Macroscopic traffic state estimation: Estimating the state based on cumulative vehicle number point-observations in space-time

Paul B.C. van Erp (corresponding author), Victor L. Knoop, Serge P. Hoogendoorn
Department of Transport & Planning
Faculty of Civil Engineering and Geosciences
Delft University of Technology
Stevinweg 1, 2628 CN Delft, The Netherlands
Email: {p.b.c.vanerp,v.l.knoop,s.p.hoogendoorn}@tudelft.nl

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1 Conclusions and discussion

In this research, we developed a methodology to estimate macroscopic traffic conditions based on point-observations of the cumulative vehicle number in space-time, i.e., $N(x, t)$. We propose to obtain these point-observations from combining observations related to the change in the cumulative vehicle, e.g., from road-side detectors and vehicle-based sensing equipment. These data are fused to obtain point-observations of the cumulative vehicle number. The PON estimation methodology does not incorporate information in the form of a fundamental diagram or traffic flow model.

The PON estimation methodology assumes homogeneous and stationary traffic conditions. If this assumption holds the methodology perfectly estimates the macroscopic traffic conditions in space-time. If this assumption is violated, errors are induced. Here, we make a difference between errors induced when estimating the conditions for the triangular areas that form the basic estimation unit and the errors induced when going from the triangular areas to the desired areas. The relation between these assumptions and the estimation errors explain that a positive relation exists between the level of inhomogeneity and non-stationarity of the traffic conditions and the required data-availability to reach a similar estimation performance. If the traffic conditions change highly over space and time, e.g., from free-flow to congestion, having sufficient point-observations is important to localize the different traffic phases. However, in the conducted case-study we still only needed to observe around 1 $\%$ of the vehicles in combination with the upstream and downstream 10 km link boundary to reach the same density estimation performance in terms of RMSE as having loop-detectors installed every 500 m. In this case, the flow estimation performance is similar for a penetration rate of 5 $\%$. The estimation performance for the same link was also evaluated for solely free-flow conditions. Here, the PON estimation methodology already outperforms loop-detector data-based estimated in terms of both flow and density estimates at a penetration rate of 0.10%. The PON estimation methodology does not have clear advantages when estimating speed.

The estimation performance seems to be largely determined by the ability to localize the changes in traffic conditions in space and time. Especially, miss-localizing different traffic phases, i.e., free-flow and congestion, results in large errors. In the simulation study, we discuss the estimation accuracy dependent on the penetration rate. However, to localize the changes in traffic conditions in space and time, the penetration rate is just one of the important parameters. Combined with the flow, the penetration rate determines the number of observed vehicles over time. Therefore, to accurately localize free-flow and congested conditions on a road stretch we expect a negative relation between the number of lanes and the required penetration rate.

The cumulative vehicle number N is the core macroscopic traffic flow variable. If we know N over space and time, we can derive all three macroscopic traffic flow variables. In this research, we obtain estimates of N by fusing observation of ΔN. Heterogeneity in the slope of the boundaries in space-time over which ΔN is observed improves the ability of fusing observations on this level. Therefore, we believe this research yields two important general insights. Firstly, relative flow observations are highly valuable for macroscopic traffic state estimation. And secondly, fusing this information on the cumulative vehicle number level is a good approach for estimating the macroscopic flow variables.