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The Contribution of Ramp Demand in the Capacity of Merge Bottleneck Locations

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Abstract

Transportation engineers rely on the Highway Capacity Manual (HCM) for estimating capacity at freeway segments. According to the HCM 2010 (TRB, 2010), the capacity of basic freeway segments is a function of the free-flow speed and it ranges from 2,400 passenger cars per hour per lane (pc/h/ln) for FFS 70 or 75 mi/h, to 2,250 pc/h/ln for FFS 55 mi/h. The freeway merge segments methodology in the HCM 6th Edition uses these same capacity values in the analysis procedure, although research has shown that capacities at these bottleneck locations are considerably lower. Researchers have also observed that capacity varies significantly from day to day and from one site to the other. This lower capacity and variability have been attributed to driver behavior and variability in the types of interactions between mainline and ramp vehicles at these junctions The HCM 6th edition does not account for the varying relative demands of the two conflicting movements and the contribution of the ramp vehicles on the overall merge junction capacity.

This paper investigates the relationship between freeway and ramp demand and capacity at merge junctions. For the purposes of this research, historic data at merge bottleneck locations across North America with different geometric and operational characteristics were analyzed. The results of the analysis show that, there is a clear correlation between ramp demand, freeway demand and freeway capacity. More specifically, higher demand on the on-ramps produces lower overall capacity values. In addition, this paper proposes new capacity values for merge junctions as a function of the freeway and ramp demand and number of lanes.

Keywords: highway capacity, merging operations, traffic breakdown, bottlenecks

1 Introduction

The Highway Capacity Manual (TRB, 2010) is considered the primary document for transportation engineers to evaluate traffic operations at freeway segments. The current edition of the Highway

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Capacity Manual (HCM 2010) considers that the capacity of basic freeway segments is a function of free flow speed (FFS) and it ranges from 2,400 passenger cars per hour per lane (pc/h/ln) for FFS 70 or 75 mi/h, to 2,250 pc/h/ln for FFS 55 mi/h. The freeway merge segments methodology in the upcoming HCM 6th Edition uses these same capacity values in the analysis procedure, although research has shown that capacities at these bottleneck locations are considerably lower. In addition, research has shown that ramp flow significantly contributes to the occurrence of the freeway flow breakdown, and therefore it affects capacity (Elefteriadou, et al., 2009).The HCM 6th Edition acknowledges that capacity values at bottlenecks may be considerably lower than those at basic freeway segments, but it does not provide specific capacity values for those segments. Furthermore, the HCM does not account for the effect of ramp demand on merge capacity.

The objective of this research is to investigate the relationship between freeway capacity and ramp flow. More specifically, this paper aims to:

- Obtain data at various merge bottleneck locations across North America, with varying number of lanes and operating conditions;
- Identify breakdown occurrences and obtain the capacity, the breakdown flow and the ramp flow that led to the occurrence of the breakdown;
- Develop models of capacity as a function of the upstream freeway demand, the ramp demand, and number of lanes along the mainline;
- Propose capacity values for merge bottlenecks.

The following section provides a literature review on merge bottleneck capacity. Section 3 presents the study sites and data collection performed for this study. Section 4 presents the identification of freeway breakdown events while section 5 discusses the proposed regression models. Section 6 presents the proposed capacity values for merge bottlenecks. Concluding remarks are presented in the last section.

2 Literature Review

Several researchers that study breakdown-related freeway capacity have established that capacity is stochastic and it does not occur under a given set of volumes (e.g., (Elefteriadou, Roess & McShane, 1995), (Hall & Agyemang-Duah, 1991), (Persaud, Yagar, Tsui, & Hook, 2001), (Lorenz & Elefteriadou, 2001), and (Brilon, 2005)). Furthermore, field observations show that capacity varies considerably on a daily basis, and between sites. It is further noted that the literature has focused on bottleneck locations, such as merge or diverge junctions in order to measure capacity.

Researchers have also proposed various potential definitions for capacity. For example, (Elefteriadou & Lertworawanich, 2003) used three different definitions. The first is defined as the 5- or 15-min flow immediately before the breakdown. The second is defined as the maximum 5- or 15-min flow before the breakdown. The third is the maximum 5- or 15-min discharge flow (i.e., during oversaturated conditions). (Brilon, 2005) recommended to "use the 50th-percentile of the breakdown probability distribution as the nominal capacity". After reviewing several definitions of capacity, (Elefteriadou, Hall, Brilon, Roess, & Romana, 2006) selected the maximum pre-breakdown 5-minute value and they proposed to use either the mean or the 15th-percentile of the distribution as the capacity measure. Recent research (Kondyli, St. George, & Elefteriadou, 2015) has used the 85th percentile of the 15-min average pre-breakdown flow rate. Generally, a 5-minute capacity value is greater than a 15-minute capacity, and a maximum pre-breakdown flow is almost always greater than the average flow. In addition, discharge flow (i.e., after the breakdown) is always less than the pre-breakdown capacity. To be consistent with the literature, we defined capacity as the 5-minute pre-breakdown flow rate.

An important finding of the literature is that, irrespective of which capacity definition is used, the final capacity values at merge bottlenecks are considerably less than those traditionally accepted by the

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