Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 3658 - 3668, 2005

ANALYZING THE RELATIONSHIP BETWEEN GRADE CROSSING ELEMENTS AND ACCIDENTS

Jinsun LEE, Ph.D.
Research Fellow
Korea Railroad Research Institute
374-1 Woulam-Dong, Uiwang
Gyeonggi-Do, Korea 437-050
Fax : 82-31-46-8373
E-mail : jinsun@krri.re.kr

Doohee NAM, Ph.D.
Research Fellow
The Korea Transport Institute
2311 Daehwa-Dong, Ilsan-Gu, Koyang
Gyeonggi-Do, Korea 411-701
Fax : 82-31-910-3235
E-mail : doohee@koti.re.kr

Dongjoo PARK, Ph.D.
Assistant Professor
Kongju National University
182 Shinkwan-dong, Kongju,
Chungnam, Korea
Fax: +81-41-850-8629
E-mail: djpark@kongju.ac.kr

Abstract: Highway-rail grade crossing accidents result in severe crashes with trains and other vehicles every year and, account for approximately 60 percent of all grade crossing fatalities. Despite the number of highway-rail grade crossing accidents, quantification of the effect of possible countermeasures has been surprisingly limited due to the absence of data needed to rigorously analyze factors affecting the frequency of highway-rail grade crossing accidents. This study provides some initial insight into this important problem including a detailed database on roadway geometric and grade crossing elements to analyze highway-rail grade crossing accidents on one hundred individual grade crossings in Korea. Zero-inflated models of accident frequency are developed and the findings isolate a wide range of factors that significantly influence the highway-rail grade crossing accident frequency. The marginal effects of these factors are computed to provide an indication on the effectiveness of potential countermeasures. The findings show promise for the methodological approach undertaken and provide important directions for future railroad research.

Key Words: highway grade crossing, Zero-Inflated Poisson, ZIP, ZINB

1. INTRODUCTION

About 60 percent of railroad accidents in Korea are associated with highway-rail grade crossing and the characteristics of roadway geometric and grade crossing elements have a significant effect on the frequency of such accidents. Such accidents account for about 39 of all railroad fatalities last 3 years from 1999 to 2001. These statistics on highway-rail grade crossing accidents indicate the continued need for research to develop cost-effective countermeasures to reduce the accident frequency.

A number of recent studies have specifically addressed highway-rail grade crossing accidents and the effect that surrounding topography have on such accidents. Some of this work has dealt with the likelihood of accidents caused by pedestrians trespassing grade crossings at a general level (Moore et al. 1991; Cina et al. 1994; Pelletier et al. 1997; Brenda et al. 2001) and several previous attempts have been made to quantify the relative emphasis these factors such as traffic control devices, grade crossing width, flashing light and automatic gate (Smith et al. 1995; Ward et al. 1995; Goldberg et al. 1998). However, the lack of detailed roadway geometric and grade crossing element data associated with highway-rail grade crossing accident, due primarily to the cost of data collection, has been an obstacle to the development of sophisticated statistical models of the relationship between roadway geometric, grade crossing characteristic and accident frequency.

The intent of the research is to develop statistical models that provide additional insight into the impact that roadway geometric and grade crossing elements have on the frequency of highway-rail grade crossing accidents. An extensive database collected from one hundred grade crossing sections was used. These data give a rich source that allows isolation of the impact of roadway geometric and grade crossing elements on highway-rail grade crossing accident frequency while accounting for traffic and environmental conditions with other factors that affect the accident frequency.

2. METHODOLOGICAL APPROACH

In terms of methodological perspectives, many applications of statistical modeling of accident frequency have been undertaken. However, some methodological approaches have been shown to be superior to others. For example, Jovanis and Chang (1986) and Miaou and Lum (1993) demonstrated that conventional linear regression models are not appropriate to model vehicle accident events on roadways, and they found inferences drawn from these models are often erroneous. They concluded that Poisson and negative binomial regression count models are more appropriate tools for accident frequency modeling. In recent years there have been numerous applications of Poisson and negative binomial regression models to accident frequency analysis (Shankar, Mannering and Barfield 1995; Milton and Mannering 1998).

As an extension of standard Poisson and negative binomial regression, zero-inflated probability processes, such as the zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) regression models have gained considerable recognition in accident frequency analysis (Miaou 1994; Shankar et al. 1997). These models account for the fact that the traditional application of Poisson and negative binomial models does not address the possibility of zero-inflated counting processes. Zero-inflation may be present because some highway-rail grade crossing sections can have accident probabilities that are so low over some time period that they can be considered to be virtually safe (in a zero accident state). Other highway-rail grade crossing sections may follow a normal count process for accident frequency in which non-negative integers (i.e., including zero) are possible accident frequency outcomes over a specified time period.

To illustrate the family of count model alternatives as applied to accident frequency (number of accidents on a highway-rail grade crossing section in some time period) we start with the Poisson model. In applying Poisson regression in accident frequency analysis, let n_{ij} be the number of accidents on highway-rail grade section i during period j. The Poisson model is,

$$P(n_{ij}) = \frac{exp(-\lambda_{ij})\lambda_{ij}^{n_{ij}}}{n_{ij}!} \tag{1}$$

where $P(n_{ij})$ is the probability of n accidents occurring on a highway-rail grade crossing section i in time period j, and λ_{ij} is the expected value of n_{ij},

$$E(n_{ij}) = \lambda_{ij} = exp(\beta X_{ij}) \tag{2}$$

for a highway-rail grade crossing section i in time period j, β is a vector of unknown regression coefficients that can be estimated by standard maximum likelihood methods (Greene 1997), X_{ij} describes highway-rail grade crossing section geometric characteristics, surrounding topography and other relevant roadway and grade crossing conditions that affect accident frequency.

A well-known limitation of the Poisson distribution is that the variance and mean must be approximately equal. The possibility of overdispersion (having variance exceeding the mean, rather than equaling the mean as the Poisson requires) is always a concern in modeling accident frequency and may result in biased, inefficient coefficient estimates. To relax the overdispersion constraint imposed by the Poisson model, a negative binomial distribution (based on a Gamma-distributed error term) is commonly used (Miaou 1994; Shankar *et al.* 1995; Milton and Mannering 1998; Jinsun and Mannering 2002). The negative binomial model is derived by rewriting equation 2 such that,

$$\lambda_{ij} = exp(\beta X_{ij} + \varepsilon_{ij}) \tag{3}$$

where $exp(\varepsilon_{ij})$ is a Gamma-distributed error term, and this addition allows the variance to differ from the mean as below,

$$Var[n_{ij}] = E[n_{ij}][1+\alpha E[n_{ij}]] = E[n_{ij}]+ \alpha E[n_{ij}]^2 \tag{4}$$

Poisson regression model is regarded as a limiting model of the negative binomial regression model as α approaches zero, which means that the selection between these two models is dependent upon the value of α. The negative binomial distribution has the form,

$$P(n_{ij}) = \frac{\Gamma((1/\alpha)+n_{ij})}{\Gamma(1/\alpha)n_{ij}!}\left(\frac{1/\alpha}{(1/\alpha)+\lambda_{ij}}\right)^{1/\alpha}\left(\frac{\lambda_{ij}}{(1/\alpha)+\lambda_{ij}}\right)^{n_{ij}} \tag{5}$$

Standard maximum likelihood methods can be used to conduct the estimation of λ_i (Greene, 1997).

To address the possibility of zero-inflated accident counting processes on highway-rail grade crossing sections, the zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) regression models have been developed. Both zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) assume that two different processes are at work for some zero accident count data. One process is the zero accident state where the highway-rail grade crossing section is virtually safe. The other process has the highway-rail grade crossing section in a non-negative count state for accident frequency (i.e., a state that has a frequency outcome determined by a Poisson or negative binomial distribution). The zero-inflated Poisson (ZIP) assumes that the events, $Y = (Y_1, Y_2, \ldots\ldots, Y_n)$, are independent and

$$Y_i = 0 \text{ with probability } p_i + (1 - p_i)e^{-\lambda} \tag{6}$$
$$Y_i = y \text{ with probability } (1 - p_i)e^{-\lambda i}\lambda_i^y/y!, \quad y = 1, 2, \ldots\ldots \tag{7}$$

where y is the number of accidents. Maximum likelihood estimates are used to estimate the coefficients of a zero-inflated Poisson (ZIP) regression model and confidence intervals can be constructed by likelihood ratio tests.

The zero-inflated negative binomial (ZINB) regression model follows a similar formulation and assumes that the events, $Y = (Y_1, Y_2, \ldots\ldots, Y_n)$, are again independent and,

$$Y_i = 0 \text{ with probability } p_i + (1 - p_i)\left[\frac{1/\alpha}{(1/\alpha)+\lambda_i}\right]^{1/\alpha} \tag{8}$$

$$Y_i = k \text{ with probability } (1 - p_i)\left[\frac{\Gamma((1/\alpha)+k)u_i^{1/\alpha}(1-u_i)^k}{\Gamma(1/\alpha)k!}\right] \quad , k = 1, 2, \ldots\ldots \tag{9}$$

Maximum likelihood methods are again used to estimate the coefficients of a zero-inflated negative binomial (ZINB) regression model.

The choice of an appropriate accident frequency model, zero-inflated or not, is critical. However, one cannot test this directly because the traditional Poisson or negative binomial model and their zero-inflated counterparts are not nested. To test the appropriateness of using a zero-inflated model rather than traditional model, Vuong (1989) proposed a test statistic for non-nested models that is well suited for this setting when the distribution can be specified. Let $f_j(y_i/x_i)$ be the predicted probability that the random variable Y equals y_i under the assumption that the distribution is $f_j(y_i/x_i)$, for j = 1, 2, and let

$$m_i = \log\left(\frac{f_1(y_i|x_i)}{f_2(y_i|x_i)}\right) \tag{10}$$

Where $f_1(y_i/x_i)$ is the probability density function of the zero-inflated model and $f_2(y_i/x_i)$ is the probability density function of the Poisson or negative binomial distribution. Then Vuong's statistic for testing the non-nested hypothesis of zero-inflated model versus traditional model is (Greene, 1997),

$$v = \frac{\sqrt{n}\left[(1/n)\sum_{i=1}^{n} m_i\right]}{\sqrt{(1/n)\sum_{i=1}^{n}\left(m_i - \overline{m}\right)^2}} = \frac{\sqrt{n}(\overline{m})}{S_m} \tag{11}$$

where $\overline{m}$ is the mean, S_m is standard deviation, and n is a sample size. Vuong's value is asymptotically standard normally distributed, and if $|v|$ is less than 1.96 (the 95% confidence level for the t-test), the test does not indicate any other model. However, the zero-inflated regression model is favored if the v value is greater than 1.96, while a v value of less than –1.96 favors the Poisson or negative binomial regression model (Greene, 1997).

3. EMPIRICAL SETTING

Highway-rail grade crossing element data available for this study were collected on one hundred crossing sections. These data were collected over a period from September 2002 to April 2003. To investigate the relationship between roadway geometrics, environmental factors and highway-rail grade crossing accidents, data were combined with additional databases; the Korean National Railroad (KNR) grade crossing accident database and the roadway geometric/grade crossing element database in the vicinity of the one hundred grade crossings. For highway-rail grade crossing accident frequency, information from the accident database was extracted from January 1, 1999 to December 31, 2001. These data were combined with the roadway geometric/traffic database, which includes geometric measurement information on grade crossing widths, traffic control devices, flashing light, warning time, stop signs, number of lanes, the presence of skid prevention facility, humps, grade, angle and traffic information such as traffic volume, train volume as a percentage of daily traffic, and legal speed limit.

The data revealed that there have been a significant number of fatalities for highway vehicles colliding with a train and approximately 64 percent of these crashes involved in motorists not stopping. Figure 1 provides a major cause of crashes in the highway-rail grade crossings during 3 years and Table 1 provides summary information on some of the key highway-rail grade crossing characteristics available in the database.

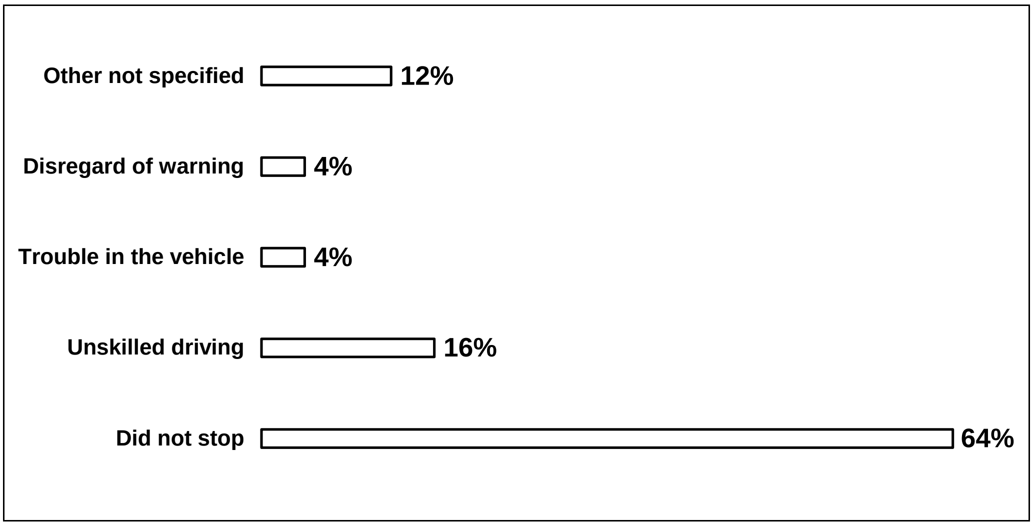

FIGURE 1 Major causes of highway-rail grade crossing accident

4. MODEL ESTIMATION

Highway-rail grade crossing accident frequency model showed that there was a significant difference in the factors compared with previous studies. Previous research has shown that conventional linear regression is not appropriate for estimating the relationships among grade crossing accident frequency, roadway geometric and grade crossing elements. Poisson or negative binomial regression (for overdispersion) is a more proper analysis approach. However, when a preponderance of zeros exists in the accident frequency data, zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) regression models are more suitable.

For estimating accident frequency model, a decision rule was needed to select the appropriate model form. The regression-based test for overdispersion by Cameron and Trivedi (1986, 1990) can determine the appropriateness of negative binomial regression models over Poisson regression models, and Vuong's test statistic is suitable for testing the appropriateness between the zero-inflation model and the traditional Poisson or negative binomial regression.

TABLE 1 Summary Statistics for Grade Crossing Sections

Variable	Mean	Min.	Max.	Standard Deviation
Angle (degrees)	82.8	10	140	25.3
Average annual daily rail cars volume	118.4	5	461	103.9
Average annual daily traffic (AADT)	122055	128	797547	128833
Control device falling time (in sec)	9.49	0	50	9.67
Control device length (in meters)	6.1	0	14.3	2.44
Control device rising time (in sec)	6.33	0	15	3.31
Effective lane width in the grade crossing (in meters)	14.42	2.5	108	16.43
Grade crossing accident frequency (per month)	0.009	0	1	0.09
Grade crossing width (in meters)	10.77	2.2	60	11.53
Guardrail height (in meters)	0.67	0	2	0.56
Guardrail length (in meters)	4.83	0	150	16.25
Left clearing sight distance (in meters)	130.5	5	1500	177.0
Left distance from the grade crossing to the back site of coming rail car (in meters)	279.2	3	1000	239.4
Left distance from the grade crossing to the front site of coming rail car (in meters)	303.6	10	2000	279.5
Left lane width (in meters)	9.10	1.8	60	9.67
Number of lanes	2.24	0	11	1.77
Number of passenger passing through the crossing	1468	0	15272	2407
Rail speed passing through the grade crossing (km/h)	100.3	25	140	28.1
Right clearing sight distance (in meters)	115.8	5	500	106.1
Right distance from the grade crossing to the back site of coming rail car (in meters)	289.6	10	2000	286.3
Right distance from the grade crossing to the front site of coming rail car (in meters)	326.4	10	2000	298.2
Right lane width (in meters)	9.52	1.8	60	10.15
Speed limit (km/h)	20	20	20	0
Warning time (in sec)	13.57	0	300	41.88

This decision rule was adopted in selecting the proper econometric method for grade crossing accident frequency models and the model was estimated with *LIMDEP* software package.

For highway-rail grade crossing accident frequency, the zero-inflated Poisson (ZIP) regression model was determined to be the most appropriate count model. The overdispersion parameter α was statistically not significant (*t*-statistic of 0.786) indicating the appropriateness of the Poisson regression model relative to the negative binomial regression model. Zero-inflation was confirmed (the Vuong statistic of -2.197 was less than the -1.96 corresponding to the 95% confidence level) indicating the appropriateness of the zero-inflated Poisson regression model over a simple Poisson model.

The model results of the zero-inflated Poisson specification for highway-rail grade crossing accident frequency are presented in Table 2. The coefficients for both non-zero accident state (Poisson accident state) and zero-accident state were found to be statistically significant and of plausible sign. In viewing the Poisson accident state results in Table 2, the building indicator variable was found to increase the frequency of grade crossing accidents in the Poisson accident state (a positive coefficient) and increase the likelihood of the grade crossing accident being in the zero-accident state (a positive coefficient). This finding represents the overall effects associated with high traffic caused by land use in the vicinity of grade crossings and this indicates that building indicator variable push the model into the Poisson accident state but increase the frequency in this state. As expected, the statistical findings indicated that the presence of guardrail would increase the likelihood of accidents on grade crossing.

TABLE 2 Zero-Inflated Poisson Estimation Results

Variable	Estimated Coefficients	t-statistic
Poisson accident state		
Constant	-5.018	-3.112
Roadway characteristics		
Building indicator (1 if the presence of buildings, 0 otherwise)	0.637	1.271
Guardrail indicator (1 if the presence of guardrails, 0 otherwise)	0.799	1.597
Hump indicator (1 if the presence of humps, 0 otherwise)	-1.651	-1.979
Number of lanes	-0.714	-2.192
Stop sign indicator (1 if the presence of stop signs, 0 otherwise)	-0.511	-1.444
Grade crossing characteristics		
Angle (degrees)	0.089	1.718
Control device indicator (1 if the presence of control devices, 0 otherwise)	-0.807	-1.224
Management indicator (1 if the KNR manages, 0 otherwise)	0.674	1.901
Number of tracks	1.011	3.001
Right clearing sight distance (in meters)	-0.014	-1.337
Right grade indicator (1 if the presence of right grades, 0 otherwise)	0.633	1.228
Warning time (in sec)	-0.298	-1.693
Dispersion parameter α	1.984	1.771
Zero-accident state		
Constant	0.873	1.441
Roadway characteristics		
Average annual daily traffic (AADT)	-0.049	-2.811
Building indicator (1 if the presence of buildings, 0 otherwise)	0.394	2.667
Grade crossing characteristics		
Control device indicator (1 if the presence of control devices, 0 otherwise)	1.098	2.001
Effective lane width in the grade crossing (in meters)	0.623	1.624
Restricted Log-likelihood	-207.35	
Log-likelihood at Convergence	-183.09	
Number of Observations	3,600	
Vuong Statistic	-2.1974	

This could be because even though guardrail gives a sense of security to both vehicle and locomotive driver but they can often act as an obstacle to block the sight distance. This is likely due to insufficient stop sight distance with poor surrounding topography. If there is insufficient sight distance, the driver is unable to make a safe stop. The presence of humps decreases the chance of grade crossing accident. As expected, all else being the same, humps located in front of grade crossings resulted in a lower accident frequency, reflecting the effect of low speeding of vehicle. It is important to note that the number of lanes in a section is an intuitive variable with a statistically significant. An increased number of lanes in the vicinity of grade crossings provide a driver with less opportunity to rush for the grade crossings whereas a smaller number of lanes can cause poor clearing sight distance and provide less space for driver corrections. Stop sign indicator was associated with a lower frequency of highway-rail grade crossing accidents. A plausible explanation is that the presence of stop sign could be expected to allow a lower vehicle traveling speed, creating a lower likelihood for accidents on highway-rail grade crossings.

As with previous roadway characteristics findings, the statistical findings of grade crossing elements discussed below. As the crossing angle of grade crossings increases, grade crossing accident frequencies are likely to increase. An increase in the crossing angle may reduce the visual impact of the curve between grade crossings and roadway, and this finding indicates that the curve is more likely to be an important problem with sharp topographical features. Control device indicator variable was found to reduce the frequency of grade crossing accidents in the Poisson accident state (a negative coefficient) and increase the likelihood of the grade crossing accident being in the zero-accident state (a positive coefficient). The purpose of traffic control device at highway-rail grade crossings is to permit safe and efficient operation of rail and highway traffic over such crossings. Highway vehicles approaching a highway-rail grade crossing should be prepared to yield and stop if necessary if a train is at or approaching the grade crossing. This finding underscores the effects of the presence of control device on grade crossing accident frequencies. It is surprising that, if grade crossing is operated by the governmental administration, the likelihood of accidents on grade crossings increases. Further evaluation is needed to make a proper selection of the appropriate grade crossing system. Drivers' perception of risk may be determined by the number of tracks, as the number of tracks in grade crossings increase, so does the number of accidents. This could be because effective lane was long. Longer right clearing sight distance has a negative effect on accident frequency in grade crossings. A vehicle driver needs minimum sight distance to be able to see an approaching train. So, wherever possible, deficient sight distance should be improved by removing structures or seasonal vegetation within the affected area. Right grade indicator shows that accident frequency for grade crossings was higher. This finding suggests that the presence of right grades may be critically influenced by risky situations, reflecting the sudden vehicle stop in the tracks. Longer warning time in the grade crossing was associated with lower grade crossing accident frequencies (Poisson accident state). Reasonable and consistent warning times reinforce system reliability and credibility.

Turning to the zero-accident state estimation findings, it is not surprising that, with regard to the average annual daily traffic, as the AADT increases, the frequency of accidents in the zero-accident state decreases (a negative coefficient in zero-accident state) because accident exposure increases with higher traffic volumes. However, research has shown that the correlation between traffic flow and accident probabilities follows a U-shape (McShane and Roess, 1990). Accordingly, accident probabilities are assumed to be highest with very low traffic volume, to decrease as traffic volumes increase, and then to increase again as traffic flow increase further. Evidence was found only for the increase in grade crossing accidents for higher traffic volumes. A lower number of accidents were likely to occur in wider lane in the grade crossing (positive coefficient in zero-accident state). This is likely due to more safe, comfortable and unobserved effects associated with effective lane widths passing though the grade crossings. Wider grade crossings allow uncontrolled vehicles more space to recover and give a sense of security.

To provide some insight into the implications of our estimation results, elasticities were computed to determine the marginal effects of the independent variables in the highway-rail grade crossing accident frequency models. Elasticity of highway-rail grade crossing accident frequency λ_{ij} is defined as,

$$E_{x_{ijk}}^{\lambda_{ij}} = \frac{\partial \lambda_{ij}}{\lambda_{ij}} \times \frac{x_{ijk}}{\partial x_{ijk}} \tag{12}$$

where E represents the elasticity, x_{ijk} is the value of the kth independent variable for highway-rail grade crossing section i in month j, and λ_{ij} is the mean accident frequency on highway-rail grade crossing section i in month j. However, the elasticity in equation 12 is only appropriate for continuous variables such as number of lanes, angle, number of tracks, right clearing sight distance, warning time, effective lane width and average annual daily traffic. It is not valid for non-continuous variables, indicator variables (i.e., those dummy variables that take on values of zero or one).

TABLE 3 Elasticity Estimates for Highway-rail Grade Crossing Accident Frequency

Poisson accident state	
Variable	Elasticity
Roadway characteristics	
Building indicator (1 if the presence of buildings, 0 otherwise)	0.051
Guardrail indicator (1 if the presence of guardrails, 0 otherwise)	0.062
Hump indicator (1 if the presence of humps, 0 otherwise)	-0.551
Number of lanes	-0.365
Stop sign indicator (1 if the presence of stop signs, 0 otherwise)	-0.593
Grade crossing characteristics	
Angle (degrees)	0.441
Control device indicator (1 if the presence of control devices, 0 otherwise)	-0.198
Management indicator (1 if the KNR manages, 0 otherwise)	0.039
Number of tracks	0.551
Right clearing sight distance (in meters)	-0.611
Right grade indicator (1 if the presence of right grades, 0 otherwise)	0.601
Warning time (in sec)	-0.930
Zero-accident state	
Variable	Elasticity
Roadway characteristics	
Average annual daily traffic (AADT)	-0.844
Building indicator (1 if the presence of buildings, 0 otherwise)	1.399
Grade crossing characteristics	
Control device indicator (1 if the presence of control devices, 0 otherwise)	0.449
Effective lane width in the grade crossing (in meters)	1.515

For indicator variables, a "pseudo-elasticity" can be computed to estimate an approximate elasticity of the variables. The pseudo-elasticity gives the incremental change in highway-rail grade crossing accident frequency caused by changes in the indicator variables. The pseudo-elasticity is defined as,

$$E_{x_{ijk}}^{\lambda_{ij}} = \frac{\exp(\beta) - 1}{\exp(\beta)} \tag{13}$$

The elasticities for each of the independent variables are shown in Table 3. The interpretation of elasticities is straightforward and gives a good indication of the relative importance of variables (which would be critical for using our findings for safety management system). As an example, a one-percent increase in right clearing sight distance causes a 0.611 percent reduction in highway-rail grade crossing accident frequencies. Similarly, if control devices are present in grade crossings, the accident rate will be 19.8 percent lower than grade crossing sections without control devices.

5. CONCLUSIONS AND RECOMMENDATIONS

Grade crossings present a major hazard to motor vehicle drivers and are the greatest cause of fatalities and injuries resulting from railroad operations. This study provides an empirical and methodological analysis of highway-rail grade crossing accident frequency. By accounting for relationships among roadway geometrics, grade crossing characteristics and highway-rail grade crossing accident frequency, this research analysis provides some initial direction needed to identify cost-effective countermeasures that improve grade crossing designs by reducing the probability of vehicle not stopping.

In terms of roadway and grade crossing element treatments, results show that highway-rail grade crossing accident frequencies can be reduced by decreasing the crossing angle, by increasing right clearing sight distance, by increasing warning time, by increasing effective lane width and by decreasing average annual daily traffic passing through the grade crossing. Estimation results show that highway-rail grade crossing accident is a complex interaction of indicator variables such as the presence of humps, right grades, buildings, stop signs, guardrails and control devices. Some of these contribute to frequency as the result of train-object impact where as others appear to mitigate frequency, presumably by altering driver's awareness in the grade crossing section. It appears that a complex interplay of environmental and geometric factors affect vehicle and pedestrians passing through the highway-rail grade crossings.

With respect to suggestions for future railroad research, there is a need for additional surrounding geometric feature data for empirical analysis. And also, without the historical adjustment, the model prediction should not be expected to equal the actual experience, particularly for a small group of grade crossing such as one hundred of this application. For other applications, grade crossing safety is being enhanced as part of efforts to develop improved train control system. Significant progress can be made in improving the safety of grade crossings through following areas such as driver warning systems with intelligent transportation systems (ITS). In the end, grade separation of the highway-rail tracks is both the most effective and the most expensive treatment to eliminate risk at a grade crossing. Yet, the model still can provide guidance in allocating funds among the grade crossings by upgrading warnings based on relative risk. More research is needed into these and other approaches that offer potential for risk reduction at lower cost than grade separation.

REFERENCES

Cameron, A. Colin and Trivedi, P. K.(1986) Econometric models based on count data: Comparisons and applications of some estimators and tests, *Journal of Applied Econometrics* 1, 29-53

Cameron, A. Colin and Trivedi, P. K.(1990) Regression-based tests for overdispersion in the Poisson model, *Journal of Econometrics* 46, 347-364

Cina, S. J., Koelpin, J. L., Nichols, C. A. and Conradi, S. E.(1994) A decade of train-pedestrian fatalities: the Charleston experience, *Journal of Forensic Science* 39 (3), 668-673

Gitelman, V. & Hakkert, S. The Evaluation of Road-Rail Crossing Safety with Limited Accident Statistics. *Transportation Research Record*, 1114(1987). pp. 131-140.

Goldberg, B. A., Mootha, R. K. and Lindsey, R. W.(1998) Train accidents involving pedestrians, motor vehicles and motorcycles, *American Journal of Orthopedics* 27 (4), 315-320

Greene, W. H.(1997) Econometric analysis, 3rd Edition, Prentice Hall

Jovanis, P. and Chang, H.-L.(1986) Modeling the relationship of accidents to miles traveled, Transportation Research Record 1068, 42-51

Lee, J and Mannering, F.(2002) Impact of Roadside Features on the Frequency and Severity of Run-off-Roadway Accidents: An Empirical Analysis, *Accident Analysis and Prevention* 34 (2), 149-161, 2002

Lobb, B., Harre, N. and Suddendorf, T.(2001) An evaluation of a suburban railway pedestrian crossing safety programme, *Accident Analysis and Prevention*, 33, 157-165

McShane, William R. and Roess, R. P.(1990) Traffic Engineering, Prentice Hall

Miaou, S. P.(1994) The relationship between truck accidents and geometric design of road sections: Poisson versus negative binomial regressions, *Accident Analysis and Prevention*, 26 (4), 471-482

Miaou, S. P. and Lum H.(1993) Modeling vehicle accidents and highway geometric design relationships, *Accident Analysis and Prevention*, 25 (6), 689-709

Milton, J. and Mannering, F.(1998) The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies, *Transportation* 25, 395-413

Moore, T. J., Wilson J. R., Hartman M.(1991) Train versus pedestrian accidents. *South Medical Journal* 84, 1097-1098

Pelletier A.(1997) Deaths among railroad trespassers. The role of alcohol in fatal injuries. *Journal of the American Medical Association* 277 (13), 1064-1067

Shankar, V., Mannering, F. and Barfield, W.(1995) Effect of roadway geometrics and environmental factors on rural freeway accident frequencies, *Accident Analysis and Prevention*, 27 (3), 371-389

Shankar, V., Milton, J. and Mannering, F.(1997) Modeling accident frequencies as zero-altered probability processes: An empirical inquiry, *Accident Analysis and Prevention*, 29 (6), 829-837

Smith, G.(1995) Incidents involving trains, *Australian Journal of Emergency Care* 2 (2), 30-34

Vuong, Quang H.(1989) Likelihood ratio tests for model selection and non-nested hypotheses, *Econometrica*, 57 (2), 307-333

Ward, N. J. and Wilde, G. J. S.(1995) Field observation of advance warning/advisory signage for passive railway crossings with restricted lateral sightline visibility: an experimental investigation, *Accident Analysis and Prevention*, 27 (2), 185-197