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How big data serves for freight safety management at highway-rail grade crossings? A spatial approach fused with path analysis

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ABSTRACT

Future vehicle warning systems needs a local (instead of global) analysis of real-time information transmitted between vehicles and infrastructures, to provide local warning information matching the instantaneous driving contexts. Spatial modeling techniques extracting the location information into the analysis fulfill the needs of local analysis. For truck-involved collisions at highway-rail crossings, the local warnings seem to matters more, than for traffic crashes at the normal highway segments and regular intersections. Crashes at rail grade crossings can result in severe injuries and fatalities to vehicle occupants, while truck-involved crashes at crossings can further result in serious damage to train, crossing and railway equipment. Truck-involved crashes at grade crossings have received limited attention compared with crashes involved with passenger cars. This study presents a methodology of improving safety of trucks at railroad crossings, by taking advantage of the big data containing location information. Unlike previous studies that constructed a direct relationship between the safety outcomes and associated factors, this study investigates direct relationships together with indirect relationships through the truck driver behaviors before collisions, using path analysis techniques. To sum up, this study applies a spatial approach fused with path analysis to uncover the local relationships between truck driver injury severity and crossing controls across the space. By doing so, the research is able to: i) provide a benchmark of identifying potentially risky vehicles on a real time basis; ii) evaluate current control devices at railroad crossing across the country and pin point the potentially problematic crossing sites. An empirical study was conducted by using a rich crash database from the Federal Railroad Administration ($N=4738$ for 2004–2014). The results show that truck-involved crashes occurring at crossings without gate controls are generally associated with higher chance of injury, while the associations vary significantly across the space. In general, crashes in the Midwest and Great Lake regions are associated with an even higher chance of injury at crossings without gates, compared with other regions. More Results and implications are discussed in the paper.

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1. Introduction

As the roll-out of the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) technologies, electronic sensors will be installed on connected vehicles to transmit data wirelessly between vehicles and nearby infrastructures. Such sensors make the data collection transit from conventional means (e.g., loop detector or video detections), to emerging means, such as Dedicated Short Range Communication (DSRC) devices. Measurements that are previously unknown are now available, which include but not be limited to: vehicle speeds, positions, arrival rates, rates of acceleration and deceleration, queue lengths, stopped time and complex information about the instantaneous driving contexts (location, road condition, traffic control device, etc.) [43–45]. These, referred to as big data, are valuable information that can generate significant traffic safety benefits when mined properly [44–47]. A great number of studies have investigated the benefits from an overall prospective, based an assumption that the correlates of traffic safety outcomes are stationary [26,48,49,55,61,63,78,81]. Few studies have been focused on exploring the non-stationary correlates, because of the unavailable location data. This study, taking advantage of the big data containing

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location information, answers an important research question – whether the correlates of traffic safety outcomes are stationary/non-stationary, through spatial modeling techniques. The answer matters to the transferability of safety improvement recommendations and the future connected vehicle warning systems. In terms of safety improvement recommendations, for example, a wine prohibition policy shows its great effectiveness on driving safety base on an overall examination in the country; however this policy may not be working within an area where residents do not drink wine but beers. For future connected vehicle warning systems, real-time information transmitted between vehicles and infrastructures need a local (instead of global) analysis of the information, to provide warning information matching the instantaneous driving contexts. For example, potential high risky vehicles can be pin pointed when they enter a dangerous zone at a risky speed. Warnings can be sent through DSRC devices and lives are saved on a real time basis.

Further, a great portion of traffic safety studies have been focused on the passenger vehicles at the normal highway segments and regular intersections [10,21,23,25,39–41,53,56,69,72,73,8], while the safety at highway-railroad grade crossings is fairly under-explored, especially for the freight vehicles. During 2004–2014, there were 26,274 collisions between highway users and trains at highway-rail grade crossings in United States, as reported by Federal Railway Administration [20]. Of these collisions, 6196 (23.58%) occurred between large trucks and trains. However, annually there were only about 10% (even less) of highway crashes involved with large trucks in the whole US highway system (BTS [6]). Unlike crashes involved with only passenger vehicles, truck-involved crashes at grade crossings can result in not only severe injuries and fatalities to vehicle occupants (mainly truck drivers), but also serious damage to train, crossing and railway facility [10,51,71,76,77]. In spite of its serious consequences, the truck–rail collision is under investigated.

By digging through the limited literature, it is discovered that mechanical condition of truck and train is not an influential factor, while driving behavior right before the collision is vital factor. For example, picking up phone call, no stopping before passing [51], or gate violation [29,31], they all increase the possibility of truck–rail collision. Most previous studies constructed a direct relationship between crash outcomes and associated factors [14,30,61,81]. However, behavior data is difficult to be collected on a large scale. Therefore, the past studies had two choices: one is to base analysis merely on descriptive, none vital factors, this is not ideal; the other choice is to collect limited behavior data and drawn conclusion based on that, these conclusions drawn based on limited sample size can be misleading. One way to improve the past analysis is to apply the path analysis technique and base the analysis on factors that influence human behavior and, at the same time, can be collected on a large big data scale. This way, reliable results can be concluded from a large number of sample size and vital behavior factors are considered. Therefore, this study explores using path analysis techniques to investigate direct factors together with indirect factors that lead to truck–rail collisions.

To sum up, this study aims to apply a spatial approach fused with path analysis to uncover the local relationships between truck driver injury severity and crossing controls across the space, by taking advantage of the big data containing location information and the massive computing power. By doing so, the research is able to: i) provide benchmark of identifying potential risky vehicles on a real time basis; ii) evaluate current control devices at railroad crossing across the country and pin point the potential problematic crossing sites.

2. Literature review

Given the objectives and the methodology of this study, this study conducts a comprehensive literature review in three categories: 1) highway-rail grade crossing safety studies; 2) driver behavioral observations at highway-rail grade crossings; 3) crash modeling techniques including the conventional crash models, path analysis and spatial modeling techniques.

2.1. Highway-rail grade crossing safety

The latest national highway-rail grade crossing inventories 133,825 public highway-rail grade crossings and 82,921 crossings located on private property in the United States [19]. To ensure the joint safety and efficient operation of both highway and railroad traffic at grade crossings, special highway traffic control devices, such as gates, flashing lights, bells, stop sign, crossbuck, pavement markings, and their combinations are regulated for installation at highway-rail grade crossings by Federal, State, and local authorities [15,52]. Increased research has been focused on examining the effectiveness of crossing control devices. Crash Modification Factor (CMF) or Crash Reduction Factor, defined as a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site, is used to index the safety effectiveness [24]. Elvik et al. gave a 0.55 CMF and reported a 45% crash reduction adding gates at crossings that previously had flashing lights and audible warnings [13]. Park et al. gave a 0.21 CMF and reported a 79% crash frequency reduction by upgrading passive crossings to flashing lights [54]. However, the majority of previous studies were focused on general highway traffic that includes passenger cars, trucks, buses, motorcycles, etc. Studies on specific category of highway users at highway-rail are few and truck safety at grade crossings is even more under-explored.

2.2. Driver behavioral observations

Comprehension and compliance are two major factors that affect safety at highway-rail grading crossing. To obey the rules, one must first understand them. A survey was conducted by Richards et al. to reveal divers' recognition and understanding of regular control devices on grade crossings [57]. A total of 176 drivers together with 35 city police officers were involved. It turns out that many commonly used control devices are badly perceived, such as crossbuck and flashing lights. Some drivers even have the impression that the train operator is supposed to decelerate or stop at the crossings to ensure safety [57]. Another survey with 829 licensed drivers was performed by Tidwell et.al. It reveals that the majority of the drivers are lack of knowledge regarding required actions at the crossings even with the knowledge of the grade crossings' dangerous nature [68]. Burnham's study confirms that over 80 percent of drivers do not fully understand the meaning of highway STOP sign place at railroad crossings [7]. To sum up, installation of traffic control devices at railroad crossings require thorough investigation and consideration to avoid unnecessary confusion and misinformation [28,37].

Intentional disobeying the rules is another major cause of the safety issues. It is reported that around 10-20% of drivers choose to "beat the train" even when traffic lights are flashing and the train is within sight [74]. This finding is confirmed by Tenkink et.al. that drivers do drive around the gates during the first six seconds of lights flashing [66]. It is also confirmed by Meeker et.al. with the observation of 60 violators at a grade crossing. One major reason for these violations is the poor credit of warning system. Many drivers rationalize their violation as "train was not in sight" or "the train was stopped to an unreasonable amount of time" [1]. There is a clear increase in the number of risky violation when warning time exceeds 30 s [58].