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Calibration and validation of simulated vehicle safety performance at signalized intersections

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Abstract

A systematic procedure is presented for calibrating and validating a microscopic model of safety performance. The context in the model application is the potential for rear-end crashes at signalized intersections. VISSIM® v.4.3 provides the simulation platform for estimating the safety performance for individual vehicles and has been calibrated and validated using separate samples of observed vehicle tracking data extracted from the FHWA/NGSIM program. The calibration exercise involves four sequential steps: (1) heuristic selection of initial model inputs, (2) statistical screening using a Plackett–Burnman design, (3) fractional factorial analysis relating inputs to safety performance, and (4) genetic algorithm procedure for obtaining best estimate input values. Three measures of safety performance were considered: crash potential index, number of vehicles in conflict and total conflict duration per vehicle. Model consistency was assessed by comparing simulated and observed safety performance based on a separate validation sample of vehicle tracking data. The suggested procedure was found to effectively estimate model input parameters that closely matched safety performance measures in the observed validation data. This procedure yields an objective and efficient means for simulation model calibration applied for estimating safety performance at signalized intersections.

Keywords: Road safety; Safety performance measures; Signalized intersections; Microscopic simulation; Microscopic simulation calibration; Microscopic simulation validation

1. Introduction

The potential application of microscopic traffic simulation models for safety assessment was initially investigated in the late seventies by Cooper and Ferguson (1976) and Darzentas et al. (1980). The basic premise behind these applications is that lack of safety can be expressed through a safety performance function or measure established from speed and spacing profiles experienced by individual vehicles in real time. More recently, a number of microscopic simulation models have attempted to explain the complex process that gives rise to these crashes on a given road segment (Sayed et al., 1994; Archer, 2005; Huguenin et al., 2005).

The usefulness of microscopic simulation for assessing safety depends on the ability of these models to capture complex behavioural relationships that could lead to crashes and to establish a link between simulated safety measures and crash risk. Furthermore, it becomes necessary to estimate model inputs such that they accurately replicate safety performance at a given location over time. Accordingly one of the major steps in applying simulation is to ensure that important model inputs have been accurately determined based on observational data, and that simulation models produce estimates of safety performance that can be verified from real-world observations.

The main objective of this paper is to suggest a systematic and objective procedure for specifying model inputs based on safety performance measures for rear-end crashes at signalized intersections. A second objective is to assess the transferability of selected model inputs for different traffic conditions (model validation). This objective investigates whether the input values suggested in the calibration yield safety performance measures that reflect observable real-world safety profiles.

One of the major concerns for considering signalization at intersections is the increased potential for rear-end crashes involving vehicles travelling along both major and minor approaches (Persaud et al., 2003; Cunto and Saccomanno, 2007). This issue is used to provide a practical context for the case study application presented in this paper.

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The simulation model used to demonstrate the calibration/validation procedure is VISSIM® version 4.3 distributed by PTV America. VISSIM® is based on psycho-physical driving algorithms and accounts for four different driving regimes: (1) un-influenced driving, (2) closing process, (3) following process and (4) emergency braking. These four driving states, defined by six human thresholds, represent situations where drivers should behave in a similar (but not equal) manner with respect to desired spacing, speed and actions needed to achieve them by means of acceleration and deceleration rates (Wiedemann and Reiter, 1992).

Simulated profiles of speeds and spacing in VISSIM® are used to estimate safety performance for individual vehicles over time. The underlying assumption in this analysis is that individual vehicle safety performance provides a fundamental indication for crash risk. The link between safety performance measures and actual crashes is not considered to be within the scope of this paper but nevertheless will need to be investigated empirically in subsequent research.

2. Observational vehicle tracking data

The observational vehicle tracking data used to calibrate and validate safety performance were obtained from the Next Generation SIMulation (NGSIM) program administered by the FHWA. One of the major aims of this program is to provide high quality and detailed vehicular information in real time that can be used to improve driving simulation algorithms (Kovvali et al., 2007). The products of the NGSIM program are freely available to transportation researchers and practitioners from the FHWA web site http://www.ngsim.fhwa.dot.gov.

The NGSIM vehicle tracking data were extracted for a segment of Lankershim Boulevard in Los Angeles, California. This segment is approximately 500 m in length consisting of three to four lanes and four coordinated signal-controlled intersections (Fig. 1). Digital video images were collected from five cameras mounted on a 36-story building over a 9 h period from 7:00 a.m. to 12:00 p.m. and 3:00 p.m. to 7:00 p.m. (FHWA, 2006).

Individual vehicle trajectories were transcribed for every 1/10 s and grouped into two independent 15 min samples: (1) from 8:30 to 8:45 a.m. and (2) from 8:45 to 9:00 a.m. The first 15 min sample was used for calibration, while the second sample was used to validate the model results. The NGSIM data analysis report also provides detailed information on several parameters of use in calibration and validation, such as, vehicle type distribution, O–D matrix, traffic volume for 5 min intervals, average speed, average travel time, number of lane changes, headway and spacing analysis.

The case study application introduced in this paper focuses on potential rear-end crashes on the southbound approach of Universal Hollywood Driveway and Lankershim Boulevard (intersection 2) and over a segment bounded by the stop line on the major approach and a point 100 m upstream (see Fig. 1).

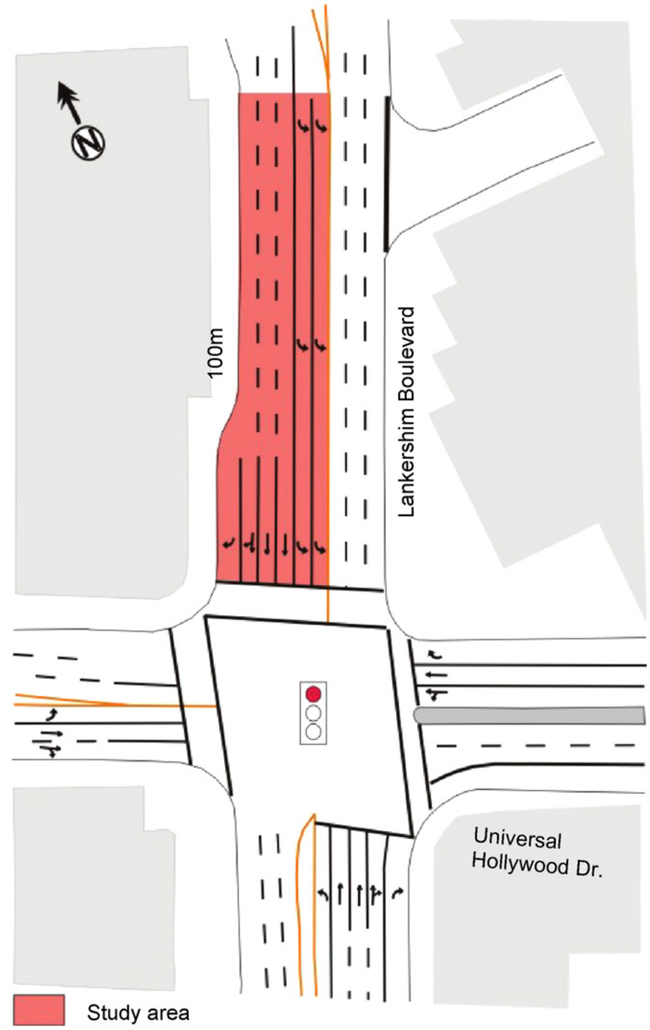

Fig. 1. Lankershim Boulevard in the vicinity of the target intersection.

3. Measuring safety performance

Safety performance measures attempt to capture real-time vehicle interactions in the traffic stream and hence explain their potential for crashes. Safety performance is a more inclusive expression of high risk driving behaviour than reported crash history, since it also accounts for near-misses that are indicative of lack of safety but do not result in actual crashes.

A number of measures of safety performance can be established, including time to collision (TTC), deceleration rate to avoid the crash (DRAC), post encroachment time (PET), among others (FHWA, 2003). The above FHWA report and a subsequent work by Archer (2005) have explicitly recognized the relevance of DRAC as a safety performance measure. This measure considers the role of speed differentials and decelerations in crash occurrence and is expressed as a function of the time/space and deceleration profiles experienced by individual vehicle pairs in the traffic stream (lead and following). It reflects the following vehicle deceleration required to come to a timely stop or attain a matching lead vehicle speed and hence avoid a rear-end crash.