Severity of Pedestrian Crashes at Highway-Rail Grade Crossings

by Aemal Khattak and Li-Wei Tung

The objective of this research was to quantify the impacts of various factors on three different severity levels of pedestrian injuries sustained in crashes reported at highway-rail grade crossings. This research utilized the 2007-2010 crash and crossing inventory data. The three crash severity levels of pedestrians' injuries were: no injury, injury, and fatality.

Data analysis showed that pedestrian fatalities were associated with higher train speeds and with female pedestrians. Highway-rail grade crossings with a greater number of crossing lanes and those equipped with standard flashing light signals were associated with a lower likelihood of pedestrian fatalities.

INTRODUCTION

The objective of this research was to quantify the impacts of various factors on three different severity levels of pedestrian injuries sustained in crashes reported at highway-rail grade crossings (HRGCs). These severity levels were based on the intensity of pedestrians' injuries and included: no injury, injury, and fatality. HRGCs are conflict points between users of highways/streets and crossing trains. Since trains have the right of way at HRGCs, almost all crashes at these locations are the result of violations by highway/street users. The number of pedestrian crashes reported at HRGCs has increased by 55.4% over the 2001-2010 period. According to the Federal Railroad Administration (FRA), 2,017 crashes were reported at HRGCs in 2010 across the United States (FRA 2012a). Of these, 143 crashes involved pedestrians that resulted in 79 (55.2%) fatalities, 48 (33.6%) non-fatal injuries, and 16 (11.2%) no injuries.

Railroad companies report crashes at HRGCs on the FRA's Highway-Rail Grade Crossing Accident/Incident Report form (FRA F6180.57). As part of this form, narrative event descriptions are filed by involved railroad companies. Three such narratives from the 2010 HRGC crashes involving pedestrians highlight the three injury severity levels as well as show that crashes at HRGCs invariably result from encroachment of rail right-of-way by highway/street users:

- "An intoxicated pedestrian was struck by train while attempting to cross track at crossing. Pedestrian was hit by snow plow located on front of engine. After being struck pedestrian got back up and began to walk away from accident. He was detained by crew and checked out by EMS at the scene. No further medical attention needed" (incident number 000076300).
- "Train 798 moving north, 10 mph, across the 22nd street crossing in Fort Payne, AL when trespasser attempted to mount a moving rail car in the train and slipped and fell amputating his left foot" (incident number 039139).
- "Pedestrian was walking a dog eastbound through Coast Blvd crossing. Gates were down, lights and bells were working. Crew states man never looked up and continued through the crossing. Whistle was blowing continuously and train placed into emergency. Pedestrian was struck by front corner of locomotive and succumbed to his injuries one hour later" (incident number 04272010).

The organization of the remaining paper is as follows. After this introduction a brief review of pertinent literature on pedestrian injury severity at highway-rail crossings is given. The next section presents conceptualization of different variables affecting pedestrians' injury severity levels and data compilation. The ensuing section presents data analysis and results while conclusions and a brief discussion complete this paper.

LITERATURE REVIEW

A review of published literature uncovered publications dealing with pedestrian safety at HRGCs, although the possibility of less accessible reports held by railroad companies or government agencies exists. Lobb (2006) reported on the issue of train-pedestrian crashes and commented on the "remarkably" little research available on this topic. Lobb (2006) highlighted major types of railway crash research and suggested the use of behavioral and cognitive psychology to obtain insights into trespassing incidents.

Studies have shown that while crashes at HRGCs are relatively uncommon (compared with crashes on the rest of the highway system), such crashes are more likely to result in death or severe injuries (Goldberg et al. 1998, Evans 2003). Alcohol consumption on the part of pedestrians appears to play a role in train-pedestrian crashes; Pelletier (1997) reported 82% of trespasser fatalities in North Carolina tested positive for alcohol use while Cina et al. (1994) reported 80% of the fatalities in their study were intoxicated. It should be noted that these two studies were focused on trespassers not necessarily at HRGCs.

Silla and Luoma (2011) reported on the effects of fencing, landscaping, and use of message signs on reducing trespassing on rail tracks. Fencing was the most effective, reducing trespassing by 94.6% followed by landscaping, which reduced trespassing by 91.3%, while message signs reduced trespassing by 30.7%. The majority of illegal crossings were committed alone (i.e., not in the company of another person) and the violators were mostly adult males.

In another study, Silla and Luoma (2012) reported on the main characteristics of train-pedestrian fatalities on Finnish railroads. The 2005-2009 data showed that 311 pedestrians were killed in train-pedestrian collisions, including 264 (84.9%) suicides, 35 (11.3%) accidents, and 12 (3.9%) unclassified events. Male victims were the majority for each type of event. Most suicide victims were in the 20–29 year age group and, on average, younger than people who chose some other form of suicide. About half of all victims were intoxicated by alcohol, medicines, and/or drugs. Both suicides and accidents occurred most often at the end of the week but no specific peak for time of year was found. Crashes occurred most frequently during rush hours and in densely populated areas. The authors recommended a systems approach involving effective measures introduced by authorities responsible for urban planning, railways, education, and public health.

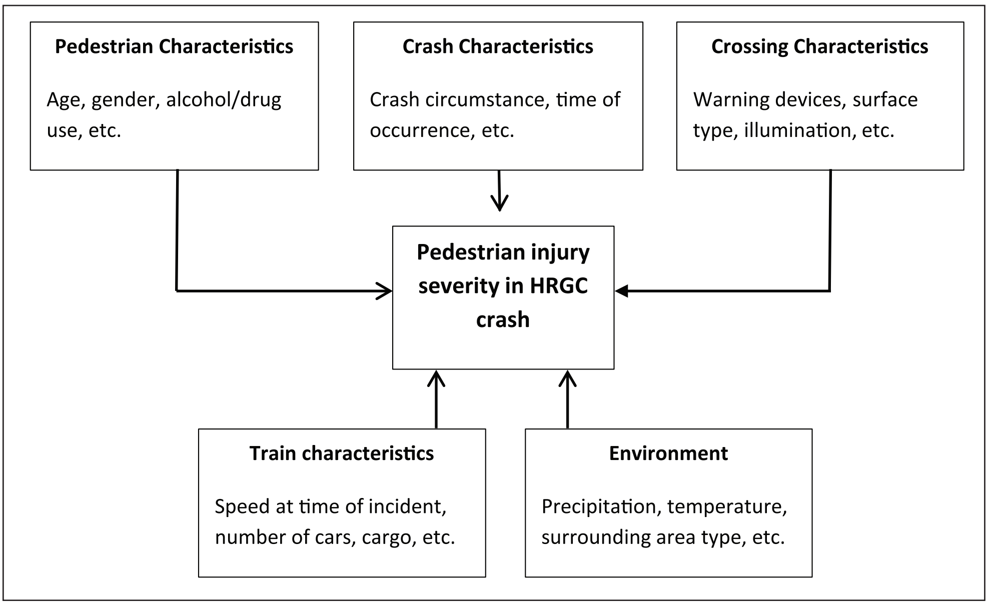
Transportation agencies responsible for public safety have produced guides for improving the safety of pedestrians at HRGCs. Transport Canada developed a pedestrian grade crossing safety guide (Transport Canada 2007) that provides different strategies on improving pedestrian safety at grade crossings. FRA also provided guidance on pedestrian safety crossings at or near passenger stations (FRA 2012b). Suggested safety-improving approaches included audible and visual warnings, infrastructure improvements, enforcement, and education of crossing users to improve pedestrian safety.

In summary, limited published literature is available on train-pedestrian crashes; of the available literature most is focused on trespassing pedestrians not necessarily at HRGCs. Prominent characteristics of train-pedestrian crashes include higher levels of injuries compared with other crashes, alcohol consumption by pedestrians, young adults, and male pedestrians. Some transportation agencies provide guidance on making HRGCs safer for pedestrians. However, this review of literature did not uncover publications dealing with severity levels of pedestrian injuries sustained in HRGC crashes. Knowledge of variables associated with different levels of pedestrians' injuries can potentially help with more informed decisions regarding safety improvements at HRGCs. This study attempts to quantify the impacts of different variables on severity levels of pedestrians' injuries sustained in HRGC crashes. The next section presents conceptualization of variables that may potentially impact injury severity levels of pedestrians and a description of the dataset compilation used for analysis presented herein.

CONCEPTUALIZATION AND DATA COMPILATION

A number of variables can potentially affect the severity of pedestrians' injuries. These were grouped in five categories: pedestrian characteristics, crash characteristics, crossing characteristics, train characteristics, and environment (Figure 1). Each category consists of multiple variables and ideally each variable should be analyzed for relevance to pedestrians' injury severity levels. However, available crash data collected using FRA form F6180.57 and crossing inventory data collected via FRA form F6180.71 limit the number of variables that may be investigated.

Figure 1: Conceptualization of Variables Affecting Pedestrians' Injury Severity



This research utilized the 2007-2010 HRGC crash data and the national highway-rail crossing inventory data. Both datasets were obtained from the FRA Office of Safety Analysis website: <http://safetydata.fra.dot.gov/officeofsafety/ default.aspx> (accessed June 18, 2012). Readers interested in details of data collection and measurement of different variables are referred to the FRA Guide for Preparing Accident/Incident Reports (FRA 2003) and the U.S. DOT Crossing Inventory Form Data File Structure and Field Input Specifications (FRA undated) or the more recent Guide for Preparing U.S. DOT Crossing Inventory Forms (FRA 2015) in lieu of the undated FRA document.

Crash data for 2007-2010 were combined (487 crashes) and then reduced to records pertaining to pedestrian crashes reported at public HRGCs (the crash database identifies pedestrians as a distinct type of highway user). However, these data included 47 crashes that were suicides or attempted suicides. These records were excluded from the data leaving 440 crashes involving pedestrians only. They were excluded because these crashes are the result of deliberate efforts on the part of the suicidal person and the underlying reasons are different than other (non-suicidal) crashes. Crash records contain limited grade crossing related information; more details are available in the national highway-rail crossing inventory data. Therefore, crash and highway-rail crossing inventory data files were merged together using the unique USDOT crossing identification number (available in both data files). The merging procedure produced 400 records of HRGC pedestrian crashes along with relevant HRGC details that were subsequently analyzed. Three pedestrian crash severity levels were obtained based on the intensity of their injuries: no injury (coded as 0 in the data), injury (coded as 1), and fatality (coded as 2). This variable was named "Severity" and it was the dependent variable in the analysis.

DATA ANALYSIS

Table 1 presents salient features of the final dataset as presentation of information on all variables in the dataset was not feasible. It contained many more fatal crashes than injury or no injury crashes, reflecting the ominous nature of HRGC crashes. About 76% of the crashes involved train speeds in excess of 26 miles per hour (mph) at the time of the incident. This speed is either estimated or obtained from the train recorder after an incident. About 95% of the crashes involved rail equipment (e.g., locomotives) striking pedestrians rather than the pedestrian striking rail equipment (e.g. a pedestrian running into or somehow pushed into a moving train).

Traversing highways consisted of two lanes at 64% of the rail crossings where crashes were reported; 65% of the involved pedestrians were male. Standard flashing light signals were installed at 72% of the crossings while the crossbuck sign (consisting of two wooden or metal slats in the shape of an X with Railroad Crossing printed) was present at 52% of the crossings. The incident crossings were located in different types of developments with 55% reported in commercial type areas. Concrete and asphalt were common types of crossing surfaces; relatively few crashes were reported occurring during cold (less than 32^{o}F) or hot (greater than 80^{o}F) temperatures, perhaps due to the presence of relatively few pedestrians during such temperatures. Analysis of this dataset was based on the ordered probit model, which is explained below. Readers familiar with this model may go to the subsection titled Modeling Results.

Table 1: Characteristics of HRGC Pedestrian Crash Data (n=400)

Variable	Description/categories	Frequency	Percent
Severity	Crash severity level		
	No injury	16	4.0
	Injury	142	35.5
	Fatality	242	60.5
Trnspd	Train speed at time of incident, mph		
	< 25 mph	96	24.0
	26-45 mph	155	38.8
	>45 mph	148	37.0
	Missing	1	0.3
Typacc	Crash circumstance		
	Rail equipment struck pedestrian	378	94.5
	Pedestrian struck rail equipment	22	5.5
Traficln	Number of traffic lanes at crossing		
	1 lane	5	1.3
	2 lanes	256	64.0
	3 lanes	21	5.3
	4 lanes	87	21.8
	> 4 lanes	31	7.6
Pedgen	Pedestrian gender		
	Female	73	18.3
	Male	258	64.5
	Unknown/Missing	69	17.3

Table 1 (continued)

Variable	Description/categories	Frequency	Percent
Gates	Crossing gates		
	Present	366	91.5
	Not present	34	8.5
Stdfls	Standard flashing light signals		
	Present	286	71.5
	Not present	114	28.5
Hwy_Sig	Highway signals		
	Present	23	5.8
	Not present	377	94.3
Xbux	Crossbuck sign		
	Present	192	48.0
	Not present	208	52.0
Develtyp	Type of area development		
	Open space	30	7.5
	Residential	90	22.5
	Commercial	220	55.0
	Industrial	48	12.0
	Institutional	12	3.0
Xsurface	Crossing surface type		
	Timber	72	18.0
	Asphalt	63	15.8
	Asphalt and flange	51	12.8
	Concrete	140	35.0
	Concrete and rubber	12	3.0
	Rubber	59	14.8
	Unconsolidated	3	0.8
Weather	Weather conditions		
	Clear	299	74.8
	Cloudy	78	19.5
	Rain	13	3.3
	Fog	5	1.3
	Snow	5	1.3
Temp	Temperature at time of incident (F)		
	0-32	36	9.0
	33-60	126	31.5
	61-80	178	44.5
	81-105	60	15.0

MODEL BACKGROUND

The dependent variable was injury severity level, which was ordinal in nature. Usual models to use for ordinal data are ordered probit/ordered logit and multinomial logit models. The analysis presented herein utilized the ordered probit model (the results from the ordered logit model are fairly similar). According to Long (1997), the ordered probit model can be derived from a measurement model in which a latent, unobservable, continuous variable y^* ranging from $-\infty$ to $+\infty$ is mapped to an observed ordinal variable, e.g., injury severity with three levels, denoted by y. Variable y* provides severity propensity and variable y is thought of as providing incomplete information about the underlying y* according to the measurement equation:

(1) $y_i = m$ if $\tau_{m-1} \le y_i^* < \tau_m$

Where the τ's are threshold points between the intervals. The extreme categories, 1 and J, are defined by open-ended intervals with $\tau_o = -\infty$ and $\tau_J = \infty$. The observed y is related to y* according to the measurement model:

$$(2)\quad y_i = \begin{cases} 1 \Rightarrow No\ \ injury\ \ if \quad \tau_o = -\infty \le y_i^* < \tau_1 \\ 2 \Rightarrow Injury\ \ if \quad \tau_1 \le y_i^* < \tau_2 \\ 3 \Rightarrow Fatality\ \ if \quad \tau_2 \le y_i^* < \tau_3 = \infty \end{cases}$$

The ordered probit model has the structural form:

(3) $y_i^* = \mathbf{x}_i \boldsymbol{\beta} + \varepsilon_i$

Where:

$\mathbf{x}_i$ is a row vector (with 1 in the first column for the intercept),
β is a column vector of structural coefficients (with the first element being the intercept β_o), and
ε is an error term.

Maximum likelihood (ML) estimation is used to estimate the regression of y* on **x**. Its use requires assuming a distribution of the error term, ε. For the ordered probit model, ε is assumed distributed normal with mean 0 and variance 1. After specification of the error term, the probabilities of observing values of y given **x** can be computed. The probability of any observed outcome y = m given **x** is:

(4) $\Pr(y_i = m \mid \mathbf{x}_i) = \Phi(\tau_m - \mathbf{x}_i\beta) - \Phi(\tau_{m-1} - \mathbf{x}_i\beta)$

The marginal effects of variables **x** on the underlying crash severity propensity can be evaluated by taking the partial derivative of Equation 4 with respect to $\mathbf{x}_i$. The marginal effect is the slope of the curve relating $\mathbf{x}_i$ to $\Pr(y = m|\mathbf{x})$, holding all other variables constant and is usually computed at the mean values of all variables. For a dummy independent variable, the derivative while treating it as a continuous variable provides an approximation. The marginal effects are useful to obtain a sense of the direction of effects of independent variables on the interior categories of an ordered dependent variable (for detail see Washington et al. 2011). A measure of the model goodness of fit (ρ^2) can be calculated as:

$$(5)\quad \rho^2 = 1 - \left[\frac{\ln L_b}{\ln L_o}\right]$$

Where ln L_b is the log likelihood at convergence and L_0 is the restricted log likelihood. The ρ^2 measure is bound by zero and one. Values of ρ^2 closer to one indicate a better fit of the model. The estimated coefficients can be tested for statistical significance using the student's t-test. An absolute t-value of 1.64/1.96 shows statistical significance at the 90/95% confidence level). Alternatively, readers may utilize p-values for judging statistical significance.

MODELING RESULTS

During model estimation (using NLogit software Version 5, Econometric Software, Inc.) an attempt was made to include as many independent variables as possible in the model specification from among the available variables. Statistical significance of the independent variables was used to retain or exclude them from the model specification. Table 2 presents an ordered probit model with pedestrians' injury severity as the dependent variable and a set of nine independent variables. Positive estimated coefficients in the model imply increasing likelihood of fatalities and decreasing likelihood of no injuries, while marginal values provide information on how injury severity probabilities change with a unit change in the value of an independent variable beyond its mean, while all other variables are held at their mean values.

Train speed (Trnspd) at the time of incident from the train characteristics category (Figure 1) was included in the model specification with the expectation that higher train speeds will contribute to more severe injuries. The estimated coefficient for this variable was positive and statistically significant (95% confidence level), implying that higher speeds of trains increased the probability of pedestrian fatalities. The finding is plausible and as expected.

Table 2: Estimated Ordered Probit Model for Pedestrians' Crash Injury Severity Levels

Variable	Brief Description	Estimated Coefficient	t-statistic	p-value	Variable Mean	Marginal Values		
						No Injury	Injury	Fatality
Trnspd	Train speed in mph	0.025	6.969	0.000	40.774	-0.001	-0.008	0.009
Typacc	Indicator for rail equipment struck pedestrian	0.678	2.588	0.010	0.945	-0.058	-0.207	0.265
Female	Indicator for female pedestrians	0.584	3.119	0.002	0.183	-0.019	-0.184	0.203
Commr	Indicator for commercial type areas	0.333	2.434	0.015	0.549	-0.016	-0.110	0.126
Temp	Temperature in degree Fahrenheit	0.007	2.005	0.045	62.987	-0.0003	-0.0024	0.0027
Clear	Indicator for clear weather	-0.324	-2.045	0.041	0.747	0.013	0.106	-0.119
Traficln	Number of traffic lanes at crossing	-0.118	-2.212	0.027	2.759	0.006	0.039	-0.045
Stdfls	Standard flashing light signals at crossings	-0.275	-1.881	0.060	0.714	0.011	0.091	-0.102
Timber	Indicator for crossing surface of timber	0.262	1.488	0.137	0.178	-0.010	-0.086	0.096
Constant	Model constant	0.409	1.040	0.299	-	-	-	-
τ_1		1.758	12.807	0.000	-	-	-	-
	Model Summary Statistics							
	Number of observations	399	Note: Dependent variable: Severity (No injury, injury, and fatality)					
	ρ^2	0.145						
	$\chi 2$	92.510						
	p-value for $\chi 2$	0.000						

The marginal value for train speed showed that each 1-mph speed increase in train speed beyond its mean value of 40.774 mph increased the probability of a fatal crash by 0.009 (i.e., 0.9%), while the probabilities of no injury and injury categories decreased by 0.001 (0.1%) and .008 (0.8%), respectively. The marginal effects for any variable sum to zero, which follows from the requirement that the probabilities add to 1.

Crash circumstance (Typacc) from the crash characteristics category (Figure 1) was included in the model specification with the expectation that crashes involving pedestrians struck by rail equipment would be more severe. The statistically significant estimated coefficient indicated that fatal crashes were more likely when rail equipment struck pedestrians (as expected) rather than when pedestrians struck rail equipment. The marginal values show that the likelihood of fatality increased by 26.5% when pedestrians were struck by rail equipment compared with crashes in which pedestrians struck rail equipment. From the pedestrian characteristics category, pedestrians' gender was included in the model. Before model estimation, the expectation was that female pedestrians may be more severely injured; this expectation was based on research showing higher fatality risk for females compared with males of the same age in vehicular crashes (NHTSA 2013). The result showed that females were more likely to die in pedestrian crashes at HRGCs compared with others (males + unknown/missing values).

Three independent variables from the environment category were included in the model: commercial area type (Commr, which was part of Develtyp variable in Table 1), temperature at the time of crash (Temp), and clear weather conditions (Clear). Results showed that fatalities were more likely at HRGCs located in commercial type areas; this finding is plausible as pedestrians in commercial areas may be distracted by signs and billboards and may fail to take crash evasive maneuvers, resulting in more severe injuries. Higher temperatures at the time of crash were associated with pedestrian fatalities although the reason for this is not readily apparent.

Table 2 shows the marginal values for temperature to four decimal points because of the small values. The estimated coefficient for clear weather (compared with adverse weather) was negative, showing that fatalities were less likely (by 11.9%) than no injuries/injuries in clear weather compared with crashes in adverse weather.

Several variables from the crossing characteristics category were tried as independent variables in the model specification. Results showed negative estimated coefficients for a greater number of traffic lanes at crossings (Traficln) and presence of standard flashing light signals at crossings (Stdfls, statistically significant at 90% confidence level). The results implied reduced probability of pedestrian fatalities at HRGCs with a greater number of traffic lanes, perhaps due to the greater area for evasive maneuvers by pedestrians coupled with standard flashing light signals.

Different types of crossing surfaces were tried in the model because of the possibility that crossing surfaces may affect pedestrians' ability to cross safely. Only timber type surface (Timber) showed limited positive association with fatal crashes but it was not statistically significant. Many other independent variables (e.g., highway average annual daily traffic, total daily train traffic, presence of illumination at the crossing, etc.) were tried but none showed strong statistical evidence of association with pedestrians' injury severity levels.

CONCLUSION AND DISCUSSION

This research achieved its objective of quantifying impacts of various variables on three different severity levels of pedestrians' injuries sustained in HRGC crashes using a dataset that combined both crash and HRGC inventory data. Variables possibly affecting severity levels of pedestrians' injuries were first conceptualized and then identified using the assembled dataset and the ordered probit model. The conclusion is that diverse variables pertaining to characteristics of pedestrians, trains, crossings, environments, and crashes exist that are associated with higher or lower levels of pedestrians' injury severity. Amongst these, higher train speeds were associated with a higher likelihood of pedestrian fatalities. While slowing down train speeds at HRGCs (especially those with significant pedestrian traffic) may not enable trains to readily stop but it may afford pedestrians that extra moment or two to get out of harm's way. The probability of a female pedestrian fatality at HRGCs was higher; this information can be used in safety campaigns targeted toward female HRGC users.

HRGCs located in areas designated as commercial were found to be associated with pedestrian fatalities. New research is uncovering relationships between urban forms and traffic safety (e.g., Dumbaugha and Raeb 2009), and this finding lends support to a relationship between pedestrians' injury levels sustained in HRGC crashes and type of area. Clear weather was found to be associated with a lower likelihood of pedestrian fatality compared with adverse weather conditions. Education programs aimed at improving pedestrian safety at HRGCs should emphasize extra caution when using HRGCs in adverse weather conditions. Presence of standard flashing light signals was associated with lower probability of pedestrian fatality; and where not installed, transportation agencies may consider installing such signals.

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