Effectiveness of Stop-Sign Treatment at Highway-Railroad Grade Crossings

-- FINAL REPORT --

Contract No.

Submitted to
Southeastern Transportation Center (STC)

By

Stephen H. Richards, Ph.D., P.E.
Xuedong Yan, Ph.D.
The University of Tennessee

Hal Millegan, Ph. D., P.E.
Montana Tech of the University of Montana

Center for Transportation Research
Department of Civil & Environmental Engineering
The University of Tennessee
Knoxville, TN 37996-4133

September 2009
Project Title: Effectiveness of Stop-Sign Treatment at Highway-Railroad Grade Crossings
Principal Investigator: Stephen H. Richards, Ph.D., P.E. and Xuedong Yan, Ph.D.
University: The University of Tennessee
Telephone: (865) 974-1813
Email Address: stever@utk.edu
Project Start Date: December 1st, 2008
End Date: December 30th, 2009
Other Milestones, Dates:
August 1st, 2008—A paper was submitted to TRB meeting for presentation and publication

Project Objective:
The objective of this proposed study is to utilize FRA crash database to evaluate safety effectiveness of stop-sign treatment on public highway-railroad grade crossings.

Project Abstract:
Engineers and policy makers who make decisions about traffic control posting configurations are not in complete agreement if stop signs are effective when used at highway-railroad grade crossings. Using the Federal Railroad Administration database, an overall analysis of effectiveness of stop-sign treatment at highway-railroad grade crossings is proposed to be conducted. This proposed study will focus on a before-and-after and cross-sectional statistical analysis of crash history at public highway-railroad grade crossings that were upgraded from Crossbuck-only to stop signs without using other TCDs or automatic countermeasures. Specifically, the objectives of this research are to: 1) determine if the stop-sign treatment can lead to a lower vehicle-train accident frequency after stop controls were implemented at passive grade crossings, and 2) utilize negative binomial regression model to analyze and predict how specific risk changes may be expected after stop-sign installation at specific grade crossings.

Task Description: This project includes five major research tasks as described in the body of the proposal.

- Task 1: Literature Review
- Task 2: Data Preparation
- Task 3: Annual Accident Rate Analysis
- Task 4: Statistical Modeling of Accident Frequency
- Task 5: Final Research Report

Total Budget: $25,000

Student Involvement (Thesis, Assistantships, Paid Employment):
One Ph.D. students involved this project to assist in data preparation and statistical analyses. The research study was developed into his dissertation dissertation topic.

Relationship to Other Projects:
No direct relationships

Technology Transfer Activities:
Research results will be submitted for publication to international transportation conferences (TRB or ITE), STC journal, and other journals in the field of transportation safety (AAP or TRF).

Potential Benefits of Project:
A unique and statistical robust approach will be developed and used, which resolves the inherent problems normally associated with evaluations of stop-sign effectiveness at passive crossings. This research will clarify the controversy about the effectiveness of stop-sign use at grade crossings.

TRB Keywords:
Grade Crossing; Statistical Model; Accident Frequency; Crossbuck; Stop Sign
ACKNOWLEDGEMENT

The work described in this final report was sponsored by the Southeaster Transportation Center from a U.S. Department of Transportation Grant through the University Transportation Centers Program. The recommendations of this study are those of the authors, and they do not represent views of U.S. DOT.
The safety benefit of stop-sign treatment employed at passive highway-rail crossings has been a subject of research for many years. The objective of this study is to assess the effectiveness of the stop-sign treatment on crossing safety. Using the Federal Railroad Administration database, the research focused a 26 years of vehicle-train accident history in the United States from 1980 through 2005. A before-and-after and cross-sectional statistical analysis was conducted for 7,394 public highway-railroad grade crossings that were upgraded from crossbuck-only to stop signs without involvement in other TCDs or automatic countermeasures.

Approximately 232 accidents occurred annually at the 7,394 population crossing sites. An annual average of 137 accidents occurred during the crossbuck-controlled period and 95 crashes occurred during the stop-controlled period. Results indicate 27.131 crashes per 1000 crossings per year for stop-controlled crossings and 39.869 crashes per 1000 crossings per year for crossbucks-controlled crossings. On average, the accident rate at crossbucks-controlled crossings is 12.738 more or 46.95% higher than that at stop-controlled crossings.

This study developed Negative Binomial (NB) accident prediction models respectively for paved and unpaved highway-rail grade-crossings that include effect for stop-sign treatment. For the paved crossing model, it is found that control treatment, percent trucks, AADT (Annual Average Daily Traffic), number of crossing tracks, crossings adjacent development type, and interaction terms between control treatment, AADT, trains per day, percent trucks, and MAXTSPD (maximum timetable speed) are significantly associated with the accident rate at crossings. For the unpaved crossing model, number of crossing tracks is not a significant parameter, as on paved roads, and number of lanes is a significant variable that is not in the paved road model. Furthermore, the unpaved crossing model shows fewer interaction terms than the paved model.

Through evaluating the factors affecting safety at the passive crossings based on the NB models, the follow conclusions can be drawn:
At paved highway rail grade crossings,

- Accident frequencies at the crossings increase as AADT, percentage of trucks, the number of trains per day increases, and the number of track;
- Stop-sign treatment is more effective at low vehicle and train volume crossings than at higher volume crossings;
- Stop-sign treatment is more effective at crossings with multi tracks than those with few tracks;
- Higher train speeds would reduce the effectiveness of the stop-sign treatment;
- As the percentage of trucks in traffic increases, there is a corresponding increase in accident frequency;
- The proximity of crossings to industrial areas leads to a higher number of accidents.

At unpaved highway rail grade crossings,

- Stop-sign treatment is less effective at crossings with higher train volumes;
- Accident frequencies at the crossings increase as AADT and the number of highway lanes;
- The proximity of crossings to industrial areas leads to a much higher number of accidents, while the proximity of crossings to residential areas is associated with a lower number of accidents.

Based on specific attributes of the current crossbuck-only-controlled crossings, decision makers and traffic engineers can use the models to examine the accident risks at crossings and assess the potential effectiveness of stop-sign treatment.
STC Research Project Description.................................................................................. i
Acknowledgement........................................................................................................... ii
Executive Summary........................................................................................................ iii
Table of Content.............................................................................................................. v
List of Tables .................................................................................................................. v
List of Figures.................................................................................................................... vi
Chapter 1 - Introduction ................................................................................................. 1
Chapter 2 – Methodology ............................................................................................... 5
  2.1. Federal Railroad Administration Database ......................................................... 5
  2.2. Data Preparation.................................................................................................... 5
  2.3. Annual Accident Rate Computation ..................................................................... 7
  2.4. Statistical Modeling of Accident Frequency......................................................... 8
Chapter 3 – Annual Accident Rate Analysis ................................................................. 11
Chapter 4 – Accident Frequency Regression Model ......................................................... 15
  4.1. Paved Crossing Model ......................................................................................... 16
  4.2. Unpaved Crossing Model ..................................................................................... 18
Chapter 5– Conclusion and Discussion .......................................................................... 21
References ...................................................................................................................... 24

LIST OF TABLES

Table 1: Descriptive statistics for accident distributions .............................................. 11
Table 2: One-sample Kolmogorov-Smirnov test for normality .................................. 11
Table 3: Parameter estimates of the NB regression models ........................................ 16
List of Figures

Figure 1: Standard Crossbuck with Stop sign on separate mounting and Stop sign and supplemental number of tracks sign mounted on Crossbuck post (MUTCD, 2003).......................... 2
Figure 2: Accumulative number of crossings by crossing type........................................... 7
Figure 3: Accident rate comparison between crossings before and after stop-sign treatment in the test group and crossings in the control group. ................................................................. 12
Figure 4: 26-year accident decreasing trend comparison between test group and control group 13
Figure 5: After ISTEA accident decreasing trend comparison between test group and control group ......................................................................................................................... 14
CHAPTER 1 - INTRODUCTION

At highway-rail grade crossings, vehicle-train crashes are the most dangerous traffic accidents. The average weight ratio of train to automobile is about 4,000 to one (Railroad Crossing Safety Factsheet, 2003). Such a huge mass difference results in a great injury/fatality rate in train-automobile crashes. Therefore, compared to highway intersections, although the annual crash frequency of grade crossings is relatively lower, rail-highway grade-crossings’ safety issues are more special and critical.

Highway-rail grade-crossings are generally categorized as two groups, namely active and passive grade crossings. Active grade crossings’ devices detect approaching trains and warn motorists by initiating sequences of flashing lights, bells, and/or gate closures. Passive grade crossings do not have devices to detect approaching trains. Instead, motorists must take notice of the passive controls (signs and markings), understand what they mean, then search/listen for trains and respond appropriately.

During the past 30 years, the annual accident rate has significantly decreased at rail-highway grade crossings. However, this reduction has come about largely through improvements to the level of grade-crossing control (i.e., flashing lights, automatic gates, grade separation), as well as through improvements to active warning devices. For passive crossings, there has been no clear improvement in driver behavior or crash experience (Lerner et al., 2002).

The Manual on Uniform Traffic Control Devices (MUTCD) provides guidance on what traffic-control devices (TCDs) should be used at public passive rail-highway grade-crossings. As a minimum, one crossbuck sign shall be used on each highway approach to every highway-rail grade crossing, alone or in combination with other traffic control devices in order to mark the location of the railroad tracks at the point where they cross the road (MUTCD, 2003). The optional TCD treatment at passive crossings includes a yield sign or a stop sign. Yield signs have not been frequently deployed at rail-highway grade crossings (Lerner et al., 2002), and no research appears to have been done comparing yield signs to crossbucks at crossings (Raub, 2006). Stop signs should be used at the discretion of the responsible State or local highway
agency if highway-rail grade-crossings have two or more trains per day and are without automatic traffic control devices.

Figure 1: Standard Crossbuck with Stop sign on separate mounting and Stop sign and supplemental number of tracks sign mounted on Crossbuck post (MUTCD, 2003)

Engineers and policy makers who make decisions about traffic control posting configurations are not in complete agreement if stop signs are effective when used at highway-railroad grade crossings. The safety benefit of stop-sign treatment employed at passive crossings has been a controversial focus point for many years. The NCHRP Report 470 (Lerner et al., 2002) indicated that there were differences of opinion regarding the use of stop signs at passive grade crossings: don’t use at all, use only under certain conditions, and use at all passive crossings unless hazardous.

The use of stop signs was authorized by the Intermodal Surface Transportation Efficiency Act (ISTEA) (U.S. Congress, 1991) and the Federal Highway Administration’s (FHWA, 1992). A prior study (Eck and Shanmugam, 1981) reported that upgrades from no signs or crossbucks to stop signs can significantly reduce accident rates at both low-volume and higher-volume highway-rail grade crossings. The National Transportation Safety Board (NTSB) (1998)
suggested a broader use of stop signs at railroad-highway grade crossings and recommended stop signs as an interim device until intelligent transportation systems are developed to warn the driver. Sanders et al. (1978) found that stop signs were used more frequently in urban areas and that crossings having stop signs tend to have higher train volumes; accident rates for stop-sign crossings were lower than those for crossbuck-only crossings for higher vehicle-train exposure values; and stop signs, when properly used, resulted in improved driver behaviors adequate for the detection and avoidance of trains. They suggested that stop signs should be applied selectively, only at hazardous passive grade crossings, and should not be used indiscriminately at all passive grade crossings. Additionally, in Canada, it was found that the stop-sign countermeasure can improve crossing safety performance by as much as 35% (Saccomanno et al., 2007).

On the other hand, other researchers did not suggest the use of stop signs because observational studies showed that motorists frequently disregarded stop signs at grade crossings (Bezkorovainy and Holsinger, 1966; Burnham, 1994). The high level of noncompliance might increase and carry over to other locations if the stop sign is used indiscriminately (Lerner et al., 2002). Those observational studies showed that percentage of drivers not coming to a complete stop was higher than the percentage found at highway intersections, but one needs evidence to support that the high noncompliance rate correspondingly leads to a high accident rate at stop-controlled crossings.

A recent study (Raub, 2006) examined 10 years of collision data in seven Midwestern states using the FRA accident database, and compared collision rates among four types of crossings: crossbucks, stop signs, flashing lights, and gates. The collision rate calculation was based on millions of crossing vehicles, average daily trains, and product between them (exposure factor). It was reported that, compared to the other type of crossings, collision rates for crossings with stop signs are much higher, especially when using millions of crossing vehicles as the collision rate calculation base. However, those collision rate calculations neglected some other significant risk evaluation factors, such as number of tacks, road surface type, and train speed, which are often used to investigate effectiveness of countermeasures at grade crossings (Park and Saccomanno, 2005; Miranda et al., 2005).
The safety benefit of the stop-sign treatment employed at passive crossings appears still unresolved and controversial. Thus, one question that raises based on the previous conflicting opinions and research findings is what happened to crossings where a change was made from crossbucks to stop signs. A before-and-after analysis of stop-sign treatment has not yet been conducted at a nationwide scale. The before-and-after and cross-sectional statistical analysis method has been used to evaluate the effectiveness of a countermeasure on highway safety by a number of researchers (Hauer, 1997; Harwood et al., 2000; Shen and Gan, 2003). In these studies, the effectiveness of given countermeasures is determined by comparing collisions at each crossing before and after the introduction of a given countermeasure. Additionally, there has also been a lack of statistical models for passive crossings developed for planners and decision makers to select significant input risk factors and assess benefit of using a stop-sign countermeasure at specific grade crossings.

Using Federal Railroad Administration database (FRA, 2008), the research covers 26 years of vehicle-train accident history in the United States from 1980 through 2005. During the analysis period, 7,394 public highway-railroad grade crossings were upgraded from Crossbuck-only to stop signs without using other TCDs or automatic countermeasures. The objectives of this research are to 1) determine if there is a decrease, increase, or no change in vehicle-train related crashes before and after stop controls were implemented at passive grade crossings; and 2) develop accident frequency prediction models to assess how specific risk changes may be expected after stop-sign installation at specific grade crossings. As will be described, a unique and statistical robust approach was developed and used, which resolves the inherent problems normally associated with evaluations of stop-sign effectiveness at passive crossings.
CHAPTER 2 – METHODOLOGY

2.1. Federal Railroad Administration Database

Since the 1970’s the Federal Railroad Administration (FRA) began keeping records of train-related accidents across the entire United States (FRA, 2008). The FRA database was identified as the single most complete and accurate large-scale datasets available for this research. It contains three sub-databases:

1. **The Grade-Crossing Inventory database**: it is a record of the current crossing inventory. Reference attributes in this database reflect the current state of each crossing.

2. **The Grade-Crossing Inventory History database**: it reflects the state changes of the crossing, including a reason for the update and an effective date for the change.

3. **The Grade-Crossing Accident History database**: it provides a record of accidents that have occurred at the crossings and the conditions at the time of the accident.

The three databases are linkable to each other by common crossing ID. In this study, the Grade-Crossing Inventory was used to identify independent factors that reflect crossing-related attributes such as, crossing surrounding, control treatment, number of tracks, maximum timetable speed (MAXTTSPD), trains per day, highway pavement type, number of lanes, annual average daily traffic (AADT), percentage of trucks, etc. The Grade-Crossing Inventory History was used to identify when passive crossings were updated from crossbucks-only to stop sign control and ensure that during the research period the crossings were not involved in other control treatments. The Grade-Crossing Accident History database was applied to obtain the accident frequency for each target passive crossing during the period of specific control treatment (crossbucks-only or stop signs added).

2.2. Data Preparation

This research addresses public highway-railroad grade-crossings that are stop-controlled after having been updated from crossbuck-only within the analysis period. The research covers 26 years of accident history. The beginning date of 1980 was selected for the study period because
the database was deemed to be mature (i.e., relatively complete, unambiguous, accurate, and stable) and well understood by those entering and maintaining the data. The ending date of 2005 was selected as a date close enough to the present to be completely entered and current.

The current FRA grade-crossing inventory contains 406,395 entities split between public, private and pedestrian-only crossings. It can be seen from the data that fully 75 percent of the inventory consists of at-grade crossings (361,128), with roughly two-thirds of those being public crossings (214,980). Approximately 50 percent of public grade crossings are controlled by crossbucks or stop signs (120,016). Of these, 106,503 (94%) are controlled by crossbucks and only 13,513 (6%) are controlled by stop signs.

Among the crossbuck-controlled crossings, there are 60,024 crossings that have always been controlled by Crossbucks-only during the 26 years of study period. These crossings can be considered as the control group, which displays a basic trend of accident risk through the observation years.

Among the stop-controlled grade crossings, the test crossing group is the crossings that were controlled by Crossbucks and subsequently upgraded to add stop signs without involvement in other TCDs or automatic countermeasures. 7,394 crossings were identified for the study period as belonging in the target group, in which each crossing had been open and operating during the 26 years. Each crossing was further divided into two time periods: when it was controlled by crossbucks-only and when it was controlled by stop signs. At the beginning of the study period (1980), all crossings in the population were controlled by crossbucks-only. By the end of the study period (2005), all crossings in the population had stop signs added. These crossings were upgraded nationwide at a rate of approximately 274 sites per year, although yearly upgrade rates varied considerably. A plot of the accumulated number of crossings by control type for the target population is shown on Figure 2.
The varying upgrade dates provide subgroups, crossbucks-only (before) and stop signs (after), with various durations. Comparing the annual accident rates before and after for the same crossing group over the 26-year period is ideal because the crossing characteristics are the same for the population, the difference being limited to before-after sign controls.

2.3. Annual Accident Rate Computation

Annual accident rates were computed for the crossings, noting if control was by crossbuck or stop sign. Annual accident rates were computed by summing the yearly number of accidents occurring at crossbucks and dividing by the number of crossbuck-controlled crossings that existed that year. The same was done for stop-controlled crossings.

\[
\bar{K}_y = \frac{\sum K_y}{n_y / 1000}
\]  

(Eq. 1)

Where:
\[ \bar{K}_y = \text{Average accident rate (per 1000 crossings) in year } y \]
\[ K_i = \text{Number of accidents at crossing } i \text{ in year } y \]
\[ n_y = \text{Number of crossings existing in year } y \]

This process yielded a tabulation of accident rates for both the crossbuck-only-controlled crossings (before) and the stop-controlled crossings (after) for each year in the study period and the difference in number of crashes in the two periods (before and after) noted. The results were tabulated by accidents per 1000 crossings per year and plotted for each year for each control type. A statistical analysis was conducted to test the null hypothesis, that there is no difference in annual accident rates at the highway-railroad grade crossings comparing the before period when controlled by crossbucks-only to the after period when controlled by stop signs.

2.4. Statistical Modeling of Accident Frequency

The objective of this part of the research was to develop statistical accident frequency models for accident prediction in the target population of crossings in order to evaluate safety performance of stop-controlled crossing attributes and identify significant accident risk factors that reflect crossing-related attributes. The models are developed from the number of accidents, expressed as count data, which occurred at each crossing during respective sign-control periods. A previous study (Saccomanno et al., 2004) indicated that using Poisson models to predict accident frequency at grade crossings was associated with “overdispersion.” Therefore, the Negative Binomial (NB) model was applied in this study for accident frequency analysis and prediction at passive crossings.

The NB regression model introduces an error term \( \varepsilon_i \) to account for the bias caused by the overdispersion as shown in Equation 2.

\[
\ln(\lambda_i) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i + \varepsilon_i
\]  
(Eq. 2)

Where:
\[ \beta = \text{Intercept} \]
$X_i$ = Independent variables of interest (crossing attributes)  

$\beta_i$ = Model coefficients for independent variable $X_i$  

$\lambda_i$ = Expected number of collisions

Introducing this error term into the formulation of the NB model allows the variance to be different from the mean in such a way as shown in Equation 3.

\[ \text{Var}(k_i) = E(k_i) \left[ 1 + \alpha E(k_i) \right] \]  

(Eq. 3)

Where:

- $E(k_i)$ = Expected value of accident counts at crossing $i$
- $\alpha$ = Measure of the dispersion, equal to the variance of the error term (gamma distributed rather than normally distributed in the case of the Poisson model)

The difference and dynamic of the NB model rest with the measure of dispersion $\alpha$. It should be noted that as $\alpha \rightarrow 0$, $\text{Var}(k_i) \rightarrow E(k_i)$, converging to a Poisson model. In this study, by assuming the NB model and observing the dispersion term, $\alpha$, the null hypothesis of equi-dispersion was tested. The negative binomial distribution has the form, as shown in Equation 4.

\[ P(k_i) = \frac{\Gamma(1/\alpha + k_i)}{\Gamma(1/\alpha)k_i!} \left( \frac{1/\alpha}{(1/\alpha) + k_i} \right)^{1/\alpha} \left( \frac{k_i}{(1/\alpha) + k_i} \right)^{k_i} \]  

(Eq. 4)

Since the duration of the control period for crossbucks-only or stop signs is different at each crossing, the duration of the control period was selected as an offset variable (N) in the NB model. Thus, the NB model is to estimate the accident rate at each crossing per year ($\mu = \frac{\lambda_i}{N}$) when a crossing is controlled by either crossbucks-only or stop signs. While the control pattern was treated as an independent factor, the other independent variables of crossing characteristics were recorded in the Grade-Crossing Inventory database. Therefore, the expected accident rate at each crossing per year depends on the explanatory variables and can be expressed exponentially as Equation 5.
The SAS program procedure, GENMOD, was used for model development and the hypothesis testing was based on the 0.05 significance level.
Approximately 232 crashes occurred annually at the 7,394 population crossing sites. An annual average of 137 crashes occurred at Crossbuck-controlled crossings and 95 crashes occurred at Stop-controlled crossings. Descriptive statistics compiled for the two distributions are reflected in Table 1. Results indicate 27.131 crashes per 1000 crossings per year for Stop-controlled crossings and 39.869 crashes per 1000 crossings per year for crossbuck-controlled crossings. There is a difference of 12.738 crashes/1000 crossings/year or a 46.95% higher crash accident rate at Crossbucks than at Stop signs.

Table 1: Descriptive statistics for accident distributions

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Stop</th>
<th>Crossbuck</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Mean</td>
<td>27.131</td>
<td>39.869</td>
</tr>
<tr>
<td>S.D.</td>
<td>5.4108</td>
<td>12.8419</td>
</tr>
<tr>
<td>95. C.I. L.B.</td>
<td>24.945</td>
<td>29.316</td>
</tr>
<tr>
<td>95. C.I. U.B.</td>
<td>29.316</td>
<td>34.682</td>
</tr>
<tr>
<td>95. C.I.</td>
<td>23.6</td>
<td>96.8</td>
</tr>
<tr>
<td>Absolute</td>
<td>.106</td>
<td>.254</td>
</tr>
<tr>
<td>Positive</td>
<td>.068</td>
<td>.254</td>
</tr>
<tr>
<td>Negative</td>
<td>-.106</td>
<td>-.206</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>.539</td>
<td>1.293</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.934</td>
<td>.071</td>
</tr>
</tbody>
</table>

Table 2 shows results of the Kolmogorov-Smirnov normality test accident distribution. The goodness-of-fit test was done to test if the accident-rate data could be normally distributed. It was found that accidents were normally distributed at both crossbuck- and stop-controlled crossings at the P>0.05 significance level. ANOVA results show that the difference between the two normal distributions is significant (F(1,51) = 21.726, P < 0.001).
The accident rates, taken per 1000 crossings, were plotted and are shown on Figure 3. It illustrates that Stop signs posted at previous Crossbucks-only crossings sustained a lower accident rate. Secondly, one is aware of the chaos resulting from low numbers of postings on each end of the graph for opposite controls. Thirdly, one sees that Crossbuck accident rates remained fairly constant in magnitude, whereas stop-controlled crossings experienced a steady decrease, tending toward the lower bound as the number of postings increased. An interesting finding is that the annual accident rates for both crossbucks-controlled and stop-controlled period in the test group are consistently higher than the annual accident rates at crossings in the control group that were always controlled by Crossbucks. This funding indicates that the two crossing groups represent entirely different levels of danger and may operate differently. It is reasonable to assume that the engineers chose those dangerous crossbucks-controlled crossing or those with crash records to apply the stop-sign treatment.

Figure 3: Accident rate comparison between crossings before and after stop-sign treatment in the test group and crossings in the control group.

As seen on Figure 4, the general linear regression in accident rates at crossings in the test group compared to those in the control group shows a downward trend. Comparing the slopes of the
general linear trends, the accident decreasing rate in the test group is 1.6 times (-0.4533 / -0.2818) higher than that in the control group in which the crossings were always controlled by crossbucks. Further examination of the study period illustrates a more apparent accident decreasing trend after ISTEA, as shown in Figure 5. It was found that as the number of crossings with stop sign treatment increased, the accident decreasing rate in the test group is 8.0 times (-1.278 / -0.160) higher than that in the control group in which the crossings were always controlled by crossbucks.

Figure 4: 26-year accident decreasing trend comparison between test group and control group
Figure 5: After ISTEA accident decreasing trend comparison between test group and control group
During analysis of the output, it was found that the AADT (Annual Average Daily Traffic) distribution for the paved roads at grade crossings is apparently different from the unpaved roads; and the higher the AADT, the more likely the grade crossings are to have paved roads. These trends are logical and expected. As reflected on Figure 3, most unpaved-crossing accidents occur when AADT is less than 100 vehicles per day; most paved-crossing accidents occur when AADT is less than 300 vehicles per day. A previous study reported that low-volume road grade crossing characteristics are significantly different from those of higher-volume road grade crossings, and the differences were more evident for physical characteristics than for operational characteristics (Eck and Shanmugam, 1981).

Therefore, in this study, the NB models were separately developed for paved and unpaved crossings in order to avoid the collinearity problem. Otherwise, it may cause the relationships between crash frequency and some independent factors that cannot easily be explained intuitively (Austin and Carson, 2002).

Table 3 presents the significance tests of the model parameters for both paved and unpaved crossings. For the paved crossing model, it is found that control treatment, percent trucks, AADT, number of crossing tracks, crossings adjacent development type, and interaction terms between control treatment, AADT, trains per day, percent trucks, and MAXTSPD are significantly associated with the accident rate at crossings. For the unpaved crossing model, number of crossing tracks is not a significant parameter, as on paved roads, and number of lanes is a significant variable that is not in the paved road model. Furthermore, the unpaved crossing model shows fewer interaction terms than the paved model. In Table 3, the measure of dispersion $\alpha$ is 25.4 for the paved model and 32.6 for the unpaved model. Both of them are significantly larger than zero, displaying a very strong overdispersion effect, which means that the NB regression is the appropriate model instead of the Poisson model. The coefficient estimates of the model parameters reflect how the independent variables are associated accident risk at the crossings: the mean number of expected accidents increases (if coefficient is positive) or
decreases (if coefficient is negative) when the value of the independent variable increases. The effects of the risk factors on crossing safety are respectively explained for paved and unpaved crossing models as follows.

Table 3: Parameter estimates of the NB regression models

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Paved grade crossing</th>
<th>Unpaved Grade Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Standard Error</td>
</tr>
<tr>
<td>Intercept</td>
<td>-10.1719</td>
<td>0.5129</td>
</tr>
<tr>
<td>Control Treatment (Stop sign vs. Crossingbucks)</td>
<td>-5.5172</td>
<td>0.7072</td>
</tr>
<tr>
<td>No. Traffic Lanes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Percent Trucks (Continuous variable, %)</td>
<td>0.0491</td>
<td>0.0126</td>
</tr>
<tr>
<td>AADT (Continuous variable, per 1000)</td>
<td>0.4075</td>
<td>0.0934</td>
</tr>
<tr>
<td>Trains per day (Continuous variable)</td>
<td>0.0200</td>
<td>0.0223</td>
</tr>
<tr>
<td>No. Crossing Tracks (Continuous variable)</td>
<td>1.3169</td>
<td>0.2088</td>
</tr>
<tr>
<td>MAXTTSPD (Continuous variable, mph)</td>
<td>-0.0200</td>
<td>0.0103</td>
</tr>
<tr>
<td>Development Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0.2206</td>
<td>0.2584</td>
</tr>
<tr>
<td>Commercial</td>
<td>-0.2331</td>
<td>0.3746</td>
</tr>
<tr>
<td>Industrial</td>
<td>1.2587</td>
<td>0.4313</td>
</tr>
<tr>
<td>Institutional</td>
<td>-1.7452</td>
<td>0.9256</td>
</tr>
<tr>
<td>Open Space</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Interactions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control*AADT</td>
<td>0.6322</td>
<td>0.1778</td>
</tr>
<tr>
<td>Control*Trains</td>
<td>0.1103</td>
<td>0.0310</td>
</tr>
<tr>
<td>Control*Tracks</td>
<td>-0.5472</td>
<td>0.2911</td>
</tr>
<tr>
<td>Control*MAXTTSPD</td>
<td>0.0891</td>
<td>0.0155</td>
</tr>
<tr>
<td>Dispersion</td>
<td>25.4236</td>
<td>0.6126</td>
</tr>
<tr>
<td>DF</td>
<td>7841</td>
<td></td>
</tr>
<tr>
<td>Deviance</td>
<td>0.7084</td>
<td>0.5455</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>-10189.1227</td>
<td></td>
</tr>
</tbody>
</table>

4.1. Paved Crossing Model

The variable control treatment’s coefficient is -5.517 for the paved model. It indicates that the average number of accidents (events) is significantly reduced after the stop signs were installed.
at these crossings that were originally controlled by crossbucks-only. This result is consistent with the previous finding in the annual accident rate analysis that the accident rate at crossbucks-controlled crossings is significantly higher than that at stop-controlled crossings. However, the modeling results show that the stop-sign effect on paved crossings’ safety performance is complexly interacted with AADT, trains per day, percent trucks, and MAXTTSPD. To better explain the interaction effects, the modeling results from Table 3 were further expressed by Equations 5 and 6 for crossbuck-only and stop-sign control, respectively:

For crossbucks-only control:

\[
\mu_x = \exp \{ -10.172 + 0.049 \text{ (Percent Trucks)} + 0.408 \text{ (AADT)} \\
+ 0.020 \text{ (Trains per Day)} + 1.317 \text{ (No. of Crossing Tracks)} \\
- 0.020 \text{ MAXTTSPD} + [0.221(\text{Residential}) - 0.233(\text{Commercial}) \\
+ 1.259(\text{Industrial}) - 1.745(\text{Institutional})] \}
\]  
(Eq. 5)

For stop-signs control:

\[
\mu_s = \exp \{ -15.689 + 0.049 \text{ (Percent Trucks)} + 1.039 \text{ (AADT)} \\
+ 0.130 \text{ (Trains per Day)} + 0.770 \text{ (No. of Crossing Tracks)} \\
+ 0.069 \text{ MAXTTSPD} + [0.221(\text{Residential}) - 0.233(\text{Commercial}) \\
+ 1.259(\text{Industrial}) - 1.745(\text{Institutional})] \}
\]  
(Eq. 6)

In both Equations 5 and 6, the positive coefficients for AADT and Trains per day indicate that the accident frequencies at crossings increase as AADT increases by 1000 vehicles per day and the number of trains per day increases. These findings are consistent with many previous research results in crossing accident frequency modeling studies (Austin and Carson, 2002; Saccomanno et al., 2004; Oh et al., 2006). However, the coefficients of AADT and Trains per day in Equation 6 are larger than those in Equation 5. This means that the increasing rate of accident risk with increments of AADT and Trains per day is larger when the crossings were controlled by stop signs compared to when controlled by crossbucks only. This finding supports
the previous research conclusion drawn by Eck and Shanmugam (1981): stop-sign treatment is more effective at lower-volume road grade-crossings than at higher-volume road grade crossings.

The interaction effect between control treatment and number of crossing tracks is marginally significant (p = 0.0602). When increasing one track at crossings, a vehicle-train accident is $e^{1.317}$ times more likely to occur at the crossings controlled by crossbucks, while it is $e^{0.770}$ times more likely to occur at the crossings controlled by stop signs. The accident increasing rate with number of crossing track for crossbucks-only-controlled crossings is larger than that for stop-controlled crossings. It implies that the stop-sign treatment is more effective at crossings with multi tracks than those with few tracks.

The model shows that an increase in the maximum timetable speed (MAXTTSPD) of 1 mile per hour is expected to increase accident frequency by $e^{0.069}$ times at stop-controlled crossings but decrease accident frequency by $e^{0.020}$ times at crossbuck-only-controlled crossings. This interaction effect between Control Treatment and MAXTTSPD shows that the higher train speeds would reduce the effectiveness of the stop-sign treatment compared to crossbuck only.

The positive sign of the coefficient for percent trucks indicate that as the percentage of trucks in traffic increases, there is a corresponding increase in accident frequency. There is no difference between the two treatment methods. Trucks can be 40 or more times heavier than the other vehicles in the traffic stream. Large trucks are generally less maneuverable, accelerate slower, and take longer to stop (FMCSA, 2001). Due to physical and operational characteristics of the heavy trucks, they can significantly impact traffic system performance and safety.

Development types were treated as a single categorical variable with five sublevels, with Open Space selected as the reference category. Compared to crossings at open space, the crash frequency of the crossings at industrial areas is $e^{0.069}$ times higher (p=0.0035), while the crash rates for the crossings at residential (p = 0.3934), commercial (p = 0.5336), and institutional areas (p = 0.0594) are not significantly different.

4.2. Unpaved Crossing Model
The variable Control Treatment’s coefficient is -4.6330 for the unpaved model. As similar as the effect illustrated in the paved model, the accident frequency is also significantly reduced after the stop signs were installed at those unpaved crossings. The modeling results were further expressed by Equations 7 and 8 for crossbucks-only control and stop-signs control, respectively:

For crossbucks-only control:

\[
\mu_x = \exp\{-13.110 + 1.160 \text{ (No. Traffic Lanes)} - 0.049 \text{ (Percent Trucks)} + 3.152 \text{ (AADT)} \\
- 0.033 \text{ (Trains per day)} + 0.074 \text{ MAXTTSPD} + [-1.456(Residential) \\
- 0.3511(Commercial) + 3.005(Industrial) - 1.628(Institutional)]\} \tag{Eq. 7}
\]

For stop-signs control:

\[
\mu_s = \exp\{-17.742 + 1.160 \text{ (No. Traffic Lanes)} - 0.049 \text{ (Percent Trucks)} + 3.152 \text{ (AADT)} \\
+ 0.101 \text{ (Trains per day)} + 0.074 \text{ MAXTTSPD} + [-1.456(Residential) \\
- 0.3511(Commercial) + 3.005(Industrial) - 1.628(Institutional)]\} \tag{Eq. 8}
\]

In the unpaved model, there is only one variable, number of trains per day, which has a significant interaction effect with control treatment. The coefficient of trains per day in Equation 8 is positive (0.101), while that in Equation 7 is negative (-0.033). This means that as the number of trains per day increases, the crash frequency is increasing at stop-controlled crossings, but decreasing at crossbucks-only-controlled crossings. The result implies that the stop-sign treatment is less effective at crossings with higher train volumes. This analysis is consistent with finding for paved crossing model.

Although multiple-lane unpaved roads are not common, specific coefficient estimate (1.1595) reported in Table 3 indicate that an increased number of lanes crossing tracks results in an increased accident frequency (0.0003). One possible explanation is that when a wide unpaved road is treated as multiple-lane roadway by drivers, vehicles stopped in order to yield to an oncoming train at the crossing may be a temporary sight obstruction for drivers in the adjacent (virtual) lane, thus leading to potential accident risk. This type of collision was also concerned by
FRA who designed a corresponding variable in the Grade-Crossing Accident History database (reference).

Similar to the paved model, AADT is positively correlated with accident frequency in the unpaved model. The higher the traffic volume, the higher the crash frequency. However, the variables, percent trucks and MAXTTSPD, display a different effect on crossing safety from the paved model, as shown in Table 3. It is found that the accident frequency will slightly decrease if the percentage of trucks and MAXTTSPD increase. This finding seems not to be intuitive because more trucks in traffic and higher train speed are generally considered as risk factors for crossing safety. A possible explanation for the modeling results is that for the unpaved crossings with higher train speed and truck volume, engineers would realize their potential risk and take protective actions to enhance crossing safety, such as clearing sight obstructions, increasing sign visibility, or applying additional warning information.

Adjacent development type is also associated with crash frequency at the unpaved crossings. Compared to the crossings at open space, the proximity of crossings to industrial areas leads to a much higher number of accidents ($p < 0.0001$), which is consistent with the analysis in the paved model. An interesting finding is that the proximity of unpaved crossings to residential areas is associated with a lower number of accidents ($p = 0.0004$). A possible explanation is that most of the road users at residential areas are local drivers who may benefit from familiarity with the surroundings and operation at the crossings. However, the crash rates for the crossings at commercial ($p = 0.6938$), and Institutional areas ($p = 0.6273$) are not significantly different.
CHAPTER 5 – CONCLUSION AND DISCUSSION

This study was focused on a 26-year accident history of passive highway grade crossings that were originally controlled by crossbucks-only and were later upgraded to stop controls. The first objective of the research was to assess the effectiveness of the stop-sign treatment on crossing safety. It was found that the annual accident rates during the period when the crossings were controlled by crossbucks-only were consistently higher than the accident rates after the stop-sign installation. The study finding supports that stop-sign treatment should be an effective and inexpensive method to improve safety at public grade crossings. This conclusion is consistent with prior accident rate analyses for stop-sign usage at passive crossings (Sanders et al., 1978; Eck and Shanmugam, 1981).

Secondly, this study developed NB accident prediction models for both paved and unpaved highway rail grade crossings that include the effect of stop-sign treatment. The model results corresponded to the analysis of annual accident rates that stop-sign treatment reduced accident frequency. Through evaluating the factors affecting safety at the passive crossings based on the NB models, the follow conclusions can be drawn:

At paved highway rail grade crossings,

- Accident frequencies at the crossings increase as AADT, percentage of trucks, the number of trains per day increases, and the number of track;
- Stop-sign treatment is more effective at low vehicle and train volume crossings than at higher volume crossings;
- Stop-sign treatment is more effective at crossings with multi tracks than those with few tracks;
- Higher train speeds would reduce the effectiveness of the stop-sign treatment;
- As the percentage of trucks in traffic increases, there is a corresponding increase in accident frequency;
- The proximity of crossings to industrial areas leads to a higher number of accidents.
At unpaved highway rail grade crossings,

- Stop-sign treatment is less effective at crossings with higher train volumes;
- Accident frequencies at the crossings increase as AADT and the number of highway lanes;
- The proximity of crossings to industrial areas leads to a much higher number of accidents, while the proximity of crossings to residential areas is associated with a lower number of accidents.

Based on specific attributes of the current crossbuck-only-controlled crossings, decision markers and traffic engineers can use the models to examine the accident risks at the crossings and assess the potential effectiveness of stop-sign treatment. This risk evaluation process may help them mitigate crossing accident hazards before vehicle-train accidents occur.

Additionally, some limitations of this study should be discussed. The goodness-of-fit for the models showed that the deviance values are not very close to one (see Table 3), which indicates model misspecification to some extent. One reason is that the Grade-Crossing Inventory in the FRA database may neglect some important factors associated with crossing accident risk such that the factors can appear in the model. For example, sight distance as an important engineering factor is not recorded in the Grade-Crossing Inventory. However, one primary consideration for using a stop sign is limited sight distance at a crossing (Lerner et al., 2002), and restricted sight distance was identified as a significant risk factor in previous crossing studies (Knapp, 1997; Oh et al., 2006). Another reason is that the model fitting was based on the crossings in the entire United States, and therefore, the crossings’ design attributes, environmental features, and driver characteristics are not as homogenous as those in local crossing databases. It would lead to a larger variation of accident frequency.

Limited by research scope and data availability, this study only focused on vehicle-train accidents and did not assess the effect of stop-sign treatment on non-train related crashes. The NCHRP Report 470 (Lerner et al., 2002) points out that another critical concern of the use of stop signs is the possible increment of vehicle-vehicle crashes especially rear-end types. The authors strongly recommend conducting further studies to address this issue.
Finally, several potential points of confusion were discovered when manipulating the FRA databases. Some duplicates of data are found in the Grade-Crossing Inventory database. Also, records reflected in one database may not be in agreement with records in another because they are maintained separately. For example, it was discovered that entry codes for attribute domains differ between the Grade-Crossing Inventory Database and the Grade-Crossing Accident History Database.

In like manner, posting updates are made by the railroad companies and are not always timely. Consequently, reference attributes that reflect conditions at the time of a crash in the Grade-Crossing Accident History database do not always reflect the state for the same period in the Grade-Crossing Inventory database or even the Grade-Crossing Inventory History database. Also, the databases are not linked which makes evaluation difficult. The lack of relational or object-oriented design makes understanding the databases challenging to those who do not study the data structure closely when examining crossing characteristics.

Crossings generally have two approaches and each may differ greatly in geometry, development, visibility and other factors. Unfortunately, there is only one entry for each crossing in the inventory rather than one for each approach.

Although Stop and Yield controls have been legal since ISTEA (1991), there is no code for Yield controls available in the database. This is compounded by the fact that entry codes for attribute domains differ between the Grade-Crossing Inventory Database and the Crossing Accident History Database. An especially careful effort is required in order to not confuse the code domains when evaluating the two together. Authors recommend that FRA should accordingly enhance the quality of the databases.
REFERENCES


