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Sensitivity analysis of CORSIM with respect to the process of freeway flow breakdown at bottleneck locations

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ABSTRACT

Various microscopic simulation models have been used for studying traffic operations along freeway segments. An important desirable function of these models is their ability to obtain capacity and replicate the breakdown process realistically. The objectives of this paper are to evaluate the capability of a microsimulation model, CORSIM, to replicate the process of breakdown and to perform a sensitivity analysis on driver behavior parameters. The research findings indicate that CORSIM has some strengths and some weaknesses with respect to the breakdown process. Sensitivity analysis shows the different effects of these parameters on the breakdown occurrence and provides recommendations on the application of these parameters to provide a more realistic representation of traffic operations.

1. Introduction

Microscopic simulation models have been extensively used to replicate freeway operations. These models are typically based on algorithms modeling driver behavior. Attaining freeway capacity and replicating the freeway breakdown process in a model can be very important for obtaining realistic results when evaluating congested conditions. However, no previous research on how well existing simulation tools can replicate the breakdown process was found in the literature. This study evaluates a popular simulation model with respect to its ability to replicate the breakdown process at a freeway on-ramp, and the effect of driver behavior-related parameters on modeling the breakdown. The objectives of this paper are:

- To evaluate how well CORSIM (Version 6.0) replicates freeway breakdown events at a typical bottleneck location (a freeway merge).
- To perform a sensitivity analysis on driver behavior parameters of CORSIM and determine which parameters affect the breakdown process.

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The findings of this research provide useful guidance for calibrating and validating the process of the freeway-flow breakdown at active bottlenecks. The first section of this paper summarizes literature related to the breakdown process at bottlenecks as well CORSIM's capabilities and driver behavior-related algorithms. The next section evaluates CORSIM in terms of its ability to replicate the breakdown process at freeway merges. Following that, the paper presents the sensitivity analysis results for five factors that affect traffic operations and breakdown at freeway merging sections. The last part of the paper provides conclusions and recommendations.

2. Literature review

This section briefly summarizes the literature on freeway breakdown and the freeway breakdown process and on CORSIM's abilities to replicate congested conditions at freeway bottlenecks.

2.1. Causes and breakdown process in the field

There are several articles in the literature that describe the breakdown process using field observations and data. Buckley and Yagar [3] state that at an entrance ramp (or lane drop) drivers merge into minimal gaps in the adjacent lane. As they travel further downstream, they attempt to increase the spacing between vehicles to a more acceptable distance. They state that a consequence of one driver slowing down is that those upstream need to decelerate more rapidly. This shock wave moving upstream is ultimately seen as the flow breakdown closer to the lane drop, which then becomes the longer-term slow-and-go traffic condition observed upstream. According to Banks [1] and Gazis and Herman [9] the breakdown process started with the formation of dense platoons behind slower moving vehicles as the increased flows and densities would prohibit any lane changes. Eventually, speeds in the platoons become unstable, leading to a drastic speed reduction at the point the shock wave began. Kerner and Rehborn [10] state that in the vicinity of bottlenecks, the breakdown occurs due to local speed decrease and density increase that is observed when on-ramp vehicles squeeze on the highway, or due to unexpected speed decrease and lane changing activity. Lastly, Daganzo [4] concludes that the breakdown of free flow traffic can be "traced back to a lane change in front of a highly compressed set of cars".

The breakdown is typically defined as the transition from uncongested to congested conditions and it is associated with a sharp speed reduction [11,6]. Persaud et al. [15,16] examined the breakdown process at ramp merging segments and defined the breakdown as the transition from free-flowing conditions to queue formation. Further research [5,12,14] investigated the occurrence and probability of freeway breakdown at ramp merges. Elefteriadou and Lertworawanich [5] studied the transitions from non-congested to congested conditions and developed definitions for three flow parameters: the maximum pre-breakdown flow, the breakdown flow, and the maximum discharge flow. The maximum pre-breakdown flow was defined as the highest flow that occurs before the breakdown during non-congested conditions; the breakdown flow was defined as the per lane 5-min flow rate for the interval before the breakdown; and the maximum discharge flow was defined as the highest per lane 5 min flow rate occurring during congestion. More recent work by Brilon [2] defined breakdowns to occur when the speed drops below 70 km/h and the associated speed reduction is at least 10 km/h, to avoid short intervals of recovery. Furthermore, Brilon [2] treated the breakdown events as random and derived the distribution of the breakdown flow by applying a technique called lifetime data analysis. Shawky and Nakamura [18] developed three definitions for merging capacities: the maximum outflow rate before the breakdown, the breakdown flow rate when breakdown starts, and the outflow rate during the queue discharge. The authors defined the breakdown event as "a reduction in speed at the detector at the merge area to be under a critical value and this condition sustains for at least 15 min while the downstream speeds at remain over this critical value". Recently, Elefteriadou et al. [7] defined breakdowns to occur when the speed drops below 10 mph for at least 5 min.

2.2. Assessment of CORSIM

CORSIM is a microscopic simulation model developed by the Federal Highway Administration [8] in the mid-1970s, and designed to study traffic operations of freeways and surface streets. CORSIM networks are based on a link-node representation. Each link represents a one-directional roadway segment while nodes represent intersections and entry/exit points.

Several studies have evaluated CORSIM to assess whether it can replicate operations accurately at freeway merging segments. With respect to merging operations, researchers [17,13] used previous versions of CORSIM (FRESIM module and TSIS 4.2) and showed that the simulation model fails to adequately replicate the impact of adjacent ramps (prediction errors tend to increase as the proximity of the adjacent ramps gets smaller), and that it is not sensitive to the acceleration lane length. With respect to driver behavior algorithms, three components of driver behavior in CORSIM version 6.0 [8] are discussed here: car following, lane changing, and free flow speed.

The car-following algorithm in CORSIM (Pitt's car-following model) is implemented using the car-following sensitivity factor, the sensitivity multiplier, the Pitt car-following constant and the acceleration/deceleration lag time. This model estimates the space headway between the leader and the follower, subject to their speeds and the sensitivity of the follower as shown in the following equation:

$$d_{\mathrm{AB}} = L + 10 + ku_{\mathrm{A}} + bk(u_{\mathrm{B}} - u_{\mathrm{A}})^2 \quad \text{(in feet)} \tag{1}$$