
Statistical Analysis of High-Flow Traffic States

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1 Introduction

It is well known that traffic exhibits metastable states and hysteresis behavior [1]: At high vehicle flow rates, a transition from free to congested flow is likely to occur—resulting in a considerable decrease of the flow rate and significant changes of other traffic characteristics such as the average velocity. To restore high traffic flows after such a transition, it is necessary that the flow rate drops below a threshold value first.

But states of high traffic flow are not only interesting from a physical point of view. At high flow rates, the road is operating close to its optimum. Therefore, it is also of practical importance to investigate under what conditions these so-called high-flow states occur.

We will present an analysis of detector data collected from the motorway network of state of North Rhine-Westphalia (e.g., see [2, 3]). This analysis focuses on the characteristics of so-called high-flow states (e.g., when and how often do they occur, on which lane can they usually be observed). In the following, we refer to a flow rate as high, if it exceeds 50 vehicles per minute and lane (i.e., 3000 veh/h/lane).

2 Analyzed Data

Our analysis is based on detector data provided by more than 3000 loop detectors during December 19, 2011 and May 31, 2013 on the motorway network of the state of North Rhine-Westphalia (Germany). Inductive loop detectors still are the most common source of traffic data: for each (1 min)-interval, loop detectors count the number of passing vehicles, they measure the vehicles' velocity distinguished by vehicle type (passenger cars and trucks), and they determine the fraction of time within they are occupied by passing vehicles.

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We restricted our analysis to 178 800 measurements exhibiting high flow characteristics (flow > 50 veh/min) and to valid values only for each of the just mentioned observables. Figure 1 shows the frequencies of high-flow states depending on the corresponding flow rate (1(a)).

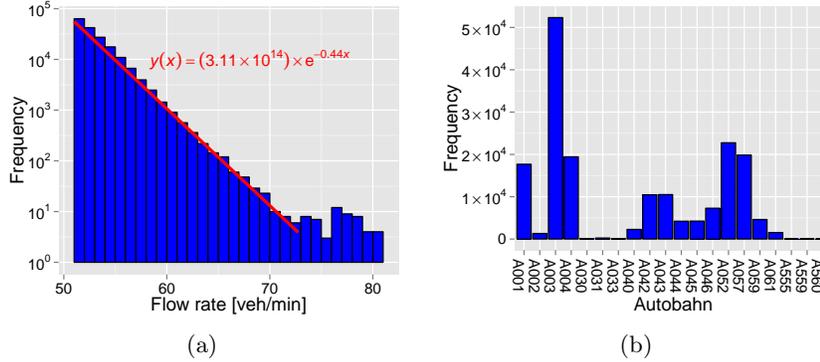


Fig. 1. (a) Frequency of high-flow states and (b) the number of the Autobahn.

It turns out that, up to flow rates of about 73 veh/min, the frequencies of high-flow states of a given flow rate J follow the power law

$$\text{frequency} = A \times \exp(-\alpha \times J)$$

with $A \approx 3.11 \times 10^{14}$ and $\alpha \approx 0.44$.

For the small number of data sets with a higher flow rate (less than 0.03%, 47 total) it is not clear whether they actually deviate from the power law or whether these data sets indicate erroneous measurements: As we will see, the average velocity of high-flow states varies between 60 km/h and 120 km/h. Therefore, high flow rates with an average time headway of 1 s and less pose an actual risk for drivers. Even though such time headways have already been observed at similar velocities for single vehicles [4], it may be doubted whether this behavior can be observed for a sequence of 70 (and more) vehicles.

3 Share of Trucks & Lane Usage

As the detectors used for this analysis classify the detected vehicles into two groups [5], namely ‘trucks’ and ‘passenger cars’, we can also investigate the influence of heterogeneous traffic flow on the occurrence of high-flow states. From figure 2(a) it becomes obvious that the likelihood of high traffic flows

decreases with an increasing share of trucks contributing to the total flow rate. This phenomenon is caused by trucks that generally are restricted to a velocity of 80 km/h in Germany. Therefore, trucks lower the maximum achievable average velocity in traffic flow and, due to their length, they block detectors for a longer period. On the other hand, high traffic flows require high average velocities (60 km/h to 120 km/h). Consequently, high-flow traffic states are expected to favor an almost homogeneous flow of the faster passenger cars.

At least some high-flow traffic measurements including trucks may be explained by the classification of the detector loops: light trucks (e.g., SUVs and small buses / vans) are classified as trucks, but the general speed limit for trucks does not apply to them and they exhibit driving characteristics similar to passenger cars.

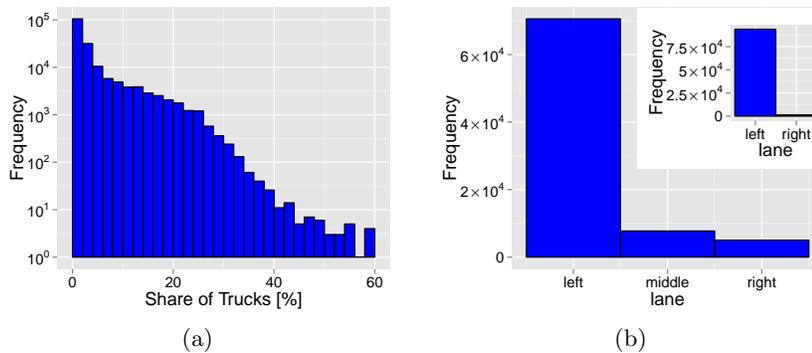


Fig. 2. Frequencies of high-flow traffic states (a) for a given share of trucks and (b) resolved by the lane, on which they were observed for three-lane and two-lane (inset) motorways.

For a similar reason the occurrence of high traffic flows is practically limited to the leftmost lane (see figure 2(b)). In Germany, the leftmost lane is reserved for fast-traveling vehicles to overtake, whereas the right lane is reserved for slow vehicles (i.e., usually trucks). Therefore, traffic flow on the left and middle lanes is characterized by a relatively low share of trucks and high average velocities, which facilitates the formation of high flow rates.

These results also confirm an observation first made by Sparmann [6] and Leutzbach and Busch [7] that is known a *lane inversion*: They found that, close to the optimal flow rate, the vehicle density in the left lane surmounts the density in the right lane. This is surprising as by German law drivers are required to use the right (and middle) lane whenever possible.

4 Average Velocities of High-Flow Traffic States

As already stated in the previous section, the average velocities of high-flow states range from approximately 60 km/h to 120 km/h. In figure 3(a), one can see the distribution of the average velocities. For better analysis, these measurements were subdivided into two classes: (i) measurements without trucks (in this case the depicted average velocity is identical to the average velocity of all cars on the road) and (ii) measurements in which at least one vehicle was identified as a truck.

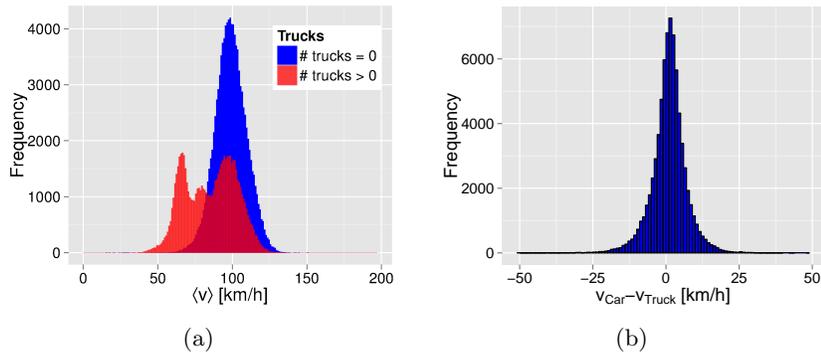


Fig. 3. Average velocities $\langle v \rangle$ of high-flow states and the difference in the average velocities of trucks (v_{Truck}) and cars (v_{Car}).

From these histograms we see that the average velocity in homogeneous traffic, consisting of passenger cars only, is considerably higher than in mixed traffic with passenger cars and trucks with a single peak at approximately 100 km/h. In mixed traffic, we observe two peaks: one at 100 km/h and another one at approximately at 60 km/h. The first one (at 100 km/h) corresponds to a very low number of trucks contributing to the total flow. The second one results from measurements with roughly four or more trucks. This could be verified by varying the threshold (i.e., the number of trucks) which separate the two curves [not depicted]. It should also be noted that the classification of vehicle types, which is mostly based on the estimated vehicle length [5], is not free of fault. Therefore, it is safe to assume that a certain amount of the measurements contributing especially to the first peak consisted of passenger cars only.

Figure 3(b) shows the difference in the average velocities of trucks and passenger cars for the observed high flow states. This histogram illustrates very well the synchronization of average velocities in high traffic flow: the distribution's mean is at 0 km/h (0.52 km/h) with a variance of $\sigma^2 \approx 35$ (km/h)².

Moreover, the resulting distribution is strongly peaked around its mean (leptokurtic with a sample excess kurtosis of 3.89).

5 Temporal Occurrences & Lifetimes of High-Flow Traffic States

The histograms given in figure 4 show the temporal occurrence and the duration (i.e., lifetime) of high-flow states. If one considers that a high flow rate indicates a high traffic volume, the results of figures 4(b) and 4(c) are easy to understand. High-flow states occur on work days during peak-hours. At these times, there is a huge demand of commuters (i.e., many passenger cars) traveling to or from work.

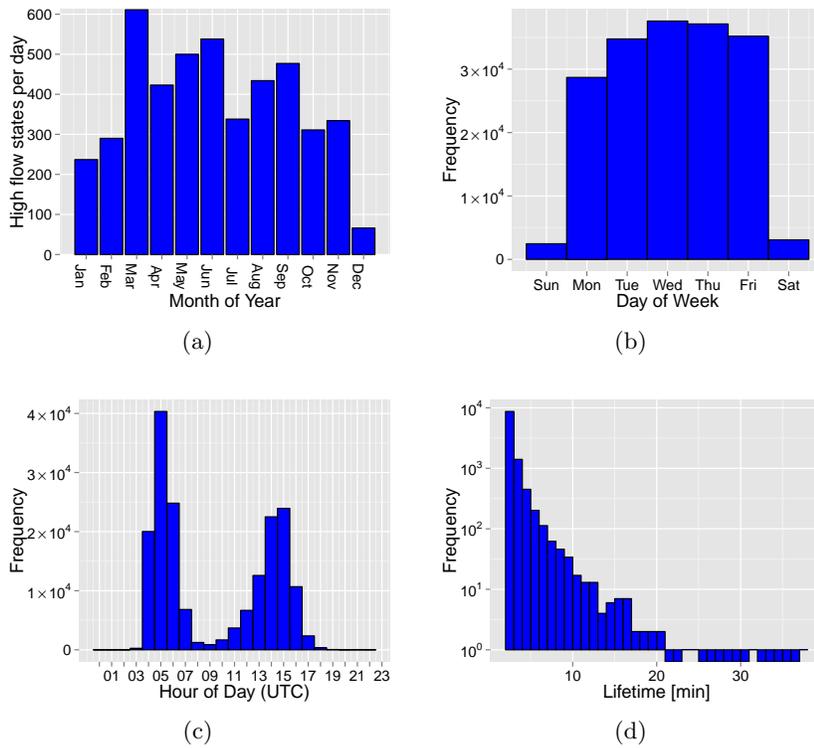


Fig. 4. Temporal distribution of high-flow states depending on (a) the month, (b) the weekday, and (c) the hour of day. (The hour of day is given as UTC. The actual hour of day by adding one or two hours—depending on daylight saving time.) (d) The frequency of successive measurements classifying as high-flow.

As the lifetime of a high-flow state we defined the number successive (1 min)-intervals that were classified as “high-flow state”. The resulting distribution of lifetimes is given in figure 4(d). One can easily see that such states hardly last longer than a few minutes. This observation only confirms the long-known metastable character of traffic flow: An increased flow rate also increases the probability of a traffic breakdown [1, 8]. Especially at flow rates such as the ones considered in this article traffic flow is very unstable and long-lasting high-flow states could not be expected.

6 Conclusions

The findings of our analysis can be summarized as follows: high-flow states make high demands on the traffic conditions.

- As a large number of vehicles is required for high-flow states, such states are usually observed during the morning and evening peak hour on workdays (from Monday to Friday).
- The requirement of good road conditions is reflected by the fact that high-flow states are more likely to be observed in the summer.
- The share of trucks must be close to zero for high flows to occur as high average velocities are required. The lower the share of trucks, the higher is the average velocity.
- The lifetime of high-flow states is typically limited to intervals of a few minutes length because traffic flow tends to be very unstable on this regime.

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