Comparison of MFD-based approaches with microscopic simulation data for real networks: Production hysteresis and trip lengths

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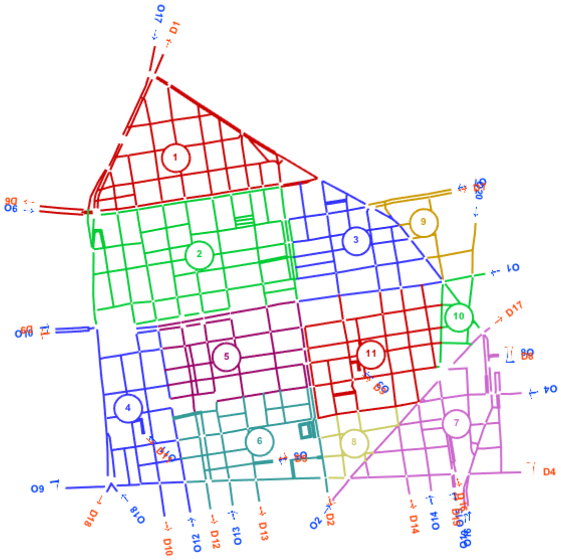
Extended abstract

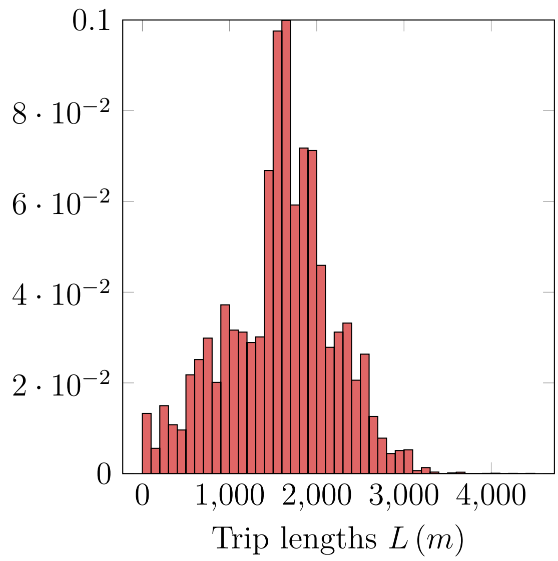
In the recent past, Macroscopic Fundamental Diagram (MFD) proved to be an attractive alternative to describe the traffic states at the network level. Several works (Knoop and Hoogendoorn, 2014, Yildirimoglu and Geroliminis, 2014, Kouvelas *et al.*, 2017) employed MFD-based approaches in variety of applications like perimeter control, modeling large-scale cities, *etc.* Even though Geroliminis and Daganzo (2008) verified the existence of MFD, the stability of its shape faces certain challenges like hysteresis phenomenon (Gayah and Daganzo, 2011), heterogeneity of the traffic in urban networks (Geroliminis and Sun, 2011). Ji and Geroliminis (2012) has shown that partitioning of heterogeneous networks into homogeneous regions can be a solution to obtain a well defined MFD. However, this approach might not be robust as hysteresis may be driven by other factors rather than the network attributes.

Most of the previous works on MFD approach employ the so-called accumulation-based MFD model to predict the traffic state dynamics. Kouvelas *et al.* (2017) used the average trip length per region in computation of system dynamics for their proposed perimeter control. Yildirimoglu and Geroliminis (2014) concluded that using constant average trip length has significant impact on the accuracy of the outflow by comparing to the microscopic simulation results. Recently, Mariotte *et al.* (2017), Lamotte and Geroliminis (2016) refined the idea introduced in Arnott (2013) and proposed the so-called event-based approach in the framework of trip-based MFD simulation for a single reservoir system. This approach considers that all users travel at the same speed at a given time and exit the zone once they have completed their individually assigned trip length. Even though accumulation-based approach is relatively simple and computationally less demanding, it has few shortcomings in fast-varying conditions (Mariotte *et al.*, 2017) and inclusion of individual trip lengths in this approach is not trivial. On the other hand, accounting for different trip lengths is relatively straightforward in trip-based model. However, this approach is computationally more demanding and modeling of congestion propagation in this framework is still under study. The trip-based approach is extended to multi-reservoir systems with multiple trip lengths in each reservoir in Mariotte and Leclercq (2018). There has been complex formulations proposed in the MFD based simulation approaches in the literature but very few detailed validation on real networks. Hence, this work focuses on a thorough validation of the MFD simulators on real networks.

In the present study, both accumulated-based and trip-based approaches proposed in Mariotte *et al.* (2017) are applied on a real network and traffic state dynamic results are compared to microsimulation ones. The chosen network in this work is Lyon 6, which is shown in fig. 1a.



(a) Link level representation of Lyon 6.

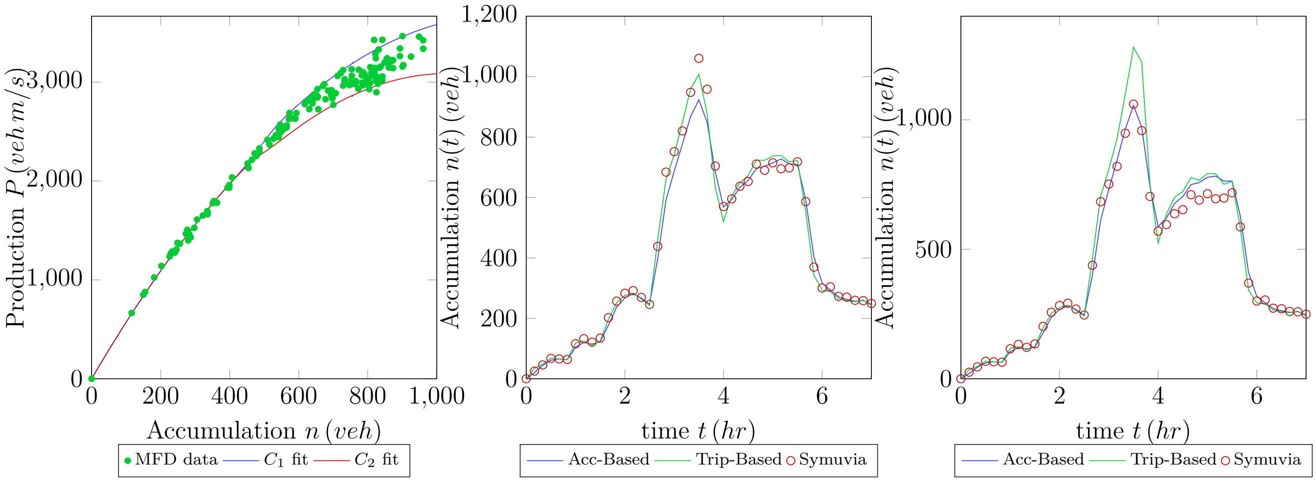


(b) Distribution of trip lengths.

Figure 1: Lyon 6 network: schematic of area and trip length distribution based on real data.

The OD matrix and demand level used in the simulations are estimated from the real data of morning rush hour of Lyon 6 and hence, microsimulation can be used to reproduce the actual scenarios. It is noticed from the results of microsimulation, there exists a well-defined MFD for Lyon 6, which is shown in fig. 2a. It can be observed from the plot that the scatter of the production increases close to the critical accumulation as a result of production hysteresis. However, the scatter of the MFD data can be influenced by the aggregation time period used in the computation of mean variables. This work investigates the existence of an optimal aggregation time period for which a well defined MFD shape and scatter can be obtained. Although existence of the hysteresis phenomenon is well established in the literature, there have not been previous attempts to account for the production hysteresis in MFD-based simulation models. Therefore, this study is the first attempt to include the production hysteresis in both accumulation-based and trip-based approaches. In order to account for the hysteresis during onset and offset of congestion in MFD simulators, two quadratic curves are fitted to the MFD data that encloses most of the data points. During the onset of congestion, quadratic curve C_1 is used to compute production for a given level of accumulation. Similarly, during the offset of congestion, curve C_2 is employed in production computations. This ensures that hysteresis is taken into account in the MFD-based simulations.

Another question this study addresses is the importance of the level of description of trip lengths. Figure 1b shows the distribution of trip lengths for the considered OD matrix. Since the individual trip lengths are known *a priori* from the micro-simulation data, an accurate model can be built by considering each individual trip length in the MFD simulators. However, this approach is computationally expensive in the case of trip-based model. On the other side, individual trip lengths in the accumulation-based model might add numerical diffusion to the scheme as there can be as few as 1 vehicle in a given trip length during the whole simulation time. Hence, other variants of trip length description like single mean trip length, mean trip length per class and dynamic evolution of mean trip length are considered in this work. The objective of the study is to propose a trip length description method in order to obtain a good compromise between accuracy and computational time in both accumulation-based and trip-based approaches. In addition, this work proposes to verify the mean trip length hypothesis Geroliminis and Daganzo (2008) by resolving the accumulation-based model



(a) MFD data and quadratic fits.
(b) Evolution of accumulation taking production hysteresis into account.
(c) Evolution of accumulation without production hysteresis.

Figure 2: Lyon 6 network: MFD data and evolution of total accumulation for a congested scenario.

by production MFD and outflow MFD that can be computed from the micro-simulation data.

The research questions proposed earlier are studied with several test cases. A reference free-flow scenario and a congested scenario are used in the present work. These scenarios are created by scaling the demand from loop detector data of Lyon 6 network. The congested scenario is created by either increasing the demand level of the network or by creating more internal trips to study the behavior of MFD simulators in both cases. The OD matrix is assumed to be constant during the whole simulation and hence, trip lengths are predefined. However, OD matrix changes dynamically in the real time situations and therefore, OD matrix is changed artificially to study the influence of change in trip length distributions on the MFD simulators. This study can provide an useful insight on the sensitivity of MFD simulators on changes in trip length distributions.

Figures 2b and 2c show the preliminary results of aggregated accumulation with time using accumulated-based and trip-based approaches in a congested scenario with and without production hysteresis, respectively. For the comparison to be fair, both approaches use the mean trip length per class in the computations and production hysteresis is taken into account for both models. The class in this simulation is defined based on starting and ending locations of trips, *i.e.*, the origin and destination of the trip are inside or outside of Lyon 6 network. The results are compared with micro-simulation data and it can be observed that in the free-flow regime, both approaches give very similar results. During the onset of congestion, *i.e.*, after $t > 3\,hr$ an increasing discrepancy between trip-based and accumulation-based models can be observed. On one hand, trip-based approach provided a good estimate of peak accumulation compared to micro-simulation data whereas, on the other hand, accumulation-based under-predicted the peak accumulation as high as 10%. During the offset of congestion, both trip-based and accumulation-based models result in slight under-prediction of accumulation. This can be addressed by refining the shape of hysteresis loop in production MFD. The establishment of proper explanation for the differences in the results between accumulation-based and trip-based is still an ongoing work.

Keywords: Large network modeling, Macroscopic Fundamental Diagram, hysteresis, trip-based, microsimulation

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References

Arnott, R. (2013). A bathtub model of downtown traffic congestion. *Journal of Urban Economics*, *76*, 110 – 121.

Gayah, V. V. and C. F. Daganzo (2011). Clockwise hysteresis loops in the Macroscopic Fundamental Diagram: An effect of network instability. *Transportation Research Part B: Methodological*, *45*(4), 643 – 655.

Geroliminis, N. and C. F. Daganzo (2008). Existence of urban-scale macroscopic fundamental diagrams: Some experimental findings. *Transportation Research Part B: Methodological*, *42*(9), 759 – 770.

Geroliminis, N. and J. Sun (2011). Properties of a well-defined macroscopic fundamental diagram for urban traffic. *Transportation Research Part B: Methodological*, *45*(3), 605 – 617.

Ji, Y. and N. Geroliminis (2012). On the spatial partitioning of urban transportation networks. *Transportation Research Part B: Methodological*, *46*(10), 1639 – 1656.

Knoop, V. L. and S. P. Hoogendoorn (2014). Network transmission model: a dynamic traffic model at network level. In *Transportation Research Board 93rd Annual Meeting Transportation Research Board*, 14-1104. Washington.

Kouvelas, A., M. Saeedmanesh and N. Geroliminis (2017). Enhancing model-based feedback perimeter control with data-driven online adaptive optimization. *Transportation Research Part B: Methodological*, *96*, 26 – 45.

Lamotte, R. and N. Geroliminis (2016). The morning commute in urban areas: Insights from theory and simulation. In *Transportation Research Board 95th Annual Meeting Transportation Research Board*, 16-2003. Washington.

Mariotte, G. and L. Leclercq (2018). Flow exchanges in multi-reservoir systems with spillbacks. *Transportation Research Part B: Methodological*. (Submitted).

Mariotte, G., L. Leclercq and J. A. Laval (2017). Macroscopic urban dynamics: Analytical and numerical comparisons of existing models. *Transportation Research Part B: Methodological*, *101*, 245 – 267.

Yildirimoglu, M. and N. Geroliminis (2014). Approximating dynamic equilibrium conditions with macroscopic fundamental diagrams. *Transportation Research Part B: Methodological*, *70*, 186 – 200.