

# The effects of lighting on driver's injury severity at highway-rail grade crossings

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## SUMMARY

This study estimates the safety effect of illumination on accidents at highway-rail grade crossings in the United States, using data from exhaustive data from Federal Railroad Administration database covering the period 2002–2011. Using mixed logit modeling approach, the study explores the determinants of driver injury severity at unlighted highway-rail grade crossings compared with lighted highway-rail grade crossings in the United States. Several key issues are explored including availability of relevant highway-rail grade crossing accident inventory data; relevant data element structures; specification and estimation of models to estimate driver's injury severity with lighting and without lighting; and techniques to interpret model parameters. Overall, highway-rail grade crossing lighting improves safety by reducing the probability of high-level injury severity through improvements in driver's visibility compared with unlighted intersections. Copyright © 2015 John Wiley & Sons, Ltd.

**KEY WORDS:** effects of lighting; injury severity; highway-rail grade crossing accidents; mixed logit model

## 1. INTRODUCTION

Vehicle-train crash collisions are the most dangerous traffic accidents at highway-rail grade crossings because the average weight ratio of a train to a motor vehicle is about 4,000 to 1 [1]. Although the annual average collision rate for highway-rail grade crossings is relatively low when compared with highway crossings, these highway-rail crossing collisions result in high fatality rates making the study of highway-rail crossing collisions critically important.

One frequently encountered dangerous situation is nighttime accidents. Road lighting is widely applied as a safety measure in some countries. However, the costs and the energy consumption associated with road lighting are making it less attractive. The effect of highway-rail grade crossing lighting is a key issue in today's transportation research and has been recognized in the American Association of State Highway and Transportation Officials Highway Safety Manual [2]. A primary purpose for installing highway-rail grade crossing lighting is to increase the visual range afforded by vehicle headlamps while driving at night. Highway-rail grade crossing lighting improves safety by reducing the probability of high-level injury severity through improvements in driver visibility. While several studies examined highway-rail grade crossing accidents, none of these studies investigated the relationship between highway-rail grade crossing lighting and driver's injury severity.

A previous observational study comparing crashes at highway intersections with and without fixed lighting showed 25% lower nighttime crash rates, 39% fewer nighttime crashes, and 31% lower night-to-day crash ratios at highway intersections at intersections with fixed lighting [3]. Before-after studies show reductions in nighttime crash rates of 45–52%, reduction in nighttime crash frequency of 13–49%, reductions in night-to-day crash ratios of 22–40%, and substantial reductions in fatal and injury crashes following installation of intersection lighting.

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According to the highway-rail crossing inventory data, there were 25,945 highway-rail crossing accidents in the United States between 2002 and 2011 [4]. Using data from the Federal Railroad Administration's (FRA) database, 5,793 highway-rail grade crossing accidents were found to occur under darkness. As shown in Figure 1, the records were split into two data sets including approximately 39% of collisions occurring at lighted highway-rail grade crossings and 61% of collisions occurring at unlighted crossings. In addition, 4.3% of accidents at lighted highway-rail grade crossings were fatal compared with 8% at unlighted intersections.

There are several studies revealing that lighted highway intersections had significantly fewer crashes than unlighted ones. Most studies conducted before-and-after evaluations [5–8] to understand the effects of illumination from unlighted to lighted conditions but did not address the level of injury severity influenced by illumination. In general, the literature revealed the prevailing risk of traffic fatalities is much larger in unlighted conditions compared with lighted conditions. Each of these studies is reviewed next.

The effect of illumination was examined at highway grade intersections [5]. This study compared lighted and unlighted intersections on the basis of accident incidence. The study found that night accidents are significantly reduced at rural intersections with illumination. Illumination resulted in a 45% reduction in the night accident rate and a 22% reduction in the night accident/total accident ratio.

Accident frequency was studied at rural grade intersections using data from the 3-year period before and after lighting [6]. Results from 47 intersections revealed a 49% overall reduction in night accidents after lighting. The average night accident rate per million entering vehicles was 1.89 before lighting and 0.91 after lighting, which is a reduction of 52%. This reduced night accident rate after lighting is found to be statistically significant at the 99% level.

Public lighting was evaluated as an accident countermeasure to reduce night time crash frequency. An analysis of this research indicated a 30% reduction in nighttime junction crashes [7]. The nighttime crash results found in the studies attributed to regression on illumination summarized the results of 62 lighting and crash studies from 15 countries. Eighty-five per cent of the results showed lighting to be beneficial with an overall average reduction on nighttime crashes of at least 30% because of lighting improvement.

The reductions of nighttime crashes were modified by using proportions of day and night crashes from Minnesota and North Carolina [8]. In addition, the American Association of State Highway and Transportation Officials' Strategic Highway Safety Plan implementation guide for addressing non-signalized intersection accidents indicated that lighting is a proven safety countermeasure.

Hardwood *et al.* developed an accident modification factor for at-grade intersections along urban and suburban arterials [9]. The lighting effectiveness measures for road segments were the most comprehensive available information to apply to intersections. While roadway lighting does indeed offer significant safety improvements, this effect is limited to nighttime exposure which represents only

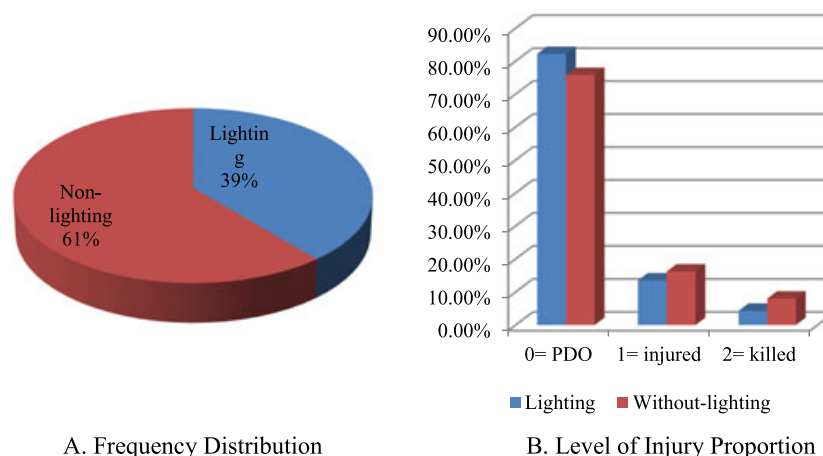


Figure 1. Highway-rail crossing collision by lighting condition at highway-rail grade crossings in the United States (2002–2011).

20–25% of the total exposure. The installation of roadway lighting at intersections will result in an expected 4% reduction in total crashes on urban and suburban arterials.

The effects of road lighting on accidents under dark conditions on Dutch roads were studied using data from a database containing 763,000 injury accidents and 3.3 million property damage accidents covering the period 1987–2006 [10]. The study found that injury accidents were reduced by 50% after road lighting was introduced. The effect of road lighting is significantly smaller during adverse weather and when road surface conditions are poor than during good lighting and roadway conditions. The average risk of accident was estimated to be 17% on lit rural roads and 145% on unlit rural roads. The average increase in risk during rainy conditions is about 50% on lit rural roads and about 190% on unlit rural roads.

The effect of the driving activity on accident reduction was associated with road lighting levels [11]. The intent of the study was to specify the driver's visibility needs in a way consistent with state-of-the-art lighting engineering practice, comparing driver and passengers' status conditions. The safety effects of roadway lighting at intersections were discussed. This paper describes a proposed framework to estimate the safety effects of intersection lighting. Several key issues are explored including availability of relevant crash, lighting, and roadway inventory data. Data from 1999 to 2002 were used from California and data from 2001 and 2004 were used from Minnesota to estimate expected crash frequencies during day and night time conditions. The technique utilized to interpret model parameters included variable elasticity and test of model transferability across states. Results indicated that a lower overall safety benefits from lighting than previous published studies. In another study, a method for assessing the visibility benefits of roadway lighting was examined [12]. A photometric simulation was utilized to analyze a large variety of roadway intersection lighting configurations to make context-specific predictions of visual performance level and spatial configuration for drivers of different ages. The study found that it was important to illumination for drivers on high-speed roadways with intersections.

In another study, the effect of roadway lighting on traffic safety at intersections was investigated [13]. The effects of lighting on crash frequency for different intersection types in Minnesota were assessed using regression models. The models included many geometric and traffic control variables to estimate the association between lighting and nighttime, and the resulting night-to-day crash ratio was determined. Overall, the presence of roadway intersection lighting was found to be associated with an approximately 12% lower night-to-day crash ratio than unlighted intersections. Visibility improvements from roadway lighting could serve as a countermeasure in reducing crash frequency at intersections.

In sum, previous studies have been focused on investigating the relationship between highway accidents influenced by illumination. No research studies have been conducted to investigate the influence of illumination on driver's injury severity at highway-rail grade crossings. To overcome previous limitations in the literature, this study aims to estimate the safety effect of road lighting on driver's injury severity at highway-rail grade crossings in the United States using data from the FRA database covering the period between 2002 and 2011. Using a mixed logit modeling approach, the study explores the determinants of driver injury severity at unlighted highway-rail grade crossings compared with lighted highway-rail grade crossings.

## 2. METHODOLOGY

The methodology undertaken in this study includes developing, estimating, and analyzing statistical models that predict the probability of injury severity outcomes. A variety of methodological techniques have been applied to analyze crash-severity data. Three discrete driver-injury severity outcomes are considered: property damaged only (PDO), injury, and fatality. To address this type of discrete outcome data, researchers have used a variety of methodological approaches including multinomial logit (MNL) models [14–21], ordered probit models [22–26], latent class modeling [27], nested logit models [28], and mixed (random parameters) logit models [29–33]. A complete review of crash injury severity models and methodological approaches can be found in Savolainen *et al.* [34]. The following subsections describe the mixed logit model approach, the calculation of elasticity, and the likelihood test.

### 2.1. Mixed logit model

Mixed logit models are developed to estimate the probability of discrete driver-injury severity outcomes conditioned on an accident having occurred and having been reported to police. The mixed logit model, which has received more attention in recent years, addresses several limitations to previous models by: (i) allowing for a complete and total relaxation of the independent and identically distributed condition; (ii) avoiding the violation of the independence from irrelevant alternatives condition; and (iii) allowing for heterogeneity in parameter effects. Compared with MNL model, there are several advantages for mixed logit model. In general, in the MNL model, we can only estimate  $(J-1)$  out of  $J$  outcomes (injury severity levels) because one of the categories or injury levels has to be used as the reference. However, in mixed logit estimation, there are  $J$  categories. It is found that the mixed logit model is more interpretive than the MNL, because the former includes the randomness associated with parameters of some variables in propensity functions, rather than being fixed for each variable by allowing both a mean and standard deviation. That is to say, depending on the parameter distribution, the parameter effects for the mixed logit model can vary across individual crash, ranging from positive to negative and of varying magnitudes [34]. This results in the prediction of a mean value and standard deviation for the probability of each severity level rather than a single point probability.

From the data, three injury severity outcomes are identified: property damaged only, injury, and fatality. To derive an estimated model of discrete outcomes, we start with a function that determines driver-injury severity [29, 30],

$$S_{in} = \beta_i X_{in} + \varepsilon_{in} \quad (1)$$

where  $S_{in}$  is a severity function determining the driver-injury severity category  $i$  in highway-rail grade crossing accident  $n$ ,  $X_{in}$  is a vector of explanatory variables that affect driver-injury severity category  $i$  in highway-rail grade crossing accident  $n$ ,  $\beta_i$  is a vector of estimate parameters for driver-injury severity category  $i$ , and  $\varepsilon_{in}$  is an error term which is assumed to be generalized extreme value distributed. To arrive at the mixed logit model, random parameters are introduced with  $f(\beta_i|\varphi)$ , where  $\varphi$  is a vector of parameters of the chosen density function (mean and variance). The resulting mixed-logit injury-severity probabilities [35] are

$$P_n(i|\varphi) = \int \frac{e^{\beta_i X_{in}}}{\sum_{\forall I} e^{\beta_i X_{in}}} f(\beta_i|\varphi) d\beta_i \quad (2)$$

where  $P_n(i|\varphi)$  is the probability of injury severity  $i$  conditional on  $f(\beta_i|\varphi)$ . If the variance in  $\varphi$  is determined to be significantly different from zero, there will be accident-specific variations of the effect of  $X$  on injury severity across each crash observation  $n$ , with the density function  $f(\beta_i|\varphi)$  used to determine the values of  $\beta_i$  across crashes.

Maximum likelihood estimation of mixed logit models is computationally cumbersome because of the required numerical integration of the logit formula over the distribution of the random, unobserved parameters [29]. As a result, simulation-based maximum likelihood methods are typically employed using Halton draws, which have been shown to provide a more efficient distribution of draws for numerical integration than purely random draws [36]. Details of the evolution of simulation-based maximum likelihood methods for estimating mixed logit models are provided in numerous references [37, 38].

To assess the effect of individual parameter estimates on injury-severity outcome probabilities, elasticity can be computed from the partial derivative for each observation  $n$  ( $n$  subscripting omitted) as

$$E_{X_{ki}}^{P(i|\varphi)} = \frac{\partial P(i|\varphi)}{\partial X_{ki}} \times \frac{X_{ki}}{P(i|\varphi)} \quad (3)$$

where  $P(i|\varphi)$  is the probability of injury-severity outcome  $i$  and  $X_k$  is the value of variable  $K$ . Elasticity values can be roughly interpreted as the percent effect that a 1% change in  $X_{ki}$  has on the injury-

severity outcome probability  $P(i|\varphi)$ . For indicator variables, a pseudo elasticity can be calculated which gives the percent effect on the injury-severity outcome probability of the variable going from a value of zero to one [30].

## 2.2. Likelihood ratio tests

To determine whether significant differences existed between parameter estimates for lighted and unlighted conditions, a likelihood ratio test was performed in a manner similar to that in studies [30, 39, 40]. The test involved determining the transferability of coefficients developed for the lighted model to the unlighted model. Such a test is powerful in detecting a significant difference between two groups. The union of the variables is used to estimate a joint model for both conditions. The likelihood ratio statistic is

$$LR = -2(L_j - L_L - L_U) \quad (4)$$

where ( $J = K_L + K_U - K_j$ ,  $K_j$ ,  $K_L$ , and  $K_U$  are the number of coefficients in the joint model, the lighted model, and the unlighted model, respectively) and  $L_j$ ,  $L_L$ , and  $L_U$  are the log-likelihoods at convergence for the joint model, the lighted model, and the unlighted model, respectively.

The null hypothesis for Equation (4) is that the restricted model (joint model) does not have a significantly lower log-likelihood compared with the unrestricted models (separate lighted and unlighted models), indicating a lack of significant difference between the lighting condition-specific models and the joint model.

The transferability of coefficients from the lighted model to the unlighted model was also tested. For instance, a model is estimated for the unlighted condition. The resulting model is applied to data for the lighting condition with all coefficients restricted to the values estimated for the condition without lighting, yielding the restricted log-likelihood  $L_R$ . Then the exact same model specification is set free and coefficients estimated on the data for the lighting condition, yielding the unrestricted log-likelihood  $L_U$ . The likelihood ratio statistic is then

$$LR = -2(L_R - L_U) \quad (5)$$

where  $\chi^2$  is distributed with degrees of freedom, where  $J$  is the number of restrictions.

The null hypothesis for Equation (5) is that the coefficients are equal for both the lighting and the no lighting conditions. If the test of transferability rejects transferability at a high significance (the significant level is at 0.05), it is statistical evidence that the lighting and no lighting conditions are not equivalent and lighting has an impact on crash severity at highway-rail grade crossings.

## 3. DATA

### 3.1. Federal Railroad Administration accident data source

The data used in this analysis comes from the FRA highway-rail grade accident database. The original national highway-rail crossing inventory database was started by FRA on January 1, 1975. The database includes both current and historical records with 80,000 to 100,000 crossings updated per year. Three sub databases including the highway-rail grade crossing inventory, the highway-rail crossing history file, and the highway-rail crossing accident data are contained in the FRA database. The three databases, which are described below, are linked to each other by a common crossing ID number.

The highway-rail grade crossing inventory reflects the current state of each crossing with reference attributes. This database was used in this study to identify independent factors which reflect crossing-related attributes and train/vehicle traffic patterns. In our database, four types of information were obtained from highway-rail grade crossing inventory database including warning device type, annual average daily traffic (AADT), and percentage of trucks.

The highway-rail crossing history file reflects changes made to crossings including the reason for the update and when it was made. In our study, the highway-rail crossing history file was not utilized.

The highway-rail crossing accident history data provide a historical file of accidents occurring at the crossings and the surrounding conditions at the time of the accident. Six types of factors in our final sample database are sourced from highway-rail crossing accident data file including time factors (month, hour, and AM&PM), vehicle information (vehicle speed and vehicle type), train information (train speed), weather information (visibility and weather condition), and driver's information (age, gender, and driver's injury levels).

### 3.2. Data preparation

A careful and detailed data collection is essential to obtain reliable conclusions. The original dataset obtained from the FRA database included 25,945 highway-rail grade crossing accidents that occurred in the United States from 2002–2011. In this study, the final database included 5,793 highway-rail grade crossing accidents that occurred under 'dark' conditions. The data set was split into two data sets including collisions occurring at highway-rail grade crossings with lighting and collisions occurring at crossings without lighting under darkness conditions. A description of the variables used in this analysis is shown in Table I.

Injury severity is the dependent variable which is ranked as 0—property damage only (PDO), 1—injury, and 2—killed. For the lighted highway-rail grade crossing accidents dataset, the percentage of crashes for the three injury levels is as follows: 82.20% PDO, 13.50% injured, and 4.30% killed. For the unlighted highway-rail grade crossing accidents dataset, the percentage of crashes for the three injury levels is as follows: 75.80% PDO, 16.20% injured, and 8.00% killed. In addition, the independent variables in this study include vehicle speed, weather condition, train speed, driver's age, gender, area type, and roadway pavement and annual average daily traffic. Table I shows the frequency and percentage distribution of these variables.

Table I. Description of highway-rail collision characteristics.

Description		Lighted intersection		Unlighted intersection	
		Frequency	Percentage	Frequency	Percentage
Dependent variable					
Driver	PDO	1851	82.20	2684	75.80
	Injured	304	13.50	574	16.20
	Fatality	97	4.30	283	8.00
Independent variables					
Vehicle speed	More than 50 mph	65	2.90	124	3.50
	Less than 50 mph	2187	97.10	3417	96.50
Weather	Cloudy	468	20.80	690	19.50
	Rain	214	9.50	308	8.70
	Fog	29	1.30	127	3.60
	Sleet	7	0.30	11	0.30
	Snow	72	3.20	96	2.70
	Clear	1462	64.90	2305	65.10
Train speed	More than 50 mph	245	10.90	535	15.10
	Less than 50 mph	2007	89.10	3006	84.90
Area type	open space	259	11.50	1222	34.50
	other areas	1993	88.50	2319	65.50
Roadway pavement	non-paved	79	3.50	478	13.50
	paved	2173	96.50	3063	86.50
AADT	Less than 10,000	1657	73.60	3102	87.60
	More than 10,000	595	26.40	439	12.40
Driver's age	65 and older	60	3.04	130	3.67
	Otherwise	1913	96.96	3411	96.33
Gender	Male	1752	77.80	2642	74.60
	Female	500	22.20	899	25.40

PDO: property damage only; AADT: annual average daily traffic.

#### 4. RESULTS AND DISCUSSION

Two mixed logit models are estimated in this study for collisions at highway-rail grade crossings occurring at (i) lighted highway-rail grade crossings and (ii) unlighted highway-rail grade crossings. As described in Section 2.2, a likelihood ratio test was performed to determine whether significant differences existed between parameter estimates for these two models. Although our estimation results show that individual coefficient estimates varied significantly across lighted highway-rail grade crossing/unlighted highway-rail grade crossings, likelihood ratio tests were conducted to confirm these difference. For differences between lighted highway-rail grade crossings and unlighted highway-rail grade crossings, all tests indicate that the hypothesis that lighted highway-rail grade crossings and unlighted highway-rail grade crossing models are equal and can be rejected with over 99.5% confidence. This includes comparing a combined lighted/unlighted model with separate lighted/unlighted models (as indicated in Equation (4)) and comparing lighted-converged coefficients using unlighted data and unlighted-converged coefficients using lighted data (Equation (5)). Therefore, separate models for the lighted and unlighted condition were developed. The results of these two models in this study uncover crucial determinants of driver's injury severity as a function of lighting conditions at highway-rail grade crossings in the United States and may offer insights into potential prevention strategies that could be undertaken to reduce injury levels. Possible countermeasures and intervention points are discussed in the latter section (Tables II and III).

In general, it is expected that, as the speeds of vehicles crossing the railroad increase, higher injury severity levels are expected. This impact of vehicle speeds on injury severity may be explained by the fact that increased vehicle speed will result in the inability of drivers to visually detect an on-coming train, thereby increasing the likelihood of a higher injury severity once they have collided with a train. The study results in Table IV show that high vehicle speed increases the likelihood of fatality by 56% under the lighted condition and 87% under the unlighted condition. The higher likelihood for more severe injuries during high vehicle speeds may be due to poor sight distance at unlighted highway intersections, which makes it difficult to stop, given the presence of an approach train, compared with lighted highway intersections [13]. These findings are also consistent with previous studies [41], which examined the safety effects of vehicle speed on severe accidents and found that high vehicle speed is always associated with high accident severities.

Similarly, for train speeds, a higher train speed means less reaction time for vehicle drivers. The higher likelihood for more severe injuries under higher train speeds at unlighted highway-rail grade crossings may be due to poor sight distance when vehicle drivers perform the crossing maneuver. The injury severity model results in Table IV show that higher train speed increases the likelihood of fatality by 37% under the lighted condition and 68% under the unlighted condition. As a consequence, a reduction in the speed limit could be particularly effective in lessening the severity of injuries by allowing more reaction time for last minute maneuvering and braking moments before the impact.

Examining driver's age, elder drivers (age 65 and over) are found to have severe injuries at unlighted highway-rail grade crossings due to driver's physiological factors associated with advanced age. Elder drivers are found to increase the likelihood of fatality level accidents by 20% under the lighted condition and 58% under the unlighted condition in Table IV. This is because of the longer reaction time and poor visibility for older drivers especially at unlighted highway-rail grade crossings. Another explanation is that roadway lighting improves safety for elder drivers by reducing the frequency of crashes occurring at night through improvements in driver visibility [42]. In addition, these findings are also consistent to previous studies which found that drivers over 60 years are more likely to have severe injuries given that an accident occurred [43, 44]. As a result, an education program could be beneficial to educate elder drivers to be more vigilant of their high risks in being injured at unlighted highway-rail grade crossings.

An examination of gender's influence, female drivers were associated with a likelihood of fatality increase of 3.7% in the likelihood of fatality under the lighted condition and 4.9% under the unlighted condition in Table IV. This finding was also confirmed by previous studies which indicated that women sustain more severe injuries than men because of physiological differences [1].

For weather conditions, the modeling result suggests that unlighted highway-rail grade crossings under bad weather conditions (sleet, snow, fog, rain, and cloudy) were deadly to motor vehicle drivers.

Table II. Mixed logit model estimation results for lighted intersections.

Variable name	Injury severity	Coefficient	<i>t</i> -statistic	<i>p</i> -value
Alternative specific constant				
Property damage only	PDO	−3.652	−8.75	0
Injury	Injury	2.571	4.23	0
Speed				
Vehicle speed > =50 mph	PDO	1.352 (0.021)	6.38	0
Vehicle speed > =50 mph	Fatality	2.571 (0.018)	4.23	0.007
Train speed > =50 mph	Injury	2.321 (0.031)	4.67	0
Train speed > =50 mph	Fatality	2.316 (0.035)	5.62	0.003
Driver's characteristics				
Age > = 65 years	PDO	0.536 (0.015)	5.36	0.003
Age > = 65 years	Fatality	1.361 (0.012)	6.32	0.012
Female	PDO	0.472	4.53	0.025
Female	Fatality	0.653	5.67	0
Weather				
Weather, cloudy	Injury	0.869	−8.65	0.002
Weather, cloudy	Fatality	1.123	−7.25	0.025
Weather, fog	PDO	0.925	−7.86	0
Weather, fog	Injury	1.017	−7.28	0
Weather, fog	Fatality	1.276	−6.28	0.009
Weather, snow	PDO	0.852	−5.68	0.018
Weather, snow	Fatality	1.183	−3.98	0.027
Weather, rain	PDO	0.879	0.97	0.003
Weather, rain	Injury	1.215	0.86	0.023
Weather, rain	Fatality	1.531	0.58	0.005
Weather, sleet	PDO	0.874	3.78	0.007
Weather, sleet	Fatality	1.687	2.13	0
Area type				
Open space area	PDO	0.839	4.57	0.031
Open space area	Fatality	2.675	6.85	0
Roadway				
Non-paved roadway	PDO	0.695 (0.031)	6.71	0.012
Non-paved roadway	Injury	0.783 (0.025)	5.24	0
Non-paved roadway	Fatality	1.801	4.93	0.005
Traffic volume				
AADT > =10,000	PDO	0.341 (0.016)	5.58	0.006
AADT > =10,000	Fatality	0.865 (0.0011)	3.97	0.002
Model statistics				
Number of observations		2252		
Log-likelihood at constants		−1321.25		
Log-likelihood at convergence		−652.25		
McFadden		0.576		

Parentheses indicate standard error of random parameter estimates. PDO: property damage only.

Cloudy weather is found to increase the likelihood of fatality level accidents by 6% under the lighted condition and 13% under the unlighted condition. Fog is found to increase the likelihood of fatal accidents by 9% under the lighted condition and 17% under the unlighted condition. Snow is found to increase the likelihood of fatal accidents by 12% under the lighted condition and 25% under the unlighted condition. Rain is found to increase the likelihood of fatal accidents by 4% under the lighted condition and 9% under the unlighted condition. Sleet is found to increase the likelihood of fatal accidents by 15% under the lighted condition and 32% under the unlighted condition. Previous studies showed that bad weather made roads less skid resistant which resulted in reduced braking and steering capability and worse impact angles which led to more severe injuries. From the relationship between lighting and bad weather condition accidents, higher illumination would result in greater visibility to reduce the risk caused by bad weather, such as fog, rain, and cloudy conditions [42]. The results suggest a reduced

Table III. Mixed logit model estimation results for unlighted intersections.

Variable name	Injury severity	Coefficient	<i>t</i> -statistic	<i>p</i> -value
Alternative specific constant				
Property damage only	PDO	−6.251	−13.16	0.001
Injury	Injury	−5.728	−9.26	0
Speed				
Vehicle speed > =50 mph	Injury	4.621 (0.021)	5.63	0.012
Vehicle speed > =50 mph	Fatality	7.827 (0.016)	6.76	0.002
Train speed > =50 mph	PDO	3.642	8.52	0
Train speed > =50 mph	Fatality	5.281	7.83	0
Driver's characteristics				
Age > = 65 years	Injury	1.518 (0.009)	8.27	0.012
Age > = 65 years	Fatality	2.351 (0.007)	7.51	0.001
Female	PDO	0.854	7.38	0
Female	Fatality	1.015	4.58	0
Weather				
Weather, cloudy	PDO	1.321	−7.53	0.032
Weather, cloudy	Fatality	2.569	−5.32	0
Weather, fog	Injury	1.763	−5.72	0
Weather, fog	Fatality	1.982	−4.38	0
Weather, snow	PDO	1.423	−5.82	0
Weather, snow	Injury	1.536	−7.59	0.016
Weather, snow	Fatality	2.831	−8.21	0.008
Weather, rain	PDO	1.586	1.76	0.006
Weather, rain	Fatality	1.581	0.91	0
Weather, sleet	PDO	1.135	6.47	0
Weather, sleet	Injury	1.472	4.85	0
Weather, sleet	Fatality	2.151	3.81	0.008
Area type				
Open space area	PDO	0.985 (0.032)	8.37	0
Open space area	Injury	1.018 (0.021)	9.52	0.012
Open space area	Fatality	2.779 (0.036)	5.56	0.005
Roadway				
Non-paved roadway	PDO	0.751 (0.015)	7.36	0.021
Non-paved roadway	Fatality	2.267 (0.012)	5.45	0.018
Traffic volume				
AADT > = 10,000	PDO	0.853(0.009)	7.79	0.012
AADT > = 10,000	Injury	0.631 (0.005)	5.58	0
AADT > = 10,000	Fatality	1.358 (0.016)	6.86	0
Model statistics				
Number of observations		3541		
Log-likelihood at constants		−1619.24		
Log-likelihood at convergence		−786.69		
McFadden		0.732		

Parentheses indicate standard error of random parameter estimates. PDO: property damage only; AADT: annual average daily traffic.

effectiveness of driver's reaction at unlighted highway-rail grade crossings because of the limitations in visibility, coupled with the inability of drivers to slow or stop as a result of bad weather.

For area type, the study found that drivers in an open space area are more likely to have higher injury severity accidents at unlighted highway-rail grade crossings compared with lighted crossings. Open space area is found to increase the likelihood of fatality level accidents by 8% under the lighted condition and 18% under the unlighted condition. This can be explained by the fact that vehicular drivers may drive more recklessly at unlighted highway-rail grade crossings in open space areas compared with lighted highway-rail grade crossings. The higher likelihood for more severe injuries in open space areas may be due to poor visibility conditions at night time for unlighted highway rail grade intersections, which made it difficult to stop to avoid a collision, given that an accident happened, compared

Table IV. Average direct pseudo-elasticities of the variables.

Variables description	Injury level	Lighted	Unlighted
Vehicle speed $\geq 50$ mph	PDO	-2.90%	-3.50%
	Injury	/	8.50%
	Fatality	56%	87%
Train speed $\geq 50$ mph	PDO	-0.50%	-1.50%
	Injury	5.60%	/
	Fatality	37%	68%
Age $\geq 65$ years	PDO	-1.60%	-2.90%
	Injury	/	-5.90%
	Fatality	20%	58%
Female	PDO	-1.80%	-2.70%
	Injury	/	/
	Fatality	3.70%	4.90%
Weather, cloudy	PDO	/	-1.80%
	Injury	-5.00%	/
	Fatality	6%	13%
Weather, fog	PDO	-1.20%	/
	Injury	-6.00%	-9.00%
	Fatality	9%	17%
Weather, snow	PDO	-1.60%	-1.90%
	Injury	/	-12.00%
	Fatality	12%	25%
Weather, rain	PDO	-0.50%	-1.90%
	Injury	-3.00%	/
	Fatality	4%	9%
Weather, sleet	PDO	-1.50%	-2.10%
	Injury	/	-16.00%
	Fatality	15%	32%
Open space area	PDO	-0.60%	-2.10%
	Injury	/	-8.00%
	Fatality	8%	18%
Non-paved roadway	PDO	-1.90%	-3.50%
	Injury	11.00%	/
	Fatality	5%	12%
AADT $\geq 10,000$	PDO	0.80%	0.50%
	Injury	/	-1.50%
	Fatality	-2.80%	-5.10%

‘/’: means ‘not exist’; PDO: property damage only; AADT: annual average daily traffic.

with lighted highway intersections. In addition, an explanation for this interesting result is that operating speeds in an open space area may tend to be higher than in other areas as open space areas generally have lower traffic densities [45, 46]. This is consistent with previous studies which examined injury severity in open space areas and found that drivers are used to driving faster in open space areas and in such cases, the presence of lighting will help visual performance, thus reducing driving injury severity [13].

Looking at roadway pavement, highway drivers on highways which are not paved at unlighted highway rail grade crossings are more likely to have more severe injuries compared with lighted highway-rail grade crossings. Unpaved roadways are found to increase the likelihood of fatality level accidents by 5% under the lighted condition and 12% under the unlighted condition. An explanation is that an unpaved road has a lower friction force and therefore requires much more time to stop [47]. In addition, unpaved roadways together with unlighted highway-rail grade crossing intersections were more deadly to motor vehicle drivers [44]. Higher illumination would result in greater visibility to yield fewer nighttime crashes [13]. As a result, illumination at unpaved highway-rail grade crossings could be particularly effective in moderating injury severity.

For traffic volume, drivers in low volume traffic locations at unlighted highway-rail grade crossings are more likely to have severe injury accidents. This is consistent with the study which found that darkness with a low traffic volume is associated with higher crash severity due to the fact that people drive

more recklessly at unlighted highway crossings [11]. Therefore, it was expected that lower traffic volumes result in an increased likelihood of higher speed, which contributes positively to the crash severity especially at unlighted highway-rail grade crossings.

## 5. CONCLUSIONS

Utilizing the most recent data (2002–2011) for highway-rail grade crossing accidents, the results of two mixed logit models in this study uncovered crucial determinants of highway driver injury severity at unlighted highway-rail grade crossings compared with lighted highway-rail grade crossings. The findings offer insights into potential implications, which could be undertaken to reduce driver injury levels.

Estimation results show striking and significant differences between these two models. The results of this study suggest the need to look more carefully at how drivers react to darkness at highway-rail grade crossing accidents. The results of this study have implications to those who aim to reduce accidents under darkness conditions. Based on the analysis results, it was found that the factors significantly impacting driver injury severity at highway-rail grade crossings include motor vehicle speed, train speed, driver's age, gender, area type, weather condition, roadway pavement condition, and traffic volume.

The impact of our analysis on injury prevention will be discussed in this paragraph. This study's findings show that substantial differences exist among different lighting conditions given that an accident happened. It is clear that safety policy must begin to seriously address lighting-related matters because there are compelling differences and considerable potential to improve safety if these differences are properly addressed. For example, older drivers have higher fatality and injury probabilities when driving in an open space area in an unlighted highway-rail grade crossings. Open space area is found to increase the likelihood of fatality level accidents by 8% under the lighted condition and 18% under the unlighted condition. The fact that a driver was over the age of 65 years was found to increase the likelihood of fatal accidents by 20% under the lighted condition and 58% under the unlighted condition because of physiological factors associated with advanced age. Therefore, education programs could be beneficial to educate elder drivers to be more vigilant of their high risks in being injured in such situations. In addition, drivers are found to be more likely to have severe injuries with high vehicle speeds and at unpaved unlighted highway-rail grade crossings. Stricter police enforcement on speeding at night and at unlighted highway-rail grade crossings might be considered as an effective prevention policy. As far as the influence of pavement condition, unpaved roadway is found to increase the likelihood of fatality level accidents by 5% under the lighted condition and 12% under the unlighted condition. Moreover, unlighted highway-rail grade crossings together with bad weather conditions (sleet, snow, fog, rain, and cloudy) were more deadly for motor vehicle drivers. Drivers in low volume traffic locations at unlighted highway-rail grade crossings are more likely to have severe injury accidents.

In summary, the findings offer insights into analysis of the effects of lighting on driver's injury severity at highway-rail grade crossings. The findings can help transportation engineers address highway-rail grade crossing safety problems.

## 6. FUTURE STUDIES

Future studies can address the limitations of the database used in this analysis. The primary data source used in this study is the FRA database data file which covered three sub databases including highway-rail grade crossing inventory, highway-rail crossing history file, and highway-rail crossing accident data. There is no secondary data source available for this study. Therefore, only the driver's age and gender are included. To better capture impacts of driver behavior on the injury severity, future studies could include more driver related factors such as alcohol use and educational status. Second, most current studies using lighting data only indicate its presence or absence. A complete lighting management system would be a next logical step to develop a complete understanding of safety effects of illumination at highway-rail grade crossings. The following are sample data elements which may be included in the future inventory: installation date, mounting height, spacing, and luminance. Estimates of driver's

injury severity outcomes at highway-rail grade crossings will afford designers with the opportunity to compare the cost-effectiveness of a contemplated illumination system with a similar scenario without lighting.

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