Accident Analysis and Prevention 117 (2018) 21–31

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Crash sequence based risk matrix for motorcycle crashes

Kun-Feng Wu[a,*], Lekshmi Sasidharan[b], Craig P. Thor[c], Sheng-Yin Chen[a]

[a] Department of Transportation and Logistics Management, National Chiao Tung University, Taiwan
[b] School of Mathematical and Statistical Sciences, University of Texas-Rio Grande Valley, Edinburg, Texas, USA
[c] Turner-Fairbank Highway Research Center, Federal Highway Administration, United States

ARTICLE INFO

Keywords:
Traffic safety
Risk matrix
Motorcycle crashes
Sequence of events

ABSTRACT

Considerable research has been conducted related to motorcycle and other powered-two-wheeler (PTW) crashes; however, it always has been controversial among practitioners concerning with types of crashes should be first targeted and how to prioritize resources for the implementation of mitigating actions. Therefore, there is a need to identify types of motorcycle crashes that constitute the greatest safety risk to riders - most frequent and most severe crashes. This pilot study seeks exhibit the efficacy of a new approach for prioritizing PTW crash causation sequences as they relate to injury severity to better inform the application of mitigating countermeasures. To accomplish this, the present study constructed a crash sequence-based risk matrix to identify most frequent and most severe motorcycle crashes in an attempt to better connect causes and countermeasures of PTW crashes. Although the frequency of each crash sequence can be computed from crash data, a crash severity model is needed to compare the levels of crash severity among different crash sequences, while controlling for other factors that also have effects on crash severity such drivers' age, use of helmet, etc. The construction of risk matrix based on crash sequences involve two tasks: formulation of crash sequence and the estimation of a mixed-effects (ME) model to adjust the levels of severities for each crash sequence to account for other crash contributing factors that would have an effect on the maximum level of crash severity in a crash. Three data elements from the National Automotive Sampling System - General Estimating System (NASS-GES) data were utilized to form a crash sequence: critical event, crash types, and sequence of events. A mixed-effects model was constructed to model the severity levels for each crash sequence while accounting for the effects of those crash contributing factors on crash severity. A total of 8039 crashes involving 8208 motorcycles occurred during 2011 and 2013 were included in this study, weighted to represent 338,655 motorcyclists involved in traffic crashes in three years (2011–2013)(NHTSA, 2013). The top five most frequent and severe types of crash sequences were identified, accounting for 23 percent of all the motorcycle crashes included in the study, and they are (1) run-off-road crashes on the right, and hitting roadside objects, (2) cross-median crashes, and rollover, (3) left-turn oncoming crashes, and head-on, (4) crossing over (passing through) or turning into opposite direction at intersections, and (5) side-impacted. In addition to crash sequences, several other factors were also identified to have effects on crash severity: use of helmet, presence of horizontal curves, alcohol consumption, road surface condition, roadway functional class, and nighttime condition.

1. Introduction

Recent studies have reported that there is a steady increase in the use of motorcycles and other powered-two-wheelers (PTWs), primarily in Asia, South America, Southern Europe, and in the United States (e.g. Manan and Várhelyi, 2012; WHO, 2015). In the US, these riders have a 27-fold higher probability of death than people driving other types of vehicles (NHTSA, 2016). There has been considerable research conducted concerning with the causes and countermeasures for motorcycles and other PTW crashes (e.g. Preusser et al., 1995; Lin and Kraus, 2009; Haque et al., 2009; Pai, 2009; Vlahogianni et al., 2012; Manan, 2014). However, it always has been controversial among practitioners concerning which types of crashes should be first targeted and which countermeasure needs to be installed first to effectively reduce motorcycle crashes and associated fatalities and injuries. Therefore, there is a gap in our understanding of the types of motorcycle crashes that pose the greatest safety risk; crashes that occur most frequently and have most severe outcomes. This is critical to prioritize resources for implementating mitigating actions.

The analyses commonly referred to as crash characterization

* Corresponding author.
E-mail addresses: kfwu@nctu.edu.tw (K.-F. Wu), lekshmi.sasidharan@ivt.baug.ethz.ch (L. Sasidharan), Craig.Thor@dot.gov (C.P. Thor).

https://doi.org/10.1016/j.aap.2018.03.022
Received 16 January 2017; Received in revised form 23 February 2018; Accepted 23 March 2018

analysis is critical not only for studying how and why crashes occur, but also for developing targeted countermeasures (e.g. Snyder and Knoblauch, 1971; Knoblauch, 1977; Cross and Fisher, 1977; Retting et al., 1995; Preusser et al., 1994; Preusser et al., 1995; Wu et al., 2016). Nevertheless, the crash typing employed in crash databases include over-simplified description of the events, such as head-on, sideswipe, rear-end, angle, and hit fixed-object. This approach is limited in its ability to serve as an informative resource as it only provides information on crash severity (e.g. head-on crashes are associated with most severe outcomes and rear-end crashes usually have the least severe outcomes) and provides almost no information on how a crash generating process, hereafter referred to as crash sequence, can be addressed. This study proposes the use of a risk matrix based on crash sequences to not only classify the crashes in terms of their frequency and severity, but also to better connect causes and countermeasures of PTW crashes. This in turn will help to identify high frequency, high severity crashes and thereby prioritizing the countermeasure applications.

1.1. Motorcycle and other powered-two-wheelers (PTW) safety management

Significant research has been conducted on different factors related to motorcycle and other PTW crashes (e.g. Preusser et al., 1995; Lin and Kraus, 2009; Haque et al., 2009; Pai, 2009; Vlahogianni et al., 2012). A thorough review was conducted to classify these risk factors using a Haddon matrix, including human/driver behavior, road-infrastructure/environment, and vehicle related risk factors in terms of pre-event, event, and post event stages (Lin and Kraus, 2009; Vlahogianni et al., 2012). Lin and Kraus (2009) further identified a set of modifiable factors such as helmet wearing, alcohol and other drug use, inexperience and lack of proper driver training, conspicuity of the motorcycle and rider, licensure and ownership, riding speed, and risk-taking behaviors as factors increasing the risk of crash occurrence and severity. Previous studies have reported several crash contributing factors associated with motorcycle crashes and consequently proposed countermeasures. However, it always has been controversial among practitioners regarding which types of crashes should be targeted first and which countermeasure needs to be installed first to effectively reduce motorcycle crashes and associated fatalities and injuries. In today's world of limited safety budgets, it is also important to maximize the return of safety investment. Therefore, from a practitioner's perspective, there is a need to identify types of motorcycle crashes with the greatest safety threat in order to prioritize resource allocation.

It is true that not all traffic crashes can be eliminated all at once, and not all conceivable countermeasures are economically feasible. From a practical standpoint, many organizations and agencies have adopted a safety management procedure to systematically assess and control potential hazards that could have adverse consequences. This involves different steps including identifying hazards, constructing a risk matrix, analyzing causes and risk factors, and implementing countermeasures. A risk matrix is a table that has several categories of likelihood or frequency for its rows and several categories of severity for its columns (Cox, 2008), as shown in Table 1. A risk assessment matrix is useful to assess risks and set priorities in addressing potential hazards (e.g. Federal Highway Administration (FHWA), 2006; Federal Aviation Administration (FAA, 2007). FHWA constructed a risk matrix to address issues as diverse as unexpected geotechnical problems at bridge piers to the unwillingness of landowners to sell lands near critical road junctions (FHWA, 2006). In order to ensure a steady improvement in the level of aviation safety the FAA implemented a procedure for hazard identification and risk assessment based on a risk matrix as part of the safety management system (SMS), (FAA, 2007). One of the major goals of developing a risk matrix is to identify the most frequent and severe hazards and develop countermeasures to mitigate the risks accordingly. The use of a risk matrix has been adopted extensively in practice to set priorities and guide resource allocation, and has been recommended in national and international standards (e.g. ISO39001) (Cox, 2008).

In terms of road traffic safety management, a similar concept, the systemic approach, has been proposed by the Federal Highway Administration (FHWA) to complement the "hot-spot "approach. The systemic approach is more cost-effective than the traditional hot-spot approach (Sawyer et al., 2011; Preston et al., 2010; Wu et al., 2013; Aguero-Valverde et al., 2016) because it considers targeted crashes, i.e. those most frequent and severe crashes, as shown in Table 1, when identifying sites with promise. This information is combined with roadway inventory and other crash data to identify high risk features where those countermeasures can be deployed effectively to mitigate those target crashes (Sawyer et al., 2011).

1.2. Crash sequences

A large proportion of crashes are the result of a confluence of factors, and most crashes are caused by more than one factor (Treat et al., 1979; Shinar, 2007; Wu and Thor, 2015). There are many factors associated with crash risk, and they contribute to crash occurrence or severity at different stages in a crash, i.e. the crash progression (Wu and Thor, 2015). As crashes are usually the result of multiple factors, construction of a risk matrix based on collision types such as head-on, rear-end, sideswipe, angle, and fixed object, would not result in good safety investment. Instead, an advantage of studying crash sequence is to identify the causative chain that leads to the occurrence of crashes and subsequently the identification of effective countermeasures that may feasibly mitigate crash risk (Wu and Thor, 2015).

It is helpful to discuss a crash sequence with the aid of an example. Consider a hypothetical example illustrated in Fig. 1, where the subject vehicle (SV-motorcycle) follows the leading vehicle (LV) too closely, and the LV is initiating an emergency brake event. Three crash outcomes are plausible, depending on which evasive maneuver is taken:

(1) SV follows too closely - LV decelerates - SV changes lane and collide with Vehicle 2- resulting in a sideswipe crash.
(2) SV follows too closely - LV decelerates, although SV also decelerates, the rider cannot stop in time, resulting in a rear-end crash.
(3) SV follows too closely - LV decelerates - SV swerves to the shoulder but subsequently losses control and hits a roadside object, resulting in a roadway departure crash.

As illustrated by this example, without information on the sequence of events, this crash would have only been classified as a (1) head-on,

Table 1
An Example of a Risk Matrix.

Crash Frequency	Crash Severity				
	Low ←				→ High
Frequent					
↑					
↓					
Infrequent					