Gate Violations by Truck Drivers at Highway-Rail Grade Crossings in Two Cities

by Aemal Khattak

Gate violations during train crossing events by truck drivers at highway-rail grade crossings in two cities were investigated. About 22% of the collected observations involved gate violations by truck drivers. Analysis showed that the frequencies of gate violations increased with higher truck traffic during crossing events and drivers of single-unit trucks displayed a greater propensity for gate violations compared with drivers of trucks with trailers. Violations were more frequent with longer times between the onset of flashing lights and train arrivals at the crossings. Options for reducing truck drivers' gate violations at gated crossings are provided.

INTRODUCTION

The objective of this research was to investigate gate violations by truck drivers at dual-quadrant gated highway-rail grade crossings (HRGCs) in two cities. Dual-quadrant gated HRGCs have gates in only two of the four quadrants, i.e., gates on both sides of the road only extend out to the middle of the road. As such, motorists can illegally pass around fully-deployed gates. HRGCs serve as junctions for multiple transport modes on the surface transportation network and they are conflict points between rail and highway traffic. For 2010, the Federal Railroad Administration (FRA) reported 2,107 incidents at HRGCs and a rate of 2.85 HRGC incidents per million train miles (USDOT 2012). These incidents involved 256 fatalities and 854 non-fatal injuries. Trucks and trucks with trailers were involved in 386 incidents, resulting in 24 fatalities and 233 non-fatal injuries. At HRGCs, train consists (units) transporting hazardous materials were involved in 47 crashes while 14 involved trucks carrying hazardous materials that required the evacuation of 471 people. Hazardous materials are frequently transported by both rail and trucks, and the implications of truck-train crashes at HRGCs are potentially more ominous compared with other highway crashes.

The issue of collisions between trucks and trains is important because of the relatively high severity of such crashes and environmental concerns arising from possible spillage of hazardous materials. Given that rail and truck traffic in the US is expected to grow, it is prudent to investigate truck-train safety at HRGCs; the ultimate goal being improvement of public safety.

This research was carried out in Nebraska where the law prohibits drivers from driving through, around or under any rail crossing gate or barrier while the gate or barrier is closed or is being opened or closed (Neb. Rev. Stat. 60-6,170, 2009). Many other states across the U.S., e.g., Missouri, New Hampshire, North Dakota, and Rhode Island have similar laws. The penalty for a first violation in Nebraska disqualifies a commercial motor vehicle driver for a period not less than 60 days. A second violation disqualifies a driver for not less than 120 days during any three-year period for separate incidents while a third violation during any three-year period for separate incidents disqualifies a commercial motor vehicle driver for a period not less than one year.

The research methodology consisted of collecting data at two dual-quadrant gated Nebraska HRGCs where truck drivers were observed during train crossing events along with other pertinent factors. The collected data were then statistically analyzed to assess the prevalence of gate violations by truck drivers. The organization of the remaining paper is as follows. A review of relevant literature follows this introduction, which is ensued by a description of data collection. The next section presents data analysis including a Poisson model of truck drivers' gate violations at the two HRGCs.

The paper ends with research conclusions and a discussion of possible options for both practitioners and researchers to improve truck drivers' safety at HRGCs.

LITERATURE REVIEW

Although not all violations by truck drivers at HRGCs result in crashes, the prevalence of such maneuvers at crossings is an indication of its safety. According to Council et al. (1980) gate violations were an appropriate surrogate measure of crashes. Similarly, a study by Abraham et al. (1998) indicated promise for the use of violation data in determining the relative hazardousness of rail-highway crossings in combination with crash histories. Overall, the use of violations to study HRGC safety is well-established; examples include Carlson and Fitzpatrick (1999), Hellman et al. (2007), Khattak (2007), Khattak and McKnight (2008), Khattak (2009), and Khattak and Luo (2011).

Davey et al. (2007) interviewed truck drivers as well as train drivers regarding their experiences and perceptions of dangers at HRGCs in Australia. The configuration of at-grade crossings was found to affect heavy vehicle drivers' visibility and effective vehicle clearance. With regard to behavior, willful violation of crossing protocols, often as a time-saving measure, as well as truck drivers' complacency due to high levels of familiarity were cited.

Heathington et al. (1990) investigated warning time needs at HRGCs and reported warning times in excess of 30-40 seconds caused many more drivers to engage in risky crossing behaviors. Most drivers expected trains to arrive within 20 seconds from the moment when the traffic control devices were activated. Drivers lost confidence in traffic control systems if warning times exceeded 40 seconds at crossings with flashing light signals and 60 seconds at gated crossings. Abraham et al. (1998) reported that the timely arrival of trains after the warning devices were triggered was an essential element that motorists assessed when taking risks.

Rys et al. (2009) evaluated the use of stop signs at passive grade crossings. Their results showed that a majority (79%) of drivers did not stop at installed stop signs and that drivers of heavy trucks had a lower level of compliance than other types of vehicles. Finally, Yeh and Multer (2008) provided a comprehensive review of research on motor vehicle drivers' behavior at HRGCs; this document was an update to an earlier report by Lerner et al. (1990).

In summary, the study of violations at HRGCs provides useful information on the safety of HRGCs. Research on truck drivers' behavior at HRGCs, while sparse, indicated that violations were for saving travel times and due to complacency resulting from high levels of crossing familiarity. Excessively long warning times at HRGCs encouraged risky behavior by motor vehicle drivers. The reviewed literature did not reveal publications specifically dealing with the frequency and characteristics of gate violations by truck drivers at HRGCs. The next section describes the data collection effort.

DATA COLLECTION

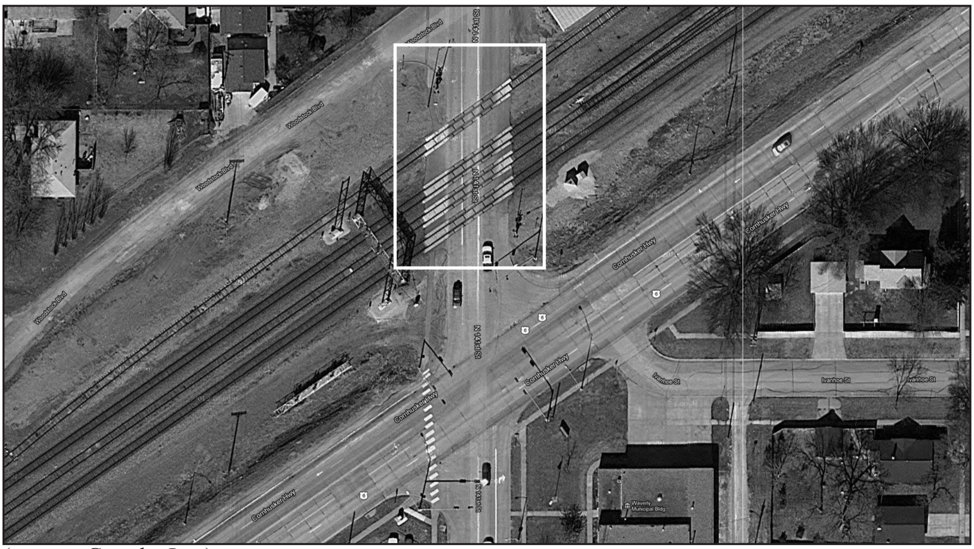
Data collection consisted of focusing on different types of gate violations (according to Nebraska law) by truck drivers at two dual-quadrant gated HRGCs. Drivers of both single unit (SU) trucks and trucks with trailers were included in this research. The following three gate violations were taken into account.

1. Trucks passing under descending HRGC gates (V1),
2. Trucks passing around fully lowered HRGC gates (V2), and
3. Trucks passing under ascending HRGC gates (V3).

An observation consisted of an event with flashing gate lights and trucks at the HRGCs with opportunities for gate violations (e.g., observations with trucks not at the front of the waiting queue were ignored). Video footage was continuously recorded at the North 141st Street grade crossing in

Waverly and at the M Street crossing in Fremont, both located in Nebraska. The Waverly HRGC (USDOT crossing no. 074940T) comprised four sets of rail tracks crossing two lanes of roadway and protected by dual-quadrant gates. The estimated average annual daily traffic (AADT) at this HRGC was 2,630 vehicles with 2% trucks. The Fremont crossing (USDOT crossing 074662E) consisted of two sets of tracks crossing two lanes of a roadway and protected by dual-quadrant gates. The estimated AADT at the Fremont HRGC was 1,315 vehicles with 4% trucks. Both crossings afforded clear sight distances in all directions and were equipped with flashing lights, crossbuck signs, and audible bells. Figures 1 and 2 show the study sites. Day- and night-vision cameras and digital video recorders (DVR) were used to record train crossing events. Instances with trucks present with opportunities for gate violations at the crossings were extracted from the video footage and subsequently used for pertinent data extraction to a spreadsheet.

Figure 1: HRGC at the North 141st Street in Waverly, Nebraska



(source: Google, Inc.)

Figure 2: HRGC at the M Street Crossing in Fremont, Nebraska

(source: Google, Inc.)

Sixteen variables representing different types of gate violations by truck drivers, counts of SU trucks and trucks with trailers, train traffic, temporal features, and environmental and pavement surface characteristics at the time of train crossings were recorded for each observation. Table 1 presents a list of those variables along with relevant coding information. A total of 476 observations were collected as part of the dataset.

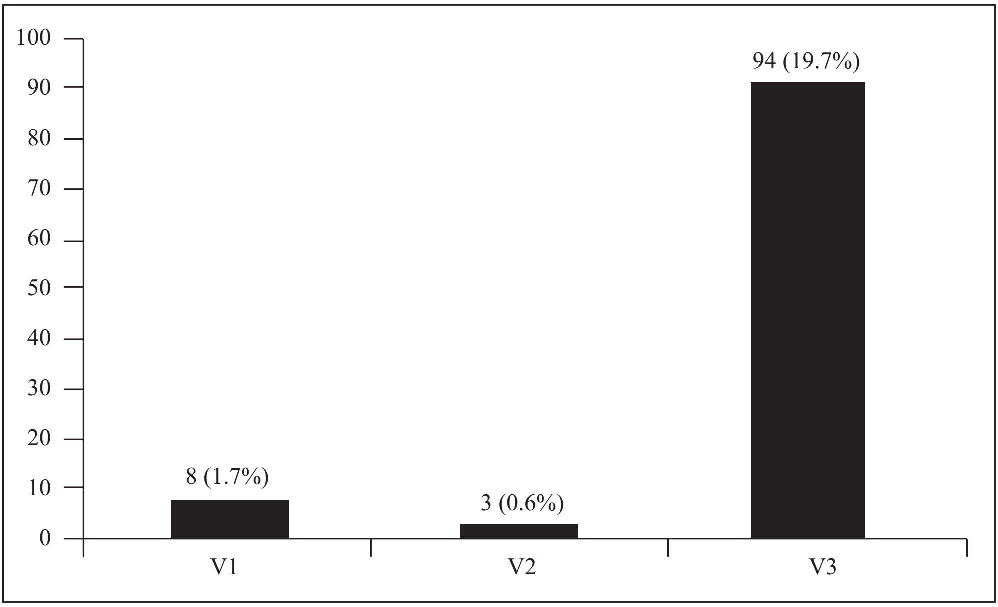
Table 1: Collected Variables

Variable	Description	Coding/Units
Su_V1	Number of SU trucks passing under descending gates during an observation	0, 1, 2, …
Su_V2	Number of SU trucks passing around fully lowered gates during an observation	0, 1, 2, …
Su_V3	Number of SU trucks passing under ascending gates during an observation	0, 1, 2, …
Ttrlr_V1	Number of trailer trucks passing under descending gates during an observation	0, 1, 2, …
Ttrlr_V2	Number of trailer trucks passing around fully lowered gates during an observation	0, 1, 2, …
Ttrlr_V3	Number of trailer trucks passing under ascending gates during an observation	0, 1, 2, …
N_Sutrks	Count of SU trucks during an observation	1, 2, …
N_Trktrlr	Count of trailer trucks during an observation	1, 2, …
N_Trains	Number of passing trains during an observation	1, 2, …
T_Stop	Indicator variable for train stoppage on the HRGC	1 if stopped, 0 otherwise
G_Down	Elapsed time from start to end of flashing lights	Seconds
T_Arrival	Elapsed time between onset of flashing lights and train arrival at the crossing	Seconds
Day	Day of week of the observation	1 if Mon, 2 if Tue, ..., 7 if Sun
Daytime	Light condition	0 if nighttime, 1 if daytime, 2 if dawn or dusk
Weather	Weather condition	0 if clear, 1 if rain, 2 if snowing, 3 if foggy, 4 if other
Pavement	Pavement surface condition	0 if dry, 1 if wet, 2 if snow on pavement

DATA ANALYSIS

Zero gate violations by truck drivers were observed in 78.2% of the 476 observations, a single gate violation was observed in 21.6% of those observations, while 0.2% observations constituted two gate violations by different truck drivers. Figure 3 shows the frequency of different types of gate violations observed; the most frequent violation type was passing under ascending gates after passage of the train. On average, truck drivers were involved in 0.22 gate violations per crossing event with a standard deviation of 0.42 violations (variance = 0.17 violations^2).

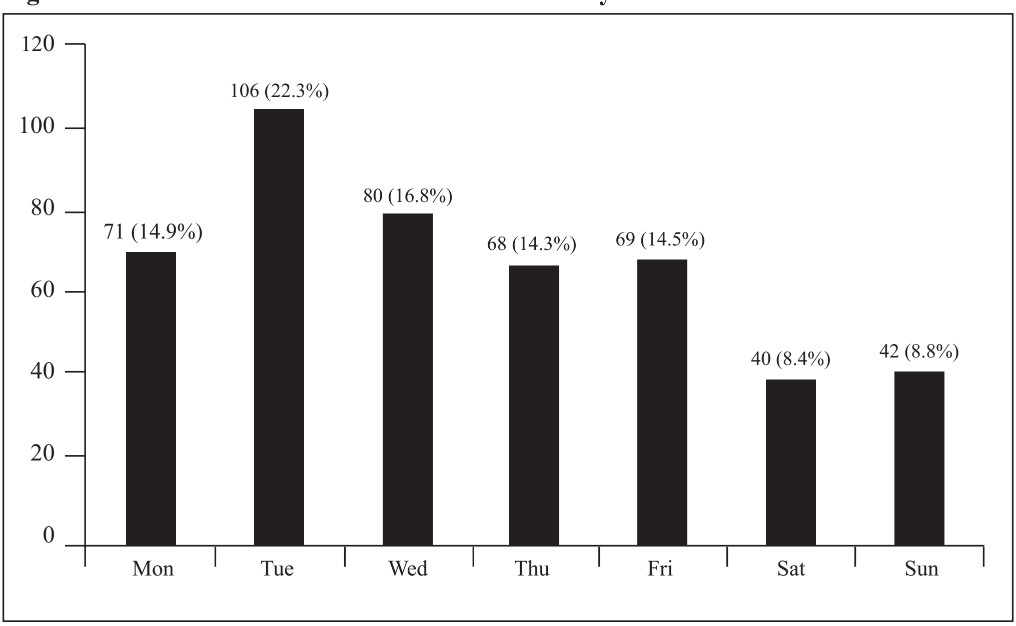
Figure 3: Frequency of Different Types of HRGC Gate Violations by Truck Drivers



During data collection, 337 SU trucks and 147 trucks with trailers were observed at the two HRGCs. The number of trains observed during data collection was 544, of which 92 (16.9%) stopped on the HRGCs. The average gate closure time of a crossing event was 363.5 seconds (about six minutes) while the average time between the onset of flashing lights and train arrival at the crossing was 46.1 seconds. Provision of 20 seconds as a minimum interval between the onset of warning devices and train arrival at the crossing is mandated.

Figure 4 shows the distribution of observations on different days of the week. Fewer observations were collected on Saturday and Sunday compared with week days. Figure 5 presents the distribution

Figure 4: Collection of Observations on Different Days of the Week



of observations across different times of the day. The majority (81.7%) of the observations were collected during daytime while somewhat equal observations were collected under dawn or dusk and nighttime conditions.

Figure 5: Time of Day Distribution of Observations

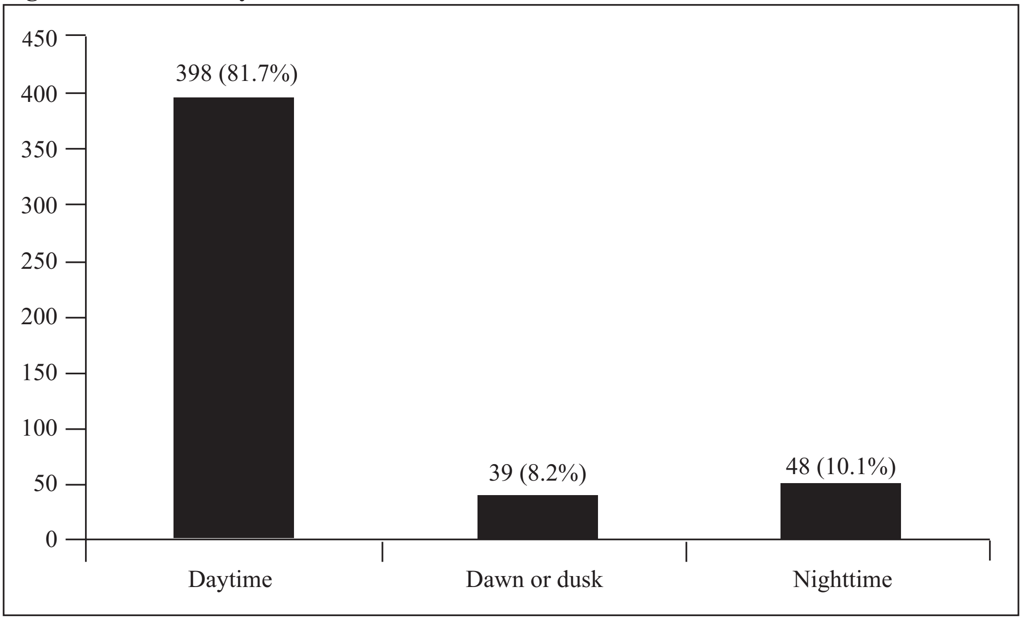


Figure 6 presents the distribution of observations in different weather conditions; the majority of observations were collected in clear weather. Figure 7 presents pavement surface conditions observed during crossing events. About 8% of the observations each were on wet and snow on pavement conditions. Moisture and snow on the pavement can stay for relatively long periods and therefore the number of collected observations under these two pavement surface conditions was larger than those collected when it was raining or snowing (Figure 6). An account of Poisson modeling of gate violations by truck drivers at HRGCs follows.

The Poisson Model

Aggregate counts of gate violations by truck drivers at HRGCs during crossing events were modeled using the Poisson distribution. This variable was obtained by aggregating the three different types of gate violations for both drivers of trucks with trailers and drivers of SU trucks (Su_V1 + Su_V2 + Su_V3 + Ttrlr_V1 + Ttrlr_V2 + Ttrlr_V3). The aggregation was necessitated as several violation categories in the collected data were sparse and did not provide meaningful results when analyzed separately.

The benchmark model for count data is the Poisson distribution (Cameron and Trivedi 1998). The Poisson model is appropriate for analysis of count data consisting of nonnegative integer values and when the mean and variance of the count variable are not significantly different from each other (as was the case with the dataset under analysis). According to Washington et al. (2011), the probability of a crossing event i having y_i gate violations (where $y_i \geq 0$), is given by:

(1) $$P(y_i) = (e^{-\lambda_i}\lambda_i^{y_i})/(y_i!)$$

Figure 6: Observations in Different Weather Conditions

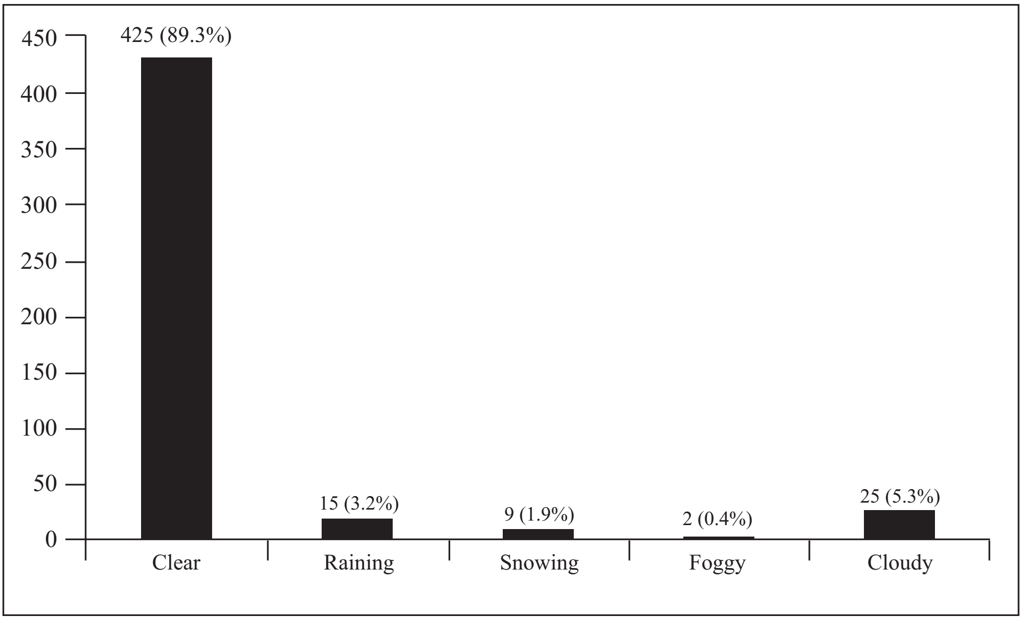
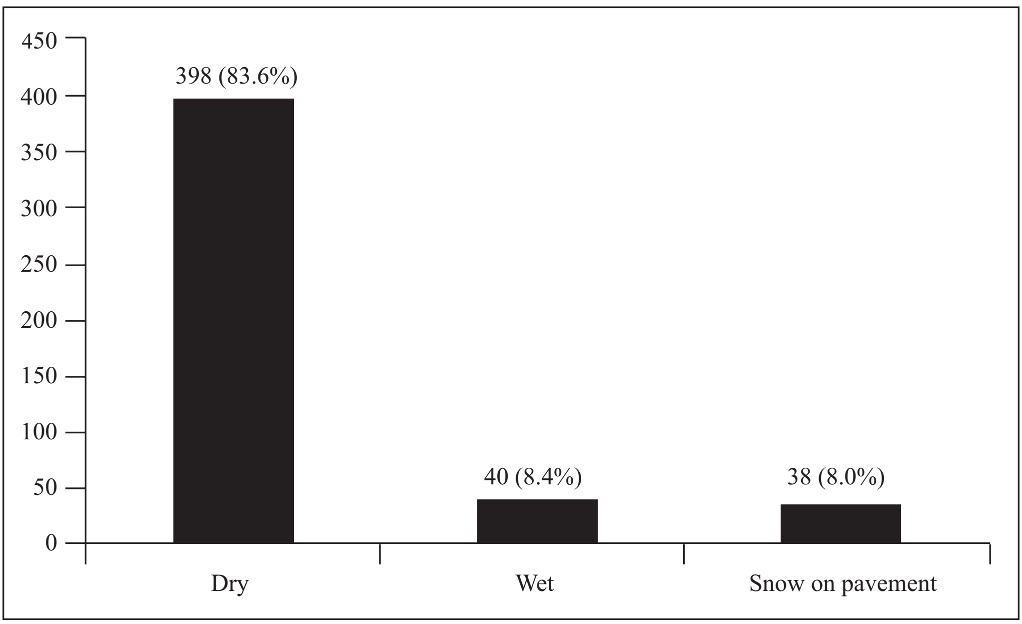


Figure 7: Observations Under Different Pavement Surface Conditions



Where $P(y_i)$ is the probability of crossing event i having y_i gate violations, e is the base of the natural logarithm, and λ_i is the Poisson parameter for crossing event i, which is equal to crossing event i's expected number of gate violations, $E[y_i]$. $y_i!$ represents the factorial of y_i.

Poisson models are estimated by specifying the Poisson parameter λ_i as a function of independent variables. The most common relationship between independent variables and the Poisson parameter is the log-linear model:

$$(2) \quad \lambda_i = e^{\beta X_i}$$

Where X_i is a vector of independent variables for crossing event i and β is a vector of estimable parameters. This model is estimable by standard maximum likelihood methods with the logarithm of the likelihood function given as:

$$(3) \quad LL(\beta) = \sum_{i=1}^{n} \left[-e^{\beta X_i} + y_i \beta X_i - Ln\,(y_i!) \right]$$

Marginal effects (evaluated at mean values) are used to determine the effects of the independent variables on the dependent variable; they provide an estimate of the impact of a unit change in the variable on the expected frequency of the count variable. Alternatively, elasticity can be computed to assess the effect of a 1% change in the independent variable on the expected frequency of λ_i.

The likelihood ratio test is used to assess competing models, usually a full or complete model over another competing model that is restricted by having a reduced number of model parameters. The likelihood ratio test statistic is:

$$(4) \quad X^2 = -2\left[LL(\beta_R) - LL(\beta_U) \right]$$

Where $LL(\beta_R)$ is the log-likelihood at convergence of the restricted model, considered to have all parameters in β equal to 0 or just to include the constant term, and $LL(\beta_U)$ is the log-likelihood at convergence of the unrestricted model. The X^2 statistic is chi-squared distributed with the degrees of freedom equal to the difference in the number of parameters in the restricted and unrestricted model. A measure of overall model fit is the ρ^2 statistics given as:

$$(5) \quad \rho^2 = 1 - \frac{LL(\beta)}{LL(0)}$$

Where $LL(\beta)$ is the log likelihood at convergence with parameter vector β and $LL(0)$ is the initial log likelihood with all parameters set to zero. The value of ρ^2 varies between 0 and 1 and values closer to 1 indicate a better fitting model compared to values closer to 0. The estimated Poisson model for frequency of truck drivers' gate violations is presented next.

Modeling Truck Drivers' Gate Violations

Table 2 shows the estimated Poisson model for counts of truck drivers' gate violations with relevant summary statistics; the model equation is:

$$(6) \quad \lambda = e^{0.699 * N\_Sutrks + 0.563 * N\_Trktrlr + 0.003 * T\_Arrival + 0.506 * Night - 1.253 * Rain - 0.789 * Snow\_Pvt - 2.366}$$

A positive estimated coefficient shows that the frequency of gate violations by truck drivers increases with increasing values of the variable while a negative estimated coefficient indicates that gate violations decrease with increasing values of the variable. Estimated coefficients in the model were statistically tested using a student's t-test to assess if they were different than zero at 95% or 90% confidence levels. Absolute t-statistic values of 1.96 or greater or 1.64 or greater indicate statistical significance at the 95% or 90% confidence levels, respectively. Alternatively, Table 2 provides p-values for the estimated coefficients; a p-value is the probability of obtaining a test statistic at least as extreme as the one that was observed/estimated. Values of 0.05 and 0.01 are thresholds for statistical significance at 95% and 90% confidence, respectively.

Table 2: Estimated Model for Counts of Gate Violations by Truck Drivers at HRGCs

Variable	Description	Estimated Coefficient	t-Statistic	P-Value	Marginal Value	Mean
N_Sutrks	Count of SU trucks during an observation	0.699	3.296	0.001	0.155	0.706
N_Trktrlr	Count of trailer trucks during an observation	0.563	2.221	0.026	0.125	0.308
T_Arrival	Elapsed time between onset of flashing lights and train arrival (sec)	0.003	1.968	0.049	0.001	46.105
Night	Indicator variable for nighttime	0.506	1.850	0.064	0.112	0.101
Rain	Indicator variable for rain	-1.253	-1.315	0.188	-0.278	0.031
Snow_Pvt	Indicator variable for snow on pavement	-0.789	-1.543	0.122	-0.175	0.080
Constant	Constant in the model	-2.366	-8.547	0.000	-0.525	-
	Model summary statistics					
	Number of observations	473				
	Log likelihood	-254.292				
	Restricted Log likelihood	-263.732				
	P^2	0.036				
	X^2 (with 6 degrees of freedom)	18.879				
	P-value	0.004				

Two variables indicating counts of SU trucks (N_Sutrks) and trucks with trailers (N_Trktrlr) were included in the model specification. When added, they represent truck traffic with opportunities for gate violations; in other words, truck drivers' exposure to gate violations where exposure was the state of being exposed to involvement in gate violations. Both variables were statistically significant at the 95% confidence level, indicating that gate violations increased with greater numbers of SU trucks and trucks with trailers arriving at HRGCs. The marginal value for SU trucks showed that for each additional SU truck (beyond its mean value and with other independent variables held constant at their respective mean values), gate violations increased by 0.155 violations per crossing event. Also, the larger marginal value of SU trucks (0.155) compared with the marginal value for trucks with trailers (0.125) indicated that SU truck drivers had a comparatively higher propensity for gate violations. This may be explained by the relatively smaller dimensions and shorter acceleration times associated with SU trucks compared with trucks with trailers.

The variable T_Arrival represented the elapsed time between the onset of flashing lights and train arrivals at the crossings. The estimated coefficient for this variable was positive and statistically significant at the 95% confidence level showing that greater values of T_Arrival were associated with more frequent gate violations by truck drivers. The model specification included an indicator variable for nighttime (Night =1 if nighttime). The estimated coefficient for this variable was positive and statistically significant at the 90% confidence level (t-statistic >1.64). Thus, nighttime was associated with higher frequency of gate violations compared with other times; its marginal value showed that an additional 0.112 gate violations per crossing event occurred during nighttime.

Finally, two indicator variables for rain (Rain=1 if raining) and snow on pavement (Snow_Pvt=1 if snow on the pavement) were included in the model to explore the effects of adverse weather and pavement surface condition on gate violations by truck drivers. The estimated coefficients in both cases were negative (indicating a reduction in gate violations) but statistically not significant at the 90% confidence level. Therefore, the collected data did not provide enough evidence regarding statistically significant relationships between frequencies of truck drivers' HRGC gate violations and rain and truck drivers' HRGC gate violations and presence of snow on pavement. The two variables, however, were retained in the model for demonstration.

Other variables available in the database were tried in the model specification but found statistically not significant. These included: elapsed time from start to end of flashing lights, the number of passing trains, train stoppage on the HRGC, an indicator variable for weekends, and an indicator variable for crossing location (Waverly or Fremont). These variables were excluded from the model specification for parsimony. Additionally, the estimated Poisson model was statistically tested for overdispersion (i.e., when the variance of the dependent variable is significantly larger than its mean) and no such evidence was detected. Conclusions and a discussion of options for reducing truck drivers' gate violations at gated crossings, including the research limitations, are presented next.

CONCLUSIONS AND DISCUSSION

This research explored gate violations by truck drivers at dual-quadrant gated HRGCs that were located in two different cities. Three different types of violations were observed during data collection: trucks passing under descending HRGC gates, trucks passing around fully lowered HRGC gates, and trucks passing under ascending HRGC gates. These three types of violations were aggregated and about 22% of the total observations involved gate violations by truck drivers. Based on the Poisson model results, the following conclusions were reached.

- At dual-quadrant HRGCs located in cities, the frequencies of gate violations by truck drivers increased with higher exposure of truck drivers.
- The propensity of SU truck drivers for gate violations at dual-quadrant HRGCs located in cities was higher compared with drivers of trucks with trailers.
- Longer times between the onset of flashing lights and train arrivals at dual-quadrant HRGCs located in cities contributed to higher frequencies of gate violations by truck drivers.
- Nighttime was associated with greater frequencies of gate violations by truck drivers at dual-quadrant HRGCs located in cities.

The conclusions are relevant to isolated dual-quadrant HRGCs located in cities and do not pertain to four-quadrant gated HRGCs or those located in corridors/rural areas. An aspect of these conclusions, pertinent to practitioners and practice-ready, is reducing truck traffic at HRGCs to limit drivers' exposure to gate violations. In a city environment, this may be feasible by restricting or prohibiting truck traffic at HRGCs where proximate grade-separated crossings are available. Another practical aspect is that of differentiated truck drivers' education. While all truck drivers should be the focus of education on the dangers of HRGC gate violations, the HRGC safety issue should be especially emphasized to drivers of SU trucks due to their higher propensity for involvement in gate violations. Such emphasis may be achieved via revisions to existing publications such as the Operation Lifesaver's Highway-Rail Grade Crossing Training for Professional Truck Drivers.

Longer elapsed times between the onset of warning devices and arrival of trains at crossings located in cities encourages drivers' disregard for traffic signs and signals. This issue was highlighted by Heathington et al. (1990) and by Abraham et al. (1998), though not specifically in the context of truck drivers. In the case of truck drivers, the issue of HRGC gate violations may be exacerbated by the need to deliver just-in-time deliverables and truck drivers' mileage-based remuneration. The research reported herein underscores the need to check excessively large warning times at dual-quadrant HRGCs located in cities beyond the minimum required time of 20 seconds. This aspect can be addressed by researchers and practitioners together. Research on reliable train detection, its speed and acceleration/deceleration estimation, and development of new algorithms for gate timing and highway traffic signal preemption (if involved) is needed. Practitioners would need to implement the outcomes of such research at city-based HRGCs to reduce elapsed times between the onset of warning devices and arrival of trains at crossings. However, in rural rail corridors with higher train speed limits, lengthening of warning times may be desirable under certain circumstances. Appropriate warning times at HRGCs depend on crossing and train characteristics and caution must be exercised in changing warning times at HRGCs.

Ways to reduce gate violations at nighttime by truck drivers are needed. Besides education, a possible practical option to reduce nighttime gate violations is stronger enforcement of motor vehicle laws at HRGCs at nighttime. Penalties for gate violations in Nebraska and some other states appear sufficiently stringent to quickly deter truck drivers from engaging in risky maneuvers at HRGCs.

Research Limitations

Limitations of the research presented herein include collection of data at only dual-quadrant HRGCs located in two cities, narrow geographic coverage, and lack of data on truck drivers' characteristics (age, driving experience, etc.). Therefore, the generalization of the findings is limited and studies involving multiple HRGCs with wider geographic coverage, including rural HRGCs in corridors and studies that collect data on drivers besides HRGC gate violations, are recommended. While this research did not uncover significant evidence regarding weather and pavement surface condition effects on HRGC safety, these two factors warrant further investigation by researchers. Finally, reduction of violations depends on strict enforcement, driver education, and recurrent training of truck drivers and consolidated efforts are needed to improve safety at HRGCs.

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