Accident Analysis and Prevention 85 (2015) 157–169

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

What are the differences in driver injury outcomes at highway-rail grade crossings? Untangling the role of pre-crash behaviors

Jun Liu[a,*], Asad J. Khattak[b], Stephen H. Richards[c], Shashi Nambisan[d]

[a] Department of Civil and Environmental Engineering, The University of Tennessee, 311 John Tickle Building, Knoxville, TN 37996, United States
[b] Department of Civil and Environmental Engineering, The University of Tennessee, 322 John Tickle Building, Knoxville, TN 37996, United States
[c] Center for Transportation Research, The University of Tennessee, 309 Conference Center Building, Knoxville, TN 37996, United States
[d] Department of Civil and Environmental Engineering, The University of Tennessee, 320 John Tickle Building, Knoxville, TN 37996, United States

ARTICLE INFO

Article history:
Received 6 March 2015
Received in revised form 23 July 2015
Accepted 8 September 2015
Available online 1 October 2015

Keywords:
Grade crossing
Pre-crash behavior
Injury severity
Controls
Path analysis
Data imputation

ABSTRACT

Crashes at highway-rail grade crossings can result in severe injuries and fatalities to vehicle occupants. Using a crash database from the Federal Railroad Administration ($N = 15{,}639$ for 2004–2013), this study explores differences in safety outcomes from crashes between passive controls (Crossbucks and STOP signs) and active controls (flashing lights, gates, audible warnings and highway signals). To address missing data, an imputation model is developed, creating a complete dataset for estimation. Path analysis is used to quantify the direct and indirect associations of passive and active controls with pre-crash behaviors and crash outcomes in terms of injury severity. The framework untangles direct and indirect associations of controls by estimating two models, one for pre-crash driving behaviors (e.g., driving around active controls), and another model for injury severity. The results show that while the presence of gates is not directly associated with injury severity, the indirect effect through stopping behavior is statistically significant (95% confidence level) and substantial. Drivers are more likely to stop at gates that also have flashing lights and audible warnings, and stopping at gates is associated with lower injury severity. This indirect association lowers the chances of injury by 16%, compared with crashes at crossings without gates. Similar relationships between other controls and injury severity are explored. Generally, crashes occurring at active controls are less severe than crashes at passive controls. The results of study can be used to modify Crash Modification Factors (CMFs) to account for crash injury severity. The study contributes to enhancing the understanding of safety by incorporating pre-crash behaviors in a broader framework that quantifies correlates of crash injury severity at active and passive crossings.

1. Introduction

Safety at highway-rail grade crossings remains an important societal concern in the United States, as well as other parts of the world. Crashes occurring at grade crossings can result in severe injuries and fatalities to vehicle occupants. Safety effectiveness of crossing controls is also important in tort liability that results from crashes. According to 2013 Federal Railroad Administration (FRA) crossing inventory database, the United States has 133,825 reported public crossings, as opposed to 82, 921 crossings located on private property, highway-railroad (vehicle) grade crossings. Of these public vehicle grade crossings, 64,626 (48.3%) are passive crossings. Such crossings are those fitted with only passive warning devices (e.g., Crossbuck and STOP signs, pavement markings and advanced warning signs) that deliver static warnings, guidance, and, in some instances, mandatory action for the driver. The remaining 69,199 (51.7%) public grade crossings are active crossings, which are additionally fitted with active traffic control devices (e.g., gates, flashing lights and bells) that provide variable messages to motorists, indicating whether or not a train is approaching or occupying a crossing (Ogden, 2007).

During 1981–2013, the number of crashes at highway-rail grade crossings has reduced by 77.8% (FRA, 2013). The decreases are typically attributed to the upgrading from passive to active crossings and the improvements made on active grade crossings (Meeker et al., 1997; Millegan et al., 2009; Lenné et al., 2011). Compared with passive controls (STOP signs and Crossbucks), active control devices (flashing lights and gates) have shown lower crash rates (Raub, 2009). This is mainly due to the potential for active controls to gain additional driver attention and lead to greater compliance (Meeker et al., 1997). Although crash frequency has declined over

* Corresponding author.
E-mail addresses: jliu34@utk.edu (J. Liu), akhattak@utk.edu (A.J. Khattak), stever@utk.edu (S.H. Richards), shashi@utk.edu (S. Nambisan).

http://dx.doi.org/10.1016/j.aap.2015.09.004
0001-4575/

Table 1
Selected studies on crash frequencies/rates.

Authors, year	Methodology	Crossing controls	Key findings
Millegan et al., 2009	Negative binomial	STOP signs vs. Crossbucks	STOP signs → 46.95% lower crash rates
Yan et al., 2010a,b	Logistic regression	STOP signs vs. Crossbucks	STOP signs → less "did not stop" and "stopped on crossing" behaviors STOP signs → higher crash rate reductions at higher volume crossings
Yan et al., 2010a,b	Hierarchical tree-based regression model	STOP signs vs. Crossbucks	STOP signs → varying crash rate reductions at different conditions
Raub, 2006	Descriptive statistics	STOP signs vs. Crossbucks	STOP signs → 60% higher crash rates by cross-sectional comparison STOP signs → 28% higher crash rates by before-and-after comparison
Mok and Savage, 2005	Negative binomial	Active vs. passive controls	Active controls → Lower crash frequencies
Raub, 2009	Descriptive statistics	Active (gates and flashing lights) vs. passive controls (STOP and Crossbuck signs)	Gates → 4.1 crashes per 10 MCV Flashing lights → 5.1 crashes per 10 MCV STOP signs → 37.4 crashes per 10 MCV
Park and Saccomanno, 2005	Poisson regression	Gates vs. passive signs Flashing lights vs. passive signs	Gates (vs. passive signs) → CMF = 0.34 Flashing lights (vs. passive signs) → CMF = 0.26
Saccomanno et al., 2007	Empirical Bayesian	Bells vs. flashing light crossings	The addition of bells → CMF = 0.45
Austin and Carson, 2002; Elvik and Vaa, 2004; Elvik et al., 2009	Poisson regression Negative binomial Meta-analysis	Flashing lights vs. passive signs Gates vs. flashing lights and bells Gates vs. passive signs	Flashing lights (vs. passive signs) → CMF = 0.49 Gates (vs. flashing lights and bells) → CMF = 0.55 Gates (vs. passive signs) → CMF = 0.33

Note. CMF = Crash Modification Factor.

the years, it is notable that fatality rates (per crash) at grade crossings have increased, from 7.7% in 1981 to 11% in 2013, as have injury rates (FRA, 2013). While studies have pointed out clear relationships between crash frequencies and associated factors, and explored correlates of crash frequencies (Oh et al., 2006), it is still unclear what key factors, especially crossing controls, contribute to the severity of outcomes (e.g., lower or higher injuries) and the behavioral mechanisms that lead to injuries, given a crash.

The main objective of this study is to investigate relationships between safety outcomes and various crossing controls, and answer how differences in safety outcomes between active and passive traffic control at highway-rail grade crossings are associated with drivers' actions prior to the event of a crash, called pre-crash behaviors.

2. Literature review

Researchers aim to reveal what types of controls at grade crossings are effective in improving crossing safety, i.e., reducing crash frequencies/rates, or lowering crash injury severity. Tables 1 and 2 summarize relevant studies that focused on the examination of crossing control effectiveness, in terms of crash frequencies/rates or crash injury severity.

2.1. Crash rates

Many studies have compared crash rate at passive controls and active controls (Austin and Carson, 2002; Elvik and Vaa, 2004; Mok and Savage, 2005; Park and Saccomanno, 2005; Raub, 2006; Saccomanno et al., 2007; Elvik et al., 2009; Millegan et al., 2009;

Table 2
Selected studies on crash injury severity and behavioral considerations.

Authors, year	Methodology	Crossing controls	Behavioral considerations	Key finding
Raub, 2006	Descriptive statistics	Yes	No	STOP signs → 12.4% crashes were fatal Gates → 31.8% crashes were fatal Flashing lights → 25% crashes were fatal
Eluru et al., 2012	Ordered logit model (Latent segmented)	Yes	Yes	Gates → Lowest injury severity Flashing lights (vs. STOP signs) → Higher injury severity Drove around or through the gates → Higher injury severity
Cooper and Ragland, 2012	Descriptive statistics	Yes	Yes	Gates → 8.8% crashes were fatal Drove around gates → 20.6% crashes were fatal
Hao and Daniel, 2014	Descriptive statistics for the control and injury severity Ordered probit model for other factors	Yes	No	Active controls → 9.11% crashes were fatal Passive controls → 6.82% crashes were fatal Higher train/vehicle speed → higher injury severity
Hu et al., 2010	Generalized logit model	No	No	No findings on crossing controls Law enforcement cameras → lower injury severity
Russo and Savolainen, 2013	Ordered logit model	No	Yes	No findings on crossing controls Did not stop → Higher injury severity Higher train/vehicle speed → Higher injury severity Older drivers, females → Higher injury severity
Fan and Haile, 2014	Multinomial logit model	No	No	Higher train/vehicle speed → Higher injury severity
Zhao and Khattak, 2015	Multinomial logit model Ordered probit model Random parameter logit model	No	No	No findings on crossing controls Ordered probit model is less suitable for modeling injury severity than other two models Higher train/vehicle speed → Higher injury severity Older drivers, females → Higher injury severity