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Centerline Curbing Treatment at Railroad Crossings for Improved Safety

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CENTERLINE CURBING TREATMENT AT RAILROAD CROSSINGS FOR IMPROVED SAFETY

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Prepared for

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EXECUTIVE SUMMARY

The objectives of this research were to study unsafe actions of motor vehicle drivers at railroad-highway grade crossings, to evaluate centerline barriers in reducing those unsafe driver actions, and to note any maintenance or other issues with the barriers. Driver actions were observed at two railroad crossings before and after installation of centerline barriers. A comparison of observed driver actions in the pre- and post-barrier periods provided information on the effectiveness of the barriers in reducing unsafe driver actions while periodic inspection of the centerline barriers provided information on maintenance needs.

A major concern of the Nebraska Department of Roads is the potential for crashes at railroad-highway grade crossings resulting from unsafe actions of motorists such as, rushing the gates to beat an oncoming train or playing “chicken” with an approaching train, among others. Playing “chicken” refers to intentional standing of a motor vehicle on railroad tracks and only moving when the train hits the brakes. Crashes at railroad-highway crossings may not necessarily involve trains as some driver actions (e.g., backing up, and U-turns) may result in crashes involving motor vehicles only.

In this research the crossing at North 141st Street in the City of Waverly, NE and the crossing at “M” Street in the City of Fremont, NE were monitored with the help of day and night vision cameras and digital video recorders. Motor vehicle driver actions were observed whenever the gates were down and instances of unsafe actions noted. In an effort to reduce gate rushing and other unsafe motorist actions, the researchers installed flexible rubber and plastic barriers on both sides of the crossings along roadway centerlines to prevent motorists from going around the gates. The actions of motor vehicle drivers were monitored in the post-barrier period and compared to the pre-install period using appropriate statistical tools. Results of the comparison show that fewer unsafe driver actions were observed after installation of the centerline barriers. In particular, installation of centerline barriers significantly reduced instances of gate rushing at the two study sites. Centerline barriers are recommended for use at railroad crossings where unsafe driver actions (e.g., gate rushes) are a concern.

Damage to the barriers as a result of abuse from roadway vehicles was noted while no snowplowing issues came to the attention of the researchers during the study period. The amount of damage was a function of traffic volume, percentage of trucks, and if sharp turns were involved. Finally, this study revealed instances of pedestrians and bicyclists engaged in unsafe actions at railroad crossings, which are recommended for investigation in a future study.

TABLE OF CONTENTS

CHAPTER 1 - INTRODUCTION

1.1. Report Organization

This report consists of five chapters; this introductory chapter is followed by a chapter that provides the literature review on intersection safety. Chapter 3 presents details of the collected data, while Chapter 4 describes analysis of the collected data and maintenance and other issues experienced during the course of this study. Chapter 5 provides research conclusions and identifies issues for future research.

1.2. Background

The safety of railroad-highway at-grade crossings is subject to actions of motor vehicle drivers to a significant extent. Unsafe maneuvers by drivers immediately before, during, and immediately after train crossings can lead to crashes with trains, as well as non-train related crashes, i.e., when only motor vehicles are involved in a crash. Examples of unsafe actions include rushing closing or closed gates to beat an oncoming train and playing “chicken” with an approaching train, which refers to intentional standing of a motor vehicle on railroad tracks and only moving when the train hits the brakes. The principal of the game is to create pressure until one player backs down and is humiliated as the “chicken.” Such activity has been reported by Nebraska Department of Roads (NDOR) and might be occurring in other states as well. Other examples of unsafe driver actions include backing up and making U-turns that can potentially result in non-train related crashes. This research was initiated by NDOR to look into unsafe driver actions at railroad-highway at-grade crossings and how to eliminate or reduce them by using centerline barriers (also known as median dividers and centerline curbing).

The objectives of this research were to study unsafe motor vehicle driver actions in close proximity of railroad-highway at-grade crossings, to evaluate the effectiveness of centerline barriers in reducing those unsafe driver actions, and to note any maintenance or other issues with the barriers. The effectiveness was judged by comparing frequencies of observed unsafe driver actions in the pre- and post-barrier periods and maintenance issues were noted by periodic inspection of the centerline barriers. Installed at two study sites, this research utilized a flexible rubber and plastic barrier from Qwick Kurb, Inc. (Ruskin, FL) as shown in Figure 1.1.

Figure 1.1. Flexible rubber and plastic barrier from Qwick Kurb, Inc.

CHAPTER 2 - LITERATURE REVIEW

As part of the literature review, several documents were examined to identify pertinent information on centerline barriers. This information is presented next while a summary of the literature review is provided at the end of this chapter.

2.1. Information from Reviewed Literature

While a plethora of literature is available on the subject of safety at railroad crossings, relatively few documents were found that studied driver actions at railroad crossings. Abraham et al. (1997) examined driver violation of traffic control devices at railroad crossings. Factors influencing safety at railroad grade crossings included the driver, vehicle, physical conditions, weather, driver age and lighting. Driver behavior at grade crossings was found to depend on many factors including perception of warning signs, decision making, vehicle control, and risk taking. Research showed that dual gate systems were highly effective in reducing unsafe behavior. An increase in warning times was directly linked with an increase in risky crossing behavior also. Abraham et al. (1997) collected data to acquire information on driver behavior at rail-highway crossings by mailing a questionnaire to those drivers who violated a traffic control device at a grade crossing. Violations were categorized into five different levels of severity and were compared with driver characteristics obtained from the questionnaire. More violations occurred at gated rail-highway crossings than crossings with flashers only. Gated crossings had more traffic control devices for drivers to violate. Single-track and two-lane road crossings tended to have more routine low risk violations due to unrealistically long warning times and motorist misperception regarding the flashing red light operations. Suggestions for improvements included improving warning time reliability and installation of non-traversable median barriers.

Coleman and Moon (1997) reported on a dual-gate railroad-highway grade crossing simulation and demonstrated the feasibility of modeling the interaction of active safety devices, driver behavior, and vehicular and train traffic. Different values of perception-reaction time (PRT) were analyzed for gate delay as well as stopping distance. Higher PRT values were found to cause more conflicts, as expected by the authors. They found that aggressive or inattentive drivers in the non-recovery zone frequently exceed stopping distances and more beyond gate arms, and therefore were likely to proceed at high risk of a collision with the train.

Carlson and Fitzpatrick (1999) reported on violations at gated highway-railroad grade crossings. Their aim was to identify operational and geometric variables that may influence violations at gated highway-railroad grade crossings. Logistic models were developed to identify gated crossings expected to have high violation rates compared to other gated crossings. The authors developed two models that related driver actions to characteristics such as, train, vehicle, and crossing geometry. The operational and geometric variables found significant in predicting violations were train speed, number of train tracks, warning time, sight distance adequacy, and number of lanes on the approach road.

Ko et al. (2004) investigated the effectiveness of a flexible traffic separator system by looking at the number of vehicles driving around the gates of a railroad-highway grade crossing. They reported a 77-percent reduction in crossing violations due to installation of the traffic separator system and a 98-percent reduction in crossing violations when used with four-quadrant gates. The authors reported high maintenance costs due to premature pavement edge cracking from vehicles driving on the edge of the pavement due to narrow lane widths resulting from the installation of the separator system. Their study shows that the traffic separators were highly effective in discouraging motorists from driving around the gates. The separator system was not shown to reduce any other crossing violation or block pedestrian or bicycle traffic.

2.2. Reviewed Literature Summary

Researchers have documented several safety aspects of railroad crossings, yet few have analyzed safety aspects relative to driver behavior at railroad crossings. Many engineering applications make crossings safer but problems still exist due to unsafe driver actions. This literature review looked at some of the research in the area of driver behavior at grade crossings as well as engineering applications that have improved safety at crossings. Applying new techniques to improve safety at railroad crossings can be effective, but should be selected carefully as each method may have drawbacks and limitations to implementation.

CHAPTER 3 - DATA COLLECTION

This chapter provides information on data collection sites and characteristics of the collected data.

3.1. Study Locations

The researchers in consultation with the project technical advisory committee (TAC) selected two at grade-crossings for this study based on considerations of: accessibility from Lincoln, NE, adequacy of train and roadway traffic, suitability for video data collection, and cooperation from local administrations. These two locations were North 141st Street crossing in Waverly, NE and the crossing at “M” Street in Fremont, NE (figures 3.1 and 3.2, respectively). The Waverly crossing has four sets of railroad tracks crossing the street and is equipped with dual-quadrant gates. The Fremont crossing has two sets of railroad tracks and is also equipped with dual-quadrant gates.

Figure 3.1. Grade crossing at North 141st Street in Waverly, NE

Figure 3.2. Grade crossing at M Street in Fremont, NE

3.2. Waverly Data Collection

The researchers collected data on driver actions at the North 141st Street crossing in Waverly by mounting a day and night vision camera and a digital video recorder (DVR) with the cooperation of the City of Waverly administration. The camera was mounted on a mast on top of the City of Waverly Fire Station that is ideally located to one side of the crossing (Figure 3.3). Use of the fire station provided electric power and a secure location for storage of the DVR. Initially, video recording actuated by motion detection was tried, i.e., the recording started when train or gate arm motion was detected in the field of view. However the mast-mounted camera was subject to winds that frequently caused false triggers of the motion detection system. As a remedy, the DVR was set to continuously record and the recording of frames per second reduced (from 30 to 8 frames per second) so that approximately six weeks of continuous data could be stored on the DVR.

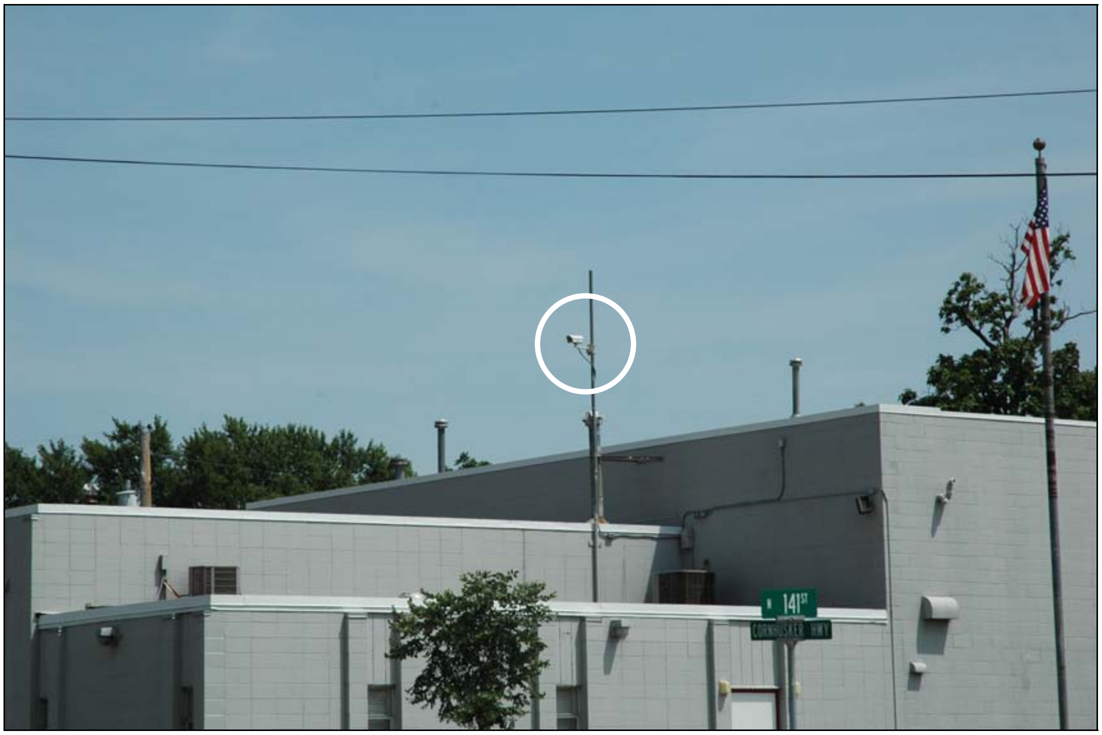

Figure 3.3. Day and night vision camera (circled) mounted on top of Waverly Fire Station

Unsafe actions on part of motor vehicle drivers were defined; these included: gate rushing to beat an oncoming train, U-turns, wrong side entry (only in the post-barrier install period), vehicles backing up, taking an alternate route (not unsafe action per se but was monitored in this study), red light running to beat a train (at a traffic signal in close proximity of the crossing), and any other generally unsafe maneuver. Additional variables that were collected included the following: day and time of observation, weather (snow, rain, fog, etc.), number of crossing trains and whether trains stopped on the tracks, roadway vehicular traffic during the train crossing and vehicle queue at gate opening, and duration of gate closure (measured in seconds and obtained from gate down and up times from time-stamped video).

Once enough data were collected, the DVR recordings were manually reviewed in the office for data compilation. An observation in this study was defined as an event when the gates came down with roadway vehicular traffic present at the crossing during the gate closure period. Motor vehicle driver actions were observed whenever the gates came down and instances of unsafe actions noted. There were a few instances when the gates came down while no train was approaching but roadway vehicular traffic was present. Such instances qualified the observation definition and were recorded in the data as gate malfunctions. Gate closures with no motor vehicle traffic present were discarded because there was no potential conflict present between train and roadway vehicular traffic.

A total of 3,283 observations were recorded of which 1,110 were made during the pre-barrier period and 2,173 during the post-barrier period. Table 3.1 shows simple frequency counts of different types of driver actions in the pre-and post-barrier periods. No one was observed playing "chicken" with an approaching train at the study site.

Table 3.1. Simple frequency counts of driver actions in pre-and post-barrier periods in Waverly

Driver Action	Pre-barrier period	% of total	Post-barrier period	% of total
Number of U-turns	181	81.53	41	18.47
Number of wrong side entries	0	0.00	11	100.00
Number of red light runnings to beat train	2	66.67	1	33.33
Number of gate rushes to beat train	250	44.25	315	55.75
Number of drivers taking alternate route	88	10.53	748	89.47
Number of drivers that backed up	33	11.26	260	88.74
Number of generally unsafe maneuvers	60	40.54	88	59.46

3.3. Fremont Data Collection

The researchers collected data on driver actions at the M Street grade crossing in Fremont by mounting a day and night vision camera and a digital video recorder (DVR) with the cooperation of the City of Fremont administration. The camera was mounted on a utility pole on the north side of the crossing (Figure 3.4). A DVR storage box was mounted on the utility pole that could be accessed at the site and power for these devices was provided by the City of Fremont. Again, video recording actuated by motion detection was tried but the same issues experienced at Waverly were encountered. As a remedy, the DVR was set to continuously record at one frame per second so a larger quantity of data could be stored on the DVR.

Unsafe actions on part of motor vehicle drivers were redefined for the Fremont site with most unsafe actions remaining the same. The unsafe actions recorded included: gate rush to beat an oncoming train, driving between train occurrences or after a train passes while the gates are still down, U-turn, wrong side entry (only in the post-barrier install period), vehicles backing up, and taking an alternate route. Additional variables that were collected included the following: day and time of observation, weather (snow, rain, fog, etc.), number of crossing trains and whether trains stopped on the tracks, roadway vehicular traffic during the train crossing and vehicle queue at gate opening, and duration of gate closure (measured in seconds and obtained from gate down and up times from time-stamped video). Once enough data were collected, the same process was followed as with the Waverly site. An observation for the Fremont data was defined in the same manner as an observation for the Waverly data, i.e., an event when the gates came down with roadway vehicular traffic present at the crossing.

The Fremont site study period included three time intervals, totaling 5,126 observations. The three time intervals were: a pre-barrier time, a limited barrier install time, and a full barrier install time. The pre-barrier time interval is defined as the period when no barrier was installed at the crossing. The limited barrier install time interval is the period in which barriers were installed on the two sides of the crossing but they did not extend fully to the gates. The reason for not fully extending the barriers to the gates was to ensure plenty of space for the railroad company's trucks that frequently ply along the railroad right of way. However, the researchers found that not fully extending the barriers to the gates provided roadway traffic to rush the gates thus limiting the barrier's effectiveness. Therefore, barriers on both sides of the railroad tracks were fully extended up to the gates. The open space between the gates was utilized by the railroad company's trucks when the gates were not closed for plying along the railroad right of way. Thus, the full barrier install interval refers to that period when the barriers were fully extended to the gates. Of the total 5,126 observations, 2,989 were made during the pre-barrier period, 892 were made during the limited installed barrier period, and 1,245 were made during the fully installed barrier period. Table 3.2 shows simple frequency counts of different types of driver actions in the three periods.

Figure 3.4. Day and night vision camera and DVR storage box mounted on a utility pole in Fremont, NE

Table 3.2. Simple frequency counts of driver actions in different observation periods in Fremont

Driver Action	Pre-barrier period	% of total	Limited installed-barrier period	% of total	Full installed-barrier period	% of total
Number of gate rushes to beat train	539	66.71	112	13.86	157	19.43
Number of drivers taking alternate route	1665	69.61	257	10.74	470	19.65
Number of U-turns	1235	85.06	85	5.85	132	9.09
Number of drivers that backed up	220	34.98	96	15.26	313	49.76
Number of between/after train	47	83.93	0	0.00	9	16.07
Number of wrong side entries	0	0.00	72	76.60	22	23.40

CHAPTER 4 - DATA ANALYSIS

This chapter provides information on the analysis of data collected at the two study sites (Waverly and Fremont) and reports on centerline barrier maintenance and other issues that were encountered during the study period. For each dataset, an exploratory investigation was first conducted followed by the development of formal relationships amongst driver actions and independent factors such as, duration of gate closure, vehicular traffic volume during train crossing event, etc. The subsequent sections describe the analysis of Waverly data, analysis of Fremont data and barrier maintenance and other related issues.

4.1. Waverly Data Analysis

Table 4.1 presents simple t-tests comparing the means of different types of driver actions in the pre- and post-barrier install periods at the Waverly crossing. In this table, an absolute t-value of greater than or equal to 1.96 indicates statistical significance at 95% confidence level; positive t-values show that mean occurrences were greater in the before period. These tests show that the number of U-turns and gate rushes reduced after installation of the barrier while the number of drivers taking alternate routes and those that backed up increased in the post-barrier period. Mean values of other types of driver actions in the two time periods were not found statistically different from each other.

These simple comparisons of means, while providing useful information do not account for other factors such as duration of gate closure, number of trains crossing, weather, motor vehicle traffic during train crossing, etc. One would expect that such factors might affect driver actions at railroad crossings. To account for the effects of such factors, the study utilized models suitable for count data – non-negative integer values, e.g., number of U-turns, number of gate rushes, etc. Analysis of count data usually requires application of Poisson or negative binomial models. The reader is referred to Appendix A for details of the two models. Reported below are results of negative binomial models estimated for total number of unsafe driver actions, number of U-turns, number of gate rushes, and number of vehicle backups.

Table 4.1. Comparison of pre- and post-barrier unsafe driver actions at Waverly

Driver action	Pre-barrier period		Post-barrier period		t-value
	Mean	Std. Dev.	Mean	Std. Dev.	
Number of U-turns	0.163	1.073	0.019	0.254	5.94*
Number of wrong side entries	0.000	0.000	0.005	0.127	-1.32
Number of red light runnings to beat train	0.002	0.042	0.000	0.021	1.20
Number of gate rushes to beat train	0.225	1.571	0.145	0.407	2.23*
Number of drivers taking alternate route	0.079	0.359	0.344	0.920	-9.24*
Number of drivers that backed up	0.030	0.180	0.120	0.728	-4.05*
Number of generally unsafe maneuvers	0.054	0.234	0.040	0.283	1.37

* Statistically significant at 95% confidence level; absolute t-value of >= 1.96 indicates statistical significance at 95% confidence level; positive t-values show that mean occurrences were greater during the pre-barrier period.

Model for total number of unsafe driver actions

A negative binomial model was estimated for the total number of unsafe driver actions. The total number of unsafe actions was obtained by summing the numbers of U-turns, wrong side entries, running red light to beat an oncoming train, gate rushes, vehicle backups, and other unsafe actions per observation (number of times an alternate route was used was not included in this total number). Table 4.2 presents the modeling results; while the overall model fit is not so good the model still provides useful information. All of the variables in the model are statistically significant at the 95% confidence level. It shows that the number of total unsafe driver actions increase with increasing duration of gate closure (converted to minutes for analysis), increase with total motor vehicle traffic observed during the crossing, increase when a train stops on the tracks, or if there was a gate malfunction (i.e., gates come down without an approaching train). A dummy variable for pre- and post-barrier install periods was included in the model specification to investigate difference in the two time periods. This dummy variable is statistically significant and shows that the total number of unsafe driver actions reduced in the post-barrier period. Statistical significance of the alpha in the model shows that data are over-dispersed and use of the negative binomial model in place of the Poisson is appropriate.

No evidence was found of weather (rain, snow, fog, etc.) and day of week affecting the total number of unsafe driver actions. Since they were not influential, therefore they were not included in the model specification. Next, individual models for number of U-turns, number of gate rushes, and number of vehicles backing up were estimated, which are reported below.

Table 4.2. Negative binomial model for total unsafe driver actions at the Waverly crossing

Variable	Est. Coeff	Std. Error	t-stat
Duration of gate closure (in minutes)	0.021641	0.002805	7.716
Total vehicular traffic	0.082939	0.006011	13.799
Train stopped on crossing (yes=1, no=0)	1.336404	0.07627	17.522
Gate malfunction (yes=1, no=0)	0.59703	0.207488	2.877
Period dummy (before=0 / after=1)	-0.33072	0.06982	-4.737
Constant	-1.82248	0.073648	-24.746
Alpha	0.422967	0.069864	6.054

Number of observations	3283
Log Likelihood	-2207.582
Restricted log likelihood	-2258.500
Chi-squared	101.836
Rho-squared	0.022

Model for number of U-turns

Results of a negative binomial model for number of U-turns are shown in Table 4.3. The model fit, again is not good despite a number of statistically significant variables. Longer duration of gate closure, greater vehicular traffic, and train stoppage on the crossing tend to increase number of U-turns by drivers. Similarly, drivers are more likely to make U-turns on weekdays as opposed to weekends, probably because of work-related time constraints. This variable is only significant at the 90% confidence level. According to the estimated model, drivers tend to make fewer U-turns when the pavement is wet, capturing drivers' concern for adverse weather. The dummy for pre- and post-barrier periods is statistically significant and shows that fewer U-turns were made in the post-barrier period. Statistical significance of the alpha in the model shows the appropriateness of estimating a negative binomial model.

Table 4.3. Negative binomial model for number of U-turns at the Waverly crossing

Variable	Est. Coeff	Std. Error	t-stat
Duration of gate closure (in minutes)	0.019305	0.009483	2.036
Total vehicular traffic	0.122175	0.014633	8.349
Train stopped on crossing (yes=1, no=0)	2.234851	0.184649	12.103
Dummy for weekday	0.320851	0.185589	1.729
Dummy for wet pavement	-3.32418	0.493261	-6.739
Period dummy (before=0 / after=1)	-2.2543	0.216713	-10.402
Constant	-3.80235	0.17509	-21.716
Alpha	1.053163	0.355491	2.963

Number of observations	3283
Log Likelihood	-488.005
Restricted log likelihood	-501.778
Chi-squared	27.546
Rho-squared	0.027

Model for number of gate rushes

Table 4.4 presents results of the model for number of gate rushes to beat an oncoming train. Model fit is slightly better than previous models. The estimated coefficients suggest that the number of gate rushes increase with longer durations of gate closure and greater roadway vehicular traffic. Gate rushes tend to decrease if the pavement is wet or if it is raining or snowing. This variable, representing adverse weather conditions, is capturing drivers' caution during such conditions at railroad crossings. The dummy variable for pre- and post-barrier periods is statistically significant showing that gate rushing decreased after installation of the barrier. The statistical significance of alpha in the model shows the appropriateness of the negative binomial model.

Model for number of backups

A negative binomial model was estimated for the number of vehicle backups (Table 4.5). Results show that the number of vehicles backing up increase with increasing gate closure duration, greater vehicular traffic at the crossing, and when trains stop on the crossing. Drivers tended to backup more often on weekdays compared to weekends, probably a result of time pressure on workdays (the variable is significant at 90% confidence). Gate malfunctions also resulted in a higher number of vehicles backing up. The dummy variable for pre- and post-barrier periods shows that the number of backups increased in the post-barrier period compared to the

Table 4.4. Negative binomial model for number of gate rushes to beat oncoming train at the Waverly crossing

Variable	Est. Coeff	Std. Error	t-stat
Duration of gate closure (in minutes)	0.020795	0.00209	9.949
Total vehicular traffic	0.051653	0.007605	6.792
Dummy for wet pavement, rain & snow	-0.48727	0.208025	-2.342
Period dummy (before=0 / after=1)	-0.29943	0.090711	-3.301
Constant	-2.0434	0.091128	-22.423
Alpha	0.438121	0.127007	3.45

Number of observations	3283
Log Likelihood	-1504.804
Restricted log likelihood	-1525.464
Chi-squared	41.319
Rho-squared	0.013

Table 4.5. Negative binomial model for number of vehicle backups at the Waverly crossing

Variable	Est. Coeff	Std. Error	t-stat
Duration of gate closure (in minutes)	0.028531	0.004885	5.841
Total vehicular traffic	0.068428	0.013127	5.213
Train stopped on crossing (yes=1, no=0)	2.480459	0.170066	14.585
Dummy for weekday	0.318352	0.166998	1.906
Gate malfunction (yes=1, no=0)	1.440138	0.499045	2.886
Period dummy (before=0 / after=1)	1.346459	0.217585	6.188
Constant	-5.08479	0.246528	-20.626
Alpha	0.914498	0.281071	3.254

Number of observations	3283
Log Likelihood	-681.632
Restricted log likelihood	-702.623
Chi-squared	41.980
Rho-squared	0.029

pre-barrier period. This is different than the previous models and it appears that while drivers reduced other types of unsafe actions upon installation of the barrier, they increasingly backed up their vehicles. Again, the statistical significance of the alpha parameter shows the appropriateness of the negative binomial model as opposed to a Poisson model.

4.2. Fremont Data Analysis

The two groups of data collected during the limited barrier install period and during the full barrier install period were combined into a single group representing post barrier install data. Table 4.6 presents simple t-tests comparing the means of different types of driver actions in the pre- and post-barrier install periods at the Fremont crossing. In this table, an absolute t-value of greater than or equal to 1.96 indicates statistical significance at 95% confidence level; positive t-values show that mean occurrences were greater in the before period. These tests show that the number of U-turns, gate rushes, and alternate routes reduced after installation of the barrier while the number of drivers backing up and driving on the wrong side of the barrier increased. Mean values of other types of driver actions in the two time periods were not found statistically different from each other. Again, negative binomial models were developed for the unsafe driver actions using other factors recorded in the study such as weather and duration of gate closure.

Table 4.6. Comparison of pre- and post-barrier unsafe driver actions at Fremont

Driver action	Pre-barrier period		Post barrier period		t-value
	Mean	Std. Dev.	Mean	Std. Dev.	
Number of gate rushes to beat train	0.180	0.684	0.126	0.369	-3.341*
Number of drivers taking alternate route	0.557	1.303	0.340	0.732	-6.958*
Number of U-turns	0.413	0.891	0.102	0.332	-15.408*
Number of drivers that backed up	0.074	0.290	0.191	0.521	10.333*
Number of times crossed closed gates between successive trains or immediately after train passage while gates were still closed	0.016	0.407	0.004	0.084	-1.288
Number of wrong side entries	0.000	0.000	0.044	0.260	9.268*

* Statistically significant at 95% confidence level; absolute t-value of >= 1.96 indicates statistical significance at 95% confidence level; positive t-values show that mean occurrences were greater during the pre-barrier period.

Model for total number of unsafe driver actions

A negative binomial model was estimated for the total number of unsafe driver actions, which was the sum of numbers of U-turns, wrong side entries, driving between/after trains, gate rushes, and vehicle backups. Modeling results (Table 4.7) show that the number of total unsafe driver actions: increase with longer duration of gate closure, increase when a train stops on the tracks, increase if the gate malfunctions (i.e., gates closed for maintenance, etc.), and increase if the gates come down and back up without train presence. The pre-install time period dummy variable was found statistically significant showing that the total number of unsafe driver actions

Table 4.7. Negative binomial model for total unsafe driver actions at the Fremont crossing

Variable	Est. Coeff	Std. Error	t-stat
Duration of gate closure (in minutes)	0.034	0.0016	21.073
Gate Up and Down (yes=1, no=0)	1.307	0.1324	9.869
Number of Trains during Crossing	0.191	0.0423	4.513
Train stopped on crossing (yes=1, no=0)	0.642	0.0449	14.303
Gate malfunction (yes=1, no=0)	1.715	0.2898	5.917
Period dummy (before=1 / after=0)	0.182	0.0459	3.972
Constant	-2.221	0.0792	-28.054
Alpha	0.431	0.0316	12.626

Number of observations	5126
Log Likelihood	-4885.321
Restricted log likelihood	-5096.178
Chi-squared	421.71
Rho-squared	0.000

reduced in the post-barrier period. Statistical significance of the alpha value in the model shows that data are over-dispersed and use of the negative binomial model in place of the Poisson is appropriate. No evidence was found of weather (rain, snow, fog, etc.), amount of vehicular traffic present and day of week affecting the total number of unsafe driver actions, and as such they were excluded from the model specification for parsimony. Individual models for number of U-turns, number of gate rushes, and number of vehicles backing up are reported next.

Model for number of U-turns

Results of a negative binomial model for number of U-turns are shown in Table 4.8. The model fit is not as good as that of the total unsafe driver actions but it still provides useful information. Longer duration of gate closure, the number of trains present and train stoppage on the crossing increase number of U-turns by drivers. None of the weather variables were found significant in this model. The dummy for pre- and post-barrier periods is statistically significant and shows that fewer U-turns were made by drivers in the post-barrier period. Statistical significance of the alpha in the model shows the appropriateness of estimating a negative binomial model.

Table 4.8. Negative binomial model for number of U-turns at the Fremont crossing

Variable	Est. Coeff	Std. Error	t-stat
Constant	-4.230	0.122	-34.553
Period dummy (before=1 / after=0)	1.181	0.082	14.409
Duration of gate closure (in minutes)	0.031	0.003	9.552
Train stopped on crossing (yes=1, no=0)	0.999	0.0698	13.314
Number of Trains during Crossing	0.173	0.0584	2.956
Alpha	0.597	0.0748	7.990

Number of observations	5126
Log Likelihood	-2935.887
Restricted log likelihood	-3009.428
Chi-squared	147.0804
Rho-squared	0.0000

Model for number of gate rushes

Table 4.9 presents the results of an estimated model for number of gate rushes to beat an oncoming train. The model fit is slightly better than the U-turn model. The variables found to affect gate rush frequency were gate malfunction and gate up and down. The positive signs of the estimated parameters suggest that number of gate rushes increase when these events occur. Weather related factors were not found statistically significant and therefore excluded from the model specification. The dummy variable for pre- and post-barrier periods is statistically significant showing that gate rushing decreased after installation of the barrier. The statistical significance of alpha parameter shows appropriateness of the negative binomial model.

Model for number of backups

Table 4.10 presents the results of an estimated model for number of drivers backing up from the crossing to take an alternate route. Results show that the number of vehicles backing up increase with: greater gate closure duration, higher number of trains during a crossing, when trains stop on the crossing, and when errant gate closures occur. The dummy variable for pre- and post-barrier periods shows that the number of backups increased in the post-barrier period compared to the pre-barrier period (similar to the Waverly finding). The statistical significance of the alpha parameter shows the appropriateness of the negative binomial model as opposed to a Poisson model.

Table 4.9. Negative binomial model for number of gate rushes to beat oncoming train at the Fremont crossing

Variable	Est. Coeff	Std. Error	t-stat
Constant	-2.092	0.0683	-30.614
Period dummy (before=1, after=0)	0.331	0.0847	3.908
Gate malfunction (yes=1, no=0)	1.623	0.5143	2.767
Gate Up and Down (yes=1, no=0)	1.019	0.1300	7.840
Alpha	1.313	0.0923	14.236

Number of observations	5126
Log Likelihood	-2331.976
Restricted log likelihood	-2410.633
Chi-squared	157.3123
Rho-squared	0.000

Table 4.10. Negative binomial model for number of vehicle Backups at the Fremont crossing

Variable	Est. Coeff	Std. Error	t-stat
Constant	-4.684	0.199	-23.504
Period dummy (before=1 / after=0)	-1.231	0.093	-13.195
Duration of gate closure (in minutes)	0.023	0.005	4.776
Number of Trains during Crossing	0.322	0.083	3.891
Train stopped on crossing (yes=1, no=0)	1.564	0.106	14.791
Gate malfunction (yes=1, no=0)	2.371	1.089	2.177
Gate Up and Down (yes=1, no=0)	1.331	0.484	2.750
Alpha	0.511	0.142	3.594

Number of observations	5126
Log Likelihood	-1632.797
Restricted log likelihood	-1644.028
Chi-squared	22.46063
Rho-squared	0.2144E-05

4.3. Summary of Results

The two study sites showed reasonably similar results – all unsafe driver actions showed a decrease in the post-installation time periods except for drivers backing up. This can be attributed to the installation of the barrier, which prevented drivers from performing a U-turn or other actions to take an alternate route. The Fremont site had a significant amount of drivers using the wrong side of the road after installation of the barrier, either for gate rushing or to take an alternate route. The most significant finding was that the number of gate rushes significantly decreased in the post-installation periods at both sites.

4.4. Barrier Maintenance and Other Issues

The researchers looked at barrier maintenance and other issues during the study period. While the barriers installed at the two study locations were similar in construction material and installation, the observed maintenance needs were different due to differences in roadway traffic, geometry, and traffic composition. The barrier at Waverly received more abuse due to higher roadway traffic and higher percentage of truck volume compared to the Fremont site. Also, the Waverly site involved a 90-degree turn from Highway 6 onto North 141st street, which exacerbated the situation with trucks frequently overrunning the end of the barrier (Figure 4.1). Hence, maintenance needs were higher at the Waverly location. The barrier manufacturer sent replacement parts for the severely abused curbing shown in Figure 4.1. Since relatively little truck traffic volume and no significant turning traffic were involved at the Fremont site, the barrier was much less abused at that location. None the less, the barrier at Fremont was overrun by roadway traffic and damaged as evident from tire tread and scuff marks in Figure 4.2, which required some maintenance.

Figure 4.1. Flattened and abused curbing due to overrunning trucks in Waverly

Figure 4.2. Tire tread and scuff marks on curbing installed in Fremont

The barriers installed at the two study sites experienced snow conditions but the researchers did not receive any information on difficulties in snowplow operations from the respective cities. The researchers also did not observe any damage to the curbing from snow plow operations. An issue experienced at the Waverly site during the study was the impact on truck access to a grain elevator, which is located in close proximity of the railroad crossing. Upon installation of the barrier, the manager of the facility reported truck drivers experiencing difficulties in coming into and going out from the grain elevator. In response, the researchers removed a small portion of the installed barrier from the north side of the railroad crossing, which alleviated the issue.

During the course of the study, the researchers observed pedestrian and bicyclist actions at the two study sites that were dangerous. Both groups of users were observed rushing the gates when trains were approaching, climbing through or going under trains that were temporarily stopped on a crossing. While such actions were of concern, they were not part of this study and as such were not perused by the researchers.

CHAPTER 5 – CONCLUSIONS

5.1. Conclusions

This study investigated unsafe actions of drivers at gated railroad-highway grade crossings and formally compared the effects of a flexible rubber and plastic barrier that was installed to study the changes in driver actions. Analysis of the data collected at the Waverly and Fremont study sites revealed the following major findings:

- The total number of unsafe driver actions reduced when a barrier preventing drivers from going through the gate was installed at the subject crossing.
- Separate investigation of driver actions showed that the number of U-turns and number of gate rushes decreased upon installation of the barrier.
- The number of vehicles backing up increased after installation of the barrier.
- The Fremont site showed a significant amount of vehicles driving on the wrong side of the barrier to take alternate routes and to gate rush.

These findings are indicative that while it is quite possible to reduce certain types of unsafe driver actions by installing barriers at railroad-highway grade crossings, drivers may resort to other types of unsafe actions in response. Fortunately, the increase is in less dangerous actions (backing up) compared to more dangerous actions such as gate rushes (which decreased in the post-barrier period). The conclusion reached is that installation of the centerline barrier was successful in reducing gate rushes and some of the more dangerous driver actions at railroad crossings while some relatively less dangerous driver actions increased in the post-barrier period.

In this study, the trade off is between reducing gate rushes and U-turns at the cost of increasing vehicle backups. Clearly, gate rushes carry a higher risk of more severe crashes between motor vehicles and trains compared to vehicle backups, which might result in fender benders. While the authors did not conduct a formal cost-benefit analysis to evaluate this trade-off, given the serious nature of gate-rush crashes the trade-off is in favor of installing barriers that prevent motorists from going around the gates. Therefore, the researchers recommend the use of centerline barriers at railroad crossings where unsafe driver actions (e.g., gate rushes) are a concern.

Centerline barriers do require periodic maintenance, which is due primarily to abuse from roadway vehicles. Maintenance is a function of roadway traffic volume, traffic composition, and site geometry, which increases with higher traffic volume, higher percentage of trucks, and if sharp turns are involved. The researchers did not come across any snowplow related issues during this study. During the course of the study, the researchers learned that barrier installation must take into account any negative impact on the access of adjacent facilities, which must be eliminated or minimized. Finally, this study revealed instances of pedestrians and bicyclists engaged in unsafe actions at railroad crossings. Pedestrian and bicyclist safety investigation is recommended for future research.

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REFERENCES

Abraham, J., T. K. Datta, and S. Datta. Driver Behavior at Rail-Highway Crossings. In *TRB 1998 Annual Meeting CD-ROM.* Transportation Research Board, Washington, D.C., 1998.

Carlson, P. J., and K. Fitzpatrick. Violations at Gated Highway-Railroad Grade Crossings. In Transportation Research Record: Journal of the Transportation Research Board, No. 1692, TRB, National Research Council, Washington, D.C., 1999, pp. 66-72.

Coleman III, F., and Y. J. Moon. System Simulation of Dual-Gate At-Grade Railroad-Highway Crossings. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1605*, TRB, National Research Council, Washington, D.C., 1997, pp. 88-95.

Ko, B., S. S. Washburn, K. G. Courage, and H. M. Dowell. Evaluation of Flexible Traffic Separators at Highway-Railroad Grade Crossings. In *TRB 2005 Annual Meeting CD-ROM.* Transportation Research Board, Washington, D.C., 2005.

APPENDIX A

Details of Poisson and Negative Binomial Models

Poisson regression is appropriate for modeling count data; for a discrete random variable Y such as, number of U-turns, with observed frequencies $y_i = 1, 2, \ldots N$, (where $y_i \geq 0$), the probability that the observed frequencies are the true frequencies is:

$$prob(Y = y_i) = (e^{-\lambda_i} \lambda_i^{y_i}) / (y_i!) \qquad (1)$$

where $$ln\lambda_i = \beta' X_i, \qquad (2)$$

β' = estimated vector of parameters, and

X_i = vector of U-turn relevant characteristics for observation i.

In this model, λ_i is both the mean and variance of the observed U-turn frequency (y_i). Thus, the Poisson model requires that both the mean and variance of U-turn frequency be equal. This requirement is frequently unmet and a way around it is the use of the negative binomial model, which relaxes this requirement. The negative binomial model arises from the Poisson model by specifying an error term, ε, where $\exp(\varepsilon)$ has a gamma distribution with a mean of one and a variance of α^2. The resulting probability distribution is:

$$prob[Y = y_i \mid \varepsilon] = \exp[-\lambda_i \exp(\varepsilon)] \lambda_i^{y_i} / y_i! \qquad (3)$$

where all variables are as previously defined. Integrating ε out of this expression produces the unconditional distribution of y_i. The formulation of this distribution is:

$$prob[Y = y_i] = \Gamma(\theta + y_i) / [\Gamma(\theta) y_i!] u_i^{\theta} (1 - u_i)^{y_i} \qquad (4)$$

where $prob[Y = y_i]$ = probability of the i^{th} U-turn occurring in a specified train crossing, and

$$u_i = \theta / (\theta + \lambda_i)$$

$$\theta = 1 / \alpha$$

Compared with the Poisson model, the negative binomial model has an additional parameter alpha (α) that gives the overdispersion in data. Both models can be estimated by the standard maximum likelihood methods. The statistical significance of the estimated alpha parameter in the negative binomial model is a confirmation of overly dispersed data.

Various measures of "goodness-of-fit" for count data models are in use; this study utilized a goodness-of-fit statistic that measures the fraction of a restricted log-likelihood explained by the model:

$$\rho^2 = 1 - [L(\beta)/L(0)] \quad (5)$$

where, L(β) is the log-likelihood at convergence and L(*0*) is the restricted log-likelihood. Values closer to 1.0 indicate a superior fit while values closer to zero indicate inferior fit.