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Identification of freeway secondary accidents with traffic shock wave detected by loop detectors

Junhua Wang[a], Wenjing Xie[a,*], Boya Liu[a], Shou'en Fang[a], David R. Ragland[b,c]

[a] School of Transportation Engineering, Tongji University, 4800 Cao'an Highway, Shanghai, China
[b] School of Public Health, UC Berkeley, United States
[c] Safe Transportation Research and Education Center (SafeTREC), University of California, Berkeley, United States

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ABSTRACT

Secondary traffic accidents are generally recorded without being specifically noted as such in the accident database, leading to difficulty in the study of such accidents. Previous research generally classified secondary incidents by predefining fixed spatio-temporal boundaries—a method that can be very subjective. Using 10,762 accident records gathered from 2012 upstream loop detector data on a California interstate freeway, this paper proposes a dynamic method for more convincing and accurate classification based on traffic shock waves detected by the loop detectors. This method identifies and associates a secondary accident with its primary accident if it is tested and found to have occurred within the spatio-temporal impact area of the primary accident. Shock waves from each accident are calculated and updated along freeway via multiple detectors, and secondary accidents are identified as those that occur within the spatio-temporal boundaries of a primary accident. Results show that secondary accidents account for 1.08% of California interstate freeway accidents, which is much lower than previous research estimates. Dispersed spatio-temporal gaps between primary and secondary accident pairs were found with an expectation of 71.09 min and 3.88 miles with a standard deviation of 55.36 min and 4.64 miles respectively.

1. Introduction

1.1. Secondary accident

Freeway accidents not only cause severe travel delays, but can also result in secondary accidents, the risk of which is estimated to be six times greater than that for a primary accident (Tedesco et al., 1994). The high potential for occurrence and the negative consequences of secondary accidents make them an issue of great concern affecting freeway safety. However, secondary accidents and their primary accidents are usually recorded separately as regular accidents in the accident database, and there is no field to specifically identify an accident as secondary. Therefore, it is difficult to distinguish and subsequently study these unique cascading events directly from the information provided in the database. Previous research classified secondary incidents by predefining fixed spatio-temporal boundaries—a method that can be very subjective. This paper proposes a method based on traffic flow shock wave theory to identify secondary accidents using data from upstream loop detectors. The results show that the proportion of secondary accidents that occur on California interstate freeways is smaller than had been estimated in previous studies.

1.2. Literature review

Many previous studies were conducted on the characteristics of secondary accidents and proposed numerous identification methods. In much of the earlier research, unified spatio-temporal boundaries were predetermined and any accident that fell within the boundaries of another accident was defined as its secondary accident. Secondary accident identification was addressed early by Raub (1997), who proposed that any crash that occurred within the duration of the primary event plus 15 min and within one mile was assumed to have been related to the primary. The 15-min threshold was based on getaway times provided by Lindley and Tignor (1979) who estimated that this amount of time following an accident can impact traffic. The distance of one mile used to link

* Corresponding author.
E-mail addresses: benwjh@163.com (J. Wang), 100931@tongji.edu.cn (W. Xie), 693577145@qq.com (B. Liu), fangsek@tongji.edu.cn (S. Fang), davidr@berkeley.edu (D.R. Ragland).

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the two events spatially was derived from observations of crashes occurring during periods of heaviest traffic flow. For an extended period, studies followed Raub, which proposed a series of different spatial and temporal thresholds. Karlaftis et al. (1999) also applied the predefined identifying parameters of time and distance proposed by Raub. While Hirunyanitiwattana and Mattingly (2006) used sixty minutes and two miles upstream as thresholds, Moore et al. (2004) established thresholds as two hours and two miles on Los Angeles freeways. Zhan et al. (2008, 2009) used incident recovery time of 33.34–52.6 min, incident dissipation time of 0–21.76 min, and maximum queue length of 1.09–1.49 miles as the threshold, calculated based on different lanes blockage assumption according to the Highway Capacity Manual (HCM).

In the aforementioned studies, which applied static methods to classify secondary incidents, there were seldom any uniform thresholds, thus resulting in subjective findings. A comparison of secondary incidents classification results, using different spatial and temporal boundaries, was conducted and showed a high dependence on these boundary numbers (Haghani et al., 2006). The conclusion could be drawn that the predefined criteria cannot meet the variation in the spatio-temporal distribution of secondary incidents because the geometric characteristics, incident type and duration, traffic conditions and other possible contributing factors vary with each primary incident.

By studying operating traffic data, some study approaches made up for the static method by proposing a range of dynamic definition methods based on concepts such as queuing theory or speed contour analysis. The dynamic methodology described in the study by Sun and Chilukuri (2010) improved upon existing static methodology by marking the end of the varying queue throughout the entire incident using incident progression curves. Incidents were classified as secondary incidents if they fell within the curve. The analysis showed a difference of over 30% compared with the outcomes generated using the static methods. However, this dynamic methodology was based on estimated primary incident progression curves (IPCs) which were regressed with past incident records. The high degree IPC function is not only ideally shaped, but is also accompanied by possible estimation errors.

Except for the method based on the queuing theory, other research proposed speed-based methodology to determine the temporal and spatio extent of the primary incident or to classify secondary incidents. Based on loop data, Chung and Recker (2012) applied binary integer programming (BIP) to an empirical speed matrix under the impact of an accident, to determine actual temporal and spatial extent of delay caused by freeway accidents. This method was also utilized in the research of rubbernecking accident by Chung and Recker (2013). Yang et al. (2013, 2014) used speed data from highway sensors to build a binary speed contour plot to indicate the impact induced by the primary incident, and then classified secondary incidents by judging whether the queue triggered by the primary had reached them. This method was performed on a highway in New Jersey and showed a great reduction in biases caused by subjective fixed spatio-temporal thresholds as a case study. However, for this method a user defined speed percentage reduction factor, which is dependent on users' experience, impacts the identification result.

With the assistance of a speed matrix to describe the impact of the primary incident, Chung (2011, 2013) proposed a method to apply different spatio-temporal boundaries, varying with different types of crashes, to identify the spatio-temporal crash impacted queue region, then locate the secondary incident to determine whether it was associated with the primary incident. Crash shock wave and clearing shock wave generated by the primary accident could also be drawn from the speed matrix. However, it must be noted that speed is only one of a range of traffic parameters to reflect traffic conditions corresponding with a secondary accident. In addition, comparing with speed distribution in crash free time, the congested speed in this study is regard as the indicator of spatio-temporal impact boundary. While a confidence level can be subjectively chosen according to different road section. For example the speed in the upstream loop can reduce from 60 mph to 30 mph due to a primary accident and 30 mph can fall in the 95% confidence level of the crash free speed distribution.

There were also some secondary incident identification methods based on simulation. Chou and Miller-Hooks (2009) developed regression models by simulating representative incidents, which were then assessed using empirical incident data to determine the impact area of the primary incident. Haghani et al. (2006) used data from detectors in simulation software. The study used the boundaries defined by typical shock waves caused by the primary incident to explain dynamic queue formation via a recognition algorithm of the mean occupancy rate patterns, converting the classification process into a feasible geometrical matching operation. These methods based on simulation experiment research are more sound and theoretical.

Shock wave theory can be used to illustrate how the conversion between two different conditions travels along traffic flow. In some studies, this theory has been applied to estimate queue length at a congested signalized intersection, as in the study by Li et al. (2013). Zheng et al. (2015) utilized shockwave theory to consider the impact of queue spillback phenomenon on travel time distributions. In another paper by Li, shock wave theory was used to estimate the real time impact scope of incidents on a city expressway, and the method showed good accuracy and applicability in estimating results. Traffic incidents can change the traffic condition at the incident point, which can result in a transferring shock wave. Shock wave theory shows how this wave is produced and its speed, which can help represent the full-scale impact process of an incident. Based on shock wave theory, one study conducted on accident data attempted to filter secondary accidents. In this study, Moore et al. (2004) applied shock wave filtering using fixed boundaries to identify secondary accidents, which required close manual attention to distinguish shock waves in loop data. However, limited installation of detectors, lack of data, and corrupted records of output data reduced data availability, which resulted in data for only sixteen accidents sufficient to execute this filtering method.

Zheng et al. (2014) proved that the shock wave could be a fair tool to identify the secondary accident. He firstly extracted spatially and temporally nearby crash pairs (up to custom static thresholds) from a large network on the basis of a crash-pairing algorithm. In the second phase, two filters are used to select crash pairs that are more likely to be primary–secondary crash pairs. One of the filters uses shockwave theory to evaluate the dynamic traffic impact of the primary incidents. Then the manual review of identified police reports was carried out to confirm actual secondary crashes. Zheng also extended the shockwave filter to a freeway network scale. However Zheng just considered the release shockwave and queuing shockwave. In an incident when the rescue party or the policeman comes to the crash site to manage the traffic, one more shock wave can be created. Moreover, the shock waves can trace each other, and this situation will be more complicated than Zheng's model. These problems could also exist in free (2011, 2013) and Yang et al.'s (2013, 2014) method.

To fill the research gap identified above, the present study establishes the primary accident shock wave impact spatio-temporal scope as the filter for the secondary accident. Upstream loop data records were used to demonstrate the possible shock waves generated by the primary accident. A total of 10,762 accidents that occurred in 2012 on a California interstate freeway with their corresponding upstream loop data were analyzed by the proposed method to demonstrate its reliability and efficiency.