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Gate-violation behavior at highway-rail grade crossings and the consequences: Using geo-Spatial modeling integrated with path analysis

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ABSTRACT

Drivers undertaking risky behaviors at highway-rail grade crossings are often severely injured in collisions with trains. Among these behaviors, gate-violation (referring to driving around or through the gates that were activated and lowered by an approaching train) seems to be one of the most dangerous actions a driver might take at a gated crossing; it may compromise the intended safety improvement made by adding gates at crossings. This study develops a nuanced conceptual framework that uses path analysis to explore the contributing factors to gate-violation behaviors and the correlation between gate-violation behaviors and the crash consequence − the driver injury severity. Further, using geo-spatial modeling techniques, this study explores whether the correlates of gate-violation behaviors and their associations with injury severity are stationary across diverse geographic contexts of the United States. Geo-spatial modeling shows that the correlates of gate-violation and its associations with injury severity vary substantially across the United States. Spatial variations in correlates of gate-violation and injury severity are mapped by estimating geographically weighted regressions; the maps can serve as an instrument for screening safety improvements and help identify regions that need safety improvements. For example, the results show that two-quadrant gates are more likely to have gate-violation crashes than four-quadrant gates in Iowa, Illinois, Wisconsin and Minnesota. These states may need to receive more attentions on the enforcement of inhibiting gate-violation at crossings with two-quadrant gates or have the priority over other states to upgrade these crossings to four-quadrant gates if financially feasible.

1. Introduction

Gates are special highway traffic control devices at highway-rail grade crossings: when activated (i.e., lowered), gates can physically separate highway users from trains passing the crossing, and intend to make it difficult for highway users to enter the crossing right-of-way (Lenné et al., 2011). Other traffic control devices, such as flashing lights, bells and signs, do not provide physical barriers that can stop highway users passing the crossing but only warn highway users about the approaching train. In terms of crash frequency, gates have been generally believed as safer control devices at highway-rail grade crossing than other types of crossing controls, found in literature and supported by historical safety statistics about grade crossings (Austin and Carson, 2002; Elvik and Vaa, 2004; Park and Saccomanno, 2005; Elvik et al., 2009; Raub, 2009). Therefore, gates have been widely equipped at highway-rail grade crossings, especially crossings with high-speed train operation, limited sight distance, and/or high-volume highway and rail traffic (Ogden, 2007). According to the recent national crossing inventory database, over one third of public crossings in the United States have been installed with gates (FRA, 2015a,b).

Though gates are consistently revealed to relate to reduced crash frequencies, it is still uncertain whether gates are also associated with less severe crashes. Without doubts, gates can provide physical barriers to reduce the chance of a highway vehicle colliding with a train. However, some drivers (perhaps due to anxiety about being late for an important appointment or meeting) may intentionally violate the lowered gates by going around gates and consequently a severe crash occurs. Thus, the behavior of gate-violation at a gated crossing may compromise the intended safety improvement made by adding gates at crossings. A previous study by Liu et al. (2015) revealed that gate-violation relates to a higher level of injury severity than other driver actions prior to a crash at a grade crossing. Other actions include "stopped and then proceeded", "did not stop", "stopped on crossing", and other behaviors (such as suicide, went around or through temporary barricade, and unclassified behaviors), as reported in Highway-Rail Grade Crossing Accident/Incident Report – Form 6180.57 (see http://safetydata.fra.dot.govhttp://safetydata.fra.dot.gov). Gate-violation is a special type of driver behaviors that only occur at crossings

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equipped with gates. The scope of this study is limited to crashes at gated crossings.

It remains unclear what contributing factors are associated with gate-violation at a gated crossings and the severity of injuries sustained by a driver in a gate-violation crash. In other words, the behavioral pathways (factors → gate-violation → injuries) that lead to injuries are under-explored. Further, it is also not clear how the correlates of gate-violation behaviors and their correlations with injury severity vary across the diverse landscape of the United States. Revealing the spatial patterns of risky behaviors and crash outcomes is important when transportation practitioners need to prioritize certain geographic regions for safety improvements. The Highway Safety Manual (HSM) synthesizes many studies on highway safety (AASHTO, 2010), but rail crossing safety is sparsely covered. HSM's Crash Modification Factors (CMFs) do not cover crash types or injury severity for rail grade crossings (Gross and Persaud Lyon, 2010). Neither does it consider whether risk factors and CMFs vary across geographies. Using geo-spatial modeling techniques integrated with path analysis, this study develops a valuable safety screening tool that provide safety improvement implications for specific geographic regions from the perspective of driver behaviors.

This study offers several contributions. Theoretically, it illustrates a way to explore behavioral pathways that lead to injuries in transportation crashes. Methodologically, the study integrates the methods of path analysis and spatial modeling to explore the increasingly available geo-referenced data. The methodology presented in this study takes full advantage of modern computational power of computers and results in a screening tool for safety improvements across geographies. Empirically, this study delivers new insights in the correlates of injury severity in gated crossing crashes.

2. Literature review

Attempting to reduce the occurrence and severity of crashes, many studies have focused on safety issues at highway-rail grade crossings (Horton et al., 2003; Raub, 2009; Rudin-Brown et al., 2012; Khattak, 2013a,b; Russo and Savolainen, 2013; Liu et al., 2014; Fan et al., 2015; Hao and Daniel, 2014; Liu et al., 2015; Liu et al., 2016a,b). Researchers believe that installing or upgrading traffic controls can be effective countermeasures for safety improvements at a grade crossing. Active traffic control devices (gates, flashing lights, and bells) are found to be associated with a lower collision rate when compared to passive control devices (stop, yield, and crossbuck signs) (Lenné et al., 2011; Liu et al., 2015). Further, within active devices, gates are found to be associated with an even lower collision rate (Austin and Carson, 2002; Elvik and Vaa, 2004; Park and Saccomanno, 2005; Ogden, 2007; Elvik et al., 2009; Raub, 2009). However, in terms of crash severity, it is uncertain whether gates are associated with less severe crashes. Raub (2006) found 31.8% of crashes at gated crossings were fatal, as opposed to 12.4% for STOP sign crossings and 25% for flashing lights crossings. Researchers have realized the role of driver behaviors, especially the risky actions such as gate-violation, at grade crossings. Witte and Donohue (2000) reported that 10%-20% of drivers are likely to go around gates that are already activated and lowered. Cooper and Ragland (2012) revealed that gated crossings seem to be tied with a higher chance of fatality than other crossings: they found 20.6% of gate-violation crashes were fatal. The authors for a previous study (Liu et al., 2015) also found that "drove around or through the gates" is the most dangerous pre-crash action, in terms of injury severity given a crash at a grade crossing.

Though some studies (Raub, 2006; Cooper and Ragland 2012) implied gated crossing crashes were more likely to be fatal, some other researcher may not agree with it. Eluru et al. (2012) and Liu et al. (2015) found that crashes at gated crossings were overall related to the least injury severity, compared with other crossing crashes. One possible reason that different conclusions were made may be because the data used by these studies were from different geographic regions: Raub (2006) investigated crashes in seven Midwestern States; Cooper and Ragland (2012) analyzed the crashes that occurred in California; and Eluru et al. (2012) and Liu et al. (2015) modeled crashes covering the entire country of the United States. Therefore, correlates of injury severity with associated factors may vary from one region to another. The variation is probably due to the influences of unobserved spatial heterogeneity that relates to the diverse geographic contexts across the country (Liu et al., 2017a,b).

Few studies have examined the spatial patterns of grade crossing crashes. Some studies have discussed the spatial patterns of transportation crashes in other contexts (LaScala et al., 2000; Graham and Glaister, 2003; Meliker et al., 2004; Noland and Quddus, 2005; Aguero-Valverde and Jovanis, 2006; Quddus, 2008; Wang et al., 2009). Geographically Weighted Regression (GWR) is one of popular spatial analytic techniques and helps researcher understand the spatially varying correlations between factors across geographic regions (Brunsdon et al., 1998). Wang et al. (2016) examined the spatially correlates of railway trespassing crash injuries by applying GWR and found that the injury correlates with factors such as the gender and behaviors of trespassers vary significantly across the United States. More studies that applied GWR for crash analysis can also be found in literature (Hadayeghi et al., 2010; Li et al., 2011; Wang et al., 2011; Li et al., 2013; Pirdavani et al., 2014; Khattak et al., 2013; Liu et al., 2016a,b; Liu et al., 2017a,b). The results of spatial analysis can be used to prioritize certain geographic regions for safety improvements. For example, gates are found to be generally associated with a lower injury severity than other control devices at a grade crossing. The spatial analysis finds in some regions the associations (i.e., magnitudes of estimated coefficients) are even greater than other places. Thus, these regions may be prioritized to install gates at grade crossings.

Further, most abovementioned studies only revealed the direct relationships between the crashes and associated factors. This study aims to reveal behavioral pathways (i.e., factors that are associated with gate-violations, which in turn are associated with injuries, given a crash) that lead to injuries; the injuries and associated factors can be indirectly linked through the gate-violation behavior. To sum up, taking the spatial-modeling advantages, this study develops a unique methodology to untangle the spatially varying pathways that lead to injuries in gated crossing crashes.

3. Data

3.1. Data extraction

The data are from two major databases: highway-rail grade crossing accidents/incidents and highway-rail grade crossing inventory, managed by Federal Railway Administration (FRA), available at http://safetydata.fra.dot.gov/http://safetydata.fra.dot.gov/. Ten years (2005–2014) of crash data were extracted from the database of highway-rail grade crossing accidents/incidents. This database covers all reported crashes/incidents that occurred at highway-rail grade crossings; these crashes/incidents were originally reported by investigators filling up the form – FRA Form 6180.57. The form allows investigators to provide details about individual crashes at highway-rail grade crossings, including highway user information, crossing control devices (of the day), crash contexts (weather, time of day, etc.), train speeds, and highway vehicle speeds. In particular, Form 6180.57 documents the highway vehicle driver actions prior to a crash. Reported actions include "went around the gate", "went through the gate", "stopped and then proceeded", "did not stop", "stopped on crossing", and other behaviors (such as suicide or attempted suicide, went around or through temporary barricade, and unclassified behaviors). This study treats the actions of "went around the gates" and "went through the gates" as gate-violation. The crash/incident records indicated as "suicide or attempted suicide" were removed from the analysis.