Dynamic Capacity Estimation for Link Selection in Macroscopic Fundamental Diagram (MFD) Modeling

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1 INTRODUCTION

Traffic congestion and the associated negative effects, such as longer journey times and pollutant emissions, are one of the main problems of urban transport and the quality of urban space as a whole. Understanding the relationships between network design and traffic management on the one hand and the quality of traffic flow on the other is an essential prerequisite for the future-oriented development of networks and the measures that control them. The Macroscopic Fundamental Diagram (MFD) offers a way of analyzing and evaluating urban transport networks on a large scale with regard to their performance and the associated external effects. However, in order to obtain usable results, it is necessary that the MFD estimate is both accurate and unique. Otherwise, there is a risk that incorrect MFD estimates will lead to a biased assessment of transport service alternatives. One of the factors that significantly impacts the accuracy of MFD estimation is the road network's dynamic traffic states (heterogeneity). Furthermore, practical constraints limit data collection to a subset of links within the road network presumed to be representative. Previous studies have attempted to address this issue through various methods, such as distance from the center (Ortigosa et al., 2015), link re-sampling (Ambühl et al., 2018), and machine learning (Saffari et al., 2020). Rizvi (2023) introduced a heterogeneity factor to account for the changing saturation of the network links during the day. The heterogeneity factor enables a selection of connections that are most representative of the overall performance of the network due to their different saturation. The author showed that selecting a subset of links according to their heterogeneity factor shifts the MFD curve closer to its upper limit, reflecting a more definite network performance.

However, a limitation of this approach is that a fixed capacity value is used to categorise links, so that fluctuations in link capacity over time due to factors such as adaptive traffic signal control at junctions or congestion from permitted turning flows are not taken into account. This could lead to low-capacity links being ranked lower, even if they perform optimally. To address these limitations, we propose to integrate a recently published methodology for estimating link capacity at signalised intersections (Fourati & Friedrich, 2021) and then select a subsample of links based on the dynamic capacity value. This ensures that the ranking of links is based on their individual capacity, resulting in a selected sample that reflects an accurate average traffic state.

2 METHODOLOGY

To capture the dynamics of traffic demand and the varying degree of saturation of the road network during the day for MFD estimation, Rizvi (2023) introduced entropy weights (EW) as a surrogate to quantify the heterogeneity in each time interval. According to Figure 1, the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) was applied in the next step. However, TOPSIS requires an ideal and worst solution to calculate a Performance Index Pi for each link i based on EW. Rizvi (2023) assigned a single fixed lane-capacity value for all the links as an ideal solution. However, in reality, the links have different capacities, which may vary with time due to signal control. For variable capacity input, we used the method of Fourati & Friedrich (2021) to assign a specific capacity value for each link.

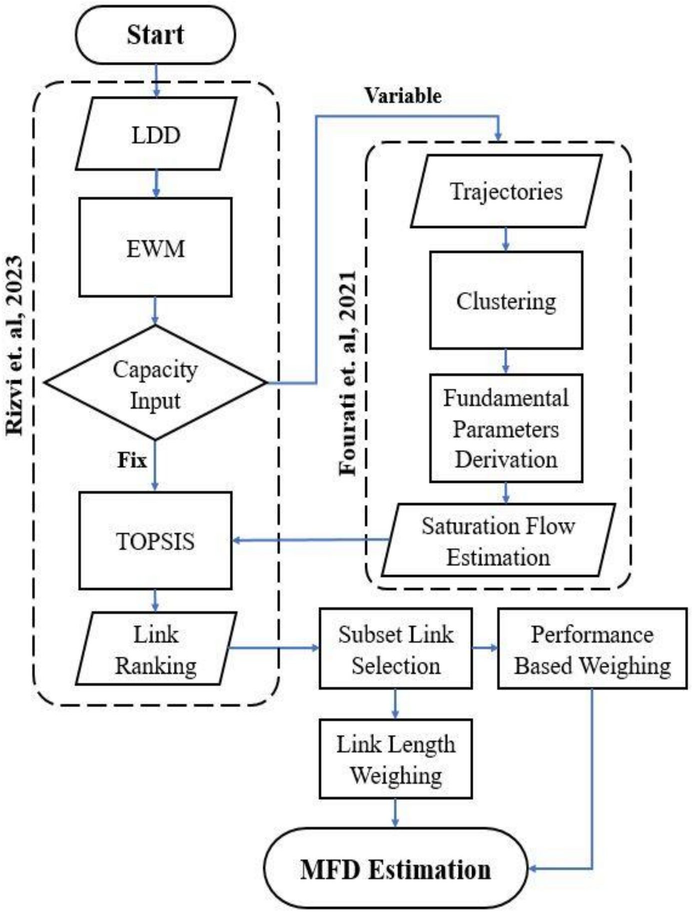

Figure 1 *Flow chart of selecting subset sample of links for MFD estimation*

The Pi of each link was calculated using fixed and variable capacity input. Once the rankings of the links were developed using different cases of capacity, subset samples were selected based on various Pi values. Moreover, the link length is a geometric property unrelated to the link's traffic states and might affect the selection of a link that performs optimally during the day. Therefore, this study aggregated the traffic data utilizing classical link length and performance of a link that is reflected by the Pi value. Finally, based on these considerations four scenarios can be distinguished as shown in Figure 1 and listed in Table 1. Each case was evaluated based on the proximity of the estimated MFD curve to the theoretical upper bound. We also analyzed the impact of variance in capacity, Pi values, and link length on the accuracy of MFD estimation in the manuscript.

Table 1 *MFD estimation scenarios*

Case	Capacity	Weighing Measure
1	Fixed	Link Length
2		Performance Based
3	Variable	Link Length
4		Performance Based

3 RESULTS AND DISCUSSION

The methodology was implemented using traffic data from Zurich (Loder et al., 2019), and the findings underscore the limitations of fixed capacity, which restricts the selection of some critical links due to their lower Pi values. Similarly, the link length limits the role of selected links in MFD estimation with shorter lengths but carrying a significant portion of the traffic, underestimating the road network's capacity. Accordingly, the lowest capacity value for the MFD is calculated for Case 1, in which the link length is used for weighting. Case 2 additionally uses the performance value for link selection and in Case 3 the links are selected according to link length and adjusted capacity. Case 4 takes both values the adjusted capacity and the performance into consideration and thus is assumed to result in the most accurate estimation of the average traffic state of the road network.

For comparative analysis, Case 4 serves as a reference (Capacity = 894 Veh/Hr/Ln) against which the other cases listed in Table 1 were compared for the estimation of the MFD (Figure 2). As anticipated, the selection of the measuring points according to Cases 1 and 2 results in a significantly lower capacity value of the MFD. Interestingly, there was minimal or no difference in estimated capacity by Case 3 due to similar links being selected and having similar link lengths. However, this condition is network-specific and could be different for other networks.

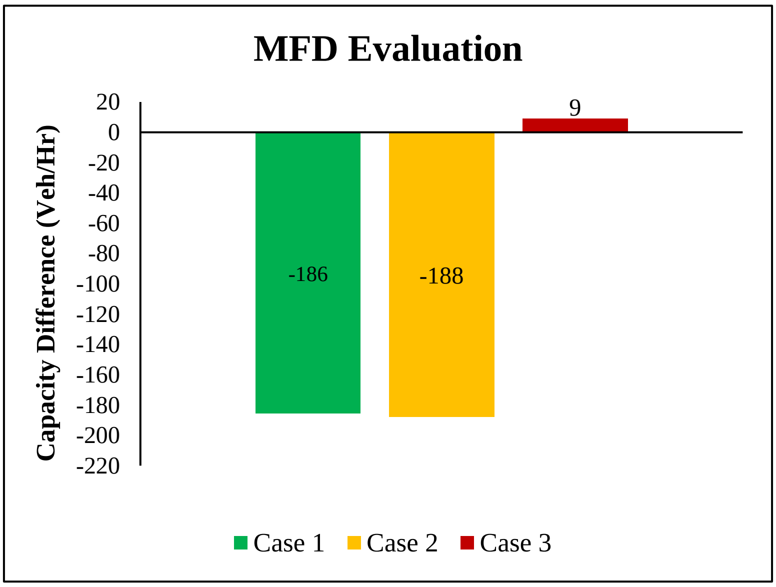

Figure 2 *Difference in capacity estimates by different MFD estimation scenarios*

Finally, the results show the sensitivity of the MFD estimate to both the consideration of the dynamics of traffic demand and the capacity of the links. Thus, it can be assumed that the actual capacity value of the MFD can be determined more accurately if these essential characteristics of the road network are correctly taken into account. As the results of the test calculations confirm the plausibility of the assumptions, it is recommended that these aspects be taken into account when determining the MFD.

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