Accident Analysis and Prevention 50 (2013) 713–723

Contents lists available at SciVerse ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Impact of traffic states on freeway crash involvement rates

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ARTICLE INFO

Article history:
Received 26 May 2011
Received in revised form 26 May 2012
Accepted 21 June 2012

Keywords:
Traffic safety
Accident
Traffic state
Crash involvement rate

ABSTRACT

Freeway traffic accidents are complicated events that are influenced by multiple factors including roadway geometry, drivers' behavior, traffic conditions and environmental factors. Among the various factors, crash occurrence on freeways is supposed to be strongly influenced by the traffic states representing driving situations that are changed by road geometry and cause the change of drivers' behavior. This paper proposes a methodology to investigate the relationship between traffic states and crash involvements on the freeway. First, we defined section-based traffic states: free flow (FF), back of queue (BQ), bottleneck front (BN) and congestion (CT) according to their distinctive patterns; and traffic states of each freeway section are determined based on actual measurements of traffic data from upstream and downstream ends of the section. Next, freeway crash data are integrated with the traffic states of a freeway section using upstream and downstream traffic measurements. As an illustrative study to show the applicability, we applied the proposed method on a 32-mile section of I-880 freeway. By integrating freeway crash occurrence and traffic data over a three-year period, we obtained the crash involvement rate for each traffic state. The results show that crash involvement rate in BN, BQ, and CT states are approximately 5 times higher than the one in FF. The proposed method shows promise to be used for various safety performance measurement including hot spot identification and prediction of the number of crash involvements on freeway sections.

1. Introduction

Freeway traffic accidents are complicated events that are influenced by multiple factors including roadway geometry, drivers' behavior, traffic conditions and environmental factors. The influence of those factors on traffic crashes cannot be fully unveiled without detailed information not only on crash itself but also on its surrounding circumstances. The database that is most commonly used for this purpose is crash reports. However, crash reports compiled at the crash scenes only record temporally invariant information: crash location and time, crash type, number of injuries or fatalities, geometric features, etc. One of the key information that is often missing is traffic conditions preceding the accident. Changes on freeway traffic conditions do require drivers' proper action to the changes and, if drivers' actions are not timely or felicitous enough, may cause occurrence of traffic crashes.

Crash occurrence and stationary traffic conditions on freeway are previously found to be closely related: vehicles travel close to each other at slower speed and, thus, are likely to have increased degree of conflicts in congested traffic conditions. In the free flow traffic conditions, meanwhile, vehicles tend to have reduced degree of conflicts at higher speed. However, freeway traffic crashes under non-stationary traffic conditions, such as growth or dissipation of congestion, has not been investigated systematically. Since traffic movements and their corresponding drivers' behavior vary substantially with traffic states, crash occurrence and its characteristics may also vary concurrently. Therefore, it is critical to categorize traffic states regarding distinct traffic conditions for evaluating the relation between traffic states and crash occurrences. In addition, the impact of road geometry such as merging, diverging and curved section is realized into the change of traffic states. For example, curved section or merging section cause deceleration of approaching traffic pinned to a certain location, by which a road geometry factors are converted into car-following situation that can be represented by the traffic states.

The objectives of the research described in this paper are to develop a new approach to relate traffic states and crashes on freeways, and to evaluate the probabilistic outcomes of crash occurrences with respect to traffic states. We developed a method to classify traffic states for a freeway section, and recorded traffic states for each time interval for each section. This collected traffic

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http://dx.doi.org/10.1016/j.aap.2012.06.023

information is then combined with traffic crash records by matching time and location of crashes. Finally, the collected data were analyzed to estimate crash involvement rates as a function of traffic states.

The remaining part of this paper is organized as follows: previous research pertinent to the present study is reviewed in Section 2. The proposed methodology is described in Section 3, and the results from the application of the proposed method to a test site are presented in Section 4. Section 5 summarizes the study findings, and the implications for practical applications are discussed.

2. Background

Over the last decades, there have been extensive research efforts devoted on the development of safety performance functions (SPFs, Hauer et al., 1988) that relates crash counts to several explanatory variables. Lord and Mannering (2010) provided the key issues and detailed comparison of the methodologies relating crash frequency and factors. However, most of these models aggregate their data into a certain time interval and examine the effects of only static variables, which did not vary over the observation, such as geometric designs and average traffic volumes of the roadway segments. However, recent evidence shows that the dynamic characteristics of traffic could also influence crash outcomes. This section reviews the latter research approach that is directly relevant to the present study.

Several studies have been undertaken to identify relations between crash occurrences on freeways and traffic flow (Ceder and Livneh, 1982; Martin, 2002; Ivan, 2004). These studies analyzed crash frequencies and macroscopic characteristics of traffic flow for specific time periods of various time intervals from hours to years and spaces of various lengths from segments to corridors, and showed that there exists a relationship between crash rate and traffic flow. Ceder and Livneh (1982) and Hall et al. (1989) reported that the relationship of traffic flow vs. crash rate displayed a U-shape. However, macroscopic measures of traffic flow in these studies were too static to represent time-varying traffic conditions on freeways and, thus, the variability in crash rates associated with many other aspects of traffic conditions might not be fully explained.

Oh et al. (2001), Lee et al. (2002, 2003) and Golob et al. (2004) used various microscopic and disaggregate measures of traffic conditions from 20-sec to 5-min loop detector data to identify traffic characteristics leading to crash occurrences, and showed the statistical relationship between time-varying traffic characteristics and crash outcomes. Oh et al. (2001) identified standard deviation of 5-min average speed as an indicator separating normal and disruptive traffic conditions, and estimated crash rate with respect to the standard deviation of 5-min average speed. This study showed that the rate of crash occurrences was higher under congested traffic conditions, and it increased as the standard deviation of speed increased. Lee et al. (2002, 2003) modeled crash frequency as a function of categorized crash precursors including speed variation and traffic densities, control factors and exposure. The categorization of crash precursors is determined in maximizing log-likelihood of crash prediction model (Lee et al., 2003). Golob et al. (2004) applied a cluster analysis to classify traffic characteristics, and investigated the levels of safety and crash types for each class. These studies demonstrated that the variability in speed is significantly associated with crash occurrences.

Abdel-Aty et al. (2004) proposed a methodology to relate crash frequency and traffic state from detector data. They concluded that 5-min average occupancy data at upstream during 5–10 min before the crash and 5-min coefficient of variation in speed at downstream are the most influencing factors on crash occurrence.

The data analysis conducted in these studies focused mostly on unveiling statistical connections among variables of interest, which are not necessarily meaningful in a physical sense. Though these approaches could show evidence that crash occurrence relates to traffic speed, they could not examine possible non-linearity between traffic states, and the relation between traffic states and crash occurrence. In the present study, therefore, traffic states are categorized based on kinematic wave theory (Lighthill and Whitham, 1955; Richards, 1956; Newell, 1993a,b) to investigate how crash outcomes vary with the traffic states and their accompanied traffic characteristics.

3. Methodology

Building on the findings from previous research, we hypothesize that crash occurrences and traffic situations are dependent. Based on the differences in traffic movements, furthermore, we postulate that different traffic states such as free flow and congestion have different impacts on crash outcomes. Thus, crash characteristics such as crash rate, type of the collisions, and fatalities, may alter over diverse traffic situations. In this research we address two fundamental questions: (i) how to define and detect traffic states with readily available traffic data; and (ii) how to relate the defined traffic states to traffic crashes.

There exists a limitation in matching crash and traffic data with available data sources because both of them are point-based measurements recorded with location information. However, the latter has fixed locations, while the former does not have predetermined locations, and can occur anywhere along the freeway. Therefore, matching crashes and the exact state of traffic cannot be obtained from detector data. Additionally, crashes are sporadic events spreading over the freeway sections, and cannot be easily captured by fixed surveillance systems. Therefore, we developed a new way to match collision and traffic data based on a freeway section that is defined by two detectors containing collisions in-between.

3.1. Section based traffic states

There are difficulties in connecting crashes to the traffic states preceding crash occurrences because traffic data are generally gathered from fixed locations (e.g., video cameras, loop detectors, etc.) while crashes are point process sporadic over the freeway. Identification of traffic state in a freeway section is often based on a point measurement from the nearest up or downstream, or the middle of the section. This identification procedure compares measured time-series traffic data with a predetermined threshold that divides free-flow and congested traffic states. Since this procedure monitors only temporal variations in traffic data, it cannot properly detect spatially varying traffic conditions such as transitions from free-flow to congestion or vice versa that accompany speed variations. Such spatiotemporal variations in traffic are prevalent in many freeways and extensive research efforts (Kerner, 2002; Treiber and Helbing, 2002; Kerner and Klenov, 2003; Kurata and Nagatani, 2003; Cassidy et al., 2009) have been devoted to unveil their mechanism. In the present study, therefore, the methodology using measurements from both input and output boundaries are proposed to capture spatial as well as temporal variations of traffic within a freeway section.

Fig. 1(a) shows a hypothetical freeway section with input and output boundary variables that are measured from both ends of a freeway section. Boundary traffic variables are speed (v), flow (q), and density (k) or occupancy (o) that is a dimensionless measure of density. The traditional fundamental diagram approach shown in Fig. 1(b) defines two traffic states on a flow-density plane for a