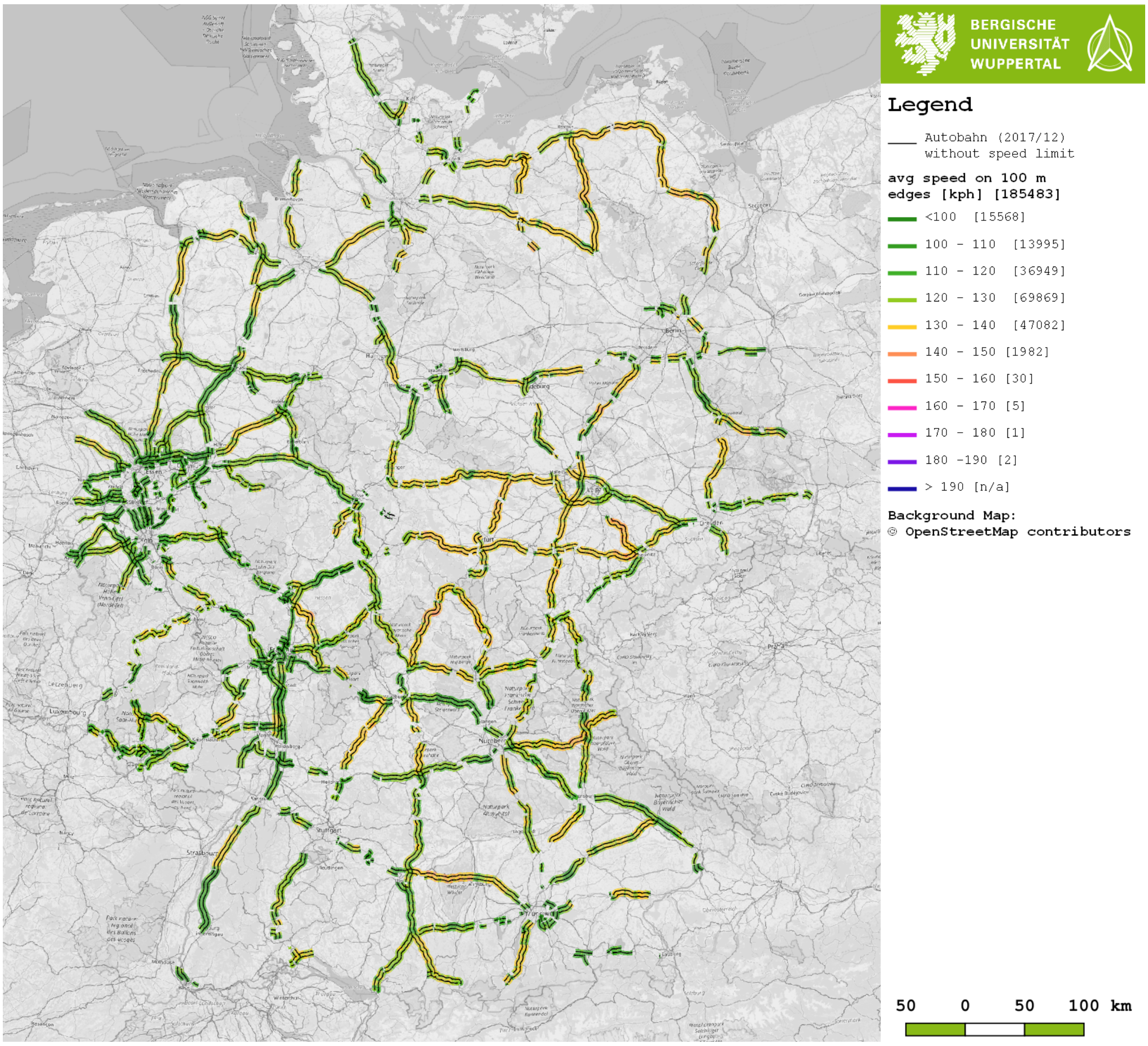


Figure 2: Speed on edges for whole April 2017 incl. weekend and night - average speed

The maximum driven speed on motorways without speed limits in rural areas is also significantly higher than in metropolitan areas (see **Figure 3**). Drivers in metropolitan areas obviously do not utilise the opportunity to accelerate to high speeds. Possible reasons are short distances between entry and exit lanes or short distances travelled on motorways combined with a higher share of daily commuters.

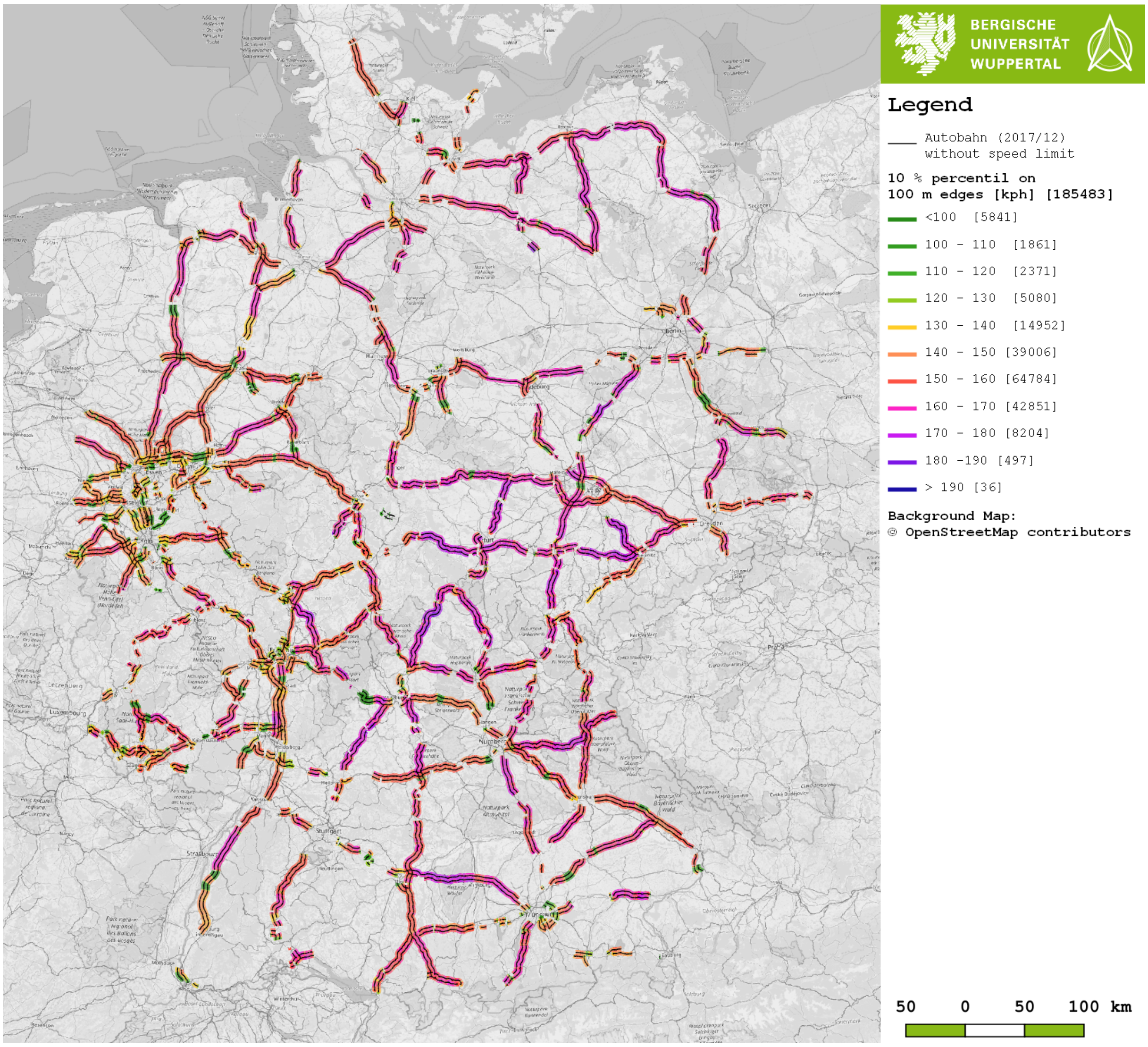
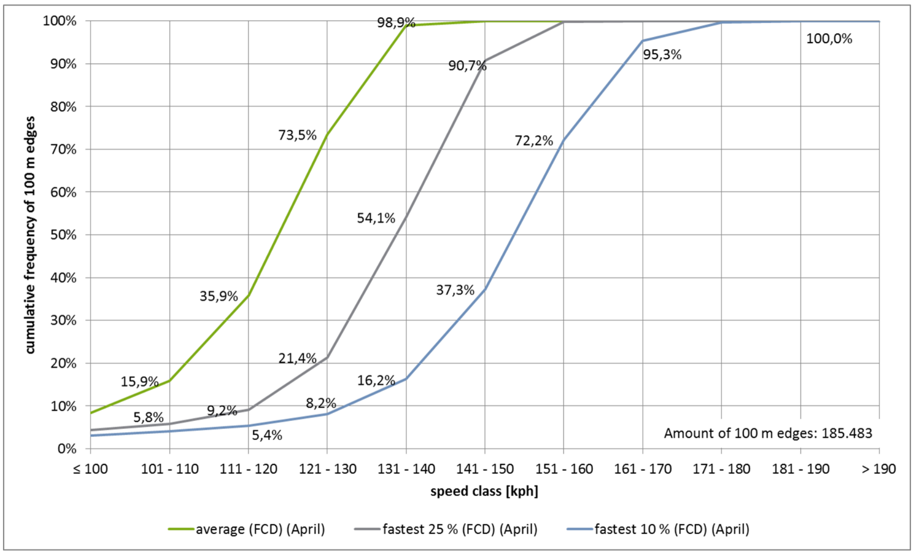


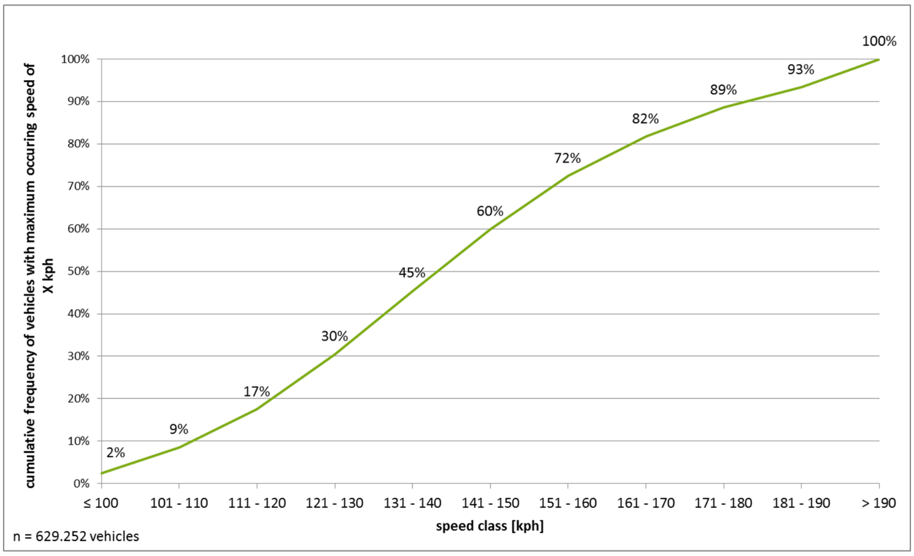
Figure 3: Speed on edges for whole April 2017 incl. weekend and night - 10 % percentile

Figure 4a compares the fastest 10 %, the fastest 25 % and the average driven speed per edge. Combined with the maximum reported driven speed per vehicle (see **Figure 4b**), it can be seen, that only 1 % of all motorway edges have an average speed of more than 140 kph while 55 % of the vehicles have a maximum speed higher than 140 kph during their trips.

In order to derive the effects of general speed limits not only the average speed on the edges or the maximum speed of individual vehicles must be considered, but also the average speed driven of each individual vehicle and each trip on the unlimited motorway edges. Accordingly, most of the vehicles do not permanently drive faster than 130 kph. Only 21 % of the vehicles have an average driven speed (on motorways without speed limit) faster than 130 kph and only 9 % faster than 140 kph.



(a) 100 meter edges by speed class



(b) Vehicle with maximum occuring speed by speed class

Figure 4: Cumulative frequency

3.1.1 Other data samples and analyses

TomTom

As already described in chapter 1, FCD_{BUW} speed data analysis is compared to *TomTom* speed data published by *ZEIT Online*.[13] According to *TomTom*, more than 61 billion traces per day are recorded worldwide.[14] Out of this data set one week in March 2019 was taken to produce the published results for Germany.

The comparison between FCD_{BUW} and *TomTom* shows a significant difference (see **Figure 5**). It has to be considered, that the data from *TomTom* are generated on motorways with and without speed limits. Therefore, the speed class below 100 kph covers nearly two thirds of the *TomTom* speed measurements. FCD_{BUW} show significantly less cars in the lowest speed class ($\leq$ 100 kph) while the speed class from 101-110 kph is nearly congruent in both samples. The classes between 111 kph and 130 kph are nearly doubled by *TomTom* compared to FCD_{BUW}. The distribution of the FCD_{BUW} shows a slightly left crooked normal distribution with the average in the class of 121 kph to 130 kph. Nearly 50 % of the edges can be found between 111 kph and 130 kph.

[13] Cf. [Biermann, K. et al., 2019].
[14] Cf. [TomTom, 2020].

The distribution of the *TomTom* data shows a left crooked normal distribution and a higher variance with the average in the class of 130 kph to 140 kph. Taking into account the data shows motorways with and without speed limits, this is a significant difference.

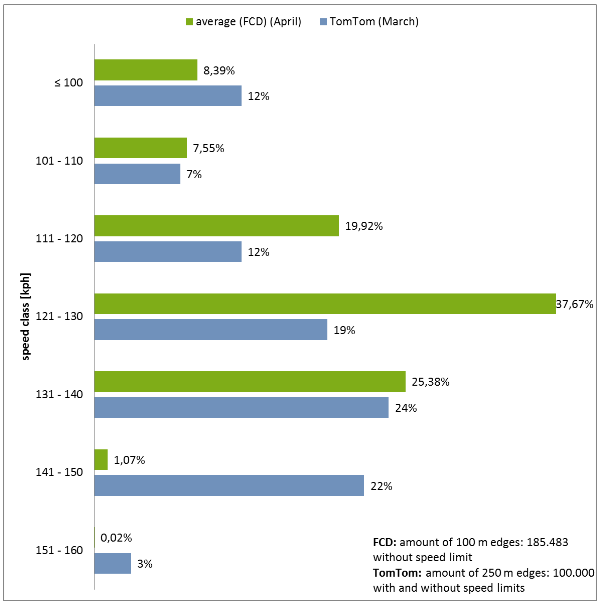


Figure 5: Average speed out of FCD_{BUW} for whole April 2017 vs. *TomTom* data

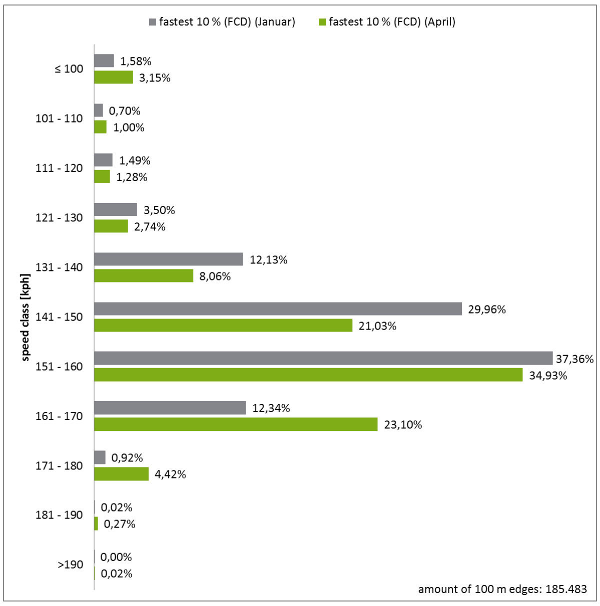


Figure 6: Comparision of 10 % percentile out of FCD_{BUW} for whole April 2017 vs. Januar 2017

These differences may result in an unknown composition of the sample in the *TomTom* data. For policy decision it is necessary to use transprarent data and methods.[15] The comparision of the distribution of reported speed at continuous counting stations (see **Figure 1a**) with FCD_{BUW} shows that the provided FCD_{BUW} sample can reproduce the real driven speeds (see chapter 2.2).

Some of the differences occure due to different months in which the data where captured. **Figure 6** shows the same analysis for January and April. The maximum speed is significantly higher in April than in January. This can be explained by two main factors:

- weather conditions and
- winter tires.

Due to the coincidence of weather, further analyses of enriched data is required. The winter tires often reduce the maximum speed to 160 kph. This explains the massive break within class 161 kph to 170 kph in January.

These results show the importance of a continous analysis over serveral months and the need for further data (e. g. weather information).

German Enviroment Agency

The *German Environment Agency (UBA)* has recently published a study on expected effects of a general speed limit on German motorways. The effects on speed distributions were estimated by transforming given speed distributions on speed restricted motorway segments (120 kph) on segments without speed limits.[16] As motorways with speed limits are mostly located in metropolitan areas, it has to be assumed, that the speed distributions are unlikely to come into being in rural areas. Subject to the condition that the speed limit will be enforced by intensive speed controls, the speed distribution will most likely show a left crooked distribution with a high share of speeds in the range of 110 kph to 130 kph (for speed limit 120 kph). Therefore the predicted effects on GHG-emission savings are giving a maximum estimation and tend to be overestimated.

[15] Assuming that every person worldwide would have a vehicle and record an average of 3.1 trips per day (average travel frequency from Mobilität in Deutschland (MiD) for all modes (Cf. [infas et al., 2018, p. 3]), this corresponds to only approx, 25 billion traces a day. This is only nearly a third of the daily produced data by *TomTom*.
[16] Cf. [Lange, M., 2020, p. 15 ff.].

3.2 Influence of day time

The influence of day time is shown in **Figure 7 and 8**. Regularily, the amount of traffic in the morning is higher due to overlapping activities (morning peak). Accordingly, the average driven speed is lower. This has to be considered when using trajectory data to parametrize or calibrate models in transport planning - especially if the speed is not manually caped at 130 kph and the real driven speed is used.

One application purpose is the useage of extracted speeds from FCD_{BUW} in network design. Following the German Guidelines for Integrated Network Design (GIND) the parametrized network should represent an empty state for initial assignment of relations to network and a stressed but not overstressed state for traveltime evaluation.[17]

In planning, usually edges without speed limit will be considered with a speed of 130 kph. To consider or to evaluate real travel times no manual modification of speed limits is done. **Figure 7 and 8** show two exemplary network states for a stressed network following GIND. **Figure 7** represents the network state for the morning hours while **Figure 8** represents the network for the afternoon. Compared to the monthly average (**Figure 2**) these two states are slightly slower.

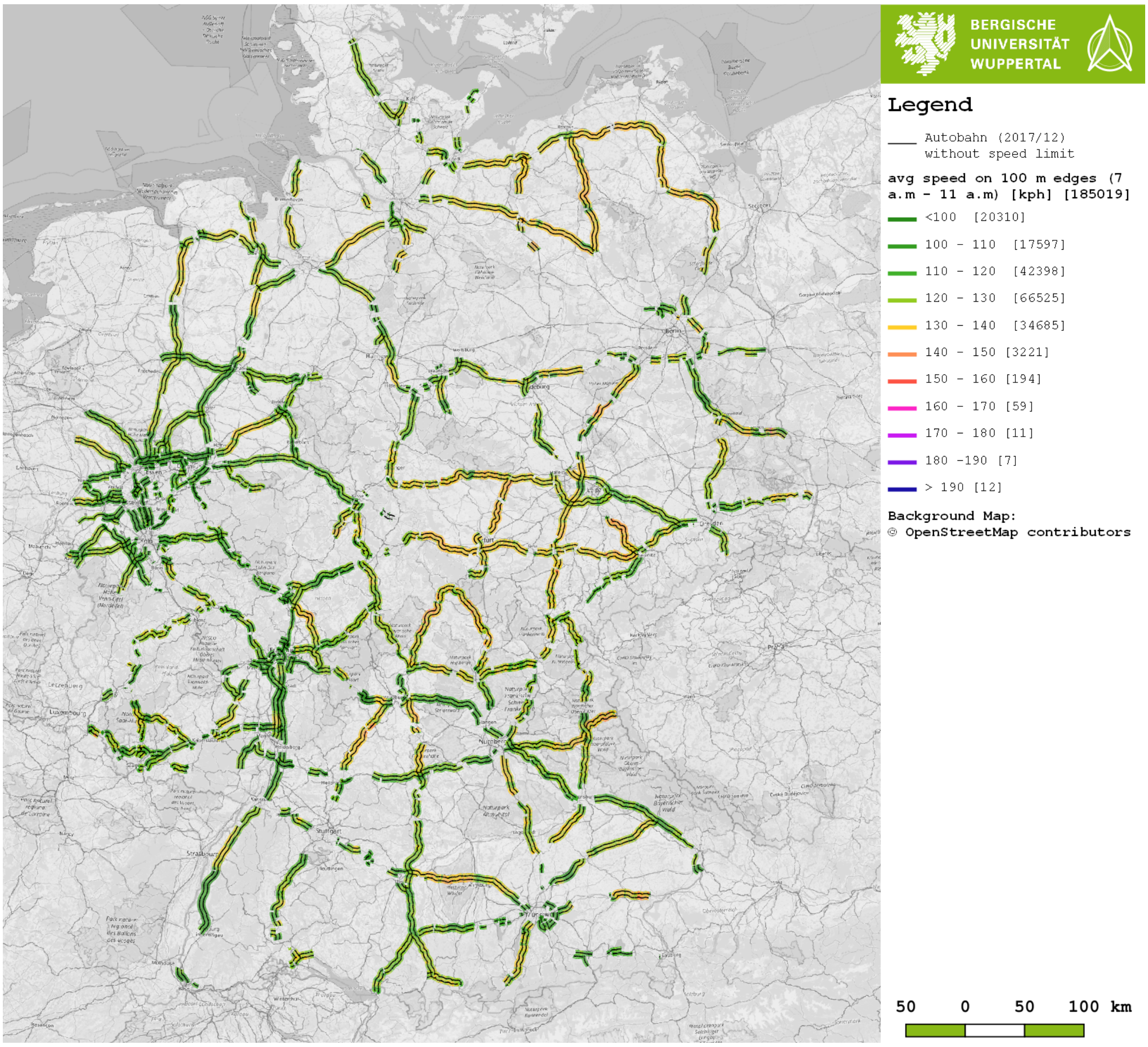


Figure 7: Average Speed on edges for Mo-Fr in April 2017, 7 a.m to 11 a.m.

Moreover, the afternoon state is slightly faster than the morning state which can be explained with more likely overcrowded motorways in the morning peak. The spatial distribution of slower and faster edges is more or less the same. In the morning state velocity on 20.6 % of the edges is higher than 130 kph

[17] Cf. [Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV) - Arbeitsgruppe Verkehrsplanung, 2008].

in average while in the afternoon state approximately 25.5 % of the edges show an average speed higher than 130 kph.

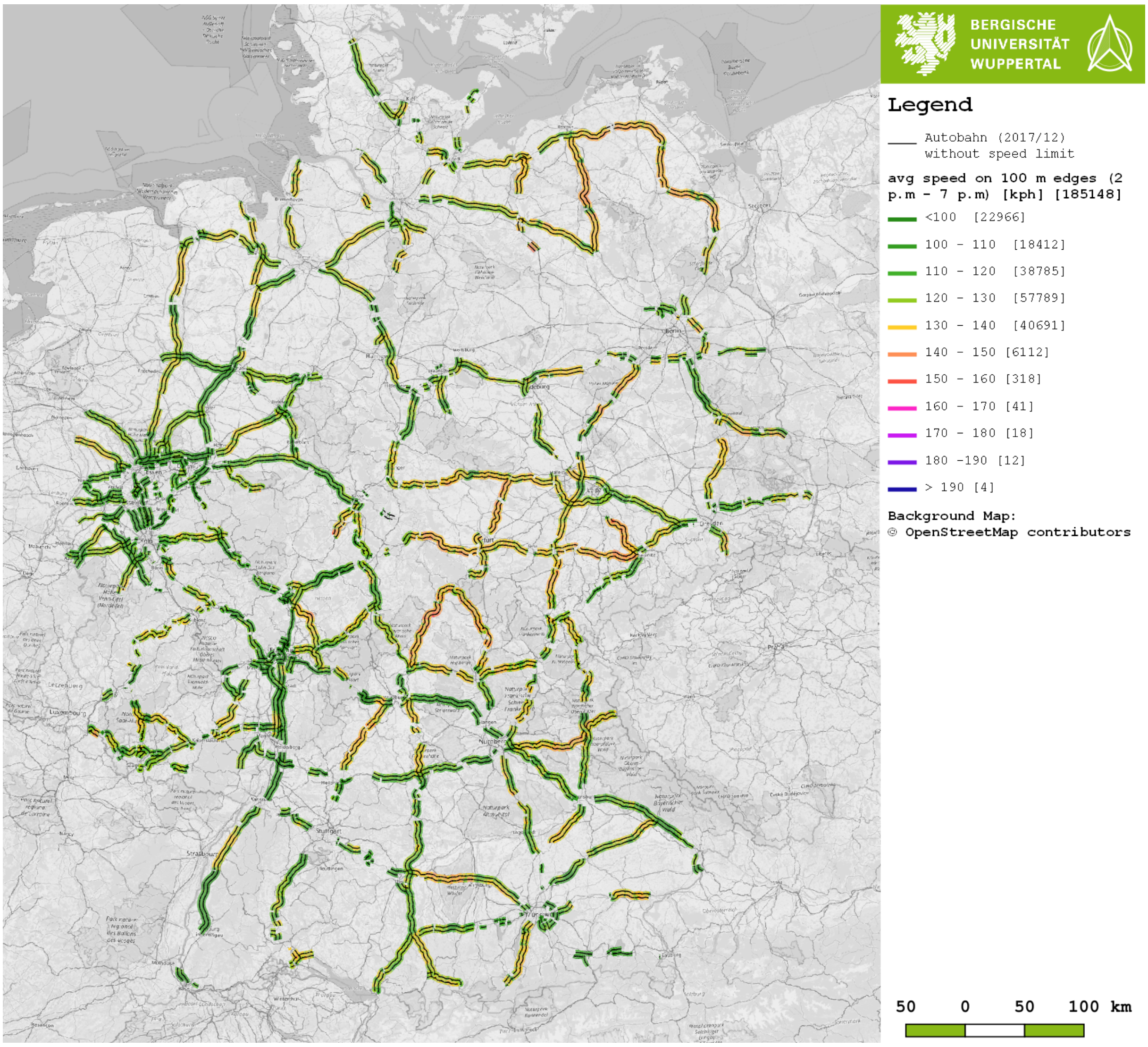


Figure 8: Average Speed on edges for Mo-Fr in April 2017, 2 p.m to 7 p.m.

In addition to the speed differences between both data samples (see **Figure 5**) it is questionable which data sample reflects reality best. In order to answer this, the raw data of both data samples must be compared with each other and with other data such as the continuous counting stations. This is the only way to create a solid database for spatial and transport planning.

4 Conclusion

For a reliable discussion different data sources have to be compared. All of this different data have to proof representativity. Therefore, it is important not only to rely on cumulative results but also on individual data evaluation. Furthermore, also the origin of raw data and the representativeness of the data is of great importance.

This article provides results from different data sets with a different sample and thus offers an expanded basis for a discussion about general speed limit. The majority of the edges have an average speed of 130 kph or below. In relation to the maximum reported speed of the vehicles, however, it can be seen that less than 30 % of the vehicles on the edges are below the target speed (130 kph). The average reported speed on motorways without speed limit for each vehicle is nearly 80 % lower or equal 130 kph. This should be considered when calculating GHG reductions by transferring speed distributions of limited motorways to unlimited motorways.

An evaluation of each individual trip is of great importance. Such an evaluation is time-consuming but also essential for the evaluation of a general speed limit. In contrast to the analyses done in this paper, it is recommended to analyse each trip separately and not cumulatively in further examinations. As a result this approach can be used to make statements about spatial structure differences, travel distance-related speed profiles and thus an exact statement about a possible reduction of GHG-emissions.

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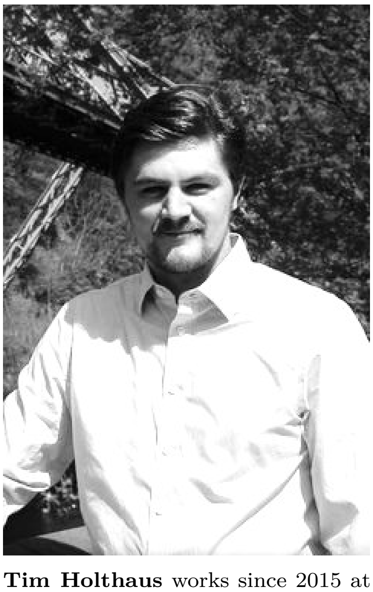

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