Accident Analysis and Prevention 117 (2018) 40–54

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Methodological evolution and frontiers of identifying, modeling and preventing secondary crashes on highways

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ARTICLE INFO

Keywords:
Secondary crash
Road safety
Crash prevention
Traffic incident
Connected vehicles
Highway

ABSTRACT

Secondary crashes (SCs) or crashes that occur within the boundaries of the impact area of prior, primary crashes are one of the incident types that frequently affect highway traffic operations and safety. Existing studies have made great efforts to explore the underlying mechanisms of SCs and relevant methodologies have been evolving over the last two decades concerning the identification, modeling, and prevention of these crashes. So far there is a lack of a detailed examination on the progress, lessons, and potential opportunities regarding existing achievements in SC-related studies. This paper provides a comprehensive investigation of the state-of-the-art approaches; examines their strengths and weaknesses; and provides guidance in exploiting new directions in SC-related research. It aims to support researchers and practitioners in understanding well-established approaches so as to further explore the frontiers. Published studies focused on SCs since 1997 have been identified, reviewed, and summarized. Key issues concentrated on the following aspects are discussed: (i) static/dynamic approaches to identify SCs; (ii) parametric/non-parametric models to analyze SC risk, and (iii) deployable countermeasures to prevent SCs. Based on the examined issues, needs, and challenges, this paper further provides insights into potential opportunities such as: (a) fusing data from multiple sources for SC identification, (b) using advanced learning algorithms for real-time SC analysis, and (c) deploying connected vehicles for SC prevention in future research. This paper contributes to the research community by providing a one-stop reference for research on secondary crashes.

1. Introduction

Traffic crashes are the most frequent incidents on highways and the ones with the most severe consequences. Statistically, about 6.3 million highway crashes are reported annually only in the United States, among which more than 32,000 are fatal crashes (NHTSA, 2016). These incidents often pose challenging problems in traffic operations and safety. Both transportation agencies and the general public are concerned about their notable direct and indirect impacts. It has been estimated that these highway crashes resulted in almost $1 trillion in economic loss and societal harm in 2010 (Blincoe et al., 2015). The hazardous traffic conditions that are formed due to traffic crashes are often exposing non-involved vehicles and incident responders to a risk of additional crashes: the so-called secondary crashes (SCs). SCs are typically defined as crashes that occur within the spatial and temporal boundaries of the impact area that is formed due to earlier primary crashes (PCs) (Owens et al., 2010). This should be distinguished from the “secondary collisions” defined in Xie et al. (2018) that are described as different phases of a single crash event. It has been reported that SCs can account for as high as 20% of all crashes and 18% of all fatalities on the United States’ freeways (Owens, 2010). Considering the significant economic and social costs as well as the potential preventability, SC mitigation has become a priority for transportation agencies around the world.

In fact, many transportation agencies are using SCs as an important indicator to monitor the safety performance of their systems. The frequency of SCs is used as a key factor in assessing a number of safety programs of the Federal Highway Administration (FHWA) and many state/local agencies consider the determination and reduction of SCs in allocating funding for the development of their traffic incident

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https://doi.org/10.1016/j.aap.2018.04.001
Received 11 December 2017; Received in revised form 21 February 2018; Accepted 3 April 2018
0001-4575/

Table 1
Summary of Studies on Identification of SCs.

Authors	Major data needs	Data facts (Total/PC/SC; period; location)	Method	Identification criteria
Karlaftis et al. (1999)	Incident	741/ 257/257; 1992–1995; Borman Expressway, INDOT	Static	1.5 km;15 min + clearance
Hirunyanitiwattana and Mattingly (2006)	Incident	354,161/15,442/15,442; 1999–2000; California highway	Static	2 miles; 1 h
Latoski et al. (1999)	Incident	8,986/689/ 689; 1996; Borman Expressway, INDOT	Static	3 miles; 15min + clearance
Moore et al. (2004)	Incident + loop detector	84,684/192/197;1999; Los Angeles Freeway, California	Static	2 miles; 2 h
Sun and Chilukuri (2007,2010)	Incident	5,514/ 397/ 397; 2003; I-70 and I-270 in Missouri	Dynamic	Incident progression curves
Zhan et al. (2008)	Crash data	7,903/ 352/413; 2005–2007; Florida I95, I75, and I595	Static	2 miles; 15min + clearance
Zhan et al. (2009)	Crash data + SMART data	7,903/ 221/ 255; 2005–2007; Florida I95, I75, and I595	Dynamic	Cumulative arrival; departure traffic delay
Khattak et al. (2009)	Incident	38,086/736/764; 2006; Hampton road, Virginia	Static	1 mile, duration of PC (+ 15 min if lane blocked)
Vlahogianni et al. (2010)	Incident + monitor + sensor data	1746/ 279/279; 2007–2008; Attica Tollway, Greece	Dynamic	Maximum queue length and queue duration
Chou and Miller-Hooks (2009)	Incident + simulated traffic data	693/27/27; 2007; I-693,New York	Dynamic	Simulated speed contour map
Chang and Rochon (2009)	Incident	19,309/ 702/ 702; 2010; CHART	Static	2 h + 2 miles; 0.5 h + 0.5 mile for opposite direction
Kopitch and Saphores (2011)	Incident	9,549/528/528; 2008; Orange county, CA	Static	2 miles upstream and 2 h
Green et al. (2012)	Crash data	9,330/362/362; 2009–2010; Kentucky's highway	Static	80 min; 6000 ft upstream and 1000 ft downstream
Khattak et al. (2012)	Incident	37,934/736/764; 2006; Hampton road, Virginia	Dynamic	Segment code; 1 mile, PC duration (+ 15 min if lane blocked)
Vlahogianni et al. (2012)	Incident + monitor + sensor data	1,465/51/51; 2007–2010; Attica Tollway, Greece	Dynamic	Dynamic threshold by upstream loop detector using ASDA
Chung (2013)	Crash + sensor data	6,200/ 182/ 212; 2001–2002; Orange county, California	Dynamic	Dynamic crash impact area using speed contour map
Yang et al. (2013b) and Yang et al. (2014aYang et al., 2014b	Crash + sensor data/virtual sensor data	1,118/ 71/ 100; 2011; 27-mile highway, New Jersey 2011	Dynamic	Representative speed contour map
Zheng et al. (2014)	Crash + hourly volume data + detailed network	7,034/67/79; 2010; 1,500-mile freeways in Wisconsin	Dynamic	Shockwave model
Imprialou et al. (2014)	Incident + monitor + sensor data	1,287/126/ 17–68; 2007–2009; Attica Tollway, Greece	Dynamic	ASDA, Real influence area method
Jalayer et al. (2015)	Crash data	NA/ NA/ NA; 2010-2013; CARE in Alabama	Static	2 miles; 2 h
Mishra et al. (2016) and Sarker et al. (2017)	Crash data + lane specific traffic sensor data	91,325/528/570; 2010–2012; Shelby county, Tennessee	Dynamic	Dynamic simple shockwave
Wang et al. (2016)	Detailed crash data + loop data	49,753/204/209; 2010–2012; interstate freeway, California	Dynamic	Spatio-temporal shockwave with 1 speed turning point
Tian et al. (2016)	Incident + crash data	NA/ NA/326; 2010; Interstate highways, Florida	Static	2 miles; 2 h or 15/30 min + clearance
Park and Haghani (2016a,2016b) and Park et al. (2017)	Incident + INRIX data	1,150/125/125; 2012–2013; INRIX data along I-695 corridor	Dynamic	Binary speed contour plot map
Xu et al. (2016)	Crash + PEMS data	8978/97/113; 2006–2010; I880 freeway, California	Dynamic	Speed contour plot map
Yang et al. (2017b) and Yang et al., 2018	Crash + probe vehicle data	Simulated incidents and probe vehicle data	Dynamic	Clustered trajectories and optimized boundary of impact area
Goodall (2017)	Incident + RITIS data	2,466/ 340/ 340; 2014; RITIS on I-66	Dynamic	Speed contour plot with incident timeline

Note: CARE: crash analysis reporting environment; CHART: coordinated highways action response team; RITIS: Regional Integrated Transportation Information System; INDOT: Indiana Department of Transportation.