Evaluation of Single Vehicle Data in Dependence of the Vehicle-Type, Lane, and Site

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Abstract. In this paper we study dependencies of fundamental diagrams, time gap distributions, and velocity-distance relations on vehicle types, lanes and/or measurement sites. We also propose measurement and aggregation methods that have more favourable statistical properties than conventional methods.

In the recent two years, traffic flow modelling has been more and more stimulated by empirical studies. In particular, single-vehicle data may shed some more light on the mechanisms of the transition from free to congested traffic flow. In contrast to early studies of, for example, the distribution of time gaps between successive cars (for an overview see [1]), Bovy and coworkers [2] have carried out separate analyses for different sample periods (morning/noon/evening) and different vehicle types (passenger-cars, articulated and non-articulated trucks). In addition, they have determined the relations between vehicle speeds and the distance gaps to the respective car in front separately for free and congested traffic, and for different cross sections of a Dutch freeway. Neubert, Santen, Schadschneider and Schreckenberg [3] mainly restrict to the analysis of one cross section of a German freeway. However, they go one step beyond the Dutch study by distinguishing not only free and congested traffic, but also different density regimes, which leads them to interesting conclusions. In the following, we try to combine both efforts by distinguishing free and congested traffic, different cross sections, and different vehicle types as well.

Our single-vehicle data are from the Dutch highway A9 from Haarlem to Amsterdam for the two periods 10/10–10/14 and 10/31–11/04/1994, but we have neglected the time intervals between midnight and 3 am. At several cross section of this freeway (see Fig. 1), double induction loops record the time of passing, the

| Loop | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 |
|------|----|----|----|----|----|----|----|----|----|----|
| km   | 43.31 | 42.25 | 41.75 | 41.3 | 40.8 | 39.6 | 37.6 | 36.9 | 36.6 | 36.89 |

Fig. 1. Investigated section of the Dutch freeway A9 from Haarlem to Amsterdam, where a speed limit of 120 km/h applies, and locations of the measurement sites.
lane, the velocity, and the length of each passing vehicle. In the following, vehicles longer than 6 m are denoted as trucks, shorter vehicles as cars. On average, there were about 20% of trucks in the right lane, and less than 1% trucks in the left lane, but the proportion was strongly varying in time [4].

Although this is not significant for the results of this study, we have not, as usual, determined macroscopic quantities like the traffic flow, the average velocity, or the vehicle density by averaging over fixed time periods (like 1 minute). In order to have comparable sample sizes, we have instead averaged over a fixed number $N$ of cars, as suggested in Ref. [5]. Otherwise the statistical error at small traffic flows (i.e. at small and large densities) would be quite large. This is compensated for by a flexible measurement interval $T_N$ (see Fig. 2). It is favourable that $T_N$ becomes particularly small in the (medium) density range of unstable traffic, so that the method yields a good representation of traffic dynamics. However, choosing small values of $N$ does not make sense, since the temporal variation of the aggregate values will mainly reflect statistical variations, then. In order to have a time resolution of about 2 minutes on each lane, one should select $N = 50$, while $N = 100$ can be chosen when averaging over both lanes. Aggregate values over both lanes for $N = 50$ are comparable with 1-minute averages, but show a smaller statistical scattering at low densities (compare results in [5] and [6]). With increasing $N$, the maxima move to higher values, and the distributions of $T_N$ become broader. The distribution for the left lane has its maxima at lower values of $T_N$, probably because of the smaller number of trucks. Throughout this paper, we use $N = 50$, but we have checked that our results don’t change significantly for $N = 30$ or $N = 100$.

Based on the passing times $t_i$ of successive vehicles $i$ in the same lane, we are able to calculate the time gaps $\Delta t_i = (t_i - t_{i-1}) > 0$. The (measurement) time interval

$$T_N = \sum_{i=0}^{i_0+N} (t_i - t_{i-1}) \equiv \sum_{i=0}^{i_0+N} \Delta t_i$$

for the passing of $N$ vehicles defines the (inverse of the) traffic flow $Q_N$ by:

$$\frac{1}{Q_N} = \frac{T_N}{N} = \frac{1}{N} \sum_{i=i_0+1}^{i_0+N} \Delta t_i.$$  \hspace{1cm} (1)

Note that the traffic flow is very much dependent on the measurement site (Fig. 3). Consequently, the following graphs are different for other sites as well, but only in the quantitative details, not in a qualitative (fundamental) way.

Now, we approximate the (brutto) distance gap $\Delta x_i$ by $\Delta x_i = v_i \Delta t_i$, where $v_i$ is the actual velocity of vehicle $i$. This assumes that the vehicle velocities do not considerably change during the time interval $\Delta t_i$ and implies

$$\frac{1}{Q_N} = \langle \Delta t_i \rangle_N = \left\langle \frac{\Delta x_i}{v_i} \right\rangle_N = \langle \Delta x_i \rangle_N \left\langle \frac{1}{v_i} \right\rangle_N + C_N,$$  \hspace{1cm} (3)

where $C_N$ is the covariance between the distance gaps $\Delta x_i$ and the inverse velocities $1/v_i$. We expect that this covariance is particularly relevant at large vehicle densities (Fig. 4, left). The density $\rho_N$ and the average velocity $V_N$ are defined by

$$\frac{1}{\rho_N} = \langle \Delta x_i \rangle_N = \frac{1}{N} \sum_{i=i_0+1}^{i_0+N} \Delta x_i \quad \text{and} \quad \frac{1}{V_N} = \left\langle \frac{1}{v_i} \right\rangle_N = \frac{1}{N} \sum_{i=i_0+1}^{i_0+N} \frac{1}{v_i}.$$  \hspace{1cm} (4)
Then, we obtain the fluid-dynamic flow relation \( Q_N = \rho_N V_N \) by the conventional assumption \( C_N = 0 \) which, however, tends to overestimate the density (Fig. 4, middle). The fact that \( V_N \) is defined as the harmonic mean value of the vehicle velocities \( v_i \) automatically corrects for the fact that the spatial velocity distribution differs from the locally measured one (see Fig. 3 for details). The common method of determining the density via \( Q_N / (\langle v_i \rangle) \) underestimates the density (Fig. 4, right).

In our investigation of time gap distributions, we have not only distinguished different density regimes, but also free traffic (f) and congested traffic (c) (Fig. 5). Measurement intervals with \( V_N < 70 \text{ km/h} \) were classified as congested, otherwise traffic was considered to be free.

In all cases we found practically continuous, unimodal time gap distributions. The distribution for the right lane is usually broader than for the left lane, and its maximum lies at higher time gaps \( \Delta t \). This is a consequence of the higher percentage of trucks. The maximum for the left lane varies from \( \Delta t_{\text{max}}^\text{free} \approx 0.9 \text{ s} \) for \( \rho_{50} = 0 - 20 \text{ vehicles/km} \) up to \( \Delta t_{\text{max}}^\text{congested} \approx 2.3 \text{ s} \) for \( \rho_{50} = 30 - 160 \text{ vehicles/km} \). Due to the existence of very large gaps, the time gap distribution is broad at small densities. It is sharpest immediately before the transition to congested traffic, and becomes much broader afterwards. While, in the right lane, the time gap distributions decay exponentially for \( \Delta t > 3 \text{ s} \), this seems to be different in the left lane (Fig. 5). Various suggestions for fitting the time gap distributions can be found in Refs. [1,2].

We have also plotted the average speeds \( v \) of vehicles over their distance headways \( \Delta x \) to the respective car in front (Fig. 7). The plots show the tendency of a density-dependent saturation of vehicle speeds with large headways, which may be interpreted as frustration effect [3]. Like in Ref. [2], we prefer to look at the data inversely (Fig. 8, upper graphs), since the circumstance that we don’t find typical headway-dependent velocities could just reflect large individual differences in the “optimal” velocity-distance relations \( v_i' (\Delta x) \), or better: distance-velocity relations, which drivers prefer [4]. This would be consistent with the broad distance gap distributions (Fig. 8, lower graphs). Note that some variation of the distance gaps \( \Delta x \) comes already from the fact that gaps with regard to faster vehicles tend to be larger, because of the increasing distance. Gaps with regard to slower vehicles tend to be larger as well, since faster cars require some additional safety distance to decelerate. (See Fig. 5 of Ref. [3].)

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Fig. 2. Distribution of the measurement intervals $T_{50}$ at different vehicle densities $\rho_{50}$. (The data were taken from all loops.)

Fig. 3. Free (f) and congested (c) traffic flow as a function of the density for the left and the right lane at different cross sections of the road: upstream (left), downstream (middle), and far enough away from an on-ramp or bottleneck (right). From left to right we observe a relaxation from congested to free traffic.

Fig. 4. Correlation $C_{50}$, density $Q_{50}/V_{50}$ according to the fluid-dynamic formula, and conventionally determined density $Q_{50}/\langle v_0 \rangle_{50}$ as a function of the density $\rho_{50}$ according to the proposed definition (4), in comparison with the usually assumed relations (—).
Fig. 5. Time gap distributions in different density regimes for different lanes and vehicle types.

Fig. 6. Half-logarithmically plotted time gap distributions for different density regimes, separately for the left and the right lane.
Fig. 7. Average vehicle velocities as a function of the distance gap for various density regimes, separately for the left and the right lane.

Fig. 8. Upper graphs: Average distance gaps as a function of the velocity at different measurement sites. Differences between free and congested traffic are found upstream of a bottleneck (left, middle), but not away from it (right). Below: The broad distance gap distributions change rather smoothly with increasing density.