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Safety Improvements at Highway-Railroad Crossing for Pedestrians and Bicyclists and the Assessment of Long- Term Effects of Centerline Curbing

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16. Abstract

The focus of the research reported herein was on assessing the long-term effectiveness of median barriers at highway-rail grade crossings (HRGCs), the impacts of barrier maintenance in resurrecting safety, and on exploring and assessing ways to improve pedestrian and bicyclist safety at HRGCs. Nebraska has about 7,000 HRGCs and each one represents a potential conflict point among trains and highway users, i.e., motorists, pedestrians, and bicyclists. Safety at HRGCs is compromised when highway users resort to unsafe maneuvers, such as passing around closed gates when trains are approaching. Gate-related violations by motorists, pedestrians, and bicyclists were studied at three selected HRGCs in Waverly, Fremont, and Lincoln, all cities located in Nebraska. The barrier at the Waverly HRGC was removed after being in place for a long time while the dilapidated barrier at the Fremont HRGC was revived through maintenance. An educational activity focused on pedestrians and bicyclists at the Fremont HRGC was evaluated for reducing gate violations.

Removal of the barrier in Waverly contributed to greater frequency of unsafe maneuvers by motorists. Specifically, the frequencies of aggregate unsafe maneuvers (i.e., the sum of motorist gate rush, U-turn and backup), as well as gate rush and U-turn, increased after barrier removal. Safety deteriorated over the long-term at the Fremont HRGC while maintenance resurrected safety by reducing the frequency of passing around fully lowered gates by 30-50%. Regarding the effects of the educational campaign focused on pedestrians and bicyclists at the Fremont HRGC, the drive successfully reduced passing around fully lowered gates by about 39%. The recommendations from this research include emphasis on maintenance of barriers in top condition after installation and educational campaigns focused on pedestrians and bicyclists for safety improvements at HRGCs.

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Table of Contents

List of Figures

List of Tables

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Abstract

The focus of the research reported herein was on assessing the long-term effectiveness of median barriers at highway-rail grade crossings (HRGCs), the impacts of barrier maintenance in resurrecting safety, and on exploring and assessing ways to improve pedestrian and bicyclist safety at HRGCs. Nebraska has about 7,000 HRGCs and each one represents a potential conflict point among trains and highway users, i.e., motorists, pedestrians, and bicyclists. Safety at HRGCs is compromised when highway users resort to unsafe maneuvers, such as passing around closed gates when trains are approaching. Gate-related violations by motorists, pedestrians, and bicyclists were studied at three selected HRGCs in Waverly, Fremont, and Lincoln, all cities located in Nebraska. The barrier at the Waverly HRGC was removed after being in place for a long time while the dilapidated barrier at the Fremont HRGC was revived through maintenance. An educational activity focused on pedestrians and bicyclists at the Fremont HRGC was evaluated for reducing gate violations.

Removal of the barrier in Waverly contributed to greater frequency of unsafe maneuvers by motorists. Specifically, the frequencies of aggregate unsafe maneuvers (i.e., the sum of motorist gate rush, U-turn and backup), as well as gate rush and U-turn, increased after barrier removal. Safety deteriorated over the long-term at the Fremont HRGC while maintenance resurrected safety by reducing the frequency of passing around fully lowered gates by 30-50%. Regarding the effects of the educational campaign focused on pedestrians and bicyclists at the Fremont HRGC, the drive successfully reduced passing around fully lowered gates by about 39%. The recommendations from this research include emphasis on maintenance of barriers in top condition after installation and educational campaigns focused on pedestrians and bicyclists for safety improvements at HRGCs.

Executive Summary

Nebraska has about 7,000 highway-rail grade crossings (HRGC) and each one represents a potential conflict point among trains and highway users, i.e., motorists, pedestrians, and bicyclists. Safety at an HRGC is compromised when highway users resort to unsafe maneuvers, such as passing around closed gates when trains are approaching. From 2004 to 2006, the Nebraska Department of Roads (NDOR) sponsored a project that evaluated the efficacy of median barriers installed at HRGCs. These are used to limit drivers' abilities to pass around fully-lowered gates at dual-quadrant gated crossings. While the barriers were found effective in reducing unsafe maneuvers by drivers, their long-term safety effectiveness and the effects of barrier maintenance on safety resurrection were unknown. While the focus was on motorists, the need for improving pedestrian and bicyclist safety was also realized during the course of the project.

The focus of the research reported herein was on assessing the long-term effectiveness of median barriers at HRGCs, the impacts of barrier maintenance in resurrecting safety, and on exploring and assessing ways to improve pedestrian and bicyclist safety at HRGCs. Gate-related violations by motorists, pedestrians, and bicyclists were studied at three selected HRGCs in Waverly, Fremont, and Lincoln, all cities located in Nebraska.

The long-term effectiveness of median barriers installed at HRGCs was evaluated by comparing data collected in 2006 to data collected in 2008 at both Fremont and Waverly HRGCs. However the barrier in Waverly was removed in 2007, so this comparison provided information on the effects of barrier removal after being in place for a relatively long period. The barrier in Fremont was not removed and the 2006/2008 comparison provides information on the long-term effectiveness of barriers at HRGCs with the barrier condition deteriorating over time

because no maintenance was performed during this period. The effect of maintenance on resurrecting HRGC safety was assessed twice in Fremont after performing maintenance in 2009 and again in 2011. After considering various safety options aimed at improving pedestrian and bicyclist safety at HRGCs, an educational campaign using Operation Lifesaver educational materials was carried out and assessed for effectiveness at HRGCs.

Results of data analysis showed that compared to 2006, unsafe maneuvers by drivers increased in 2008 at both Waverly and Fremont. Removal of the barrier at the Waverly HRGC contributed to worsening of safety while the deteriorating condition of the barrier at the Fremont HRGC contributed to reduced safety. The two assessments of barrier maintenance and subsequent changes in safety at the Fremont HRGC indicated 30-50% reductions in passing around fully lowered gates in the post-maintenance period.

Operation Lifesaver materials were used in educational campaigns at HRGCs in Lincoln and Fremont to improve pedestrian and bicyclist safety. The study at Lincoln was inconclusive because of inadequate pedestrian and bicyclist traffic. However, a similar but longer duration campaign in Fremont showed a 39% reduction in passing around fully lowered gates by pedestrians and bicyclists.

This research recommends that installed median barriers must be maintained in excellent condition for continued effectiveness. Also once installed, the removal of median barriers at HRGCs is not prudent. An educational campaign, such as the one used in this research, was effective and is recommended for and for improvement of pedestrian and bicyclist safety at HRGCs. Finally, to reduce maintenance, installation of median barriers on 6-9 inch high concrete curbs is recommended.

Chapter 1 Introduction

1.1 Report Organization

This report consists of five chapters; this introductory chapter with background information and objectives is followed by a chapter providing a review of relevant literature on motorist safety at highway-railroad grade crossings (HRGC) and pedestrian and bicyclist safety in traffic. The third chapter presents the process for data collection and reduction in terms of motorist and non-motorist unsafe maneuvers at selected crossings. The fourth chapter describes analysis of the collected data including simple statistics and statistical models. The last chapter of this report presents research conclusions and recommendations for future research.

1.2 Background

This research was focused on improving safety of pedestrians and bicyclists at highway-railroad grade crossings, as well as exploring the long-term effects of median barriers (also called centerline barriers/curbs) at HRGCs on motorist maneuvers. Nebraska has about 7,000 at-grade highway-rail crossings with each serving as a conflict point among trains and motorists, pedestrians, and bicyclists. Safety at an HRGC is compromised when highway users resort to unsafe maneuvers, such as passing around crossing gates when trains are approaching.

From 2004-2006 the Nebraska Department of Roads (NDOR) sponsored a research project titled "Centerline curbing treatment at railroad crossings for improved safety." This project investigated the effects of median barriers installed at HRGCs on reducing unsafe maneuvers by motorists. Median barriers were installed at two HRGCs in Waverly and Fremont, NE. Results of the project showed the median barriers to be effective in reducing unsafe maneuvers by drivers at HRGCs. However, the long-term safety effectiveness and the effects of maintenance in resurrecting safety were unknown at the conclusion of the project. While the focus was on motorists, the need for improving pedestrian and bicyclist safety was also realized during the course of the project.

The barriers installed on both sides of the HRGC in Waverly were removed at the request of the City of Waverly officials in December 2007 while the barriers installed in Fremont were left in place. However, by 2008 the condition of these barriers was significantly deteriorated compared to 2006, primarily due to traffic and snow plow abuse. The current research was initiated with the following objectives.

1.3 Research Objectives

There were two major objectives for this research: 1) to assess the long-term effects of median barriers on motorists' unsafe maneuvers at both Waverly and Fremont HRGCs and 2) to investigate and assess different ways to improve pedestrian and bicyclist safety at HRGCs. As part of the first objective, this research estimated median barriers' safety impact by comparing motorists' unsafe maneuvers at both Waverly and Fremont HRGCs between 2006 and 2008. Since barriers at the Waverly HRGC were removed in 2007, the comparison between 2006 and 2008 showed the effect of their removal after being in place for a prolonged period. The Fremont comparison indicated changes in safety due to lack of maintenance since no maintenance was performed during this time.

The second objective involved identifying and investigating different ways of improving pedestrian and bicyclist safety at HRGCs, selecting an appropriate method, implementing and then evaluating its effectiveness in reducing unsafe maneuvers by pedestrians and bicyclists. After considering different ways of improving pedestrian and bicyclist safety that included pavement markings, signs, fences, and pedestrian gates, user education was selected for improving safety of pedestrians and bicyclists at HRGCs. Therefore, as part of this objective a campaign utilizing Operation Lifesaver's safety educational materials was undertaken at both Lincoln and Fremont HRGCs. Data on unsafe maneuvers by pedestrians and bicyclists before and after the educational campaign were collected to assess changes in safety. The next chapter presents the results of an extensive review of literature that was conducted as part of this research.

Chapter 2 Literature Review

Topics covered in this literature review include: 1) studies on motorist safety at HRGCs, and 2) studies dealing with the safety of pedestrians and bicyclists on the highway system. A discussion on different types of models used in safety research is also provided in this chapter.

2.1 Motorist Safety at HRGCs

Three aspects of motorist safety at HRGCs are discussed below: evaluation of countermeasures based on engineering, education, and enforcement (triple "Es"); analysis of specific safety-related parameters; and identification of safety-associated factors.

2.1.1 Evaluation of Triple "Es" Safety Countermeasures

Table 2.1 presents a summary of the literature on triple "Es," while a detailed account appears below. Yeh and Multer (2) reviewed literature concerning driver maneuvers at HRGCs from 1990 to 2006 and then addressed a series of engineering design issues related to motorist safety. They summarized that safety-related engineering measures may pertain to roadway signs, pavement markings, and active control devices (e.g., flashing lights and gates) at HRGCs.

Table 2.1 Literature Summary on Triple "Es" Safety Countermeasures for Motorists at HRGCs

Research Objective	Author	Methodology	Major Findings/Results
Explore safety-related engineering designs	Yeh and Multer, 2007	Literature review	Safety-related engineering measures include roadway signs, pavement markings, and active control devices such as flashing lights and gates at HRGCs
Test the safety effectiveness of two new crossbuck designs	Zwahlen and Schnell, 1999	Simple frequency comparisons of driver compliance	New designs helped reduce drivers' noncompliance
Evaluate the safety effectiveness of stop signs at public passive HRGCs	Millegan et al., 2009	Simple accident frequency comparisons and negative binomial	Annual crash rates decreased after installation of stop signs

		regression model	(continued) Safety factors associated with accidents are annual average daily traffic, percentage of trucks, number of daily trains, number of highway lanes, number of rail tracks, and presence of adjacent industrial areas at HRGCs
Evaluate the safety effectiveness of pavement marking	Stephens and Long, 2003	Analysis of variance (ANOVA)	Application of this design at rural HRGCs reduced motorists' hazardous maneuvers both in the short- and long-term periods
Evaluate safety effectiveness of installing centerline barriers at gated HRGCs for motorists	Khattak et al., 2007, 2008, and 2009	Before/after unsafe maneuver data analysis and negative binomial regression model	Improvement in safety due to installation of the barriers was found Number of passing around gates increased with longer duration of road closure, but decreased under adverse weather conditions Driver violations at HRGCs were location-specific but the order of response to installation of the barriers in different locations was fairly similar
Evaluate the overall safety at HRGCs with an automated-horn system and its effectiveness in reducing the annoyance level for nearby residents	Gent et al., 2000	Survey	92% of locomotive engineers rated the crossings "safer" or "about the same" 78% of motorists preferred the new system 71% of the nearby residents had positive attitudes toward it
Evaluate the effectiveness of an enhanced crossing safety education and enforcement program at gated HRGCs with flashing warning devices	Sposato et al., 2006	Simple violation frequency comparisons	Changes in violations were 23% and 71% decreases for two violation types: type that traversed the crossing during gate descent or ascent, and type that traversed the grade crossing after the gates were fully deployed An 15%violation increase was noted for the type that traversed the crossing while the lights were flashing but before the gates descended
Investigate the safety effectiveness of automatic photo enforcement system at HRGCs	Carroll and Warren, 2002	Simple violation frequency comparisons	Violations at California HRGCs were reduced by 36–92% while crashes reduced by 70% Violations in Illinois and in North Carolina were reduced by 47–51% and by 78%

Zwahlen and Schnell (3) tested the safety effects of two new crossbuck designs (i.e., the buckeye crossbuck equipped with a red yield legend and retroreflective side panels, and the standard improved crossbuck equipped with a reflectorized wooden post and both-side microprismatic sheeting) at 3,833 passive crossings in Ohio. Simple frequency comparisons were conducted in terms of driver compliance maneuvers under the use of traditional and new crossbuck designs, as well as historical crash data. They concluded that the new designs helped reduce drivers' noncompliance.

Millegan et al. (4) evaluated the safety effectiveness of stop signs at public passive HRGCs (lacking gates, flashing lights, warning bells, etc.) nationwide using Federal Railroad Administration (FRA) data. Simple comparisons of annual vehicle-involved crash rates between the before-and-after stop sign control periods and the negative binomial (NB) regression model for identifying the effect of stop signs, as well as significant accident risk factors were conducted. The authors reported that annual crash rates were consistently higher during the crossbuck-only period, compared to the period after installation of stop signs. Moreover, the NB model showed the positive effect of stop signs on safety at HRGCs. Several factors associated with the increase of crash frequencies were listed, including annual average daily traffic (AADT), percentage of trucks, number of daily trains, number of highway lanes, and number of rail tracks, as well as presence of adjacent industrial areas at HRGCs. The study also indicated that stop signs were more effective with multiple tracks, lower train speeds, and lower motor vehicle and train volumes.

Pavement marking is another engineering measurement for improving safety at HRGCs. Stephens and Long (5) tested a new type of pavement marking called 25-ft X shape box in Florida. The authors used the Analysis of Variance (ANOVA) method to test the marking's safety effectiveness and identify safety-associated factors. Results indicated that the application of this design at rural HRGCs significantly reduced motorists' hazardous stopping maneuvers both in the short- and long-term periods. However, little benefit was found at urban HRGCs.

Various traffic control facilities and active warning devices have been installed and evaluated at HRGCs in the past. Khattak (6, 7), and Khattak and McKnight (8) studied the safety impact of installing central barriers at gated HRGCs that prevent motorists from going around closed gates in Nebraska. The negative binomial regression model was adopted to conduct a before-and-after study. The authors reported improvement in safety due to installation of the barriers. Moreover, the results also showed that the number of motorists passing around gates increased with longer duration of road closure due to passage of trains, but decreased under adverse weather conditions. Risky driver maneuvers at HRGCs were location-specific but the order of response to installation of the barriers in the two selected locations was fairly similar.

For active warning devices, Gent et al. (9) evaluated the overall safety at HRGCs in Ames, Iowa with an automated-horn system, as well as its effectiveness in reducing the annoyance level for nearby residents. Results of the survey showed that 92% of locomotive engineers rated the crossings "safer" or "about the same" compared to the crossings without such a device. About 78% of motorists preferred the new system compared to traditional train horns in terms of safety and 71% of the nearby residents had positive attitudes toward the new system.

The USDOT Grade Crossing Action Plan (10) and the 2004 Secretary's Action Plan on Highway-Rail Crossing Safety and Trespass Prevention (11) identified education and enforcement as key actions in reducing motorist crashes at HRGCs. To explore the safety effects of education and enforcement, Sposato et al. (12) conducted an evaluation in terms of the effectiveness of an enhanced crossing safety education and enforcement program at three gated

HRGCs with flashing warning devices in Arlington Heights, Illinois. Findings indicated that the changes in violations decreased 23% and 71% for two violation types: the type that traversed the crossing during gate descent or ascent, and the type that traversed the grade crossing after the gates were fully deployed. An increase of 15% was noted for the type that traversed the crossing while the lights were flashing but before the gates descended.

Carroll and Warren (13) investigated the safety effectiveness of an automatic photo enforcement system at HRGCs in California, Illinois, North Carolina, Florida and Texas. Results showed that violations at HRGCs in California were reduced by 36–92% using photo enforcement while crashes were reduced by 70%. Moreover, a 47–51% reduction in violations was observed in Illinois and a 78% reduction in violations was recorded in North Carolina. The authors concluded that the use of photo enforcement was effective in modifying unsafe driver maneuvers.

2.1.2 Specific Safety-Related Parameters

Table 2.2 presents a summary of safety-related parameters reported in literature while a detailed account follows. Moon and Coleman (14) collected two-day video data in terms of vehicle approaching speeds at two four-quadrant HRGCs, in Hartford and McLean, along the Chicago-St. Louis high-speed rail corridor. A hypothesis testing of differences in speed mean values was conducted. The results showed that there was a definite tendency to reduce speed when vehicles approached HRGCs. Furthermore, the speed profiles of vehicle platoons were less than the speed profiles of single vehicles at both study sites.

Estes and Rilett (15) and Cho and Rilett (16) investigated train arrival and crossing times at four HRGCs along the wellborn corridor in College Station, Texas, using two prediction technologies. Firstly, Cluster Analysis was used to categorize approaching trains into four groups. After classification, multiple linear regressions were used to predict arrival and crossing times based on speed profiles. Results showed that the predicted train arrival time by this method was within $\pm$20 seconds of its true arrival time. Secondly, a modular artificial neural network (MAAN) design was used to group the train speed profiles and then forecast train arrival times. The results were more accurate than the prediction results from the multiple regression model and traditional prediction methods (i.e., 29.7% and 46% improvement).

Table 2.2 Literature Summary on Safety-Related Parameters and Safety-Associated Factors for Motorists at HRGCs

Research Objective	Author	Methodology	Major Findings/Results
Explore the characteristics of vehicle approaching speed at HRGCs	Moon and Coleman, 1999	Hypothesis testing of differences in mean values	There was a definite tendency to reduce speed when vehicles approached HRGCs The speed profiles of vehicle platoons were less than the speed profiles of single vehicles
Investigate train arrival and crossing times at HRGCs	Estes and Rilett, Cho and Rilett, 2000, 2003	Cluster analysis , multiple linear regressions and modular artificial neural network(MAAN) design	The predicted time by Multiple regression model was within $\pm$20 seconds of its true arrival time MAAN method was created to improve the accuracy by 29.7% and 46% compared to multiple regression model and traditional prediction methods
Identify factors associated with vehicle-train crashes at HRGCs	Oh et al., 2006	Developed statistical models	Number of vehicle-train crashes increased when AADT, daily train volume, time duration between the activation of warning signals and the activation of gates increased and when crossings were located near commercial areas Crashes decreased when a speed hump was presented several predictors were different across the HRGC predicted models
Find the association between vehicle-train collisions at HRGCs and related factors	Hu et al., 2010	Negative binomial regression model	Number of crashes increased when number of daily trains, AADT and the number of tracks increased Crash frequency decreased when the crossing length increased and HRGC equipped with physical median at highway side Probability of crash occurrence increased as the AADT increased
Explore the measurements to improve safety at HRGCs	Kallberg et al., 2002	Developed statistical models	vehicle and train's crossing times were safety-associated factors Measures to improve safety of HRGCs were: improving sight distances by clearing vegetation, conducting crossing bans for trailer trucks, adding speed limits for trains, and using frequent whistles by the trains

2.1.3 Identification of Safety-Associated Factors

A summary of pertinent literature with respect to identification of safety-associated factors is given in table 2.2 and a more detailed account is as follows. Multiple researchers have investigated safety-associated factors related to vehicle and train operations, and HRGC geometry or environment. Oh et al. (17) identified factors associated with vehicle-train crashes at HRGCs in Korea using statistical models. They also examined accident prediction models for HRGC safety, including the Peabody Dimmick formula, the New Hampshire Index and the USDOT Accident Prediction formula. Some disadvantages of these models, like lacking descriptive capabilities, complexity and declining accuracy over time, were cited by the authors. Results indicated that the number of vehicle-train crashes increased when average daily traffic volume, daily train volume, and time duration between the activation of warning signals and the activation of gates increased and when crossings were located near commercial areas. Crashes decreased when a speed hump was presented at the crossing to slow motor vehicle traffic. After comparing their model and the USDOT Accident Prediction formula, they reported that several predictors were different across the models. In the USDOT model, type of highway surface, presence of stop signs and pavement markings were significant factors affecting accident frequency. But they were not found significant in the model with Korean data.

Hu et al. (18) explored the association between vehicle-train crashes at HRGCs and related factors in Taiwan by using the negative binomial regression model. According to the results, the number of daily trains, AADT and the number of tracks were significantly and positively associated with the number of crashes, while the crossing length was significantly and negatively associated with crash frequency. Moreover, an HRGC equipped with a physical median at the highway side had less traffic crashes than one without any highway separation.

The authors also conducted an analysis on marginal effect of AADT on the probability of crash occurrence. The results showed that the probability of crash occurrence increased as the AADT increased.

Kallberg et al. (19) collected field-observed data on 360 HRGCs on five main railway links in Finland. According to collected information and calculations, vehicle and train crossing times were identified as the safety-associated factors. The suggested measures to improve safety of HRGCs were: improving sight distances by clearing vegetation, conducting crossing bans for trailer trucks, adding speed limits for trains, and using frequent whistles by the trains.

2.2 Non-motorist Safety

Non-motorists on the highway system primarily consist of pedestrians and bicyclists. Compared to pedestrians, relatively few published documents were found on bicyclist safety. Some studies combined pedestrians and bicyclists; an account of the literature findings is presented below in two categories: evaluation of triple “E” countermeasures for non-motorists and identification of safety-associated factors for non-motorists.

2.2.1 Evaluation of Triple “Es” Safety Countermeasures

Table 2.3 presents a summary of non-motorist triple “E” countermeasures. Similar to the engineering design for motorists’ safety at HRGCs, the typical devices for the safety of non-motorists in traffic include various traffic signals and warning systems. Scott et al. (20) examined the effectiveness of optimized accessible pedestrian signals (APS) for providing street crossing information to blind pedestrians in Portland, Oregon and Charlotte, North Carolina. Results of before-and-after APS installation showed numerous improvements after APS installation. The installation resulted in a nearly 2 sec reduction in starting delay, which offered additional time for pedestrians to complete the crossing. In addition, only 13% of participants in each city could not finish crossing in time, compared to 44–50% before APS installation.

Nambisan et al. (21) evaluated the safety effect of automatic pedestrian detection devices and smart lighting deployed at the site on Charleston Boulevard in Las Vegas. A before-and-after study and corresponding statistical analysis were used. Results showed that after deployment of smart lighting, the numbers of pedestrians correctly using the crosswalk and carefully observing both directions increased. The percentage of motorists yielding to pedestrians also increased, as well as the vehicle stopping distance. Furthermore, the proportion of trapped pedestrians decreased and a significant reduction of pedestrian delay was noted that was accompanied by a slight rise in vehicular delay. The authors concluded that the tested devices improved visibility for both motorists and pedestrians and increased motorist compliance and pedestrians' safer crossing maneuvers.

Table 2.3 Literature Summary on Triple "Es" Safety Countermeasures for Non-Motorists on the Highway System

Research Objective	Author	Methodology	Major Findings/Results
Examine the effectiveness of optimized accessible pedestrian signals (APS) for blind pedestrians	Scott et al.,2008	Before/after data analysis	Nearly 2s reduction in starting delay after using APS 13% participants could not finish crossing in time after using APS, compared to 44–50% before APS installation
Evaluate the safety effectiveness of automatic pedestrian detection devices and smart lighting	Nambisan et al.,2009	Before/after data analysis	The numbers of pedestrians correctly using the crosswalk and carefully observing both directions increased The percentage of motorists yielding to pedestrians also increased as well as the vehicle stopping distance The proportion of trapped pedestrians decreased and a significant reduction of pedestrian delay was noted The tested devices improved visibility for both motorists and pedestrians and increased motorist compliance and pedestrians' safer crossing maneuvers
Examine the effectiveness of LED rectangular rapid-flash beacons (RRFBs) on yielding to pedestrians by motorists in multilane crosswalks	Shurbutt et al.,2009	Before/after data analysis	RRFBs produced a higher percentage of vehicles yielding to pedestrians and longer yielding distance at multilane uncontrolled crosswalk locations The numbers of vehicle in yielding queue decreased significantly
Evaluate the safety effectiveness of the high-intensity activated crosswalk (HAWK) device	Fitzpatrick and Park,2009	Before-and-after evaluation used Empirical Bayes (EB) method	Pedestrian crashes reduced in the range of 51–59.2% among the multiple sites installed HAWK devices
Identify and evaluate a series of engineering measures to reduce pedestrian deaths and injuries	Ellis and Houten, 2009	Simple crash rate comparisons	Countywide pedestrian crash rates reduced in the range of 13.3 – 49.5% at different selected sites
Evaluate a pedestrian safety educational program for elementary and middle	Gates et al.,2009	Before/after data analysis	There was a decrease in violation rates ranged from 2.42% to 18.3% in night schools An overall 23.2% increase in correct response

school students			rate in pre-and-post testing was found
Evaluate the effectiveness of enforcement of the crosswalk law	Britt et al.,1995	Simple compliance frequency comparisons	A modest increase of vehicles' compliance was detected, and the numbers of compliance at marked crosswalks were nine times than the ones at unmarked crosswalks Enforcement did not show significant benefits in locations with higher traffic volumes Some other factors, such as speed limit, road surface conditions, pedestrian volumes, the presence of single or grouped vehicles and the intensity of enforcement, may impact the change of vehicles' compliance Campaign verified the compliance maneuvers are location-specific
Evaluate the effectiveness of a comprehensive intervention program mixed communications/public safety awareness, education and punishment	Lobb et al.,2003	Chi-square tests, and Multivariate Analysis of Variance (MANOVA) and correlational analysis	A significant decrease in unsafe crossing was found after implementation of the program Punishment of unsafe maneuver was much more effective than education and communication

Shurbutt et al. (22) examined the effect of LED rectangular rapid-flash beacons (RRFBs) on motorists yielding to pedestrians in multilane crosswalks in Florida, Illinois and Washington D.C. Results showed that RRFBs produced a higher percentage of vehicles yielding to pedestrians and a longer yielding distance at multilane uncontrolled crosswalk locations. This effect was also increased by installing additional beacons on the median island. Also, the numbers of vehicle in the yielding queue, that passes or attempts to pass the vehicles which stopped in front of them, decreased significantly. After comparing the above variables with the traditional yellow flashing beacon, the RRFB was found to be more effective.

Fitzpatrick and Park (23) evaluated the safety effectiveness of the high-intensity activated crosswalk (HAWK) device installed in Tucson, Arizona. The before-and-after evaluation used the Empirical Bayes (EB) method to conduct the study. The conclusion indicated, at the multiple sites installed with a HAWK device in the city, that pedestrian crashes were reduced in the range of 51–59.2%.

Ellis and Houten (24) identified and evaluated a series of engineering measures to reduce pedestrian deaths and injuries along eight high-crash corridors in Miami–Dade County, Florida. A total of 14 engineering countermeasures were implemented. These measures included pedestrian pushbuttons, pedestrian yield signs, pedestrian zone signs, speed trailers, RRFB, offset stop lines and several traffic signal improvements, like reduced minimum green time, lead pedestrian interval and countdown pedestrian signals. Statistical analysis of these mixed engineering measures showed that countywide pedestrian crash rates were reduced in the range of 13.3 – 49.5% at different selected sites in the county.

Countermeasures involving education and enforcement have been studied for their impact on non-motorist safety in traffic. Gates et al. (25) conducted a large-scale before-and-after evaluation of a pedestrian safety educational program, designed for and delivered to elementary and middle school students at 16 participating schools in Detroit, Michigan. The results showed that among the 10 selected schools for observation, there was a decrease in violation rates that ranged from 2.42% to 18.3% in night schools. There was also a significant 4.44% decrease of the overall violation rates. Furthermore, an overall 23.2% increase in correct response rate in pre-and-post testing was found. Both of the two tests suggested that the educational program could improve safety of child pedestrians.

Britt et al. (26) evaluated the effect of enforcement of the crosswalk law in Seattle, Washington. The study concluded that a modest increase of vehicles' compliance was detected but enforcement did not show significant benefits in locations with higher traffic volumes. Some other factors, such as speed limit, road surface conditions, pedestrian volumes, the presence of single or grouped vehicles and the intensity of enforcement, may impact the change of vehicles' compliance. Finally, the authors reported that the compliance maneuvers were location-specific.

In New Zealand, Lobb et al. (27) introduced a comprehensive intervention program that mixed communications/public safety awareness, education and punishment in their study. After using chi-square tests, the study concluded that there was a significant decrease in unsafe crossings after implementation of the program. Comparisons between different parts of the program showed that unsafe crossings were reduced between communication and education and even more so between education and continuous punishment. But no significant changes were found between continuous and intermittent punishments. After applying Multivariate Analysis of Variance (MANOVA) and correlational analysis, the conclusions from surveys indicated that the correct responses increased after conducting the program. This study verified the positive effect of the whole intervention program and also showed that punishment of unsafe maneuvers was much more effective than education and communication.

2.2.2 Identification of Safety-Associated Factors

Table 2.4 shows a summary of this subsection while a detailed account is as follows. Kim and Yamashita (28) applied multiple correspondence analysis technology to explore the relationship between some variables in terms of pedestrian-involved traffic collisions in Hawaii. This method mainly examined data in a contingency table. The analysis results showed that: 1) drivers were 13.8 times more likely than pedestrians to be classified at fault when involved in pedestrian crashes in Hawaii, 2) men were more likely than women to commit errors or dangerous actions, and children (i.e., 17 years and younger), compared with adults (i.e., 18-65 years old) or seniors (i.e., over 65 years of age) were more likely to be at fault as pedestrians, 3) seniors were more likely to be seriously injured than other age groups, and 4) crashes in residential areas appeared to be more likely than in nonresidential areas. The authors suggested that more efforts in terms of enforcement and education should be directed toward drivers instead of pedestrians, as well as toward children and seniors besides having different strategies for residential and nonresidential areas for pedestrian safety.

Moudon et al. (29) collected pedestrian-involved collision data on state routes in King County, Washington from 1999 to 2004. Binomial logit model results showed that the likelihood of collision occurrence was strongly correlated to the presence of crosswalks with or without traffic signals, the number of roadway lanes, and the presence of nearby retail outlets. Additionally, other significant factors were the number of traffic signals, street block size, AADT, posted vehicle speed, bus ridership and the number of residential units; all increasing the likelihood of collisions with increasing values. The authors suggested that engineering approaches to safety should be complemented by education-and-enforcement-based measures. Moreover, facilities in areas with concentrations of retail outlets should become the targets for conducting safety programs in the future.

Table 2.4 Literature Summary on Safety-Associated Factors for Non-Motorists on the Highway System

Research Objective	Author	Methodology	Major Findings/Results
Explore the relationship between some variables in terms of pedestrian-involved traffic collisions	Kim and Yamashita,2008	Multiple correspondence analysis	Drivers were 13.8 times more likely than pedestrians to be classified at fault when involved in pedestrian crashes Men were more likely than women to commit errors or dangerous actions, and children (i.e., 17 years and younger), compared with adults (i.e., 18-65 years old) or seniors (i.e., over 65 years of age) were more likely to be at fault as pedestrians Seniors were more likely to be seriously injured than other age group Crashes in residential areas appeared to be more likely than in nonresidential areas
Explore the relationship between some variables in terms of pedestrian-involved traffic collisions	Moudon et al.,2008	Binomial logit model	The likelihood of collision occurrence was strongly correlated to presence of crosswalks with or without traffic signals, the number of roadway lanes, and the presence of nearby retail outlets Other significant factors were the number of traffic signals, street block size, AADT, posted vehicle speed, bus ridership and the number of residential units; all increasing the likelihood of collisions with increasing values

2.3 Highway Safety Modeling Approaches

A variety of modeling approaches have been adopted in safety studies focused on motorists at HRGCs and non-motorists in traffic. The following section presents a review of models for: 1) counts of vehicle-train crashes at HRGCs, 2) counts of vehicle collisions in traffic, and 3) injury severity of pedestrian-only crashes in traffic. It also found that few existing studies focused on bicyclist-related safety no matter whether at HRGCs or on the highway system.

2.3.1 Models for Counts of Vehicle-Train Collisions at HRGCs

A summary of this subsection appears in table 2.5 and a detailed account is given as follows. Hauer and Persaud (30) estimated a safety equation that was a linear combination of crossing accident history with the mean crash experience of similar crossings by the Generalized Linear Interactive Modeling (GLIM) software package. Results of this effort showed that the equation offered an effective way to estimate vehicle-train crash frequency at HRGCs. In addition, the safety evaluation of warning devices using this method showed that conversions from crossbucks to flashers, from crossbucks to gates, and from flashers to gates reduced the chance of an HRGC crash by 51, 69 and 45%, respectively.

Table 2.5 Literature Summary on Models for Counts of Vehicle-Train Collisions at HRGCs

Research Objective	Author	Methodology	Major Findings/Results
Estimate a safety equation that was a linear combination of crossing accident history with the mean accident experience of similar crossings	Hauer and Persaud,1987	Generalized Linear Interactive Modeling	The equation offered an effective way to estimate vehicle-train accident frequency at HRGCs Conversions from crossbucks to flashers, from crossbucks to gates, and from flashers to gates reduced the chance of an HRGC crash by 51, 69 and 45%, respectively
Explore the relationship between crash frequency and some variables in terms of Vehicle-train Collisions at HRGCs	Austin and Carson,2002	Poisson and negative binomial models	Crash frequency increased with greater number of nightly through trains, greater number of main track lines and traffic lanes, higher maximum timetable train speeds, greater AADT and paved highway The presence of gates and highway traffic signals reduced HRGC accident frequency
Predict the probabilities of unsuccessful crossing maneuvers that result in a vehicle-train crash, injury or fatality	McCollister and Pflaum,2007	Logit model	Estimated model had better measures of effectiveness compared to those of the FRA models Factors associated with the probability of crash occurrence at HRGCs were identified including higher number of warning devices, greater number of through trains at night, greater number of switching trains

			per day and higher train speed were associated with the greater possibilities of crashes, fatalities and injuries at HRGCs Greater traffic volume and greater percentage of trucks in the traffic were associated with the decreased possibilities of crashes
Develop a risk-based model to identify HRGC blackspots	Saccomanno et al.,2004	Negative binomial models	Collision frequency was associated with: traffic exposure (i.e., log of cross product of AADT and number of trains daily), train speed, road speed, road surface width, and number of tracks Factors associated with collision severity included train speed, number of tracks, track angle, number of vehicles and involved persons
Develop advanced statistical model for safety-associated factor identification at HRGCs	Park and Saccomanno,2005	Tree-based data mining method and Negative binomial models	The reliability of this collision prediction model was significantly improved by adding classifiers when compared to the model without interactions The effect of specific safety countermeasures at HRGCs varied based on classifiers including highway class, track angle, posted road speed, track type and surface width
Develop advanced statistical model for safety-associated factor identification at HRGCs	Saccomanno and Lai,2005	Cluster analysis and Negative binomial models	The process to predict the number of collisions following a countermeasure can take place in two ways: 1) directly obtained from prediction model if the countermeasures have been specified in the model, and 2) indirectly obtained by estimating factor scores and change in cluster membership with the introduction of the countermeasures

Austin and Carson (31) reviewed HRGC accident prediction methods and models. These included the Peabody-Dimmick formula, the New Hampshire Index, the National Cooperative Highway Research Program (NCHRP) Hazard Index, and the USDOT Accident Prediction formula. After collecting data on 1,538 vehicle-train crashes at HRGCs from six states (California, Montana, Texas, Illinois, Georgia and New York) for January 1997 through

December 1998, Austin and Carson estimated the Poisson and NB models. The authors reported that crash frequency increased with a greater number of nightly through trains, greater number of main track lines and traffic lanes, higher maximum timetable train speeds, greater AADT and paved highway. In addition, the presence of gates and highway traffic signals reduced HRGC accident frequency.

McCollister and Pflaum (32) presented a logit model to predict the probabilities of unsuccessful crossing maneuvers that result in a vehicle-train crash, injury or fatality. The authors' estimated model had better measures of effectiveness compared to those of the FRA models. Factors associated with the probability of crash occurrence at HRGCs were identified including higher number of warning devices, greater number of through trains at night, greater number of switching trains per day and higher train speed were associated with the greater possibilities of crashes, fatalities and injuries at HRGCs. In contrast, greater traffic volume and greater percentage of trucks in the traffic were associated with the decreased possibilities of crashes.

In Canada, to provide useful information for economically conducting safety improvements at HRGCs, Saccomanno et al. (33) developed a risk-based model to identify HRGC blackspots, which represent specific crossings with the highest risk of HRGC crashes. NB regression was utilized to develop risk-based models and then predict crashes at HRGCs in Canada. By ranking crossings according to prediction results and historical records, the top 22 crossings based on both risk elements were listed and illustrated on a map. The authors concluded that crash frequency was associated with: traffic exposure (i.e., log of cross product of AADT and number of trains daily), train speed, road speed, road surface width, and number of tracks. Additionally, factors associated with crash severity included train speed, number of tracks, track angle, number of vehicles and involved persons. The identified blackspots were found clustering in Saskatchewan, Ontario and Quebec, which respectively represent urban and rural areas.

Park and Saccomanno (34) presented a study that showed an advanced statistical model for a safety-associated factor identification at HRGCs. The authors developed a model using a tree-based data mining method that can discover meaningful correlations in attributes among variables in a model. Then an NB model was used to predict crash frequency at HRGCs. Their conclusions indicated that the reliability of this crash prediction model was significantly improved by adding classifiers when compared to the model without interactions. This model also showed that the effect of specific safety countermeasures at HRGCs varied based on classifiers, including highway class, track angle, posted road speed, track type and surface width.

Saccomanno and Lai (35) developed another crash prediction model using the same RODS/IRIS database by Statistical Package for the Social Sciences (SPSS). It showed the process to predict the number of crashes following a countermeasure can take place in two ways: 1) directly obtained from the prediction model if the countermeasures have been specified in the model, and 2) indirectly obtained by estimating factor scores and a change in cluster membership with the introduction of the countermeasures.

2.3.2 Safety Models of Vehicle Collisions on the Roadway System

A summary of this subsection is presented in table 2.6. Glauz et al. (36) aimed to establish a relationship between traffic crashes and traffic conflicts (or violations), which have a higher observable frequency. The authors collected 12 different types of traffic conflicts at 46 urban intersections located in the greater Kansas City metropolitan area from 1979 to 1981. The authors compared the expected crash rate as predicted by traffic conflict data with the expected crash rate as predicted by historical crash data using crash/conflict ratios. The authors concluded that conflicts were nearly as good as crashes in predicting expected crashes for certain types of intersections and, as such, are good surrogates of crashes.

Lord et al. (37) balanced statistical fit and theory among the Poisson, NB and zero-inflated (i.e., with excess zeros recorded for the dependent variable) regression models on predicting motor vehicle crashes. The objective of their study was to make an intelligent choice for modeling motor vehicle crash data from amongst several available modeling approaches. The negative binomial distribution was found to provide a superior statistical fit than the Poisson distribution for sites with medium crash exposure. In addition, some theoretically defensible solutions for modeling crash data with excess zeros were addressed, including changing the spatial or time scale of analysis involving unobserved heterogeneity terms in the NB and Poisson models, improving the set of explanatory variables, and applying small-area statistical methods.

Table 2.6 Literature Summary on Safety-Related Models on Count of Vehicle Collisions in Roadway System

Research Objective	Author	Methodology	Major Findings/Results
Establish a relationship between traffic crashes and traffic conflicts (or violations)	Glauz et al.,1985	Crash/conflict ratios calculation	Conflicts were nearly as good as crashes in predicting expected crashes for certain types of intersection and as such good surrogates of crashes
Make an intelligent choice for modeling motor vehicle crash data from amongst several available modeling approaches	Lord et al.,2005	Poisson, negative binomial and zero-inflated regression models	Negative binomial distribution was found to provide a superior statistical fit than the Poisson distribution for sites with medium crash exposure Defensible solutions for modeling crash data with excess zeros were addressed, including changing the spatial or time scale of analysis involving unobserved heterogeneity terms in NB and Poisson models, improving the set of explanatory variables, and applying small-area statistical methods

2.3.3 Safety Models of Pedestrian Injury Severity

A summary of this subsection is given in table 2.7. Sze and Wong (38) analyzed data involving a crash environment profile, casualty injury profile and vehicle involvement profile, from the Traffic Accident Database System (TRADS) maintained by the Hong Kong Police Force and Transport Department by a binary logistic regression model. Results of the estimated model showed that factors lowering the risk of pedestrian fatality and severe injury included: being male and aged below 15 years, being on an overcrowded or obstructed sidewalk, and being involved in a daytime crash on a road section with severe or moderate congestion. Factors that led to a higher risk of pedestrian fatality and severe injury were: age above 65 years, head injury, crash at crossing or within 15-meters of a crosswalk, crash on a road section with a speed limit above 50 kilometers per hour (km/h), signalized intersection, and two or more lanes. In addition, pedestrian injury risk underwent a decreasing trend from 1991 to 2004, perhaps due to remedial measures, road safety campaigns, pedestrianization, and traffic-calming strategies. These measures were undertaken in Hong Kong during the analyzed time period.

Table 2.7 Literature Summary on Safety-Related Models on Injury Severity of Pedestrian-Only in Traffic

Research Objective	Author	Methodology	Major Findings/Results
Estimate models to explore the relationship between the risk of pedestrian fatality and severe injury and associated factors	Sze and Wong,2007	Binary logistic regression model	Factors lowering the risk of pedestrian fatality and severe injury included: being male and aged below 15 years, being on an overcrowded or obstructed sidewalk, and being involved in a daytime crash on a road section with severe or moderate congestion Factors that led to a higher risk of pedestrian fatality and severe injury were: age above 65 years, head injury, crash at crossing or within 15-meter of a crosswalk, crash on a road section with a speed limit above 50 kilometers per hour (km/h), signalized intersection, and two or more lanes
Develop model to explore the relationship between non-motorist injury severity and associated factors	Eluru et al.,2008	Mixed generalized ordered response logit model	the MGORL model to be superior to the common ordered response logit model based on a comparison of measures of fit Several associated factors were: age of the individual, speed limit on the roadway, location of crashes, and time-of-day
Explore the relationship between the variance of unobserved pedestrian characteristics and the variable age	Kim et al.,2008	heteroskedastic multivariate model	The probability of pedestrian's fatal injury increased with increasing pedestrian age, male driver, intoxicated driver, the involvement of traffic signs, commercial area, darkness, sports utility vehicle (SUV) and truck crashes, freeway, two-way divided roadway, speeding-involved crash and off roadway The probability decreased with increasing driver age as well as the involvement of PM traffic peak, traffic signal control, inclement weather, curved roadway, crosswalk and walking along roadway
Investigate the relationship between the level of injury in pedestrian crashes and various associated factors	Jang et al.,2010	Ordered probit model	Injury levels tended to increase with older pedestrians (older than 65 years), alcohol consumption, cell phone use, time period between midnight and 6 a.m., weekend, precipitation, proceeding straight vehicle movement and lager vehicle involvement

Eluru et al. (39) reviewed studies on non-motorist injury severity in U.S. traffic crashes. Their findings were: 1) the logistic regression has been widely used when injury severity is in a binary form while the ordered response model has been commonly used when injury severity is recorded in multiple ordered categories; 2) there were no studies examining injury severity of both pedestrians and bicyclists; 3) few studies have considered attributes of the driver of the motored vehicle in pedestrian injury severity. The authors presented a mixed generalized ordered response logit model (MGORL) structure for modeling severity data, which was sourced from the 2004 General Estimated System (GES). The authors reported the MGORL model to be superior to the common ordered response logit model based on a comparison of measures of fit. Moreover, the MGORL presented the elasticity effect (the percentage change in the probability of an injury severity category due to a change in a variable from 0 to 1) between pedestrians and bicyclists. Several statistically significant associated factors were identified influencing non-motorist injury severity. They were age of the individual (elderly were more injury-prone), speed limit on the roadway (higher speed limits led to more severe injuries), location of crashes (those at signalized intersections were less severe compared to those elsewhere) and time-of-day (darker periods led to more severe injuries).

Kim et al. (40) developed a heteroskedastic multivariate model of pedestrian injury severity in their study. This model was mainly used to explore the relationship between the variance of unobserved pedestrian characteristics and the variable age. Results showed that pedestrian age induced heteroskedasticity across individual pedestrians. It affected the probability of fatal injury, especially for age past 65 years. The probability of a pedestrian's fatal injury increased with increasing pedestrian age, male driver, and intoxicated driver. It also increased with the involvement of traffic signs, commercial area, darkness, sports utility vehicle

(SUV) and truck crashes, freeway, two-way divided roadway, speeding-involved crash and off roadway. The probability decreased with increasing driver age as well as the involvement of PM traffic peak, traffic signal control, inclement weather, curved roadway, crosswalk and walking along roadway.

Finally, Jang et al. (41) investigated the relationship between the level of injury in pedestrian crashes and various associated factors in San Francisco by using an ordered probit model. Based on modeling results that authors concluded that injury levels tended to increase with older pedestrians (older than 65 years), alcohol consumption, cell phone use, time period between midnight and 6 a.m., weekend, precipitation, proceeding straight vehicle movement and larger vehicle involvement.

2.4 Literature Review Summary

In summary, the review of literature showed multiple sources of information on the safety of motorists at HRGCs and safety of non-motorists in traffic while relatively fewer publications were uncovered regarding pedestrian and bicyclist safety at HRGCs. Engineering, education and enforcement were found to be the main categories of countermeasures used for improving safety on highways and HRGCs. Statistical models like Poisson, negative binomial and logit models were found useful for safety predictions and associated factor identification. The next chapter provides details of data collection for this research project.

Chapter 3 Data Collection

<u>3.1 Data for Evaluation of Median Barrier's Long-Term Safety Effect</u>

Data for this research was primarily collected at the N 141st St. crossing in Waverly and the M St. crossing in Fremont, Nebraska (fig. 3.1 and fig. 3.2, respectively). The Waverly crossing has four sets of railroad tracks, two highway lanes, and is equipped with dual-quadrant gates. The Fremont crossing has two sets of railroad tracks, two highway lanes, and is also equipped with dual-quadrant gates.

Figure 3.1 N 141st St. HRGC in Waverly, Nebraska

Figure 3.2 M St. Crossing in Fremont, Nebraska

Each crossing was monitored for motorists' unsafe maneuvers using day- and night-vision cameras and digital video recorders (fig. 3.3 and fig. 3.4, respectively). At the Waverly crossing, a median barrier, consisting of vertical plastic plates and a flexible rubber base, was installed in December 2005 on both sides of the tracks. The barriers on both sides were removed in December 2007 at the request of the City of Waverly officials. The reasons cited were the dilapidated barrier condition (fig. 3.5) and complaints from businesses in proximity of the crossing. Data pertaining to unsafe motorist maneuvers were collected in 2006 and 2008 and therefore, the comparison showed the effect of their removal after being in place for a prolonged period. At Fremont, the barriers were left in place but no maintenance was performed and the condition of the barriers steadily eroded (fig. 3.6). Therefore, a 2006 versus 2008 comparison indicated changes in safety due to lack of maintenance.

Figure 3.3 Camera Installed at HRGC to Capture Crossing Maneuvers

Figure 3.4 Digital Video Recorders (DVR) Housed in Metal Box

Figure 3.5 Dilapidated Condition of Barrier at the Waverly HRGC

Figure 3.6 Dilapidated Condition of Barrier at Fremont due to Lack of Maintenance

Video was recorded continuously in the field and occasionally brought to the office for extraction of train crossing events. Figure 3.7 shows the office setup where after extraction of video clips unsafe maneuvers were visually observed and data populated in spreadsheets. Figure 3.8 shows the DVR interface used for extraction of pertinent video clips.

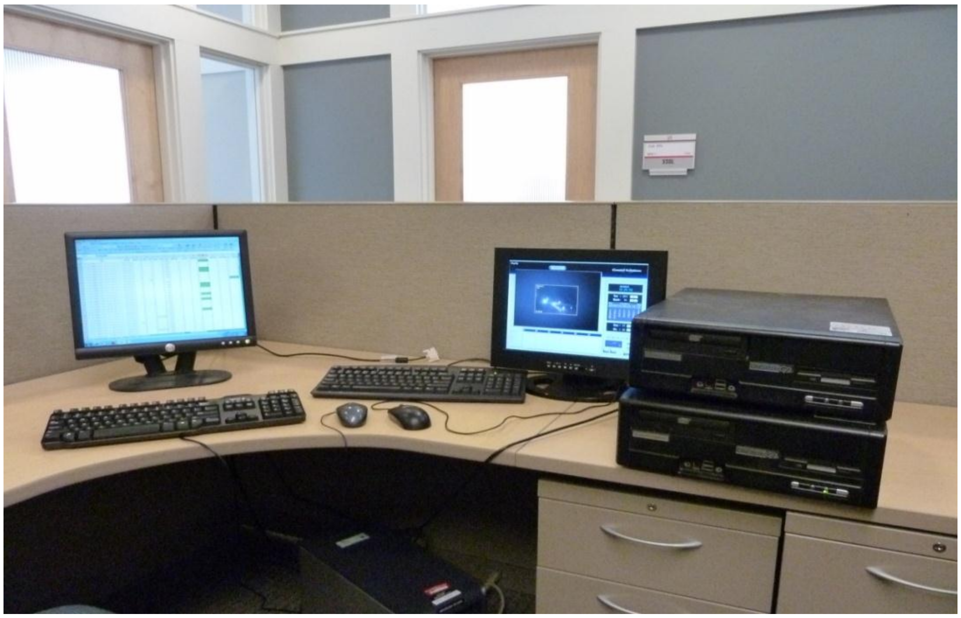

Figure 3.7 Devices for Data Extraction

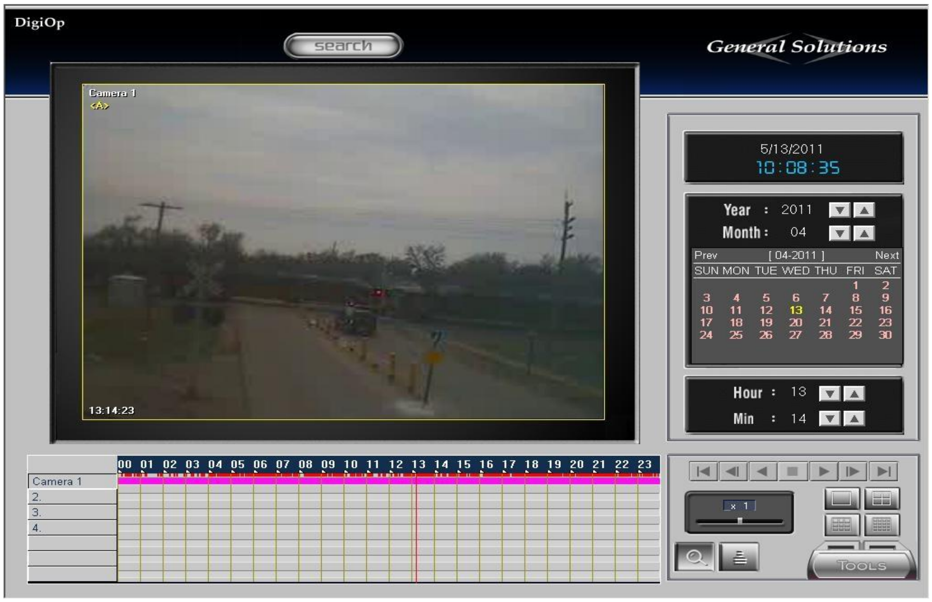

Figure 3.8 Interface of DVR Software

Four different types of gate related violations by motorists were observed and recorded in spreadsheets: passing under descending gates (gate rush 1/violation type 1), passing around fully lowered gates (gate rush 2/violation type 2), passing under ascending gates (gate rush 3/violation type 3) and passing around fully lowered gates between successive trains or a stopped train (gate rush 4/violation type 4). Examples of the first three types of gate violations are presented in figures 3.9, 3.10, and 3.11, respectively. Non gate-related violations included U-turns and vehicle backups/using wrong side of the road.

Maintenance was performed on the barriers installed at the Fremont HRGC in May 2009 to restore the condition. Data on unsafe maneuvers were collected before and after performance of the maintenance to assess changes in safety. Maintenance was again performed on these barriers in April 2011 and data collected before and after the maintenance activity. Figure 3.12 presents the condition of the barriers after the 2011 maintenance. A list of the collected variables, including coding information, appears in Appendix A as table A.1. These variables were collected for each vehicle/pedestrian/bicyclist observed at the crossing. These were then aggregated to obtain statistics for each train crossing event. The aggregated variable list also appears in Appendix A (table A.2).

Figure 3.9 Vehicle Passing Under Descending Gates (Violation Type 1)

Figure 3.10 Vehicle Passing Around Fully Lowered Gates (Violation Type 2)

Figure 3.11 Vehicles Passing Under Ascending Gates (Violation Type 3)

Figure 3.12 Barrier Condition after Maintenance in 2011

<u>3.2 Data for Educational Campaign Assessment</u>

The educational campaign was first carried out at the 44th St. crossing in Lincoln on July 27, 2011. A camera and DVR mounted on a trailer were utilized at this location (fig. 3.13) for recording video footage. Data on pedestrians and bicyclists were collected one week before the educational campaign and then after the campaign. Figure 3.14 shows preparation for the day-long campaign. Unfortunately, no significant pedestrian and bicyclist traffic was observed on the day of the campaign and therefore distribution of the educational materials, shown in figure 3.15, was extremely limited. While data were collected, because of the lack of distribution of educational materials, the study at Lincoln was deemed inconclusive and not pursued further. The Fremont educational campaign is described next.

Figure 3.13 Data Collection Setup at the 44th St. Crossing in Lincoln, NE

Figure 3.14 Preparing for the Educational Campaign

Figure 3.15 A Sampling of Operation Lifesaver Educational Material Used in the Campaign

The Fremont educational campaign was undertaken for two days on September 29 and 30, 2011 to ensure capturing pedestrian and bicyclist traffic at the crossing. Video footage was captured one week before and after the educational campaign. Significant pedestrian and bicyclist traffic was observed at this location (fig. 3.16), which was partly due to users spreading information about the campaign via word-of-mouth in the community. Figure 3.16 shows distribution of educational materials and conversations amongst research team members and the public. A significant number of materials were distributed during the two days of the campaign and therefore, the research team considered the campaign successful in reaching out to the users.

After the collection of data from the video clips, they were checked for errors. The 2006 data collected during the previous project were retrieved from archives for comparisons. Analysis of the collected data is described in the next chapter.

Figure 3.16 Education Campaign at the Fremont HRGC

Chapter 4 Data Analysis

Data analysis consisted of comparisons of simple statistics and statistical regression models. Details of the statistical models are given in Appendix B. Simple statistics can directly present the change in unsafe maneuvers before and after certain safety intervention (e.g., barrier maintenance). On the other hand, statistical regression models can account for a variety of factors besides the safety intervention. A mix of both was used in the data analysis described below.

4.1 Evaluation of Median Barrier Removal at Waverly HRGC

Table 4.1 presents means and percentage changes for motorists' unsafe maneuvers collected at Waverly HRGC in 2006 and 2008. Compared to 2006, the means of total unsafe maneuvers (i.e., the sum of gate rush, U-turn and backup), as well as gate rushes and U-turns, increased after barrier removal in 2008. Both the means of gate rush and U-turns have significant percentage changes in 2008 (i.e., around 5 times and 3.5 times of 2006 means, respectively) however, compared to 2006, the mean backups decreased in 2008.

Table 4.1 Comparison of Averages before and after Removal of the Barrier

Mean unsafe maneuvers per gate closure event			Relative 2008 performance
Maneuver	**2006 B[a.]**	**2008 NB[b.]**	**% change of 2008 NB vs. 2006 B**
Total Unsafe	0.283	0.836	195.41
Gate rush	0.145	0.680	368.97
U-Turn	0.019	0.117	515.79
Backup	0.120	0.038	-68.33

a. B represents barrier is in place
b. NB represents no barrier (i.e., removed)

Four models were estimated comparing the total number of unsafe maneuvers, gate violations, U-turns, and vehicle backups for 2006 and 2008 data collected at the Waverly HRGC. These models are presented in tables 4.2, 4.3, 4.4, and 4.5. Table 4.2 shows the estimated negative binomial model for total unsafe maneuvers. In this model the estimated α value is statistically significant at 95% confidence level (t-value > 1.96) indicating over-dispersion and therefore, the appropriateness of the negative binomial regression compared to a Poisson model. Model fit as judged by the ρ^2 statistic appears reasonable and the statistical significance of the chi-squared value (P-value <0.05) at the 95% confidence level shows that overall the model provides useful information. A positive estimated coefficient for an independent variable indicates that aggregate unsafe maneuvers increased with increasing values of that independent variable.

The model specification included a dummy variable for the two time periods (2006=0, 2008=1) representing presence and absence of the barrier. This dummy variable provided information on differences in total unsafe maneuvers with and without the barrier in place. The positive estimated coefficient (statistically significant at the 95% confidence level) showed that aggregate unsafe maneuvers per gate closure event were more frequent during 2008 when the barrier was removed compared to 2006.

Table 4.2 Model for Total Number of Unsafe Maneuvers at Waverly HRGC

Independent variable	Estimated Coefficient	t-value	Mean value
Constant	-2.459	-25.053	-
Time period dummy (2008=1, 2006=0)	1.042	17.112	0.455
Duration of gate closure (minutes)	0.047	17.222	3.859
Roadway traffic encountered during gate closure	0.081	14.313	5.095
Weekend dummy (weekend=1, weekdays=0)	0.184	3.010	0.286
Train stop dummy (stopped=1, did not stop=0)	0.568	6.670	0.058
Gate malfunction dummy (yes=1, no=0)	0.963	9.885	0.019
Clear weather dummy (clear=1, otherwise=0)	0.405	4.991	0.829
Alpha	0.501	11.249	-
Model summary statistics			
Number of observations	3990		
Log likelihood	-3572.037		
Restricted log likelihood	-4582.296		
Rho-squared(ρ2)	0.220		
Chi-squared	2020.517		
P-value for chi-squared	0.000		

Model results in table 4.2 show that longer durations of gate closure were associated with higher frequencies of aggregate unsafe maneuvers per gate closure event. As well, unsafe maneuvers increased with greater roadway traffic encountered during a gate closure event. Together, the gate closure duration and roadway traffic encountered during gate closure account for exposure in the case of HRGCs. Aggregate unsafe maneuvers were more frequent on weekends as opposed to weekdays, more frequent when trains stopped on the crossing and increased if the gate malfunctioned (i.e., gates descended without a train present in the crossing vicinity). The model further showed that the frequency of unsafe maneuvers at HRGCs was greater in clear weather compared to adverse weather conditions.

Table 4.3 presents the negative binomial model for frequency of gate rush. The dummy variable for the two time periods was positive and statistically significant showing that frequency of gate rushes per train crossing event increased in 2008 when the barrier was removed compared to 2006. The negative sign of the coefficient for the duration of gate closure implies that drivers less frequently rushed the gate when gates were closed for longer duration. Frequency of gate rush increased with greater roadway traffic encountered during gate closure events. Weekends, gate malfunctions and clear weather were associated with greater frequencies of gate rush.

Table 4.3 Model for Frequency of Gate Rush at Waverly HRGC

Independent variable	Estimated Coefficient	t-value	Mean value
Constant	-3.060	-29.146	**-**
Time period dummy (2008=1, 2006=0)	1.692	24.633	0.455
Duration of gate closure (minutes)	-0.007	-4.030	3.859
Roadway traffic encountered during gate closure	0.097	21.148	5.095
Weekend dummy (weekend=1, weekdays=0)	0.238	3.568	0.286
Gate malfunction dummy (yes=1, no=0)	0.604	4.240	0.019
Clear weather dummy (clear=1, otherwise=0)	0.462	5.748	0.829
Alpha	0.205	5.959	-
Model summary statistics			
Number of observations	3990.000		
Log likelihood	-2765.215		
Restricted log likelihood	-2790.667		
Rho-squared(ρ2)	0.009		
Chi-squared	50.904		
P-value for chi-squared	0.000		

A negative binomial model for the frequency of U-turns was estimated and reported in table 4.4. Modeling results show that U-turns increased in 2008 compared to 2006. Longer duration of gate closure and greater roadway traffic encountered during gate closure events were associated with greater frequency of U-turns. Drivers made U-turns more often on weekends compared to other days of the week. Likewise, the frequency of U-turns increased when trains stopped on the crossing and when gates malfunctioned.

Table 4.4 Model for the number of U-turns at Waverly HRGC

Independent variable	Estimated Coefficient	t-value	Mean value
Constant	-4.560	-18.850	-
Time period dummy (2008=1, 2006=0)	0.502	2.502	0.455
Duration of gate closure (minutes)	0.028	2.632	3.859
Roadway traffic encountered during gate closure	0.049	2.404	5.095
Weekend dummy (weekend=1, weekdays=0)	0.488	2.502	0.286
Train stop dummy (stopped=1, did not stop=0)	2.675	11.619	0.058
Gate malfunction	0.943	2.559	0.019
Alpha	1.824	3.090	-
Model summary statistics			
Number of observations	3990.000		
Log likelihood	-586.518		
Restricted log likelihood	-615.106		
Rho-squared(ρ2)	0.046		
Chi-squared	57.176		
P-value for chi-squared	0.000		

The backup maneuver involved a vehicle backing out of a crossing; after backing up, drivers sometimes made U-turns to head back in the direction from where they came or if the barrier was present they sometimes circumvented it by using the wrong side of the road to pass around closed gates (provided the train had not yet reached the crossing). Table 4.5 presents the estimated model. Judging from the negative sign of the estimated parameter for time period dummy variable, vehicular backups decreased in 2008 compared to 2006. Greater frequency of vehicle backups were associated with longer gate closure durations however, the model did not show any statistically significant relationship between vehicular backups and the roadway traffic encountered during a gate closure event. This variable was retained in the model specification since it is part of exposure at HRGCs and in light of evidence from previous models that show a relationship between roadway traffic encountered during a gate closure event and unsafe maneuvers. Additionally, train stoppage on the crossing was associated with greater frequency of vehicular backups.

Table 4.5 Model for the Number of Vehicle Backups at Waverly HRGC

Independent variable	Estimated Coefficient	t-value	Mean value
Constant	-3.971	-24.831	**-**
Time period dummy (2008=1, 2006=0)	-2.365	-9.760	0.455
Duration of gate closure (minutes)	0.302	14.956	3.859
Roadway traffic encountered during gate closure	0.018	1.041	5.095
Train stop dummy (stopped=1, did not stop=0)	1.684	6.473	0.058
Alpha	3.933	6.602	-
Model summary statistics			
Number of observations	3990.000		
Log likelihood	-777.115		
Restricted log likelihood	-1028.935		
Rho-squared(ρ2)	0.245		
Chi-squared	503.640		
P-value for chi-squared	0.000		

4.2 Evaluation of Median Barrier’s Long-Term Effect at Fremont HRGC

Table 4.6 presents means and percentage changes for the motorists’ unsafe maneuvers collected at Fremont HRGC in 2006 and 2008. Barrier was installed in 2006 and used at Fremont HRGC until 2008.These statistics show the impact of motorist’s unsafe maneuvers over a relatively long term. Compared to 2006, the means of total unsafe maneuvers (i.e., the sum of gate rush, U-turn and backup) and gate rush increased in 2008. Specifically, the means of gate rush had a significant percentage change in 2008, however, compared to 2006, the means of U-turns and backups decreased in 2008.

Table 4.6 Comparison of Averages Concerning Barrier's Long-Term Safety Effect

Mean unsafe maneuvers per gate closure event			**Relative 2008 performance**
Maneuver	**2006 B**[a.]	**2008 B**	**% Change of 2008 B vs. 2006 B**
Total Unsafe	0.420	1.207	187.40
Passing around gate	0.120	1.044	770.00
U-Turn	0.103	0.040	-61.20
Backup	0.190	0.123	-35.30

a. B represents barrier is in place

Similar to previous detailed analysis, statistical regression models were used. Table 4.7 shows the estimated negative binomial model for aggregate unsafe maneuvers. The alpha value was statistically significant at 95% confidence level (t-value > 1.96) indicating the appropriateness of the negative binomial compared to a Poisson model. Model fit was rather low but the statistical significance of the chi-squared value (P-value <0.05) at the 95% confidence level showed that the model provided useful information.

Table 4.7 Model for Frequency Unsafe Maneuvers at Fremont HRGC between 2006 and 2008

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (2008=1, 2006=0)	-1.280	26.178	0.238
Duration of gate closure (minutes)	0.028	23.699	7.708
Weather dummy (clear=1, otherwise=0)	0.254	3.808	0.933
Number of crossing trains	0.230	6.950	1.206
Train stop dummy (stopped=1, did not stop=0)	0.534	14.634	0.289
Number of queued vehicles at gate opening	0.049	6.528	2.386
Constant	-1.676	-20.433	-
Alpha (α)	0.224	15.284	-
Model summary statistics			
Number of observations	6600		
Log Likelihood	-6848.30		
Restricted log likelihood	-6962.25		
Rho-squared (ρ^2)	0.032		
Chi-squared	227.909		
P-value for chi-squared	0.000		

The model specification included a dummy variable for the two time periods (2008=1, 2006=0), which provided information on differences in total unsafe maneuvers during the two periods. The negative estimated coefficient (statistically significant at the 95% confidence level) showed that aggregate unsafe maneuvers were fewer during 2008 compared to 2006. The model showed that longer gate closure duration was associated with more frequent unsafe maneuvers. Aggregate unsafe maneuvers were more frequent in clear weather as opposed to adverse (snow, fog, rain, etc.) conditions and more frequent when multiple trains were crossing (either simultaneously or consecutively). Other findings from this model were that aggregate unsafe maneuvers increased if a train stopped on the crossing and also increased with greater number of queued vehicles at gate opening time (a measure of vehicular traffic).

Table 4.8 presents the estimated negative binomial model for frequency of gate rush. This model showed that the frequency of gate rush increased in 2008 compared to 2006. Drivers more often engaged in gate rush with longer duration of gate closures and in clear weather. The finding that longer duration of gate closure contributes to higher frequency of gate rush is likely explained by consecutive trains that have a small time gap between their passages. While the gates remained in down position during this gap, drivers frequently used it to pass to the other side. Train stoppage on the tracks was associated with lower frequency of gate rush (perhaps because drivers more often make U-turns or backup to go elsewhere in this situation) while greater number of queued vehicles at gate opening time (a measure of vehicular traffic) was associated with increased frequency of gate rush.

Table 4.8 Model for Frequency of Gate Rush at Fremont HRGC between 2006 and 2008

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (2008=1, 2006 =0)	2.108	30.939	0.238
Duration of gate closure (minutes)	0.023	32.429	7.708
Weather dummy (clear=1, otherwise=0)	0.207	2.376	0.933
Train stop dummy (stopped=1, did not stop=0)	-0.362	-5.939	0.289
Number of queued vehicles at gate opening	0.061	6.227	2.386
Constant	-2.194	-21.533	-
Alpha (α)	0.070	5.716	-
Model summary statistics			
Number of observations	6600		
Log Likelihood	-4240.77		
Restricted log likelihood	-4246.48		
Rho-squared (ρ^2)	0.003		
Chi-squared	11.433		
P-value for chi-squared	0.000		

The estimated model for frequency of U-turns is shown in table 4.9; it showed that U-turn frequency decreased during 2008 compared to 2006. Increased duration of gate closure was associated with higher frequency of U-turns. Weekends were associated with higher frequency of U-turns compared to weekdays. Similarly, clear weather was associated with higher frequency of U-turns as was greater number of crossing trains. More frequent U-turns were made if a train stopped on the tracks as well if there were more queued vehicles at gate opening.

Table 4.9 Model for the Number of U-turns at Fremont HRGC between 2006 and 2008

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (2008 =1, 2006=0)	-0.609	-4.160	0.238
Duration of gate closure (minutes)	0.029	9.464	7.708
Weekend dummy (weekend=1, weekday=0)	0.139	2.161	0.305
Weather dummy (clear=1, otherwise=0)	0.370	2.930	0.933
Number of crossing trains	0.233	4.006	1.206
Train stop dummy (stopped=1,did not stop=0)	1.035	14.590	0.289
Number of queued vehicles at gate opening	0.038	2.653	2.386
Constant	-2.616	-17.678	-
Alpha (α)	0.594	8.251	-
Model summary statistics			
Number of observations	6600		
Log Likelihood	-3147.32		
Restricted log likelihood	-3222.92		
Rho-squared (ρ^2)	0.046		
Chi-squared	151.208		
P-value for chi-squared	0.000		

Table 4.10 presents the estimated model for frequency of backups. Results showed that there was no statistically significant difference between the frequencies of backups in 2008 compared to 2006. Similarly, longer gate closure duration was associated with higher frequency of backups. Drivers more often backed up on weekends, more often when more trains were using

the HRGC, and more frequent when trains stopped on the crossing. Finally, more frequent vehicular backups were associated with greater number of queued vehicles.

Table 4.10 Model for Number of Backups at Fremont HRGC between 2006 and 2008

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (2008 =1, 2006=0)	-0.008	-0.085	0.238
Duration of gate closure (minutes)	0.273	5.575	7.708
Weekend dummy (weekend=1, weekday=0)	0.265	3.075	0.305
Number of crossing trains	0.421	5.509	1.206
Train stop dummy (stopped=1,did not stop=0)	1.630	17.408	0.289
Number of queued vehicles at gate opening	0.047	2.704	2.386
Constant	-4.793	-32.994	-
Alpha (α)	0.688	5.328	-
Model summary statistics			
Number of observations	6600		
Log Likelihood	-2094.69		
Restricted log likelihood	-2123.66		
Rho-squared (ρ^2)	0.027		
Chi-squared	57.955		
P-value for chi-squared	0.000		

4.3 Safety Evaluation of Median Barrier Maintenance at the Fremont HRGC

Maintenance was performed twice at Fremont; first in 2009 and then in 2011. These efforts were assessed by collecting data on unsafe maneuvers before the maintenance activity and then again after the maintenance activity.

4.3.1 Assessment of Maintenance in 2009

Table 4.11 shows means and percent change in motorists' gate-related violations at Fremont HRGC between 2008 and 2009. The total number of gate rush violations increased by 31% after maintenance, however, a closer inspection of the different types of gate violations indicated a reduction of about 52% in gate rush type 2 violations, which are the most severe type of violation. Also, a 100% reduction was observed in gate rush type 2 violations after maintenance was performed.

Table 4.11 Comparison of before-and-after Gate-Related Violations for the 2009 Barrier Maintenance

	Mean gate rush per train crossing		
Type of gate rush	**Before maint. (2008)**	**After maint. (2009)**	**% change**
Gate rush 1	0.065	0.164	152.31
Gate rush 2	0.019	0.009	-52.63
Gate rush 3	0.926	1.155	24.73
Gate rush 4	0.001	0.000	-100.00
Total gate rush	1.011	1.328	31.36

4.3.2 Assessment of Maintenance in 2011

Table 4.12 presents means and percentage changes for different types of gate-related violations by motorists at the Fremont HRGC in 2011. Data concerning motorists' gate rush maneuvers were collected before and after the maintenance in March and April of 2011. Similar to the previous maintenance evaluation, the total number of gate-related violations increased, though importantly gate rush type 2 violations decreased after the maintenance by about 30%.

Table 4.12 Comparison of before-and-after Gate-Related Violations for the 2011 Barrier Maintenance

Type of gate rush	Mean gate rush per train crossing		% change
	Before maintenance (March 2011)	After maintenance (April 2011)	
Gate rush 1	0.165	0.085	-48.48
Gate rush 2	0.024	0.017	-29.17
Gate rush 3	0.595	0.934	56.97
Gate rush 4	0.000	0.002	-
Total gate rush	0.784	1.037	32.27

Two Poisson models were estimated using the 2011 dataset. The first was for the total frequency of gate related violations per train crossing and the second was for the frequency of gate rush type 2 violations per train crossing. These models are reported in tables 4.13 and 4.14, respectively. These models are briefly discussed next.

Table 4.13 Model for Total Gate Rush Frequency at Fremont HRGC in 2011

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (after maintenance=1, before maintenance=0)	0.342	4.449	0.489
Passenger car dummy (passenger car involved=1, no passenger car involved=0)	0.098	1.450	0.496
Frequency of violation opportunity	0.162	3.663	2.177
Vehicle volume (in queue and violation)	0.017	2.943	7.508
Number of crossing trains	0.272	2.832	1.063
Daytime dummy (daytime=1, others=0)	0.150	1.712	0.737
Constant	-1.267	-7.758	-
Model summary statistics			
Number of observations	986		
Log Likelihood	-1100.74		
Restricted log likelihood	-1177.79		
Rho-squared (ρ^2)	0.065		
Chi-squared	154.097		
P-value for chi-squared	0.000		

Table 4.14 Model for Frequency of Gate Rush Type 2 at Fremont HRGC in 2011

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (after maintenance=1, before maintenance=0)	-0.255	-0.546	0.494
Vehicle volume (in queue and violation)	0.053	2.918	7.557
Time between light flashing and train arrival (minutes)	0.018	3.185	55.650
Constant	-5.566	-10.618	-
Model summary statistics			
Number of observations	974		
Log Likelihood	-86.38		
Restricted log likelihood	-95.59		
Rho-squared (ρ^2)	0.096		
Chi-squared	18.425		
P-value for chi-squared	0.000		

Table 4.13 shows the estimated model for the total frequency of gate rush maneuvers per train crossing. Model fit as judged by the ρ^2 statistic appears reasonable and the statistical significance of the chi-squared value (P-value <0.05) at the 95% confidence level showed that overall the model provided useful information. The estimated coefficient for the dummy variable for the two time periods (after maintenance=1, before maintenance=0) was statistically significant at the 95% confidence level showing that aggregate gate rush maneuvers per gate closure event were more frequent after barrier maintenance in April 2011. Passenger car involvement was associated with greater frequencies of aggregate gate rush maneuvers per gate closure event. Unsafe gate rush maneuvers increased with greater roadway traffic encountered during gate closure events and greater number of trains arriving at this HRGC. Aggregate unsafe gate rush maneuvers were more frequent with greater opportunities for violations and during daytimes.

The model for the frequency of gate rush type 2 in table 4.14 shows that the estimated parameter for the dummy variable for the two time periods was negative indicating that the frequency of gate rush type 2 decreased after the barrier was maintained. However, this variable was not statistically significant. Therefore, after accounting for different factors affecting gate rush type 2 violations, there was not enough evidence in the data to discern differences in the before-and-after time periods.

4.4 Evaluation of Educational Campaign for Non-Motorists at the Fremont HRGC

Table 4.15 presents means and percent changes for the non-motorists' gate-related violations at the Fremont HRGC in 2011. A two-day educational campaign separates the before-and-after time periods that spanned one week each. The statistics in the table show that compared to the before period, the means of gate rush type 1 and 2 decreased in the after periods. The percent changes were around 90% for gate rush type 1 and 39% for gate rush type 2. Also, the total gate-related violations reduced by about 3% after the educational campaign.

Table 4.15 Comparison of Averages Concerning Educational Activity Effect in 2011

Type of gate rush	Mean gate rush per train crossing		% change
	One week before education (Sep.2011)	One week after education (Oct. 2011)	
Gate rush 1	0.18	0.02	-88.66
Gate rush 2	0.51	0.31	-38.75
Gate rush 3	0.08	0.46	461.46
Total gate rush	0.82	0.79	-3.02

As stated before, the gate rush type 2 violation is the most dangerous maneuver amongst the different types of gate-related violations considered in this study. A Poisson model was estimated to fully investigate the effects of the educational campaign on this particular type of violation. Results of the model are reported in table 4.16. The dummy variable for the two time periods is negative and statistically significant showing that the frequency of gate rush type 2 violations per train crossing for non-motorists decreased after the educational campaign was completed. The model also shows that the tendency of pedestrians and bicyclists to pass around fully lowered gates was greater when they were crossing the tracks in groups as opposed to when they were not in groups. This variable is statistically significant at 90% confidence level only.

Table 4.16 Model for Number of Gate Rush Type 2 before and after Educational Campaign in 2011

Independent variable	Estimated coefficient	t-value	Mean value
Time period dummy (after maintenance=1, before maintenance=0)	-0.848	-2.251	0.489
Gate rush 2 opportunities for bicyclists	0.409	1.716	0.593
Gate rush 2 opportunities for pedestrians	-0.014	-0.068	0.697
Time between light flashing and train arrival (seconds)	0.011	1.513	52.05
Dummy for group crossing (group=1; individual=0)	0.836	1.903	0.229
Constant	-1.801	-3.581	-
Model summary statistics			
Number of observations	96		
Log Likelihood	-68.325		
Restricted log likelihood	-78.474		
Rho-squared (ρ^2)	0.129		
Chi-squared	20.298		
P-value for chi-squared	0.001		

Chapter 5 Conclusions and Recommendations

There were two major objectives of this research. The first was to investigate long-term effects of median barriers on motorists' unsafe maneuvers at HRGCs and the second was to investigate different ways to improve pedestrian and bicyclist safety at HRGCs. For the first objective, the long-term safety effect of median barriers on motorists was evaluated at two different HRGCs located in Waverly and Fremont, NE. The effects of removing the barriers and maintaining them in good condition were quantified. The effects of an educational campaign utilizing Operation Lifesaver educational materials on improving pedestrian and bicyclist safety were evaluated as part of the second objective. Based on the findings from the data analysis the following conclusions were drawn.

5.1 Conclusions

Removal of the barrier in Waverly contributed to greater frequency of unsafe maneuvers by motorists. Specifically, the frequencies of aggregate unsafe maneuvers (i.e., the sum of motorist gate rush, U-turn and backup), as well as gate rush and U-turn increased after barrier removal in 2008. Safety deteriorated over the long-term at the Fremont crossing while maintenance resurrected safety by reducing the frequency of passing around fully lowered gates by 30-50%. Regarding the effects of the educational campaign focused on pedestrians and bicyclists the effort at the Lincoln crossing was inconclusive but the campaign successfully reduced passing around fully lowered gates by about 39%.

5.2 Recommendations and Future Research

The recommendations stemming out of this research are as follows.

- Median barriers must be maintained in top condition after installation. Due to the frequent maintenance observed during this research the barriers should be installed on a 6-9 inch high concrete curb (see fig. 5.1 below).
- Once installed at HRGCs, subsequent removal of median barriers is not recommended.
- Educational campaigns focused on pedestrians and bicyclists are recommended for improvement of safety at HRGCs.

Future research is recommended to investigate the long-term effects of educational campaigns on improving pedestrian and bicyclist safety. Also, more-intensive educational campaigns including TV and radio commercials and outreach to schools are recommended for future undertaking. Finally, the potential for enforcement at HRGCs should be considered for evaluation.

Figure 5.1 Installation of Median Barrier on Raised Concrete Curb at an HRGC

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Appendix A

Table A.1 List of collected variables including variable coding

Variable	Label/Description	Coding/Units
EVENT	Train crossing event number	1=the first event, 2=the second event…
DATE	Date of observation	Date
USER_TYPE	Types of road users	0=vehicle, 1=pedestrian, 2=bicyclist
VEH_TYPE	Types of vehicles	0=passenger car, 1=pickup truck, 2=VAN, 3=SUV, 4=single unit truck, 5=semi-trailer truck, 6=school bus, 7=motocycle,8=tractor or other farm vehicles, 9= others
VIOLATION	Dummy variable of violations	0=no-violation, 1=violation
VOIL_TYPE	Violation Type [A]	0=no violation,1=violation type 1, 2=violation type 2, 3=violation type 3, 4=violation type 4
PED_V1	Pedestrian violation type 1	0=no violation, 1=violation
PED_V2	Pedestrian violation type 2	0=no violation, 1=violation
PED_V3	Pedestrian violation type 3	0=no violation, 1=violation
PED_V4	Pedestrian violation type 4	0=no violation, 1=violation
BIC_V1	Bicyclist violation type 1	0=no violation, 1=violation
BIC_V2	Bicyclist violation type 2	0=no violation, 1=violation
BIC_V3	Bicyclist violation type 3	0=no violation, 1=violation
BIC_V4	Bicyclist violation type 4	0=no violation, 1=violation
T_PERIOD1	Time period of barrier maintenance	0= before maintenance, 1=after maintenance
T_PERIOD2	Time period of educational campaign	0= before campaign, 1=after campaign, 2=during campaign
AGE	Adult or child	0=adult, 1= child
GROUP	Presence of users in groups	0=individual passing, 1= group passing
OPP_TYPE	Violation opportunity type [B]	0=no opportunity,1=opportunity for violation type 1, 2=opportunity for violation type 2,

		3=opportunity for violation type 3, 4=opportunity for violation type 4
VEH_OPP V1	Dummy variable of vehicle violation opportunity type 1	0=no opportunity, 1= opportunity
VEH_OPP V2	Dummy variable of vehicle violation opportunity type 2	0=no opportunity, 1= opportunity
VEH_OPP V3	Dummy variable of vehicle violation opportunity type 3	0=no opportunity, 1= opportunity
VEH_OPP V4	Dummy variable of vehicle violation opportunity type 4	0=no opportunity, 1= opportunity
PED_OPP V1	Dummy variable of pedestrian violation opportunity type 1	0=no opportunity, 1= opportunity
PED_OPP V2	Dummy variable of pedestrian violation opportunity type 2	0=no opportunity, 1= opportunity
PED_OPP V3	Dummy variable of pedestrian violation opportunity type 3	0=no opportunity, 1= opportunity
PED_OPP V4	Dummy variable of pedestrian violation opportunity type 4	0=no opportunity, 1= opportunity
BIC_OPP V1	Dummy variable of bicyclist violation opportunity type 1	0=no opportunity, 1= opportunity
BIC_OPP V2	Dummy variable of bicyclist violation opportunity type 2	0=no opportunity, 1= opportunity
BIC_OPP V3	Dummy variable of bicyclist violation opportunity type 3	0=no opportunity, 1= opportunity
BIC_OPP V4	Dummy variable of bicyclist violation opportunity type 4	0=no opportunity, 1= opportunity
V_TRAFFIC	Vehicle volume, including vehicles in queue and those involved in violations	integer
B_TRAFFIC	Bicyclist volume, including bicycles in queue and those involved in violations	integer
P_TRAFFIC	Pedestrian volume, including pedestrians in queue and those involved in violations	integer
WEEKEND	Dummy variable for weekend	0=weekdays, 1= Saturday and Sunday
G_DOWN	Gate down time from start to end of	seconds

	flashing lights at HRGC	
T_ARRIVAL	Time between light flashing and train arrival	seconds
TRAINS	Number of crossing trains	integer
SIMULTANEOUS	Dummy variable for simultaneous train crossing	0= non-simultaneous, 1= simultaneous
STOP	Dummy variable for train stoppage at crossing	0=no stop, 1=stop
WEATHER	Type of weather condition	0=clear, 1=fog, 2=wet pavement, 3=rain, 4=snow,5 snow pavement
DAYTIME	Light condition	0= night time, 1=daytime 2=dawn or dusk, 3 dark or cloudy, 4=others
G_MALF	Dummy variable for gate malfunction when no train arrives	0=non-malfunction, 1=malfunction

[A] Violation type 1 is passing under descending gates, violation type 2 is passing around fully lowered gates, violation type 3 is passing under ascending gates, and violation type4 is passing around fully lowered gates between successive trains

[B] Violation opportunity types correspond to different violation types. For example, Violation opportunity type 1 is the opportunity of violation type 1 occurrence.

Table A.2 Aggregated variables used in data analysis

Variable	Label/Description	Coding/Units
DATE	Date of observation	Date
PA_CAR	Dummy variable of passenger car involvement	0=no passenger car involvement, 1=passenger car involvement
VIO	Number of violations during train crossing	integer
PERIOD1	Dummy variable of the March data	0=else, 1= March
PERIOD2	Dummy variable of the April data	0=else, 1= April
PERIOD3	Dummy variable of the September data	0=else, 1= September
PERIOD4	Dummy variable of the October data	0=else, 1= October
OCTWEEK1	Dummy variable of the first week after education activity	0=else, 1= the first week after education activity
OCTWEEK2	Dummy variable of the second week after education activity	0=else, 1= the first week after education activity
OCTWEEK3	Dummy variable of the third week after education activity	0=else, 1= the first week after education activity
OCTWEEK4	Dummy variable of the fourth week after education activity	0=else, 1= the first week after education activity
DAY12	Dummy variable for 12-day before-after barrier maintenance	1=12-day before-after time period of barrier maintenance, 0=if not
GROUP	Dummy variable of gate violation group	0=individual passing, 1= group passing
OPP	Number of total opportunities	integer
V_TRAFFIC	Vehicle volume (including vehicles in queue and violated)	integer
B_TRAFFIC	Bicyclist volume (including vehicles in queue and violated)	integer
P_TRAFFIC	Pedestrian volume (including vehicles in queue and violated)	integer
WEEKEND	Dummy variable for weekend	0=weekdays, 1= Saturday and Sunday
G_DOWN	Gate down time from start to end of	seconds

	flashing lights at HRGC	
T_ARRIVAL	Time between light flashing and train arrival	seconds
TRAINS	Number of crossing trains	integer
SIMULTANEOUS	Dummy variable for simultaneous train crossing	0= non-simultaneous, 1= simultaneous
STOP	Dummy variable for train stoppage at crossing	0=non-stop, 1=stop
CLEAR	Dummy variable for clear weather	0= not clear, 1=clear
D_TIME	Dummy variable of light condition	0=night time, 1=non-night time
G_MALF	Dummy variable for gate malfunction when no train arrives	0=non-malfunction, 1=malfunction

Appendix B

Statistical Models

When a variable of interest is a count of an event (e.g., count of drivers' unsafe maneuvers during a gate closure event) the Poisson and negative binomial regression models are appropriate for exploration of relationship between the count variable and other explanatory variables. According to Washington et al. (43, 44), the Poisson regression model is popular; the probability of an event having y_i unsafe maneuvers (where y_i is a nonnegative integer) is given by:

$$P(y_i) = \frac{EXP\ (-\lambda_i)\lambda_i^{y_i}}{y_i!} \tag{B.1}$$

Where EXP is the base of natural logarithm and λ_i is the Poisson parameter, which is equal to the expected number of unsafe maneuvers during a train crossing event i, $E[y_i]$. Poisson regression models are estimated by specifying the Poisson parameter as a function of explanatory variables, e.g., roadway traffic encountered during gate closure event, train traffic, gate closure time. The most common formulation for λ_i is the loglinear model:

$$\ln(\lambda_i)\ = \beta X_i \tag{B.2}$$

Where Xi is a vector of explanatory variables and β is a vector of estimated parameters. Equation B.3 gives the expected number of events per period as:

$$\lambda_i = EXP(\beta X_i) \tag{B.3}$$

The above model is estimable by standard likelihood methods. The log of the likelihood function is simpler to manipulate and more appropriate for estimation; it is given by:

$$LL(\beta) = \sum_{i=1}^{n}[-EXP(\beta X_i) + y_i\beta X_i - \ln(y_i!)] \quad \text{(B.4)}$$

The Poisson distribution requires both the mean and variance of the count variable to be equal. If the variance of the count variable is significantly greater than its mean (i.e., $VAR[y_i] > E[y_i]$, the data are considered over-dispersed and the negative binomial model is utilized. This model arises from the Poisson model by specifying an error term, ε, where EXP(ε) has a gamma distribution with a mean of one and a variance of α. Equation B.3 is rewritten as:

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \quad \text{(B.5)}$$

The addition of the error term, ε, allows the variance of the count variable to differ from its mean. The Poisson regression model is regarded as a limiting model of the negative binomial regression model as the value of α (the variance of ε) approaches zero. The parameter α is often referred to as over-dispersion parameter and its statistical significance is the basis for selection between these two models. Thus the statistical significance of the estimated α parameter in the negative binomial model (i.e., rejection of the null hypothesis that α is not different than zero) confirms overly-dispersed data. The likelihood function for the negative binomial regression model is given by the following equation:

$$L(\lambda_i) = \prod_i \frac{\Gamma((1/\alpha)+y_i)}{\Gamma(1/\alpha)y_i!}\left(\frac{1/\alpha}{(1/\alpha)+\lambda_i}\right)^{1/\alpha}\left(\frac{\lambda_i}{(1/\alpha)+\lambda_i}\right)^{y_i} \quad \text{(B.6)}$$

The overall usefulness of the negative binomial regression model is judged by a Chi-squared test; its statistical significance shows that the model is giving useful information. A commonly used measure for negative binomial model fit is a rho-squared statistic (also referred to as the McFadden ρ2) that measures the fraction of a restricted log-likelihood explained by the model:

$$\rho^2 = 1 - [L(\beta)/L(0)] \quad \text{(B.7)}$$

where, L(β) is the log-likelihood at convergence with parameter vector β and L(0) is the restricted log-likelihood with all parameters set to zero. Values closer to one indicate a model that is explaining more variance while values closer to zero indicate little explanation of the variance. In this research models were estimated by using the NLOGIT (version 4.0) software.