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16. Abstract

Senate Bill 1512, which was passed into law by the 74th State Legislature in 1995, required the Texas Department of Transportation to install and operate automated highway-railroad grade crossing enforcement systems as a demonstration project. Three sites with gate arms, relatively high traffic and train volumes, and a minimum number of accidents, were selected for the demonstration study. Additionally, a violation study was conducted at 16 additional gated crossings. The purpose of the violation study was to identify roadway geometric and operational characteristics that influence violations at gated highway-railroad grade crossings. The demonstration project resulted in no statistical differences between the violations during the before period compared to the after period. However, because the project was a short term demonstration project, public education of the automated enforcement systems and a fine for the violation were not included and, therefore, were not factors. The violation study revealed that on average, one violation occurs for each gate activation at a gated crossing, and one typically enforced violation occurs for every two gate activations. A typically enforced violation was defined as a violation occurring after the gate arms had been in motion for two seconds or when the arms were in the horizontal position and prior to the train arrival. Several models were developed to predict the expected number of violations at a gated highway-railroad grade crossing.

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TRAFFIC VIOLATIONS AT GATED HIGHWAY-RAILROAD GRADE CROSSINGS

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IMPLEMENTATION STATEMENT

Senate Bill 1512, which was passed into law by the 74th State Legislature in 1995, required TxDOT to conduct an automated highway-railroad grade crossing enforcement system demonstration project. Following the conclusion of the project, the Department is to deliver a report to the Governor, the Legislature, and the Director of the Legislative Budget Board on the results of the project. The demonstration project clearly showed that automated enforcement equipment can be used at highway-railroad grade crossings to record violations, identify the license plate and owner of the vehicle, and mail educational materials.

As part of the agreement between TxDOT and TTI, TTI was to conduct a study evaluating the before-and-after effect of the automated enforcement equipment on violations. TTI also conducted a violation study which linked geometric and operational characteristics to crossing violations. The results of the violation study can be used by an agency planning on increasing enforcement at gated highway-railroad grade crossings to choose the sites where the greatest potential for reduction in violations can be expected. The before-and-after results indicate that automated enforcement of gated highway-railroad grade crossings is feasible; however, to expect a reduction in violations, consideration of public education and appropriate fine values are needed.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. This report was prepared by Kay Fitzpatrick (PA-037730-E), Paul J. Carlson, Jonathan A. Bean, and Richard T. Bartoskewitz.

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The study team recognizes TxDOT 2987 Project Director, Rick Collins, for his time in providing direction and comments for this research. This research project was a cooperative venture between the Texas Transportation Institute and Texas Department of Transportation and required significant time investment from the project director for its successful completion. This study was performed in cooperation with the Texas Department of Transportation.

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SUMMARY

Accidents at automatic gate crossings usually occur when motorists violate the law by driving around lowered gates and are subsequently struck by an oncoming train. In nearly all of these cases, drivers willfully ignore the flashing signals and lowered gates. Enforcement options are potential countermeasures to unsafe and illegal motorist behavior at highway-railroad grade crossings. A program of automated enforcement at certain highway-railroad grade crossings may represent a reliable, cost-effective means for discouraging improper or unsafe driver behavior.

Senate Bill 1512, which was passed into law by the 74th State Legislature in 1995, required the Texas Department of Transportation (TxDOT) to install and operate automated highway-railroad grade crossing enforcement systems as a demonstration project. To assist with the demands that the demonstration project would place on the department, TxDOT contracted with the Texas Transportation Institute (TTI) to identify available technology, facilitate the project, and conduct a before-and-after study.

In addition to the before-and-after study, TTI also performed a violation, or non-compliance, study. This study was conducted to identify the geometric and operational characteristics that are correlated with high violations rates and that can be used to predict violations. Knowledge of this type of information can be used to optimize the placement of automated enforcement equipment or to increase conventional enforcement, thus allowing an agency to receive the maximum safety benefits of the enforcement.

Researchers selected study sites for both studies using similar criteria. Train volume, traffic volume, number of highway lanes, and accident history were among some of the more significant criteria used. Overall, researchers evaluated 19 sites for the violation study. Three of those 19 sites were also used in the before-and-after study where the automated enforcement equipment was installed and operated.

The results of the before-and-after study indicate that the effects of sending educational materials to motorists recorded as violating the gate arms have no effect on the violation rate. However, the project limitations included not fining the violator and minimal public education. Given a more permanent automated enforcement program with appropriate public education and fine value, the violation rates would have likely decreased as found in other studies.

Approximately 50 percent of the violations observed were typically enforced violations (i.e., violations that occurred after the gate arms have been in motion for more than two seconds and when the gate arms are in a horizontal position and prior to the arrival of the train). The flashing light category (i.e., violations that occur when the lights are flashing and the gate arms either have not yet begun their motion or during the initial two seconds of their motion) represented 45 percent of the observed violations. The after train category contained 5 percent of the observed violations with most of the violations at one site. On average, one violation occurs for each gate activation at a gated crossing.

CHAPTER 1
INTRODUCTION

BACKGROUND

In lieu of crossing elimination or grade separation, installation of train-activated flashing signals and automatic gates constitutes the maximum level of safety improvement currently feasible at most highway-railroad grade crossings. In theory, highway-railroad grade crossings equipped with signals and gates should be the safest because they provide the maximum level of warning of an approaching train.

Despite the high level of warning afforded by signals and gates at highway-railroad grade crossings, collisions between trains and motor vehicles continue to be a concern at gated crossings. In 1994, 959 collisions occurred at gated public crossings, which represents 22 percent of all vehicle-train collisions at public crossings during that year. These collisions resulted in 110 deaths (22 percent of all fatalities at public crossings) and 283 non-fatal injuries (16 percent of non-fatal casualties at public crossings).

These statistics do not begin to address the complexity of safety issues at highway-railroad grade crossings. They do, however, add an appreciation for the magnitude of the safety problem at gated crossings. Furthermore, these statistics suggest the tremendous improvements that could be realized in highway-railroad safety if collisions at gated crossings could be sharply reduced or eliminated.

Motorist's Responsibility

The law is clear regarding the appropriate and required motorist response at gated crossings. The Texas Motor Vehicle Law (Article XI, Section 86 of the Uniform Act), Subsection (C), states:

> A person who is the driver of a vehicle commits an offense if the person drives the vehicle around, under, or through a crossing gate or barrier at a railroad crossing while the gate or barrier is closed, being closed or being opened.

In many cases, collisions at gated crossings occur when motorists violate the law by willfully driving around a lowered gate and are subsequently struck by an oncoming train. Driving around the lowered gates for any reason is a violation of the law. Some argue that "gate-running" is excusable if no train is present or on the approach and the gates are "stuck" down. This argument ignores the fact that under many circumstances, automatic gates are installed because some characteristic of the highway-railroad grade crossing (for example, a sight distance obstruction, the highway or track geometry, or higher train speeds) may limit the motorist's ability to detect the train and judge its speed. In other words, if it were considered safe to rely upon the motorist's judgment, such devices might not have been deemed necessary in the first place.

Improper and illegal driver behavior at gated highway-railroad grade crossings can be attributed to several factors. Outright disobedience of the law is certainly present in many cases. Ignorance of the law may be involved in a driver's decision-making processes. An important concern is that many drivers have little or no faith in active traffic control devices at highway-railroad grade crossings. Changing conditions at the intersection, including the type and operational characteristics of train traffic using the crossing and alterations to the roadway design, can reduce or limit the effectiveness of a warning system that was properly selected and designed at the time of installation. When changing conditions at the crossing produce additional delays to motorists, some motorists will become impatient and engage in risk-taking behavior at the crossing.

Enforcement Countermeasures

Enforcement options are potential countermeasures to unsafe and illegal motorist behavior at highway-railroad grade crossings. Enforcement of traffic laws at highway-railroad grade crossings can occur in basically two ways:

- **Traffic Stop.** A law enforcement officer witnesses the offense, orders the violator to stop, and then issues to the violator, in person, a citation or summons to appear. This method is commonly employed by law enforcement officials for the enforcement of most traffic laws. The *Trooper on the Train* enforcement program demonstrated by Operation Lifesaver and railroads in Texas and other states is a variation on the traditional "traffic stop" technique.

- **Automated Enforcement.** Violations are detected by a traffic detector (such as an inductive loop), captured on film by a camera to produce evidence of the violation, and a citation is issued either in person or through the mail by the appropriate law enforcement authority. This technique is also commonly called "photo enforcement."

The traffic stop technique is a highly-effective approach for general traffic law enforcement purposes, such as speed enforcement. The effectiveness of this technique for enforcing traffic laws at highway-railroad grade crossings is limited, however, by several considerations. Due to the large number of crossings and the relative infrequency of train arrivals at the crossings, having a law enforcement presence at all highway-railroad grade crossings is not feasible. Limited resources and increasing demands for other types of law enforcement activities generally preclude widespread, systematic efforts to enforce traffic laws at highway-railroad grade crossings. From a practical standpoint, it is often difficult for an officer to pursue and cite the violating motorist safely. Pursuit often requires running the gates, thus committing the same violation and risking a collision with an approaching train. These concerns support careful consideration of automated enforcement as a countermeasure to illegal motorist behavior at highway-railroad grade crossings.

RESEARCH OBJECTIVES

The research objectives for this report are:

1. To identify operational and geometric relationships that may influence violations at gated highway-railroad grade crossings, and
2. To determine the effects of sending education letters to motorists recorded as violating the gate arms.

ORGANIZATION OF REPORT

Two reports were produced from this project. The companion report (1) documents the efforts associated with a demonstration project on automated enforcement. Specifically, it discusses the methodology, installation, and operation of automated enforcement systems. It also presents observations on the methodology and on the experiences at the demonstration sites. This report details the findings from studies on violations and their relationship with geometric elements of the roadway and with operational characteristics. It also documents the study site identification and selection process. This report is divided into the following eight chapters:

- Chapter 1 contains background information on violations and defines the research objectives for this project.
- Chapter 2 provides an overview of inappropriate driver behavior at active crossings.
- Chapter 3 presents an overview of the TxDOT highway-railroad grade crossing improvement program.
- Chapter 4 presents an overview of automated enforcement at highway-railroad grade crossings.
- Chapter 5 presents the methodology used to identify study sites and to collect, reduce, and analyze the data.
- Chapter 6 discusses the results from the violation study that identified operational and geometric relationships that influence compliance at gated highway-railroad grade crossings.
- Chapter 7 discusses the results from the before-and-after study that determined the effects of sending education letters to motorists recorded as violating the gate arms during a three to four month period.
- Chapter 8 presents the conclusions and recommendations from the studies.

CHAPTER 2
INAPPROPRIATE DRIVER BEHAVIOR AT ACTIVE CROSSINGS

Railroad transportation in the 1830s was a major factor in the westward expansion of the United States by providing a reliable, economical, and rapid method of transporting people and goods. Towns depended on the railroad system and thus developed along the rail lines. Railroads were allowed to build additional tracks across existing streets largely to avoid the high capital costs of grade separations. The introduction of these at-grade railroad crossings presented a safety hazard to drivers traversing the crossing. Proper decisions must be made by the motorist upon approaching the intersection to avoid a possible collision with an oncoming train. Initially, safety at these crossings was not considered a problem. Train volumes were low, and both the speeds of trains and roadway vehicles (horse-drawn vehicles or cycles) were slow. With the arrival of automobiles, accident rates at railroad crossings began to increase, creating an increased concern for driver safety at these intersections (2).

The highway-railroad grade crossing consists of "two transportation modes, which differ both in the physical characteristics of their traveled ways and in their operations" (2). The Highway Safety Act and the Federal Railroad Safety Act of 1970 initiated federal expenditures for safety improvements at highway-railroad crossings to address the safety concerns at these crossings. These expenditures funded more than 25,000 improvement projects that were responsible for decreased accident rates and saving 6400 lives (3).

Today the U.S. has approximately 225,000 public and 140,000 private highway-railroad grade crossings. In 1994, these crossings experienced nearly 5000 accidents of which nearly 2000 resulted in injury and 615 were fatal (4). National statistics show that nearly every 90 minutes, a vehicle-train collision occurs in the U.S. A further alarming statistic is that 53 percent of all grade crossing accidents occur at sites equipped with active traffic control (5). From these statistics, it can be seen that though tremendous safety improvements have been made at highway-railroad grade crossings with the introduction of active warning devices, a safety problem remains at many crossings. This problem can be partially attributed to the lack of funds dedicated to providing state-of-the-art warning device technology at every crossing. However, the high accident rates at crossings equipped with active traffic control, especially those with gates, show that other factors may influence these accidents. Collisions that occur at highway-railroad grade crossings with active traffic control, assuming the traffic control devices are working properly, are a direct result of the motorist's violation of his or her responsibilities at the crossing. Specifically at gated crossings, motorists must drive under or around the gates for a vehicle-train collision to occur. Little is known about why drivers violate the traffic control devices at the crossings. Perhaps the driver is not aware of his or her responsibilities at the crossing, is impaired to the extent that he or she is unable to make a proper decision, or he or she lacks respect for the warning devices at the crossing and consciously chooses to violate the active traffic control.

TYPES OF TRAFFIC CONTROL

Active and passive traffic control are the terms used to describe the degree of positive guidance available at highway-railroad crossings. Crossings with both passive and active traffic control have an advanced warning sign on the approach and a crossbuck located at the crossing (6). Active traffic control devices also include one or more of the following: flashing light signals, automatic gates, cantilever flashing light signals, wigwag signals, and/or bells all activated by the approaching train. The major difference between passive and active traffic control is that active control sends a variable message activated only by the presence of a rail vehicle while passive control (signage only) sends a constant message. Ideally, all crossings would include active traffic control devices so that less decision-making on the driver's part would need to be made; however, the installation and equipment costs make this a nearly infeasible possibility. Presently, only the crossings identified as most hazardous are equipped with these devices (4). In 1996, approximately 18 percent of the nation's 162,426 total highway railroad grade crossings were equipped with flashing light signals, and 19 percent had automatic gates with flashing light signals (7).

DRIVER RESPONSIBILITIES AT ACTIVE HIGHWAY-RAILROAD CROSSINGS

The responsibility of the driver at highway-railroad grade crossings is outlined in the Uniform Vehicle Code and Model Traffic Ordinance (UVC) (8). Section 11-701 of the code describes the "appropriate actions" to be taken by the driver at grade crossings equipped with active traffic control. The driver must, in summary, stop within 15.3 m, but not less than 4.6 m from the nearest rail, and shall not proceed if a crossing gate is lowered or until it is "safe" to do so if a clearly visible electric or mechanical signal device gives warning of the train. The UVC also states that "no person shall drive any vehicle through, around or under any crossing gate or barrier at a railroad crossing while such gate or barrier is closed or is being opened or closed."

Several types of violations are possible at a gated highway-railroad grade crossing. A driver approaching a crossing after the onset of the warning device could possibly violate by:

1. Driving through the flashing light signals (FLS) without stopping,
2. Driving under the gates as they are descending,
3. Driving around the gates after they are in the horizontal position,
4. Driving through the gates after they are in the horizontal position, and
5. Driving under the gates as they are ascending.

Though some of these violation types may be considered less hazardous than others, they are all considered illegal and thus inappropriate.

CORRELATION BETWEEN ACCIDENTS AND VIOLATIONS

It is intuitive that a relationship should exist between the number of accidents and the number of violations that occur at highway-railroad grade crossings. An active crossing with gates that experiences a large number of accidents relative to other similar crossings is assumed to have a larger number of gate violations. Because a violation must occur in order for an accident to occur, assuming the warning devices are working properly, it seems reasonable that as more violations occur, the accident probability also increases.

Accident prediction formulas have been developed to estimate the degree of hazard presented at highway-railroad grade crossings. Highway-railroad grade crossing accidents, however, are highly infrequent events when considering a single crossing or small group of crossings. Research conducted by Abraham et al. (9) identified surrogate measures to be used in determining the hazard presented by a specific crossing or small set of crossings. Driver behavior was observed at seven highway-railroad grade crossings with active gated warning devices, and 89 violations were recorded from videos and manually by field observers. Results of the study showed a possible correlation between accident rates and violation rates at highway-railroad grade crossings. A Pearson correlation coefficient (r) of 0.49 was found to exist between the violation and accident data collected. This coefficient suggests that a "reasonable association between accidents and violations" does, in fact, exist. Though data were only collected at seven crossings, these results suggest what intuition also suggests. By studying the violation rates at a given crossing, one can estimate the degree of hazard present at a particular site (10).

CROSSING-SPECIFIC CHARACTERISTICS INFLUENCING VIOLATIONS/ACCIDENTS

Driver expectancy at highway-railroad grade crossings is an important factor in the motorist's decision to violate or comply with the active control. Many stereotypes formed by drivers regarding railroad crossings are influenced by several geometric and operational features of the crossing of interest. Expectancies related to the likelihood of a train, train speed, warning time, and the length of delay, if a train is encountered, each play a role in this decision (10, 11). Lack of credibility of the active traffic control has resulted due to excessive delay at crossings and warning device malfunctions. The type of geometry at a crossing and average daily traffic have also shown a correlation with accident rates (2, 12). The geometrics of some crossings may encourage violations by providing more space for motorists to maneuver around the warning gates. Other roadway features, such as the adequacy of the sight distance and the number of tracks, may also be related to the number of violations experienced. Several crossing characteristics that may have an influence on the frequency of violations expected at a given crossing will be discussed in this section.

Characteristics from Accident Prediction Equations

The many factors that are responsible for accidents at highway-railroad grade crossings are very difficult to quantify. A need exists, however, to prioritize the crossings within a given jurisdiction to allow appropriate allocation of funds for improvements. Predicting the degree of safety present at highway-railroad grade crossings using accident prediction models is common. These models are developed using highway-railroad grade crossing databases consisting of crossing characteristics and accident data for a given period of time (13). Many states use these accident prediction formulas in their prioritization system. Variables used in many of these formulas include: average daily traffic, train volume, train speed, protection type, past accident history, number of main tracks, pavement condition, highway type, and the number of highway lanes. Commonly used formulas, given below in equations 2-1 to 2-3, are the Peabody Dimmick Formula (14), the NCHRP 50 Model (14), and the U.S. Accident Prediction Model (9). Additional details on the variables are contained in the respective references.

$$\textit{Peabody Dimmick Formula, } A_5 = \frac{1.28 \times V^{0.170} \times T^{0.151}}{P^{0.171}} \tag{2-1}$$

$$\text{NCHRP 50 Model, } A_1 = VF \times T \times PF \tag{2-2}$$

$$\begin{gathered}\text{U.S. DOT Accident Prediction Model,}\\ A_1 = Z \times V \times T \times MT \times DT \times HP \times MS \times HT \times HL\end{gathered} \tag{2-3}$$

where:
A_i = accidents per i years;
V = AADT;
T = average daily train traffic;
P = protection coefficient;
VF = factor for traffic volume;
PF = factor for protective type;
Z = formula coefficient;
MT = factor for number of main tracks;
DT = factor for number of through trains;
HP = factor for maximum timetable train speed;
HT = factor for highway type; and
HL = factor for number of highway lanes.

From these accident estimates, along with qualitative site inspections and observations, resources can be allocated based on priority of hazard for further crossing enhancements. Faghri and Demetsky (15) conducted a comparison of actual accident rates versus predicted rates for 13 recognized accident prediction models. Using a Chi-Squared analysis, the study found that the U.S. Department of Transportation (DOT) model (equation 2-3) outperforms the other 12 models by best fitting the actual accident data. It is expected, due to the previously discussed correlation between accidents and violations, that some characteristics used to predict accidents at highway-railroad grade crossings may also be characteristics associated with the frequency of violations expected at a crossing.

Exposure

The exposure index at highway-railroad grade crossings (the product of the train volume and the average daily traffic) has proven to be an important variable in predicting accident rates (2, 15). Train volume and average daily traffic are usually the first considered when developing accident prediction models. The commonly used prediction models, discussed earlier, each account for the exposure at the crossing when predicting the degree of hazard. Intuition says that crossings with a higher exposure would, of course, yield a higher probability of accidents or violation rates. However, as the accident prediction models suggest (especially the U.S. model), other factors influence a driver's decision to violate. A driver does not decide to violate based only on the exposure. The individual decision to violate the traffic control is likely caused by several other factors, given that the individual has the opportunity to violate.

Impedance

The expected vehicular delays due to train blockage at highway-railroad grade crossings may be largely responsible for a motorist's tendency to drive around lowered gate arms. The UVC prohibits grade-crossing blockages of more than five minutes (8). This restriction does not, however, apply to trains involved in a switching operation. It is expected, therefore, that under normal circumstances, a motorist can experience more than five minutes of delay due to a single train. The time between the traffic control activation and its deactivation is called the impedance. The total impedance experienced at a particular crossing is a function of the train volume, the warning time available, and the length of the train. A specific crossing that is known for its high impedance may also experience high violation rates, especially if the majority of the crossing users are familiar with the crossing. A driver may prefer to attempt to "beat the train" rather than be delayed by the train.

Warning Time Length

The warning time provided at a crossing, or the time available between device activation and train arrival, may also influence a driver's tendency to violate. Credibility of the crossing traffic control devices decreases when the warning time provided is excessive or highly variable. Long warning times at a few crossings can, in fact, decrease credibility of not only the crossing where the excessive warning time was experienced but of all active warning devices (5). Richards and Heathington investigated the warning time needs at crossings equipped with active traffic control (16). The results of the study showed that warning times greater than 35 seconds are directly associated with an increase in risky driver crossing behavior. The study also found that drivers arriving after the onset of the warning devices and 20 seconds or more before a train arrival have a high probability of non-compliance. Based on this data, an acceptable warning time range of 20-35 seconds was suggested. The 20-second minimum warning time is consistent with the requirements in the MUTCD (6). This warning time provides sufficient time for vehicles arriving at the onset of the flashing light signals to clear the crossing before the oncoming train arrives at the crossing. The maximum warning time of 35 seconds reduces the amount of risky driver behavior experienced. Another important finding of this study was that most of the motorists arriving after the onset of the flashing light signals and before the gate descent drive through the crossing without stopping. This result demonstrates how the average driver ignores the advance warning before gate descent and attempts to "beat the gates" to avoid the expected delay due to the train. This type of behavior is analogous to the behavior found during the yellow clearance at highway traffic signals. Motorists tend to accelerate at the onset of the yellow signal so they can legally enter the intersection before the red signal and thus avoid delay.

Constant Warning Time vs. Fixed Distance Warning Time

Other studies involving warning time have shown that crossings with more consistent warning times experience lower accident and violation rates (12, 17). Constant warning time (CWT) devices estimate a train's speed as it approaches the crossing, and traffic control devices are activated accordingly to maintain a constant warning time. These devices are used as an alternative to fixed-distance warning time (FDWT) devices. FDWT devices are based on the maximum train speed using a particular crossing. The active traffic control is activated when a train passes a specified point on the tracks approaching the crossing. This point is at a fixed-distance from the crossing based on the maximum allowed train speed (timetable speed) through the crossing and a minimum warning time. It is hypothesized that warning time devices that provide a constant warning time will reduce the number of violations at the crossing by minimizing and standardizing the amount of warning time provided, thus, increasing the credibility of the warning device system.

Halkias and Eck (12) investigated the effectiveness of upgrading the warning devices from fixed distance to constant warning time devices. This study used accident rates obtained from the DOT-Association of American Railroads (AAR) crossing inventory file and the Federal Railroad Administration (FRA) accident data file for the period of January 1, 1975, to December 31, 1982, to develop effectiveness ratios of the upgrades. The study proved the intuitive hypothesis that the effectiveness of upgrading from a fixed-distance warning device to a constant-warning device increases with increased variation in train speed.

Bowman (17) also investigated the effectiveness of constant warning time devices by comparing both accident and violation rates experienced at various highway-railroad crossings equipped with either type of warning time device. Accidents in which the vehicle was struck by the train and those in which the vehicle struck the first unit of the train were used for the analysis. It was found that for all types of active controlled crossings, a slightly lower accident rate was associated with crossings equipped with constant warning time devices. This difference, however, was not significant at the 95 percent confidence level. Observation of driver behavior at six gated crossings with flashing light signals (three with constant warning time devices and three without), however, revealed a statistically significant lower violation rate at crossings with constant warning time devices versus those without (at the 95 percent confidence level). Another important finding is that most of the violations that occurred at the crossings not equipped with constant warning time devices occurred when warning time exceeded 50 seconds. This finding supports the findings discussed earlier by Richards and Heathington (16).

Train Speed

Train speeds may influence violations at railroad grade crossings. Crossings without constant warning time devices (fixed-distance devices) will produce a variable warning time if the train speed variates. This variability, as previously discussed, has proven to create credibility problems, thus influencing violations (10). Higher train speeds, according to accident prediction models, have been associated with a greater number of accidents. Research conducted by Wunderlich et al. (18), however, showed that the common misconception that high train speeds are related to high accident rates is not always true. Study results showed that high accident rates were associated with crossings with low maximum train speeds and high maximum speeds. Therefore, placing a maximum train speed restriction on a crossing may not reduce accidents. It was also stated, however, that more research is needed in this area to support this conclusion.

An explanation of the above finding is that a driver who decides to violate or comply with the traffic control may not be a good judge of the speed of the train. When judging whether to traverse a highway-railroad grade crossing, there are two main factors involving sensory and perception skills (19). Judgement of train distance and speed is often in error due to several "systematic biases":

1. The illusion of velocity and size,
2. The illusion of perspective, and
3. The deceptive geometry of collisions.

"The illusion of velocity and size arises from the fact that, the larger the object, the more slowly it appears to be moving." The illusion of perspective involves the learned responses to "monocular cues" to depth such as the visual angles subtended by distant objects (i.e., trees, telephone poles, etc.). "The effect of such monocular cues would be expected to increase the perceived distance." The deceptive geometry of collisions is related to the fact that two objects that are about to collide remain fixed in their relative lateral acceleration, and the only cue then is the change in size of the oncoming object. This rate of increase in size is low for distant objects, leading the observing driver to underestimate the train distance and speed. The systematic biases, then, are all factors influencing the overestimation of a safe time interval (sufficient time to traverse the crossing before the train arrives), placing the driver at a risk of collision (19).

Sight-Distance

Sight distance should be maintained at highway-railroad crossings so that proper decisions can be made upon approaching the crossing (5). Three types of sight distance are important: approach, quadrant, and track sight distances. Approach sight distance is related to the visibility of the crossing itself. Quadrant sight distance is the distance required for a driver to detect a train and make a safe stop prior to the crossing. Track sight distance is the distance along the track available to the driver who is stopped at the crossing. The availability of quadrant and track sight distances is less important when concerned with active traffic control; however, the driver's ability to see the train while he or she is approaching the crossing may give the driver more time to contemplate whether to violate or comply and thus, influence the driver's tendency to violate. The sight distance required is based on the speed of the vehicle, the speed of the approaching train, and the required perception-reaction time (14). Figure 2-1 illustrates approach, quadrant, and track sight distances.

It seems logical that sight distance would be one of the most important variables used to predict the degree of hazard presented by a given crossing. Sight distance, however, has not been a strong variable in accident prediction equations. Klaver (20) found that limited sight distance can be linked to the occurrence of accidents but does not seem to be a predictor of accidents. NCHRP Report 50 states that the inadequate methods of data collection, the way the data are analyzed, and the fact that sight distance is a difficult feature to measure and record for meaningful analysis explains the exclusion of sight distance from these predictive equations (14).

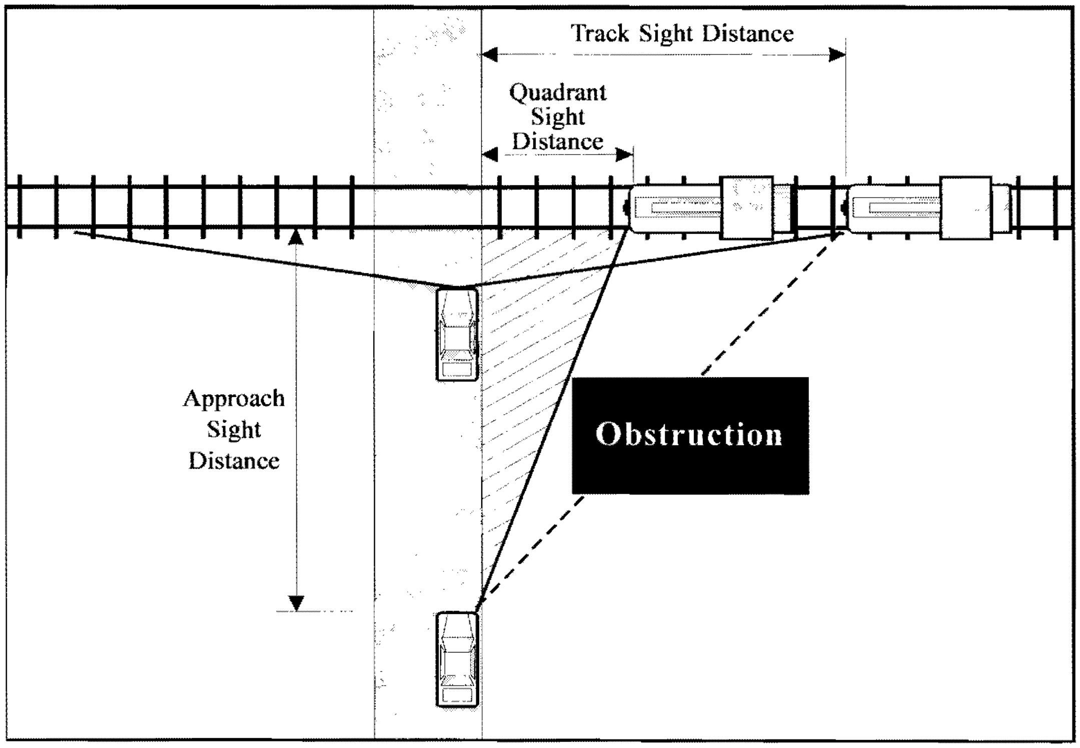

Figure 2-1. Sight Distances Required at Highway-Railroad Grade Crossings (20).

Number of Highway Lanes

Only a small portion of crossings are on highways with more than two lanes. The reduction of pavement width can influence vehicle-vehicle accidents and accidents with trains (2). Four-lane sections versus two-lane sections provide more space for vehicles to drive around lowered gates, thus possibly experiencing higher violation rates (21). The U.S. Accident Prediction Model, given in equation 2-3, includes a factor for the number of highway lanes at a given highway-railroad grade crossing.

Other Geometric Characteristics

Crossing angle, profile steepness, presence of a parallel road, and multiple tracks are other geometric considerations that may influence violations. The crossing angle may limit the available sight distance when stopped near the tracks. A steep slope on the approach to the crossing may limit the acceleration capabilities of some vehicles and the sight distance when approaching a crossing. The presence of a parallel road close to a crossing creates a high workload due to the added distraction of the intersection along with the limited storage space provided. The number of tracks at the crossing may be influential if a large number of tracks are present. An increase in the number of tracks increases the total width of the crossing and number of possible conflict points. It is logically assumed that sites with multiple tracks would have fewer violations than sites with a single track. The U.S. Accident Prediction Model, in equation 2-3, includes a factor for the number of main tracks.

DRIVER-SPECIFIC CHARACTERISTICS INFLUENCING VIOLATIONS

A study with the purpose of investigating factors that influence undesired driver behavior at highway-railroad crossings would be limited without considering the characteristics of the individual drivers using the crossing. It cannot be ignored that decision-making capabilities will vary for the particular driver or group of drivers fitting into a particular demographic group. Sensory and perceptual factors may not only depend upon the specific demographics of the driver but on the physical state of the driver as well (i.e., if the driver is fatigued, etc.). As in other contexts in the driving environment, poor decisions made at highway-railroad grade crossings are also due to a lack of knowledge of the required driver responsibility at the grade crossing. The data required to evaluate the specific characteristics of the driver, however, are very difficult and expensive to obtain. This type of data can be obtained through focus groups, surveys, and driver observation.

Driver Demographics

Richards (5) performed a discriminant analysis to determine the most influential variables in modeling a driver's potential of violating an active grade crossing. Perceived hazards, likelihood of false activation, annual mileage, age, and perceived duties were among the main factors influencing driver violation or compliance of active traffic control. A driver who has experienced long delays or warning times in the past and has a low perceived risk is likely to believe that the optimum decision is to violate the active traffic control. Younger drivers may violate more often due to peer pressure. Middle-aged drivers tend to be more cautious because of the responsibility associated with transporting children. Older drivers may violate the law at railroad crossings because of their lack of visual perception and information processing ability. Abraham et al. (9) found that males tend to violate more often than females. An additional finding from the same study was that drivers using a crossing within their city of residence tend to violate more frequently than drivers using the crossing from outside the city. A driver's familiarity with a given crossing may therefore influence his or her decision to violate.

The mental state of the driver upon approaching the crossing will also influence the driver's decisions regarding violation or compliance. The driver may not be able to process the required information if he or she is suffering from fatigue or driving under the influence of alcohol or drugs.

Driver Understanding and Knowledge of Information and Responsibilities

Many violations and accidents that occur at highway-railroad grade crossings are directly related to the driver's lack of understanding of information given at the crossings and, therefore, knowledge concerning the appropriate actions and responsibilities at the crossing. A driver who is confused or has a lack of understanding about how to respond to traffic control devices can cause significant safety problems leading to accidents with personal injuries and fatalities (22). Several research studies have addressed the operational and safety performance of railroad-highway grade crossing devices and have found that at least some unsafe behavior may be due to lack of understanding and knowledge (10, 22).

ENFORCEMENT OF TRAFFIC CONTROL DEVICES

Limited monetary and staffing resources have restricted law enforcement agencies' capabilities of enforcing the laws at highway-railroad grade crossings. With the infrequent train arrivals present at most crossings, it is difficult to warrant the allocation of a police officer to patrol a single crossing. Motorist surveys (10, 22) have revealed that most drivers (greater than 95 percent) have not received a citation for a traffic violation at a highway-railroad grade crossing. Furthermore, approximately the same number of people do not have an acquaintance who has received a citation for this type of violation. Therefore, many drivers are likely to lose respect for the traffic control devices at highway-railroad grade crossings. Without the fear of being "caught," drivers may have the tendency to disregard the traffic signals and gates and decide themselves whether traversing the crossing upon arrival is safe.

ENHANCEMENTS TO ACTIVE WARNING DEVICES

As previously discussed, alarming accident statistics continue to exist at grade crossings with active warning devices. It is recognized that this high number of accidents may be a result of higher vehicle and train volumes and/or more complex geometrics associated with active crossings. It is likely, however, that some accidents are caused by motorists' lack of perception or understanding of the present active traffic control or willful violation of the traffic control. Therefore, it seems that these active traffic control devices could be improved. Several new enhancements to crossings with active warning devices have been developed and evaluated for their effectiveness. A few of these enhancements are:

- Four-quadrant gates with flashing light signals and skirts (21);
- Highway traffic signals in-place of flashing light signals (21);
- Raised medians (23); and
- Automated enforcement (24).

Each of these systems has proven, through driver behavior evaluations, to be effective in reducing the number of violations experienced at active crossings.

CHAPTER 3
TxDOT HIGHWAY-RAILROAD GRADE CROSSING IMPROVEMENT PROGRAM

The basic elements of TxDOT's highway-railroad grade crossing safety improvement program include the following activities:

1. Developing an annual list of recommended grade crossings for Federal Highway Administration crossing safety improvement funds;
2. Administering grade crossing safety improvement projects, and
3. Coordinating on-site joint inspections of crossings for potential upgrading.

Federal funds have been available for crossing upgrades in Texas since the 1930s. The FHWA and TxDOT manage the highway-railroad grade crossing safety improvement program under a federal oversight agreement to provide federal funds to Texas for highway-railroad grade crossing safety improvements. This program was formerly funded under Section 130 Rail-Highway Crossings Program and is now funded from part of the 10 percent of Surface Transportation Program (STP) funds set aside for safety. These funds are apportioned by the ratio of the number of public crossings in the state to the total number of public crossings in the country as well as the state's population, area, and road mileage. FHWA provides 90 percent of the funding on all roadway systems for crossing improvements, and the state provides a 10 percent contribution. The Texas Transportation Commission annually approves funding of the state matching funds for the Rail-Highway Crossing program. The local governments' contribution is generally to provide any alignment improvements on the roadway approach, utility or drainage adjustments, and vegetation trimming or removal.

TxDOT uses a selection process that prioritizes the federally funded crossing safety projects by a priority index. Figure 3-1 illustrates the process for prioritizing, selecting, funding, and implementing crossing safety improvement projects in Texas. Federal funds are allocated to the top ranked projects until the available funds are expended. The top ranked projects are then evaluated on site by a "diagnostic team" comprised of professionals with railroad and highway expertise. The membership of the diagnostic team includes railroads, TxDOT officials, and local government officials. The diagnostic team considers the local conditions and alternatives and is then responsible for recommending the type of warning devices and other safety enhancements. First consideration is given to the necessity of the crossing in relation to adjacent crossings. Local authorities are encouraged to attend these evaluations and provide a local perspective on the site's proximity to schools, hospitals, businesses, or residences; traffic patterns; types of vehicles using the crossing; and other special conditions. Installation typically occurs 18 months after the project is initiated. Note that the crossing safety improvement program does not preclude FHWA, TxDOT, municipalities, and railroads from joining in crossing improvement projects outside of the normal crossing improvement process.

- Texas Transportation Commission approves lump sum allocation for Texas Priority Index Program
- TxDOT prioritizes projects and allocates funds until the established funding is expended
- FHWA approval is sought
- TxDOT completes a topographic survey of the site
- TxDOT districts prepare layouts for preliminary diagnostic site evaluations
- A diagnostic team recommends improvements with local agency participation encouraged
- TxDOT develops the project plans with local agency input
- TxDOT requests rail carriers' cost estimate, wiring diagram, and endorsement of plans
- TxDOT approves cost estimates, assembles and approves plans
- Upon request from the railroad, TxDOT issues work order to the railroad for installation to proceed
- The railroad installs project according to approved plans
- TxDOT inspects and certifies completed projects
- Railroad bills TxDOT; TxDOT pays the railroad, and FHWA reimburses the State

Figure 3-1. Texas' Grade Crossing Improvement Process and Funding Procedures (25).

TxDOT uses the most current data available to update its traffic counts and accident records for grade crossings. This practice ensures that the projects receive an accurate priority ranking. Local authorities may forward their most recent average daily traffic (ADT) counts to a TxDOT District Office. Alternatively, local authorities may request that the TxDOT District Office perform a traffic count. TxDOT also analyzes five years of accident history when determining accident trends at highway-railroad grade crossings.

There are more than 12,500 public highway-railroad grade crossings in Texas. On average, TxDOT has funds for between 200 and 300 crossing improvement projects per year. TxDOT developed a project selection procedure that uses a priority index formula to determine the relative improvement priority of all public grade crossings in the state. The Texas Priority Index uses a variation of the New Hampshire Index to prioritize grade crossings for potential upgrading. The potential for collisions at grade crossings is considered to be a function of the number and speed of trains traveling through the crossing, and the train-involved accident history for the last five years.

The Texas Priority Index Formula (TPI) is calculated as:

$$TPI = V * T * S_t * P_f * (0.01) * A^{1.15} \tag{3-1}$$

where:

TPI = Texas Priority Index Formula
V = Average daily traffic, ADT (vehicles/day)
T = Train volume (trains/day)
S_t = Train speed (miles/hour * 0.1)
P_f = Protection factor for existing traffic control devices
(Gates = 0.10
Cantilever-mounted flashing light signals = 0.15
Mast-mounted flashing light signals = 0.70
Cross bucks, wig-wag signals, or bells = 1.00)
A = Train-vehicle collisions in previous five years
(If A = 0 or 1, default value is 1)

A new TPI is calculated for every public highway-railroad grade crossing in the state each year. Because decisions as to which crossings will be considered for improvement are based on the TPI, it is important that the required data be maintained as accurately and up-to-date as possible.

CHAPTER 4
OVERVIEW OF AUTOMATED ENFORCEMENT AT HIGHWAY-RAILROAD GRADE CROSSINGS

Short of grade separation, train-activated warning devices are considered the highest form of treatment at highway-railroad grade crossings. (The most common train-activated warning devices are flashing signals, automatic gates, and bells.) Of approximately 12,700 public at-grade crossings in Texas, nearly 2400 crossings (19 percent) are equipped with train-activated signals and automatic gates (26).

Accidents often occur when motorists violate the law by driving around lowered gates and are subsequently struck by an oncoming train. In nearly all such cases, drivers willfully ignore the flashing signals and lowered gates. The Railroad Commission of Texas (RCT) analyzed recent crash data for highway-rail accidents in Texas. RCT found that in 1994, automatic gates were in place at crossings where 125 crashes occurred (27). This figure represents 22 percent of all highway-rail accidents in Texas for that year. Recent research by Cooner determined that from 1992 to 1994, more than 30 percent of all train-involved accidents in Texas occurred at crossings equipped with automatic gates (28). The national average for train-involved accidents at gated crossings, however, is approximately 20 percent. Thus, the data indicate accidents occur more frequently at gated crossings in Texas when compared to national trends. This finding suggests that Texas motorists may be more likely to drive around lowered gates at crossings, which places the motorist at greater risk of becoming involved in a collision with a train.

Enforcement options are countermeasures to unsafe motorist behavior; however, inherent problems limit enforcement levels at highway-railroad grade crossings, including:

- Defining a “violation” is difficult under certain circumstances.
- The pursuit and issuance of citations are often difficult, and may pose a threat to the officer’s or the public’s safety.
- Train arrivals at a given highway-railroad grade crossing tend to be infrequent and unpredictable.
- Fiscal and labor resources for enforcement activities are severely constrained.

Moreover, the level of enforcement necessary to have an appreciable impact on driver behavior draws critical labor resources from other vital law enforcement functions. Proponents of automated enforcement argue that this technique produces appreciable impacts on violation rates at lower overall cost.

AUTOMATED ENFORCEMENT TECHNOLOGY

The key components of highway-railroad grade crossing enforcement systems generally include an image recording device, vehicle sensors, and citation processing technology. A typical configuration (see Figure 4-1) includes a 35-mm camera or video camera to record the violations and inductive loops to detect the violations and activate the camera.

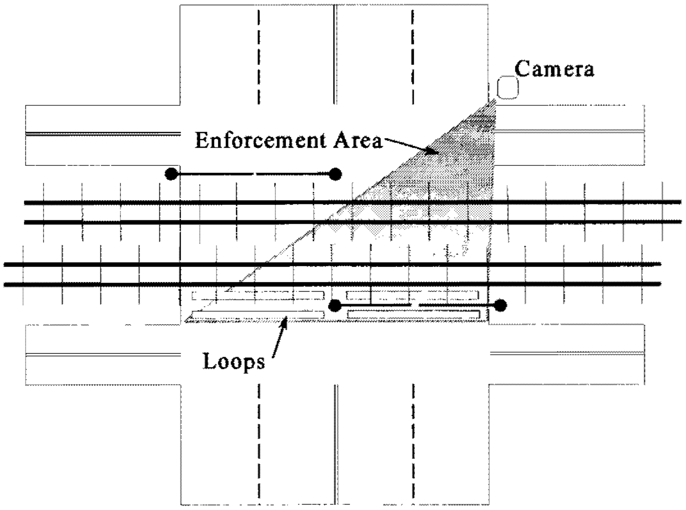

Figure 4-1. A Typical Automated Enforcement System.

GRADE CROSSING EXPERIENCES

Three cities in the United States—Jonesboro, Arkansas; Los Angeles, California; and Ames, Iowa—have implemented an automated highway-railroad grade crossing enforcement system at one or more sites. This section documents the experiences of these three cities.

Jonesboro, Arkansas

The City of Jonesboro, Arkansas, and Burlington Northern Railroad (BN, now known as Burlington Northern Santa Fe Railroad) combined efforts in 1991 to demonstrate the first automated highway-railroad grade crossing enforcement installation in the United States. The crossing, located on East Highland Drive, was chosen for its history of unusually high rates of train-involved accidents (three fatalities in 1990 and five accidents in as many years) and gate arm repairs (an average of three per week) (29-30).

Scientific studies have not been conducted to analyze the impact of the automated enforcement system on train-involved accidents at the East Highland Drive crossing. It is generally believed, however, that the crossing is now safer. Burlington Northern reported fewer incidents of broken or damaged gate arms since issuance of citations commenced. (Broken or damaged gate arms are evidence of motorists attempting to circumvent the gates as they are being lowered or once they are fully lowered.) Before the installation of the automated enforcement equipment, BN replaced or repaired the crossing gate arms three times per week on average. During the first six months of operation, however, only one gate arm was in need of repair. Within the first 12 months of operation, only six trips were needed to repair or replace the gate arms.

The violation rate was not measured before the automated enforcement equipment was installed; however, from March 1991 to approximately the summer of 1995, there was an average of only two violations per month. All citations issued to-date have been paid.

During the summer of 1995, the system began sending blank images to the Jonesboro Police Department. As of June 1997, Burlington Northern (BN) was in the process of asking the City of Jonesboro if they were interested in continued operation of the system. If so, BN would agree to diagnose the problem, correct it, and then donate the entire system to the city. The city is considering the possibilities.

Los Angeles, California

The Los Angeles County Metropolitan Transit Authority (LACMTA) operates a 35 km light rail transit line between downtown Los Angeles and the city of Long Beach, California. This line is known as the Metro Blue Line (MBL). There are more than 100 grade crossings on the MBL. Portions of the MBL run through several downtown city streets, and other segments are adjacent to 19 km of Southern Pacific main line freight trackage.

Between July 1990 and January 1995, the MBL experienced more than 250 train-vehicle and train-pedestrian accidents. The collisions resulted in 27 fatalities and numerous injuries. The simultaneous presence of slow-moving freight trains and relatively fast MBL trains operating on parallel tracks is suspected as a contributing factor in many of these collisions. Reports suggest that motorists, viewing a slow oncoming freight train, attempt to beat the train by violating the crossing signals and gates. This behavior has resulted in many violators being struck by oncoming MBL trains which were obscured from view by the freight trains.

To determine the extent of the gate violation problem, the Sheriff's Transit Services Bureau established a traffic detail to provide increased enforcement at selected grade crossings. Ten traffic detail deputies were deployed during two shifts per day, seven days per week. This operation was performed for nearly 13 weeks. The traffic deputies wrote 7760 citations in 90 days. Nearly half of the citations (3505) were issued for gate arm violations.

To address the problems of motorists violating grade crossing traffic laws, especially driving around lowered gates, LACMTA planned demonstration projects involving the installation of photo enforcement systems or other advanced technologies at grade crossings along the MBL. In 1995, four projects had been implemented. Two photo enforcement projects were implemented at gated crossings and two were implemented at non-gated crossings. Overall, the automated enforcement demonstration projects conducted on the MBL proved to be an effective tool to combat the problems of grade crossing accidents. The experience gained has shown dramatic reduction in grade crossing violations and corresponding reductions in train-vehicle involved accidents (31,32).

The success of the demonstration projects has prompted LACMTA to permanently install automated enforcement systems at 18 crossings along the MBL. As of June 1997, nine were in operation and 17 were installed. By the end of July, LACMTA officials expect 17 of the 18 sites to be fully operational. Furthermore, since operation of this stage began, more than 3000 citations using the automated enforcement equipment have been issued.

Ames, Iowa

After 11 accidents in 17 years at the highway-railroad grade crossing adjacent to the intersection of Duff Avenue and Main Street, the City of Ames decided to investigate grade crossing accident countermeasures. The city staff met with officials of the Iowa Department of Transportation and the Federal Highway Administration to identify safety improvement options. Approximately one year after this meeting, the Los Angeles photo citation program was identified. The Jonesboro project was also identified and evaluated concurrently.

The laws in Iowa do not permit the issuance of citations based on license plate numbers alone. Rather, the identification of the driver must be made. Therefore, the system must take clear pictures of the driver's face. However, the cameras currently installed at the site on Duff Avenue are not producing high enough resolution pictures to clearly identify the driver. Consequently, the Ames Police Department is issuing warning/informational letters to the registered car owner of the vehicles violating the gate arms. As of July 1997, the system is being upgraded with higher resolution cameras and more precise infrared detectors. These modifications will allow the Ames Police Department to issue citations based on the camera evidence.

The automated enforcement system on Duff Avenue began operation in May 1996. No attempt was made to measure the effectiveness of the system. During the 14 months of operation thus far (May 1996 to June 1997), 37 warning/information letters were sent to violators. However, an additional 55 violations were captured in which the license plate number of the vehicle could not be read. The system is having difficulties at night due to the amount of reflection cast by Iowa license plates which has a white background. The current modifications are anticipated to resolve this issue.

CHAPTER 5
RESEARCH METHODOLOGY

Two data collection and reduction efforts were completed—one for the *violation study* and one for the *before-and-after study*; however, the methodology overlapped in several areas for these studies. The initial efforts were to identify candidate sites that met the criteria for both studies. Then specific criteria were applied to the candidate sites to select the most appropriate sites (1) to explore the relationship between violations and geometric- and operations characteristics, and (2) to explore the effects of installing automated enforcement equipment and the sending of education letters to those observed violating the gate arms. This chapter details the procedures and events that led to the identification of potential study sites and their final selection. In addition, it discusses the methods used to collect, reduce, and analyze the field data.

SITE SELECTION

The selection of study sites involved somewhat intensive database management and manipulation. Once all the highway-railroad grade crossings in Texas were identified, a reduced database was created that met the requirements of both efforts—the violation study and the before-and-after study. The following discussion includes details of these efforts as well as the final study site characteristics.

Database

To begin the site selection and identification process, the research team obtained the Federal Railroad Administration's Crossing Inventory database of all the highway-railroad grade crossings in Texas. Using the crossing identification number from each crossing, the FRA database was cross referenced with the Texas Department of Public Safety (DPS) Crash Record Information System. The DPS database contains 245 fields of information; however, for this project, only a small number of variables were used. These variables included the classification of the road, accident year, severity of crash, traffic control (used to identify train-only involved crashes), and object struck (used to filter crossing crashes where the traffic control might have been reported as a gate arm, but the crash involved a motorist rear-ending another motorist who had stopped for the train). The result was a database consisting of 13,673 crossings.

The next step in the selection process was to remove all non-gated crossings and crossings that did not meet initial criteria established to provide some basis of uniformity to the study sites. Table 5-1 summarizes the site selection control criteria. After the criteria shown in Table 5-1 were applied, 607 potential study sites remained.

Table 5-1. Site Selection Control Criteria.

CONTROLS	CRITERIA
▸ Type of traffic control	Active traffic control with single gate arms only
▸ AADT	≥ 1,500 vpd
▸ Train volume	16 ≤ trains/day < 35
▸ Number of highway lanes	Two and four lane roadways only

Site Visits

Site investigations were then planned to obtain information not in the database that would aid in the selection of the best possible sites for the study. The site visits also allowed the researchers to validate the information contained in the database. Due to the size of Texas, travel plans were developed based on the relative locations of the study sites. More than 90 sites were visited.

The inventory of each site visit included identifying the crossing surface type, condition, and whether it was a "hump" (i.e., high-profile) crossing. The crossing surface type was categorized as rubber, asphalt, concrete panels, timber planks, concrete, or a specified other. The crossing condition was categorized as good, fair, or poor. A hump crossing was defined as a crossing with a noticeable difference in highway grades that could cause vehicles to reduce their speed when crossing the track that, therefore, could deter violations. A sketch at each site included the following:

- Geometry of the roadway and railroad crossing,
- Any parallel streets to the rail,
- Location and type of signing and pavement markings,
- Controller cabinet locations,
- Existing loops and their location,
- Location of gates and signals,
- Posted speed limit of roadway,
- Distance between gates if lowered during inventory, and
- Any possible roadside obstructions to the installation of the automated enforcement equipment.

Sight distance adequacy was also evaluated at each approach to the crossings. Each quadrant was noted as having either adequate or inadequate sight distance. The adequacy of sight distance was determined based on formulas presented by Klaver (20). These formulas, for quadrant, track, and approach sight distances, are a function of the geometry of the crossing and the train and vehicle speeds. Once the required quadrant, track, and approach sight distances were determined, the actual available sight distances were measured by a two-person team. The team used a measuring wheel to measure the required approach sight distance from the crossing along the highway (refer to Figure

2-1). If the warning devices could be seen from this point, referred to as the critical approach distance, the crossing was noted as having adequate approach sight distance. The required quadrant sight distance was measured along the tracks, again using the measuring wheel. If the person with the measuring wheel could be seen by the other person standing at the critical approach distance, the quadrant was said to have adequate sight distance. The track sight distance was measured in a similar manner as the quadrant sight distance, except the person measuring the required sight distance along the tracks must be seen by the other person standing at the stop bar instead of at the critical approach distance. If any of the approach, track, and/or quadrant sight distances at the crossing were considered inadequate, the approach was noted as having inadequate sight distance.

The crossing was also observed to determine whether it appeared to have a high rate of violations based on violations observed during the site investigation. Video and 35-mm photographs were taken along each approach to record the signing, pavement markings, geometry, and other characteristics that would aid in the selection of the study sites. Figure 5-1 is a typical picture taken at one of the potential study sites.

Figure 5-1. Picture of a Typical Crossing.

The information obtained during the site investigations was added to the database, and further eliminations of potential study sites were made. The circumstances under which further sites were eliminated included when sites had dual-gates or raised medians. Sites with no gate arms were also eliminated along with sites on roads under construction or planned for construction during the next two years. The presence of a hump crossing may deter violations and may not show the effect that the automated enforcement systems has on driver behavior; therefore, sites classified as hump crossings were also eliminated.

After the site visits were complete and unacceptable sites were eliminated from further consideration, the list of potential study sites totaled 81. This reduced database was used to select the final study sites for both the violation study and the before-and-after study.

Sites Selected for Violation Study

To obtain a better understanding of how geometric and operational characteristics relate to violations, the reduced database was used to identify 20 study sites. Table 5-2 illustrates the study site matrix used to make the final site selections. The number in each cell of Table 5-2 represents the minimum number of sites to be selected with the particular characteristics that the cell represents. During the review of the possible operational and geometric variables that may relate to a driver's decision to violate gate arms (see Chapter 2), AADT, number of highway lanes, and type of warning time provided (constant or fixed-distance) were expected to be the most influential. The matrix was designed to ensure that the study sites would yield an adequate range of operating conditions per controlling variable.

Table 5-2. Study Site Matrix for Driver Behavior Study.

Number of Highway Lanes	Warning Time	AADT (vpd)	
		< 10,000	> 10,000
2	Constant	2	2
	Fixed-Distance	2	2
4	Constant	2	2
	Fixed-Distance	2	2

Final site selection was based on the study site matrix and forethought regarding the site selection criteria used for the before-and-after study. In the before-and-after study, site selection was based on more stringent criteria (described in the following section). A minimum of six sites selected for the violation study would satisfy the criteria of the before-and-after study. This effort was used to reduce the number of data collection trips associated with both studies. Table 5-3 lists sites chosen for the studies, along with key site-specific characteristics.

Table 5-3. Selected Study Sites.

Site	Warning Time Type[1]	ADT[2]	Lanes	Daily Train Volume[2,3]	Tracks
Sites Selected for Before-and-After and Violation Studies					
Broadway Street (436003C)	FDWT	19500	4	34	2
Main Street (020464J)	CWT	13600	2	30	2
FM 2100 (762873A)	FDWT	19000	4	16	1
Oltorf Street (436004J)	CWT	16600	4	17	1
Sycamore School Road (415961F)	FDWT	14140	4	17	1
West Mary Street (023204B)	CWT	7544	2	17	1
Sites Selected for Violation Study Only					
25th Street (743197F)	CWT	11000	4	26	1
Barnes Bridge Road (021596X)	FDWT	7070	2	28	2
Higgins Street (755872B)	CWT	2330	2	17	1
Homestead Road (755866X)	FDWT	14070	2	17	1
Lawndale (288050B)	FDWT	7200	4	29	2
Magnolia Road (023202M)	FDWT	5210	2	34	1
Crowley Road (415967W)	CWT	11500	2	17	1
SH 21 (756007M)	CWT	8000	4	20	8
Telephone (288051H)	FDWT	8640	4	29	2
US 287 (755785X)	CWT	2700	4	27	1
FM 60 (022874P)	FDWT	4100	2	28	1
FM 2917 (448629R)	CWT	5400	2	18	1
FM 3155 (743726L)	CWT	11200	2	20	1
Bannister Lane (436005R)	FDWT	7181	2	17	1

Note: 1: CWT = constant warning time, and FDWT = fixed-distance warning time
2: Estimated from FRA database
3: Includes switching trains

Sites Selected for Before-and-After Study

Because the project focused on violations and not specifically crashes, study sites with notable rates of non-compliance (i.e., gate arm violations) were desired, especially for the before-and-after study. However, this type of data is not available in an established database. Furthermore, it would be extremely time consuming to obtain when the initial objective was to determine whether the site is a candidate location for the study. Consequently, the assumption was made that highway-railroad crashes of certain types are related to non-compliance of the gate arms. This assumption has been validated by Abraham et al. (9) in their finding that, "there is a reasonable association between (highway railroad grade crossing) accidents and violations."

The selection process began with the reduced database developed after including the findings from the site visits. Additional criteria were established to increase the likelihood that a selected crossing would have high rates of non-compliance. A five-year accident history was obtained for each site. Those sites with fewer than three vehicular-train involved accidents in that five-year time frame were eliminated from further consideration. Furthermore, sites with ADT of less than 7500 vpd were eliminated. These criteria reduced the potential study sites to 14. Three railroad companies were represented in this list of sites. Moreover, a wide variability of traffic and geometric variables were also included in the 14 sites.

To obtain information that could eventually lead to expeditious installations and smoother overall operations, the research team attempted to quantify how much cooperation to expect from the stakeholders associated with each site. This task was primarily conducted through telephone interviews with each law enforcement agency responsible for the traffic laws at each site and the local roadway authority (city or state). Cooperation was solicited from the law enforcement agencies because their letterhead would be used to produce the information/warning letters sent to violators. Therefore, their participation was crucial. The roadway authorities were contacted to determine their cooperation in allowing in-pavement sensors and roadside equipment to be installed. This step was crucial in identifying the final study sites. The following criteria were used to narrow the potential study sites even further:

- Remove sites from consideration if the responsible agencies did not respond to phone contacts or were not interested in participating;
- Obtain regional representation by having sites in different areas of the state; and
- Maintain representation of a minimum of three major railroad companies.

Of the potential before-and-after study sites, two sites were chosen in each of the Dallas-Fort Worth, Houston, and Austin areas. This allowed the research team to optimize travel and logistic issues associated with data collection and installation and to maintain regional representation of the state. Table 5-3 lists the sites chosen for the study, along with key site specific characteristics. Table 5-4 lists a review of all the controls and criteria used to select the before-and-after study sites.

Table 5-4. Site Selection Control Criteria for Before-and-After Studies.

CONTROLS	CRITERIA
Type of traffic control	Active traffic control with single gate arms only
Accidents	Minimum of three in previous five years
AADT	$\geq$ 7500 vpd
Train volume	$16 \leq$ trains/day < 35
Median type	No raised medians near crossing
Signalized intersection proximity	No signalized intersection within 30 m of crossing
Number of highway lanes	Two and four lane roadways only
Hump (high-profile) crossing	none
Construction (actual or planned within next two years)	none
Geographical location	Adequate dispersion throughout state
Railroad representation	At least three
Local agency cooperation	Mandatory

DATA COLLECTION AND REDUCTION

Data were collected using the procedure and equipment described below. Data collection for the before-and-after study occurred before the installation of the automated enforcement system and after the automated enforcement system had operated for a three- to four-month period. The data collection operation lasted for a continuous period of at least 96 hours at each of the before-and-after study sites. The data were collected between a Monday and the following Friday. Data collection operations lasted a minimum of 24 hours at each of the violation study sites. All recordings occurred between 6:00 a.m. on a Monday and 8:00 p.m. on a Friday. Data reduction was performed in the office after each field data collection period ended. Data collection and reduction operations experienced minimal problems, and little maintenance of equipment was required.

Data Collection Equipment

The data collection effort used the following equipment:

- Two mobile video recording systems, each with a hydraulically operated high-mast camera support;
- Surveillance cameras;

- 380-mm color monitors;
- 24-hour time-lapse video cassette recorders; and
- Gas-powered generators.

The mobile video recording systems allowed for continuous video recording for several days without requiring access to the actual camera. Each system consisted of an enclosed trailer (providing storage for the recording equipment) and a 9-m telescoping pole on which a video camera, enclosed in an environmental housing unit, was attached. The video cassette recorders (VCRs) were in the enclosed trailer, thus allowing for videotapes to be exchanged without disturbing the camera location. The cameras and VCRs were powered by an external gas-powered generator.

Data Acquisition Procedure

The mobile video recording systems were parked discretely off the railroad right-of-way to minimize distractions to motorists using the crossing or adjacent facilities. The high-mast extending from the top of the trailer placed the surveillance camera at a height ranging from 5- to 9-m, depending on site specific characteristics. The exact location of the trailer and height of the mast varied between each site due to various obstructions in the line-of-sight of the camera. The objective was to obtain a view that would include at least 46 m of track so that train speed could be approximated, and at least a two-car queue length on the roadway for each approach. Figures 5-2 and 5-3 show typical configurations of the data collection operation and illustrate the mobile video recording system setup at a site.

To obtain an estimate of the train speed, orange colored markers were placed at the farthest possible distance apart while remaining in the camera's field of view. This distance (which varied between 32 and 76 m depending on the site) and the time necessary for the train to cross the markers were used to estimate train speed.

Data Reduction

Data reduction involved viewing the videotapes of each site using a color monitor and video cassette recorder. The tapes were usually played at fast speed until the activation of the warning signals (i.e., the lights began to flash). At this point, the recording of information began. A time stamp was present on each video, and the times that the following activities occurred were recorded:

- Signal onset,
- Gate activation,
- Gates in completely lowered position,
- Violation (if any occurred),
- Train arrival,
- Train at each speed marker point,
- Train departure,
- Time gates began to rise,

Figure 5-2. Camera/Video Trailer.

Figure 5-3. Typical Data Collection Layout.

- Time gates were completely raised,
- The type of violation,
- The number of cars driven around in order to violate,
- The type of vehicle driven by the violating motorist,
- The type of vehicle using the rail,
- Whether the motorist stopped before violating, and
- Which direction the violating motorist was traveling upon violation were also recorded.

Gate activations were recorded with or without the occurrence of a train or a violation. It was very common for a train to arrive with no occurrence of violation by the motorists. In this case, measurements were recorded for train speed and time of train arrival, time of first vehicle in the queue from each approach, and the time of the gate lowering and raising. These data were important in the calculation of violation rates. The complying vehicle arrivals were recorded to compare the variables associated with compliance and with violation.

After the data were reduced from the video, they were entered in a spreadsheet program that used the times obtained from the video to calculate various key time intervals. For instance, the times when the train passed the speed markers were used, along with the known distance between the speed markers, to estimate the train speed. Where short lengths between the speed markers existed, video frames, rather than times were used to estimate the train speed. The reason for this deviation was that the time, only known to the nearest tenth of a second, was not precise enough to estimate train speed very accurately when the spacing between the markers was relatively short. However, when video frames were used, which typically correspond to a rate of 30 frames per second, more accurate estimates of speed could be obtained.

The average annual traffic at each site is available through the Federal Railroad Administration database. These values could provide an estimate of the volume present during the 24-hr period that the violations were measured. To provide a better estimate of the ADT present during the study period, the actual volume crossing the track(s) between 4 p.m. and 5 p.m. was counted. An hourly factor of 10 percent was assumed. Therefore, the ADT per lane was calculated as the hourly volume between 4 and 5 p.m. multiplied by 10 and divided by the number of lanes present at the site.

Table 5-5 shows a sample of the final database constructed through the information obtained from the FRA and DPS databases, the site visits, and the collection and reduction of video data. A reference key (see Table 5-6) describes the variable names, which are abbreviated due to space limitations.

Violation Type

It is assumed that different types of violation are influenced by different variables. Therefore, the total number of violations observed were divided into three categories. The first category of violations was defined as occurring between the onset of the flashing light signals and two seconds after the gate arms started to descend. Therefore, if a driver drove through the flashing light signals without stopping, or drove under the gates while they were just beginning to descend, this violation was classified as a flashing light (FL) violation or *a violation occurring between the time when the flashing lights were initially activated and two seconds after the gate arms began their descent.*

The second classification of violations was defined as violations occurring after the gate arm had been in motion for two seconds until the gate arms were in their horizontal position, or occurring after the gate arms were completely horizontal and before the train arrived. These are the types of violations that are typically enforced; therefore, this particular grouping of violations was referred to as TEVs or *typically enforced violations.*

The last classification category used was AT or *after the train.* The violations in this grouping occurred after the train departed but before the gates were completely raised. Therefore, the violations assigned to this category included driving around the gates after the train passed and driving under the gates before the gates were completely raised.

Table 5-5. Sample Data Set.

SITE	ACT	VIOL	VIOL_ NO	LOWER	VIOL_TM	VEH_ARR	OPP	TRN_ARR	SPD_ TM	GAT_RAIS	m/s	km/h	VTRS	VTRG	TRN_ DIS	IMPE	WT
W_MARY	1	1	1	10:12:10 AM	10:12:10 AM	10:12:10 AM	1	10:12:32 AM	2.2	10:12:59 AM	13.86	49.98	5	0	305	49	27
W_MARY	1	1	2	10:12:10 AM	10:12:07 AM	10:12:07 AM	1	10:12:32 AM	2.2	10:12:59 AM	13.86	49.98	2	-3	346	49	27
W_MARY	1	0		10:12:10 AM		10:12:13 AM	1	10:12:32 AM	2.2	10:12:59 AM	13.86	49.98				49	27
W_MARY	2	0		12:07:20 PM		12:07:40 PM	1	12:07:52 PM	2.9	12:08:17 PM	10.62	37.92				57	37
W_MARY	3	1	3	1:36:21 PM	1:36:18 PM	1:36:18 PM	1	1:36:40 PM	2.1	1:37:54 PM	14.52	52.37	2	-3	320	93	24
W_MARY	3	0		1:36:21 PM		1:36:21 PM	1	1:36:40 PM	2.1	1:37:54 PM	14.52	52.37				93	24
W_MARY	4	0		2:08:27 PM			0	2:08:47 PM	2.1	2:10:51 PM	14.52	52.37				144	25
W_MARY	5	0		3:10:28 PM		3:10:31 PM	1	3:11:14 PM	5.3	3:11:51 PM	5.75	20.74				83	51
W_MARY	5	0		3:10:28 PM		3:10:52 PM	1	3:11:14 PM	5.3	3:11:51 PM	5.75	20.74				83	51
FM_2100	1	1	1	7:11:46 AM	7:11:45 AM	7:11:45 AM	1	7:12:28 AM	2.1	7:13:16 AM	21.78	78.55	3	-1	936	90	46
FM_2100	1	1	2	7:11:46 AM	7:11:46 AM	7:11:46 AM	1	7:12:28 AM	2.1	7:13:16 AM	21.78	78.55	4	0	915	90	46
FM_2100	2	1	3	7:47:42 AM	7:47:40 AM	7:47:40 AM	1	7:48:12 AM	2.6	7:49:04 AM	17.59	63.45	2	-2	563	82	34
FM_2100	2	1	4	7:47:42 AM	7:47:43 AM	7:47:43 AM	1	7:48:12 AM	2.6	7:49:04 AM	17.59	63.45	5	1	510	82	34
FM_2100	2	0		7:47:42 AM		7:47:48 AM	1	7:48:12 AM	2.6	7:49:04 AM	17.59	63.45				82	34
FM_2100	2	0		7:47:42 AM		7:47:51 AM	1	7:48:12 AM	2.6	7:49:04 AM	17.59	63.45				82	34
FM_2100	3	0		7:52:28 AM			0	7:52:59 AM	4.6	7:54:17 AM	9.94	35.85				109	35
FM_2100	4	0		8:00:01 AM		8:00:10 AM	1	8:00:34 AM	4.5	8:01:59 AM	10.16	36.66				118	37
FM_2100	4	0		8:00:01 AM		8:00:11 AM	1	8:00:34 AM	4.5	8:46:52 AM	10.16	36.66				2811	37
FM_2100	5	0		8:44:27 AM		8:44:45 AM	1	8:45:03 AM	3.8	8:46:52 AM	12.03	43.40				145	40
FM_2100	5	0		8:44:27 AM		8:44:47 AM	1	8:45:03 AM	3.8	8:46:52 AM	12.03	43.40				145	40
FM_2100	6	0		9:00:03 AM		9:00:04 AM	1	9:00:45 AM	2.8	9:01:36 AM	16.33	58.92				93	46
FM_2100	6	0		9:00:03 AM		9:00:27 AM	1	9:00:45 AM	2.8	9:01:36 AM	16.33	58.92				93	46
FM_2100	7	0		10:53:46 AM		10:53:51 AM	1	10:54:26 AM	2.4	10:56:10 AM	19.05	68.73				144	44
FM_2100	7	0		10:53:46 AM		10:53:56 AM	1	10:54:26 AM	2.4	10:56:10 AM	19.05	68.73				144	44
OLTORF	1	0		10:12:13 AM		10:12:29 AM	1	10:12:30 AM	2.2	10:12:56 AM	14.55	52.48				43	22
OLTORF	1	0		10:12:13 AM		10:12:30 AM	1	10:12:30 AM	2.2	10:12:56 AM	14.55	52.48				43	22
OLTORF	2	1	1	12:08:51 PM	12:08:55 PM	12:08:55 PM	1	12:09:12 PM	2.9	12:09:36 PM	11.04	39.82	9	4	188	45	26
OLTORF	2	0		12:08:51 PM		12:08:59 PM	1	12:09:12 PM	2.9	12:09:36 PM	11.04	39.82				45	26
OLTORF	3	0		1:37:43 PM		1:37:43 PM	1	1:37:58 PM	2.1	1:39:25 PM	15.24	54.98				102	20
OLTORF	3	0		1:37:43 PM		1:37:47 PM	1	1:37:58 PM	2.1	1:39:25 PM	15.24	54.98				102	20
OLTORF	4	0		2:08:33 PM		2:08:32 PM	1	2:08:49 PM	2.1	2:11:02 PM	15.24	54.98				149	21
OLTORF	5	0		3:10:15 PM		3:10:17 PM	1	3:10:40 PM	5.3	3:11:17 PM	6.04	21.79				62	30
OLTORF	5	0		3:10:15 PM		3:10:39 PM	1	3:10:40 PM	5.3	3:11:17 PM	6.04	21.79				62	30

Table 5-5 (continued). Sample Data Set.

SITE	ACT	VIOL	VIOL_NO	V_TY	STOP	VEH_DIR	RR_VEH	RR_DIR	ENF_VIOL	SD	AADT	TRN_VOL	TRACKS	ADT_LN	TOD	CL_TIM	LNS	PVM_WID
W_MARY	1	1	1	3	0	4	1	1	0		7544	25	1	3772	2	22	2	13
W_MARY	1	1	2	6	0	2	1	1	0		7544	25	1	3772	2	25	2	13
W_MARY	1	0				4	1	1	0		7544	25	1	3772	2		2	13
W_MARY	2	0				2	1	3	0		7544	25	1	3772	3		2	13
W_MARY	3	1	3	6	0	2	1	3	0		7544	25	1	3772	3	22	2	13
W_MARY	3	0				2	1	3	0		7544	25	1	3772	3		2	13
W_MARY	4	0					1	1	0		7544	25	1	3772	4		2	13
W_MARY	5	0				2	1	1	0		7544	25	1	3772	4		2	13
W_MARY	5	0				4	1	1	0		7544	25	1	3772	4		2	13
FM_2100	1	1	1	6	0	3	1	4	0		17500	19	1	8750	12	43	2	15
FM_2100	1	1	2	3	0	3	1	4	0		17500	19	1	8750	12	42	2	15
FM_2100	2	1	3	6	0	1	1	2	0		17500	19	1	8750	12	32	2	15
FM_2100	2	1	4	3	0	1	1	2	0		17500	19	1	8750	12	29	2	15
FM_2100	2	0				1	1	2	0		17500	19	1	8750	12		2	15
FM_2100	2	0				3	1	2	0		17500	19	1	8750	12		2	15
FM_2100	3	0					1	4	0		17500	19	1	8750	12		2	15
FM_2100	4	0				3	1	4	0		17500	19	1	8750	1		2	15
FM_2100	4	0				1	1	4	0		17500	19	1	8750	1		2	15
FM_2100	5	0				3	1	2	0		17500	19	1	8750	1		2	15
FM_2100	5	0				1	1	2	0		17500	19	1	8750	1		2	15
FM_2100	6	0				1	1	2	0		17500	19	1	8750	1		2	15
FM_2100	6	0				3	1	2	0		17500	19	1	8750	1		2	15
FM_2100	7	0				1	1	4	0		17500	19	1	8750	2		2	15
FM_2100	7	0				3	1	4	0		17500	19	1	8750	2		2	15
OLTORF	1	0				4	1	1	0		11000	28	1	2750	2		4	15
OLTORF	1	0				2	1	1	0		11000	28	1	2750	2		4	15
OLTORF	2	1	1	3	0	4	1	3	1		11000	28	1	2750	3	17	4	15
OLTORF	2	0				4	1	3	0		11000	28	1	2750	3		4	15
OLTORF	3	0				4	1	3	0		11000	28	1	2750	3		4	15
OLTORF	3	0				2	1	3	0		11000	28	1	2750	3		4	15
OLTORF	4	0				2	1	1	0		11000	28	1	2750	4		4	15
OLTORF	5	0				2	1	1	0		11000	28	1	2750	4		4	15
OLTORF	5	0				4	1	1	0		11000	28	1	2750	4		4	15

Table 5-6. Database Reference Key.

Code	Definition	Code	Definition
ACT	Activation number	V_TY	Violation Type 1=drove around gates before train 2=violated from parallel street 3=drove under descending gates 4=drove through lowered gates 5=drove under as gates ascending 6=drove through flashing light signals before gates 7=drove around gates after train 8=other
VIOL	1=violation occurred 0=violation did not occur		
VIOL_NO	Violation number		
LOWER	Time of gate descent	STOP	Stopped at crossing 1=yes, 0=no
VIOL_TM	Time of violation occurrence	VEH_DIR	Direction of highway vehicle 1=north, 2=east, 3=south, 4=west
VEH_ARR	Time of vehicle arrival	RR_VEH	Train arrived during activation 1=yes, 0=no
OPP	1=a violation was possible before the train (i.e., vehicle arrived before the train) 0=no vehicle arrived before the train	RR_DIR	Direction train is traveling (refer to VEH_DIR codes)
TRN_ARR	Time of train arrival	ENF_VIO	Violation typically enforced (occurred $\geq$ 2 seconds after gate descent)
SPD_TM	Time lag between speed markers	SD	Sight distance 1=inadequate, 0=adequate
GAT_RAIS	Time of gate ascension	AADT	Average Annual Daily Traffic (FRA database)
m/s	Speed of train in meters per second	TRN_VOL	Train volume (observed)
km/h	Speed of train in km per hour	TRACKS	Number of tracks
VTRS	Violation time relative to signal onset(s)	ADT_LN	AADT/LNS
VTRG	Violation time relative to gate descent(s)	TOD	Time of day (codes begin at 8:00 a.m. and increase by one for each two hour interval, i.e., 1=8:00 am-10:00 am, 2=10:00 am-12:00 pm etc.)
TRN_DIS	Train distance upon violation (ft)	CL_TIM	Clearance time (TRN_ARR - VIOL)
IMPED	IMPED=GAT_RAIS - LOWER (Impedance)	LNS	Number of highway lanes
WT	Warning Time(s)	PVM_WID	Pavement width

DATA ANALYSIS

Violation Study

The data obtained through the site visits and video reduction also allowed the research team to obtain a better understanding of the operational and geometric relationships that may influence violations at gated highway-railroad grade crossings. Key variables were analyzed to determine relationships that could potentially affect highway-railroad grade crossing safety. The specific variables that were explored included:

- Train speed;
- Train volume;
- AADT per lane;
- Exposure (product of AADT and number of trains per day);
- Constant versus fixed-distance warning time devices;
- Number of highway lanes;
- Length of warning time;
- Impedance;
- Frequency of false activation;
- Number of tracks; and
- Sight distance adequacy.

Table 5-7 lists the values measured from the field data collection efforts. Statistical analyses were used to investigate the data on a site-specific level and an arrival-specific level. The purpose of the site-specific analysis was to compare average site characteristics of each crossing and develop relationships between these independent variables and the associated 24-hour violation rates at the crossings. The arrival-specific approach was used to investigate which variables have the greatest influence on the likelihood of a violation occurring when a driver has to decide whether to violate or comply with the traffic control devices at the crossing. This arrival-specific approach accounts for the variability that exists in several variables during a 24-hour period.

Site-Specific Analysis

The site-specific analysis used the statistical procedures known as the pooled t-test and the Pearson correlation coefficient to test if a significant relationship existed between the 24-hour violation rates and each of the study variables. The t-test was used for the discrete variables such as the number of highway lanes. The procedure was used to test for significant differences in violation rates for each variable category. For example, the t-test was used to test if a significant difference in the number of violations existed between crossings with a CWT warning device versus crossings with a FDWT device. A Pearson's correlation coefficient (r) was used to determine if the continuous variables demonstrated at least a reasonable relationship with the number of violations experienced. This coefficient was also used to measure the strength of the relationship between two variables. (The r-value always lies between -1 and 1. A positive relationship is shown by a positive r-value, with a negative relationship indicated by a negative r-value. A value of 0 indicates no linear

Table 5-7. Measured Variables For Violation Study.

Site	Number of Violations for all Periods	Train Volume (tpd)[1]	Train Speed (km/h)	Average Warning Time (s)	Deviation in Warning Time (s)	Warning Time[2] Type	Average Impedance (s)	Pavement Width (m)	AADT per Lane[3]
Higgins	1	11	43	37	10.6	0	153	9.75	720
SH 21	7	28	24	26	15	0	120	24.13	1735
West Mary	101	25	40	39	13	0	144	8.53	1945
Broadway	148	32	92	40	10.7	0	101	14.63	3822
FM 2100	216	19	55	38	9.2	0	126	14.63	5685
Barnes	44	33	11	23	8.6	0	173	8.53	2615
Sycamore	144	20	34	52	28	0	209	13.12	2928
Telephone	72	28	23	37	15.7	0	140	12.19	1810
Lawndale	82	29	21	47	19.6	0	167	15.24	1588
US 287	1	13	43	27	6.2	1	152	14.63	655
25th St.	4	5	34	26	2.3	1	126	14.63	1805
Oltorf	96	28	42	23	4.2	1	132	14.63	1590
Crowley	18	26	63	22	1.6	1	123	7.92	5130
Main St	66	13	77	34	3.2	1	146	9.45	5840
Magnolia	29	33	50	28	7.8	1	121	6.10	3055
Homestead	18	12	72	29	1.4	1	88	9.75	6685
FM 60	17	27	52	39	5.7	1	129	7.92	1395
FM 2917	6	16	71	23	4.0	1	194	7.32	2235
FM 3155	11	16	56	38	26.2	0	129	7.32	3765
Bannister[4]								9.14	3591

1: Average number of trains per 24-hour period.

2: 1=CWT, and 0=FDWT; this is based on collected data and not on FRA database.

3: Calculated as the volume crossing the tracks between 4 p.m. and 5 p.m. multiplied by 10 and divided by the number of lanes.

4: Site dropped from study due to equipment failure.

relationship exists between the variables, with the strength of the relationship increasing as the r-value moves farther from 0.)

The variables that showed a significant relationship were used to develop a multiple regression model. This model can be used to predict the number of violations expected during a 24-hour period given the average characteristics of a specific crossing. A linear model was developed using the familiar form below:

$$y=\beta_o + \sum_{j=1}^{n} \beta_j x_j + \varepsilon \tag{5-1}$$

Where:

y = the expected number of violations during a 24-hour period
β_o = the model constant
x_j = the value of jth crossing characteristic
β_j = the regression coefficient for jth crossing characteristic
ε_j = the unexplained random error

The unexplained error term in the above model form is assumed to be normally distributed.

Arrival-Specific Analysis

The arrival-specific analysis used graphical distributions of the data to investigate which variables appeared to have an influence on a specific driver's decision to violate versus a driver's decision to comply with the traffic control devices at the crossing. The database of all the sites was combined to analyze each vehicle arrival, during the warning device activation, as a single observation. This analysis was useful in accounting for the variability in the average characteristics of the site-specific analysis.

A logistic regression model was developed to predict the likelihood of a violation given the particular operational and geometric characteristics of a particular arrival. Equation 5-2 shows the general form of the model used. This form is otherwise known as the logit model. The logit model is used to predict a qualitative binary response (violations) using independent predictor variables (highway-railroad crossing characteristics). The response value is actually the probability that a driver will choose to violate given the prevailing conditions during the particular gate activation/vehicle arrival. The beta parameters were estimated using the method of maximum likelihood estimation. For a detailed explanation of this method, refer to (33).

The predicted number of violations can be calculated using the logit equation, the aggregated characteristics of a particular crossing, and the number of opportunities to violate. The equation would provide the probability of a violation occurring for a given set of characteristics. The number of opportunities to violate could be assumed to be a function of ADT and train volumes. The calculated probability multiplied by the estimated number of opportunities would result in the predicted number of violations.

$$p(y) = \frac{\exp\left(\beta_o + \sum_{i=1}^{n} \beta_i x_i\right)}{1 + \exp\left(\beta_o + \sum_{i=1}^{n} \beta_i x_i\right)} \tag{5-2}$$

Where:

p(y) = probability that a violation will occur given an opportunity exists
x_i = independent variables
β = regression parameters

Before-and-After Studies

The main purpose of installing automated enforcement systems is to deter illegal or unsafe motorist behavior and thus increase safety at gated highway-railroad grade crossings. To measure the extent to which motorist behavior has been affected, the change must be represented in quantifiable terms. To do so, the main measure of effectiveness used will be the violation rate (i.e., the number of violations per train, gate activation, or hour).

The numbers of violations, trains, and activations were counted in the before-and-after periods (see Table 5-8). These values were used to obtain violation rates. Table 5-8 also includes activations, or more precisely, gate arm activations. Note that the activation numbers are not consistently the same as the number of trains. There are two reasons for this. First, at some sites, maintenance vehicles were working on the tracks during the data collection periods. These vehicles frequently cause the lights and gates at the crossing to be activated. Another reason for the inconsistency between gate arm activations and trains is that the active traffic control warning devices at crossings near train switching operations are often activated during train switching occurrences even though the switching train may or may not enter the crossing. A reason that the number of trains may be greater than the number of activations is that more than one train may cross during a single activation.

A simple before-and-after comparison of the violation rates was made to determine the effectiveness of the automated enforcement systems in reducing the number of unsafe acts at the specified highway-railroad grade crossings. The statistical technique commonly known as analysis of variance (ANOVA) was used to compare the variability in the before-and-after treatment violation means. Statistical, as well as practical, significance was determined. Chapter 7 described the results of the analyses.

Table 5-8. Summary of Before-and-After Results.

Location	Period	Violations	Trains	Activations	Hours
West Mary	Before	55	82	82	102
	After	43	56	55	80
Oltorf	Before	41	88	87	102
	After	55	64	64	89
FM 2100	Before	82	76	80	96
	After	134	69	70	96
All sites	Before	178	246	249	300
	After	232	189	189	265

CHAPTER 6
VIOLATION STUDY RESULTS

This chapter presents the results of the violation study. The analyses determined the variables that would best predict the number of violations at a site. These relationships can be used to identify locations expected to have high violation rates. The analyses conducted for this study consist of a site-specific and an arrival-specific approach.

The site-specific approach examines the data site-by-site using an average for each variable (i.e., average warning time, average train speed, etc.). The site characteristics are compared to show which variables demonstrate significant relationships with the number of violations experienced at the sites. The site-specific analysis began with using the data from 19 sites. Because a wealth of information was available from the data collected at the six before-and-after study sites (see Chapter 7 for additional information on the before-and-after study), additional analyses were conducted using 24-hour data from all available sites and 24-hour periods. The extra data resulted in having data for 49 24-hour periods.

The arrival-specific analysis uses an approach in which each opportunity to violate is analyzed as a separate observation. This approach is used to identify the characteristics that affect the likelihood of violation at a site, given the opportunity to violate.

SITE-SPECIFIC ANALYSIS—19 STUDY SITES

The operations at 19 gated highway-railroad grade crossings were videotaped for a 24-hour period during the regular work week (Monday-Friday) as outlined in Chapter 5. Data were recorded each time an opportunity to violate occurred. The violations were divided into three categories defined according to the time the violation occurred relative to the onset of the flashing light signals, the gate descent, and the train arrival and departure (see Chapter 5). The reason for the division is that the decision to violate may be slightly different for each violation type. Police officers typically enforce violations that occur after the gates have begun to descend and when drivers drive around horizontal gates. Therefore, the violations were collapsed into three categories: flashing lights (FL), typically enforced violations (TEV), and after the train has passed (AT). Table 6-1 presents the number of violations experienced at each site during a 24-hour period.

Several geometric and operational characteristics of highway-railroad crossings were identified, from the literature and from observation of train operations, as having a potential relationship with the number of violations. Table 6-2 lists these variables and includes a brief description of the variables used in the analyses and the findings from preliminary statistical tests performed on the variables. The variables were divided into continuous and discrete categories, and a Pearson correlation matrix coefficient was developed. Table 6-2 shows which variables are significant at the 95 percent confidence level.

Table 6-1. Number of Violations at Study Sites.

Crossing Location (City)	Number of Violations*			
	FL	TEV	AT	Total
Higgins St. (Humble)	1	0	0	1
SH 21 (Nacogdoches)	6	1	0	7
West Mary (Austin)	7	4	0	11
Broadway Street (Pearland)	41	4	0	45
FM 2100 (Crosby)	20	9	0	29
Barnes Bridge Road (Dallas)	14	10	20	44
Sycamore St. (Fort Worth)	16	34	0	50
Telephone Road (Houston)	14	56	2	72
Lawndale St. (Houston)	13	69	0	82
US 287 (Corrigan)	0	1	0	1
25th St. (Bryan)	4	0	0	4
Oltorf St. (Austin)	4	1	0	5
Crowley St. (Crowley)	16	0	2	18
Main St. (Crowley)	8	3	0	11
Magnolia St. (Pearland)	24	4	1	29
Homestead Rd. (Houston)	9	9	0	18
FM 3155 (Richmond)	13	4	0	17
FM 2917 (Alvin)	3	0	3	6
FM 60 (Lyons)	4	7	0	11
Total	**217**	**216**	**28**	**461**

*FL = flashing light violation occurred when the warning lights were flashing and the gate arms were vertical or during the initial two seconds of the gate arm descending

TEV = typically enforced violations occurred after the gate arms had been in motion for two seconds and when the arms were in the horizontal position, prior to the train arrival

AT = after train violations occurred after the train departed the site but before the gates were completely raised

Table 6-2. Geometric and Operational Variables Expected to Influence Violations.

Variable	**Variable Description**	**Flashing Lights Violations**		**Typically Enforced Violations**	
		r*	**p-value****	**r***	**p-value****
Continuous Variables					
Exposure	Product of ADT and train volume	0.879	0.0001 YES	0.187	0.443 NO
Average Daily Traffic Per Lane	Recorded as 10 times the number of vehicles crossing the tracks between 4 and 5 p.m. during the study period divided by number of lanes at the site.	0.435	0.063 NO	-0.153	0.533 NO
Train Volume	Number of trains during the 24-hr period	0.488	0.034 YES	0.293	0.224 NO
Warning Time (s)	Average for all trains during the 24-hr period	0.287	0.233 NO	0.580	0.009 YES
Train Speed (km/h)	Average for all trains during the 24-hr period	0.349	0.143 NO	-0.463	0.046 YES
Impedance (s)	Average of all activations during the 24-hr period	-0.279	0.247 NO	0.323	0.178 NO
Discrete Variables					
Warning Time Type	A "1" is noted for constant warning time and a "0" is noted for fixed-distance warning time type	-0.058	0.815 NO	-0.356	0.135 NO
Highway Lanes	Either a "2" for two lanes or " 4" for four lanes	-0.055	0.823 NO	0.419	0.074 NO
Single or Multiple Tracks	Either "0" for single tracks or "1" for multiple tracks. Only one site had greater than 2 tracks.	-0.022	0.929 NO	0.024	0.928 NO
Presence of False Activations	Either "0" for no false activations or "1" if one or more false activation was observed at the site	0.202	0.406 NO	-0.256	0.291 NO

NOTES:

* Statistical results from Pearson correlation matrix. The null hypothesis is that no linear relationship exists between the variables and the violations.

** Lists the p-value and whether the variable is significant at the 95 percent confidence level (YES for significant and NO for not significant).

Flashing Light Violations

The number of flashing light violations experienced at a particular crossing should depend on the number of opportunities to violate. The number of opportunities to violate is, in turn, a function of the train and vehicular volumes. The product of ADT and train volume is exposure. Both exposure and train volume were significantly correlated with flashing light violations. Because train volume is included in exposure, and exposure showed a slightly higher correlation, it is examined in more detail in this section. Figure 6-1 illustrates the relationship between exposure and the flashing light violations observed at the 19 sites. Figure 6-1 shows that most of the data follow a well-defined positive trend with increasing exposure rates. This relationship is significant at the 95 percent confidence level.

However, there is some variability in the data. Three data points vary considerably from the general trend of the remainder of the data. The three points represent the number of flashing light violations witnessed at Magnolia Street, Oltorf Street, and FM 60. In other words, when compared with the remaining 16 sites, Magnolia Street and FM 60 experienced an unusually higher rate of violations while Oltorf Street experienced an unusually lower number of violations.

An explanation for the high number of FL violations at Magnolia is related to the high volume of train switching operations conducted between 6:00 p.m. and 7:00 p.m. This operation created a considerable amount of queuing at the crossing, and on several occasions highway vehicles were delayed for the duration of multiple gate activations. This delay likely caused drivers waiting during one gate activation to attempt to drive through the flashing light signals, or under the lowering gates, instead of having to wait again during the next gate activation. Ten of the 24 FL violations occurred during this hour of operation.

The FL violation rate at Oltorf Street was considerably low and at FM 60 was high when compared with the trend shown in Figure 6-1. These results are difficult to explain; however, they are an indication that other variables may have an influence on the frequency of FL violations. For example, the Oltorf crossing has advance flashing lights which could be the cause for the low FL violation rates.

The results of the FL violation analysis show that, for most sites, the FL violation rate is a function of the exposure. This result follows intuition, that the more opportunities available to violate, the higher the violation rate. From observation, it appears that drivers treat the flashing light signals similar to the yellow phase at a highway traffic signal. Most of the drivers who commit a FL violation are attempting to cross before the gates begin their descent or before they reach the horizontal position. With higher exposures, more opportunities to commit FL violations occur.

Typically Enforced Violations

Several variables were investigated as having potential influence on typically enforced violations. Table 6-2 lists the variables and the results from preliminary statistical evaluations. Using a 95 percent confidence level, only warning time is significantly correlated to typically enforced violations. To obtain a good understanding of the potential relationships between the different variables and TEVs, each variable is briefly discussed below.

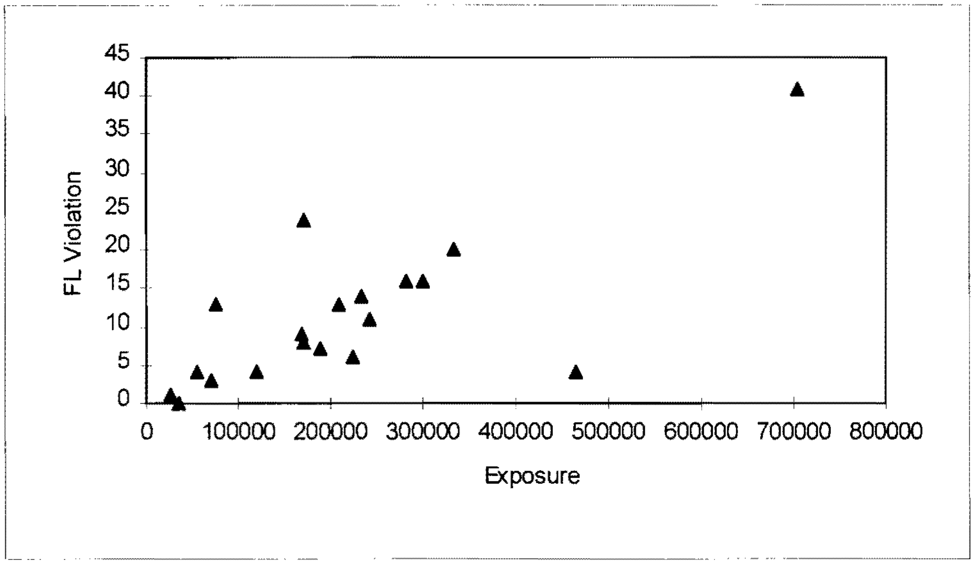

Figure 6-1. FL Violations as a Function of Exposure.

Exposure

As shown in Figure 6-2, a well-defined relationship between exposure and the number of TEVs did not exist. A high variation in the number of violations exists for sites with exposure between 200,000 and 350,000. In addition, some sites with the highest exposure values had the lowest number of typically enforced violations. In summary, other variables better explain the variability in the number of TEVs.

ADT Per Lane

An analysis of ADT per lane was conducted to determine if there was a relationship between traffic volume and the number of TEVs observed. A driver may be less likely to drive around the gates as the traffic level increases because the vehicles on the other side of the tracks may create difficulties in completing the maneuver. In another theory, high traffic volumes may increase the pressure to violate. The plot in Figure 6-3 illustrates the distribution of TEV frequency at each site versus its associated ADT per lane. The three sites recording the highest TEV rates, Sycamore School Road, Telephone Road, and Lawndale Street, have ADT per lane less than 3000 vpdpl. There are, however, seven other sites with ADT per lane below 3000 vpdpl that recorded very few violations. The relationship between volume and TEVs was not statistically significant.

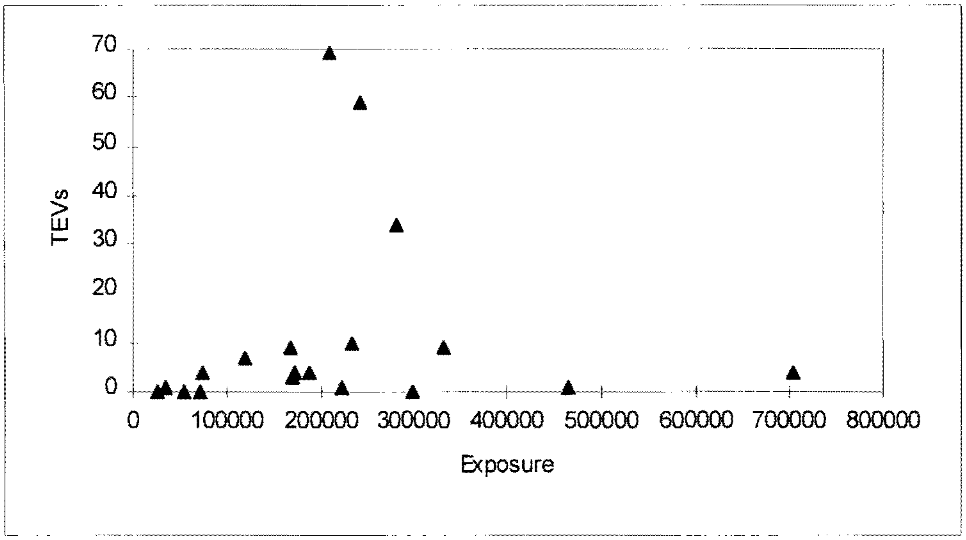

Figure 6-2. TEVs as a Function of Exposure.

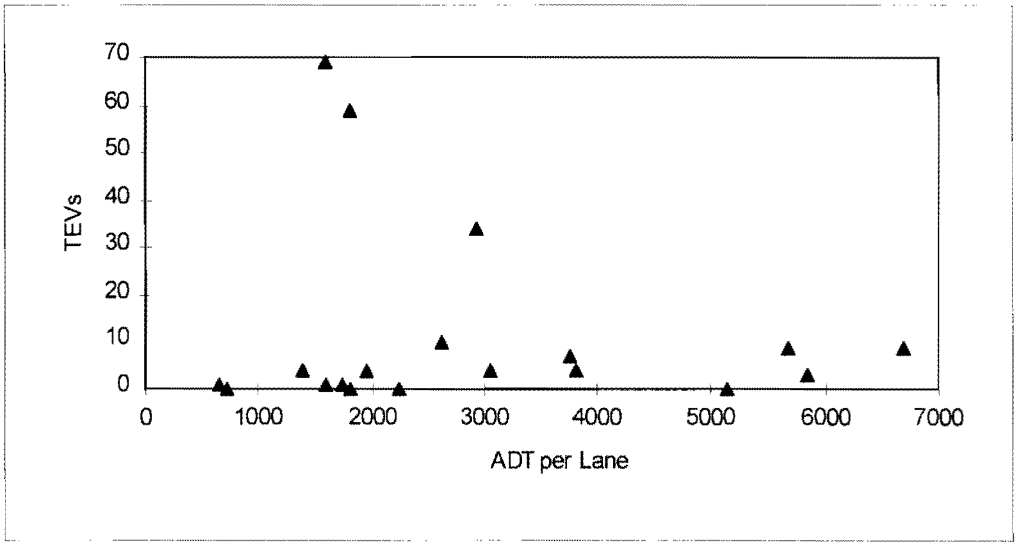

Figure 6-3. TEVs as a Function of ADT per Lane.

Number of Trains

A linear relationship between the daily train volume and TEVs was not found to be significant. This finding is further validated by Figure 6-4 which consists of a scatter plot. It was thought that the daily train volume might influence TEVs because when motorists expect many trains, they may be more willing to perform a violation to avoid being delayed if multiple trains arrive and impede their progress further. Figure 6-4 shows that the variability in number of violations increases with higher train volumes.

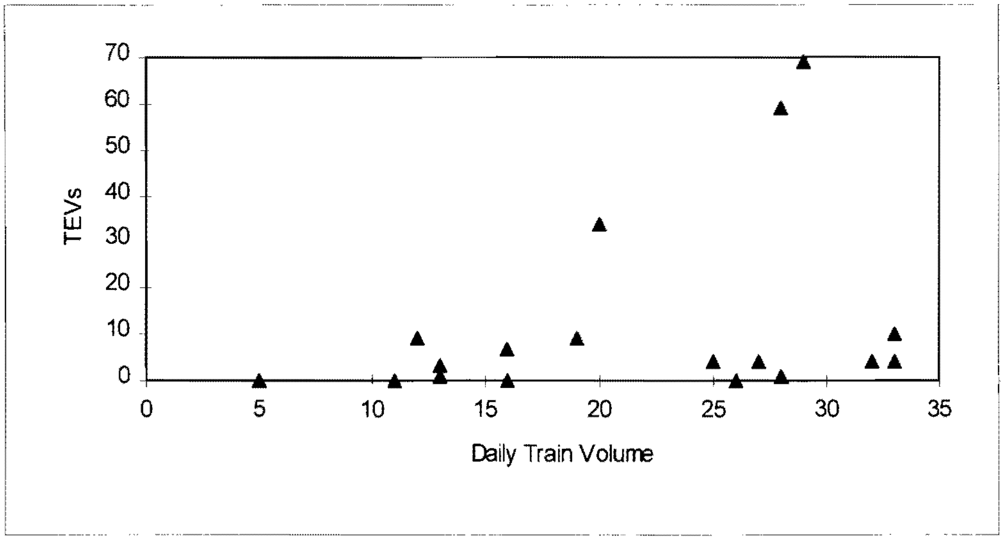

Figure 6-4. TEVs as a Function of Daily Train Volume.

Warning Time

Warning time correlated with the number of TEVs. The plot in Figure 6-5 illustrates the relationship that exists between warning time and the number of TEVs recorded. There does not appear to be much variation in the data at low average warning times (i.e., less than 35 seconds). The violation rates at these sites ranged between zero and 12 violations, with only two of the nine sites experiencing more than five violations. However, when the warning time is greater than 35 seconds, there appears to be a considerable amount of variability. Three sites, Telephone Road, Lawndale Street, and Sycamore School Road, experienced 56, 69, and 34 TEVs, respectively. The other six sites, with average warning times greater than 35 seconds, each experienced no more than nine violations during the 24-hour period.

Train Speed

The plot in Figure 6-6 illustrates that, though there appears to be some relationship in TEV and train speed, there remains a considerable amount of variability in the data. This variability appears to be greater at speeds less than 35 km/h. Three data points, representing the Telephone Road, Sycamore School Road, and Lawndale Street sites, have a much higher 24-hour violation rate than the remainder of the data. Five other sites with average speeds less than 35 km/h have TEV rates similar to the rates witnessed at sites with average train speeds greater than 35 km/h.

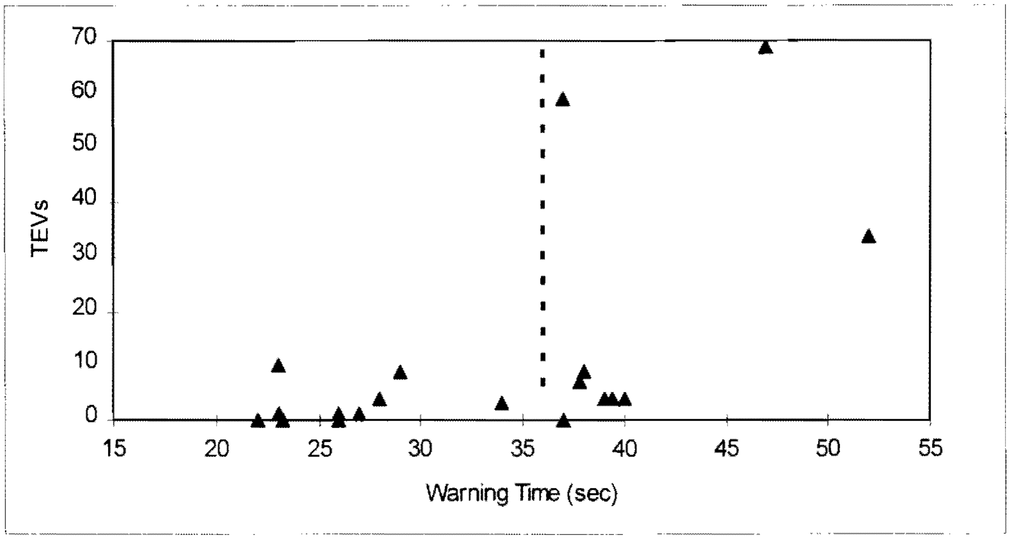

Figure 6-5. TEVs as a Function of Average Warning Time.

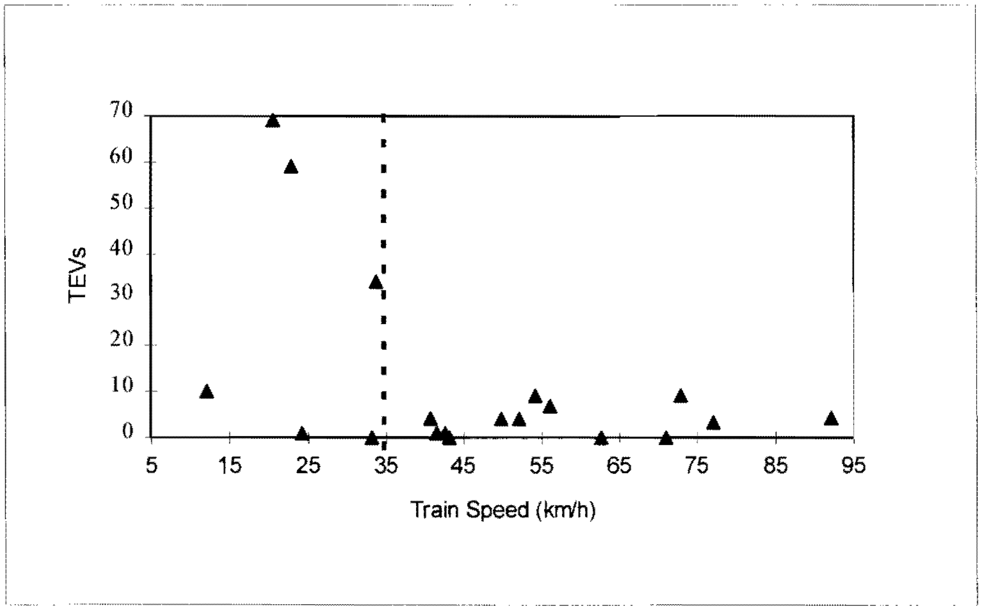

Figure 6-6. TEVs as a Function of Average Train Speed.

Impedance

The impedance is defined as the amount of time the gates are in the horizontal position. The relationship between average impedance and TEVs was not significant. The plot in Figure 6-7 illustrates the lack of relationship that exists between impedance and the number of TEVs. It is concluded, therefore, that the impedance variable does not have a significant influence on the occurrence of TEVs.

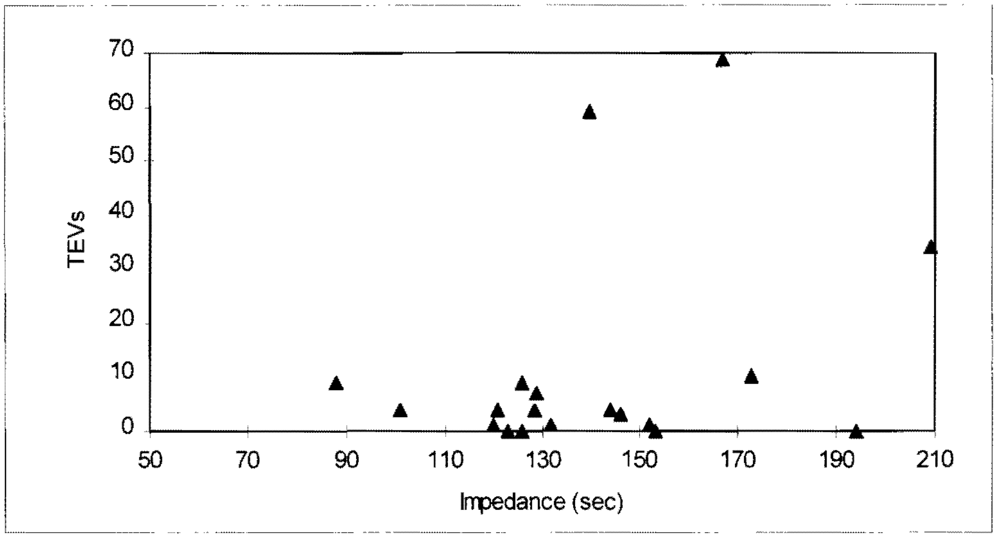

Figure 6-7. TEVs as a Function of Average Impedance.

Constant vs. Fixed-Distance Warning Time

Crossings with constant warning time experienced far fewer violations than crossings with highly variable warning times. The nine sites with constant warning times experienced an average of 2.4 typically enforced violations during the 24-hour periods. The 10 sites with variable warning time (fixed-distanced warning time devices) experienced an average of 19.7 typically enforced violations during the 24-hour periods. The t-value of 2.0245 does not indicate a significant difference (at a 95 percent confidence level) in mean TEV rates. However, the statistic is almost significant as indicated by the p-value of 0.0589. This finding supports the research of Halkias and Eck (12) and Bowman (17), as discussed in Chapter 2.

Number of Lanes

The average number of TEVs observed at two-lane and four-lane crossings showed that four-lane crossings have higher average TEV values than two-lane crossings (19.8 and 4.1 violations during the 24-hour periods, respectively). The t-test results indicated, however, that the difference is not significant at the 95 percent confidence level (p-value = 0.0893). The variation in TEVs, is much greater for four-lane crossings with a standard deviation of 27.34 violations versus 3.63 for two-lane crossings. The maximum number of violations at the four-lane crossings was 69 while the minimum was zero. The maximum number of TEVs witnessed at the two-lane crossings was 12 with a minimum of zero. This result suggests that, though crossings with two lanes do experience some violations, four-lane crossings may provide more room for a driver to traverse around the lowered gates and thus may experience a higher frequency of violations. The high variation suggests that other variables are influential at four-lane crossings.

Single vs. Multiple Tracks

Multiple-track crossings were found to have a higher TEV rate than single-track crossings with average 24-hour TEV rates of 24.3 and 5.6, respectively. Once again, though, this difference was not found to be significant at the 95 percent confidence level (p-value = 0.0562). Inspection of the p-value indicates that the statistic is reasonably close to 0.05 and justifies further investigation. A large number of switching operations took place at multiple-track crossings versus the single-track crossings. Switching operations are usually associated with long delays and multiple gate activations in very short amounts of time. These delays may cause drivers to become impatient and thus drive around the gates. False activations are also more prevalent at locations where a considerable amount of train switching occurs. The false activations may cause the warning devices to lose credibility and thus may be associated with higher violations. The presence of multiple tracks or single tracks may, therefore, be a surrogate for the type of train operation expected at a crossing.

Number of False Activations

Sites that encountered at lease one false activation during the 24-hour study period averaged 15.5 TEVs. Those sites that did not have a false activation only had an average of 3.0 TEVs. A t-test shows that this difference is not significant (p-value = 0.1365). However, the average numbers do show that during false activations, drivers can see that no train is coming and may decide not to wait for the gates to ascend. A concern is that drivers will lose respect for all warning device activations and feel that their own judgement is superior to the guidance provided by the traffic control.

Violations Occurring After The Train Departs The Crossing

After the train violations are different than the other two violation types, in that they occur after the train has already passed through the crossing and before the gates have raised. This violation type is considered especially risky at locations with multiple tracks because multiple trains can pass during a single gate activation. The driver may not be aware that there is the possibility of a second train during a single gate activation.

Table 6-1 shows that AT violations occur far less frequently than the other violation types, with only 28 total occurrences at all 19 sites. The Barnes Bridge Road site accounted for 20 of the 28 violations of this type. During the majority of gate activations at this site, the gates remained in the horizontal position for a longer period of time after the train passed than any of the other sites. No actual quantitative data of this type were obtained; however, it is believed that the added delay due to this crossing characteristic is likely the main cause of the AT violation. Another cause is that the average impedance at Barnes Bridge Road was slightly higher, at 175 seconds, than the average impedance of 138 seconds for all the sites. After a longer than average delay, many drivers are not willing to wait for the gates to ascend, especially when the gates stay in the horizontal position for what appears to be an unreasonably long period of time after the train has passed.

Development Of Linear Regression Model

Linear regression models were developed to predict the frequency of FL violations and TEVs expected at a crossing given the prevailing characteristics at the crossing. The results of the preliminary analysis were used to determine which variables are expected to be significant predictors of violations. A model was not developed to predict the frequency of AT violations because they were rare events.

Flashing Light Violation Regression Model

In the previous analysis, the FL violations were significantly influenced by exposure. A variable selection regression analysis resulted in exposure as the only significant independent variable to use as a predictor to estimate the expected number of FL violations. The regression statistics are shown in Table 6-3, and Figure 6-8 illustrates the output of this model. The FL violation rates can be predicted fairly well by this model at most sites.

Table 6-3. Regression Statistics for Flashing Light Violation Prediction Model.

Statistic	Parameter Value	p-value	Standard Error
Exposure	0.0000787	0.00001	0.00001
Constant	-1.3965	0.493	1.99309
Number of Observations	19		
Adjusted R-Squared	0.7592		

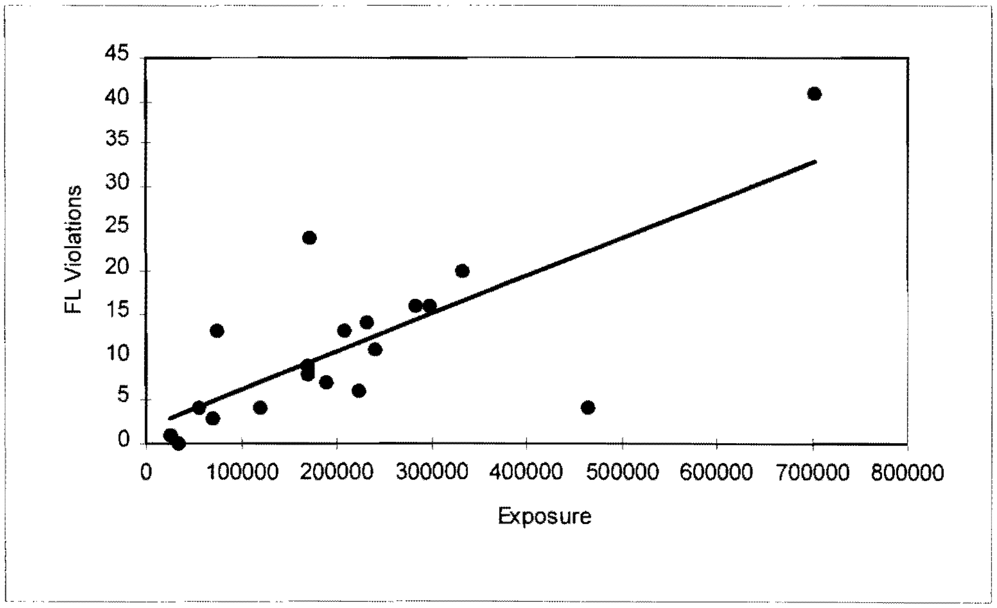

Figure 6-8. FL Violation Linear Model Output.

Typically Enforced Violation Model

In a similar manner, a multiple regression analysis was conducted to predict the frequency of TEVs. Only those variables with p-values less than 0.05 were included in the final model. The statistics for this model are shown in Table 6-4. The adjusted R-squared value of 0.461 indicates that a portion of the variation is accounted for by the model; however, a considerable amount of variation is yet unexplained. The R-squared value, however, is comparable to those associated with accident prediction models. Figure 6-9 illustrates the output of this model.

Table 6-4. Regression Statistics for TEV Prediction Model.

Statistic	**Parameter Value**	**p-value**	**Standard Error**
Train Speed (km/h)	-0.410	0.025	0.1652
Warning Time (s)	1.283	0.006	0.4010
Constant	-11.540	0.484	16.119
Number of Observations	19		
Adjusted R-Squared	0.461		

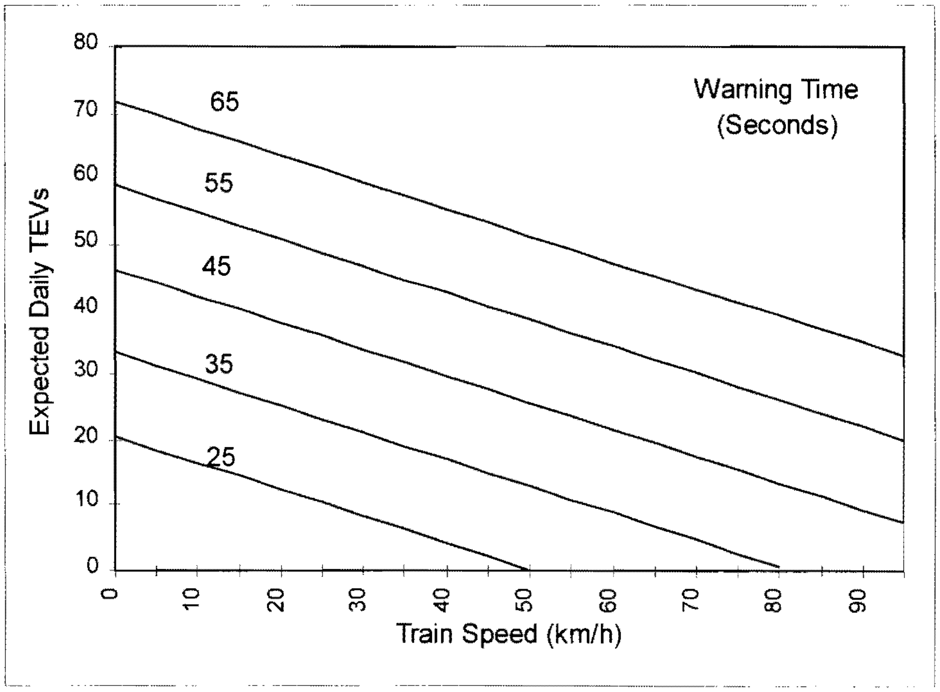

Figure 6-9. TEV Linear Model Output.

SITE SPECIFIC ANALYSES —ALL SITES AND PERIODS

The site specific analyses conducted with the 19 sites yielded satisfactory results. However, additional data are available as a result of the before-and-after study efforts. The research team decided to use the before-and-after study sites to increase the overall sample size. With the addition of the before-and-after data, the sample increased to 49 observations (i.e., 49 24-hr periods of crossing operations at 19 different locations). Once again, multiple regression techniques were used to develop statistical models to predict the number of violations.

The violations were categorized as before: FL for flashing light violations, TEV for typically enforced violations, and AT for around gate after the train violations. Table 6-5 shows some descriptive statistics concerning the violations for the 49 24-hr periods.

Table 6-5. Daily Violation Summary for the 49 24-hr Periods.

Descriptive Statistic		FL	TEV	AT	TOTAL
Average		10.7	9.0	2.4	22.1
Standard Deviation		7.9	13.8	3.6	8.8
Range	Minimum	0	0	0	0
	Maximum	33	69	20	82
Total		522	439	120	1081

Overall, 1081 violations and 972 activations were recorded. Therefore, on average, motorists committed one violation for each activation (disregarding the occurrence of a train or not). Table 6-6 shows more detail concerning the violations. Violations that occurred during each 24-hr period are shown. This table shows how the violations varied greatly from site to site as well as within sites. The numbers after the first six study sites indicate a different 24-hr period that was reduced from the video. From the data presented in Table 6-6, it appears that certain crossings have very different characteristics when compared to the remaining crossings. For instance, both the Lawndale and Telephone Road sites have a very high TEV rate compared to the other sites. Also, the data from the FM 2100 site indicate varied operations. During the third 24-hr period, only five FL violations were witnessed while 33 were recorded during the sixth 24-hr period. Variances like these will likely remain unexplained using a site-specific approach but may be revealed when each opportunity to violate is examined in the arrival-specific analysis.

Table 6-6. Number of Violations per Site and Time Period.

Crossing Location—24-hr Period	Violations				Crossing Location	Violations			
	FL	TEV	AT	Total		FL	TEV	AT	Total
West Mary - 1	6	3	7	16	Broadway - 1	15	3	8	26
West Mary - 2	6	5	3	14	Broadway - 2	32	12	5	49
West Mary - 3	7	5	1	13	Broadway - 3	27	17	3	47
West Mary - 4	6	4	2	12	Broadway - 4	18	5	3	26
West Mary - 5	14	11	0	25	Sycamore - 1	1	4	1	6
West Mary - 6	3	0	0	3	Sycamore - 2	8	25	12	45
West Mary - 7	12	0	0	12	Sycamore - 3	6	32	7	45
West Mary - 8	3	2	1	6	Sycamore - 4	9	35	4	48
Oltorf - 1	3	3	4	10	Main St. - 1	10	8	3	21
Oltorf - 2	6	1	4	11	Main St. - 2	10	4	1	15
Oltorf - 3	4	3	5	12	Main St. - 3	12	4	4	20
Oltorf - 4	2	1	5	8	Main St. - 4	4	3	3	10
Oltorf - 5	6	10	0	16	US 287	0	1	0	1
Oltorf - 6	13	0	0	13	25th Street	4	0	0	4
Oltorf - 7	6	2	0	8	Homestead	9	9	0	18
Oltorf - 8	14	4	0	18	Higgins	1	0	0	1
FM 2100 - 1	14	8	0	22	Magnolia	24	4	1	29
FM 2100 - 2	16	9	3	28	Lawndale	13	69	0	82
FM 2100 - 3	5	7	1	13	SH 21	6	0	1	7
FM 2100 - 4	10	9	0	19	Barnes	14	10	20	44
FM 2100 - 5	26	4	1	31	Telephone	11	59	2	72
FM 2100 - 6	33	18	0	51	Crowley	16	0	2	18
FM 2100 - 7	18	12	0	30	FM 2917	3	0	3	6
FM 2100 - 8	19	3	0	22	FM 60	13	4	0	17
Total all Sites	**522**	**439**	**120**	**1081**	FM 3155	4	7	0	11

FL Violations at All Sites and Periods

A correlation matrix was created to explore the possible relationships between FL violations and the variables collected throughout the data collection efforts. Table 6-7 lists the results for the significant variables: ADT, daily train volume, and exposure. Exposure is a function of the other variables (ADT and train volume); therefore, one should expect exposure to be significant. The scatter plots of these variables (shown in Figures 6-10 through 6-12) indicate that all might help predict the number of FL violations. However, when exposure was introduced into the model, the model became unstable due to the multicollinearity associated with the variables. Therefore, exposure was not included as a variable in the final model. Table 6-8 shows the final model and statistics about the model.

Table 6-7. Pearson's Correlation Coefficient with Respect to FL Violations.

Variable	**ADT**	**Daily Train Volume**	**Exposure**
Pearson's Coefficient	0.37160	0.49047	0.52863
p-value	0.0120	0.0003	0.0002

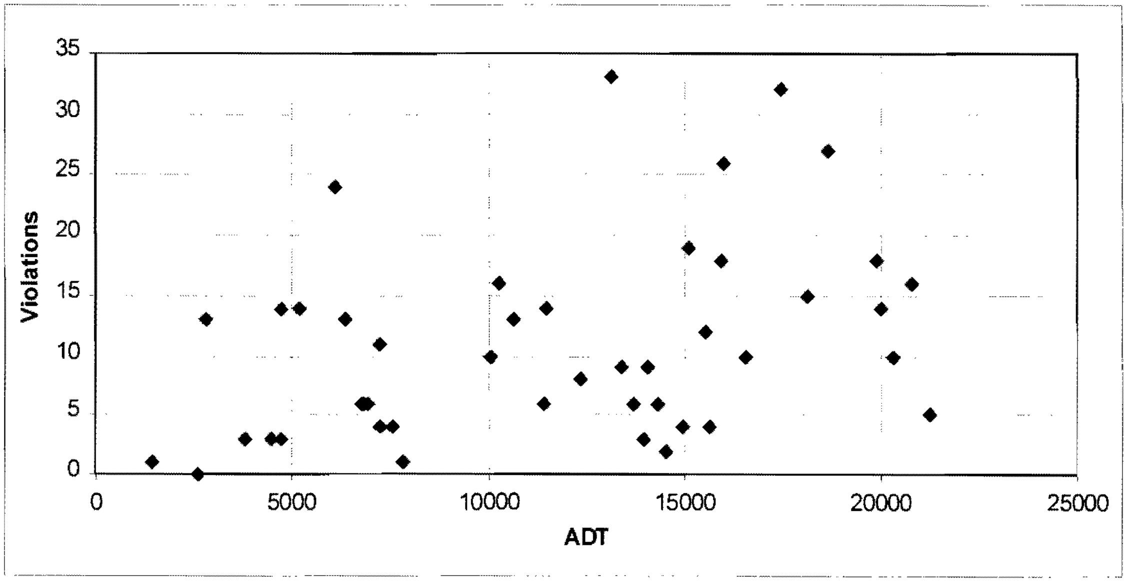

Figure 6-10. Scatter Plot of ADT and FL Violations.

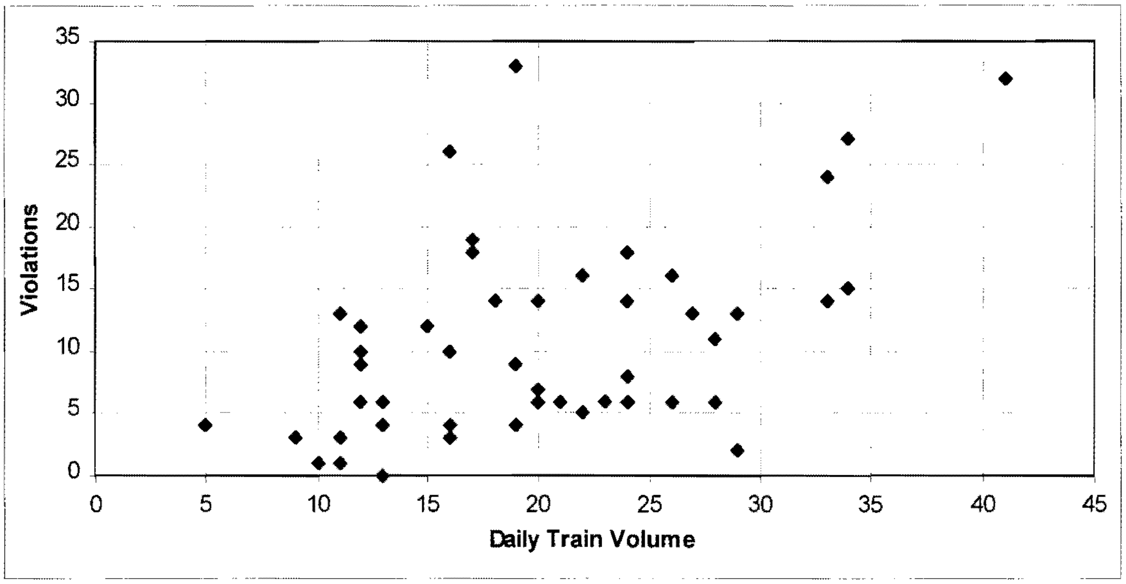

Figure 6-11. Scatter Plot of Daily Train Volume and FL Violations.

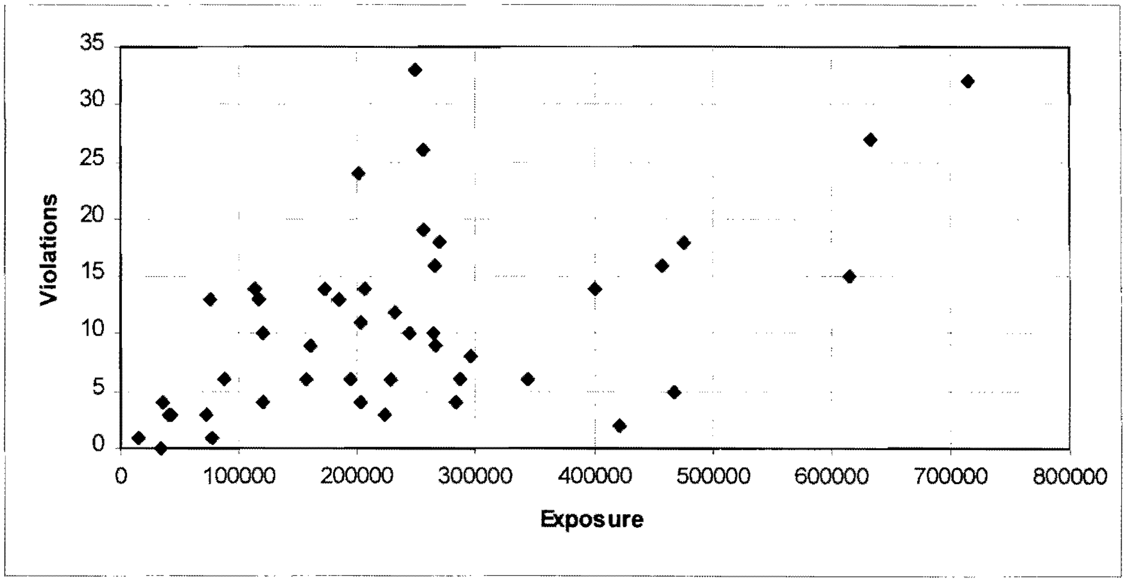

Figure 6-12. Scatter Plot of Exposure and FL Violations.

Table 6-8. Regression Statistics for FL Violations Prediction Model Using All Data.

Statistic	Parameter Value	p-value	Standard Error
ADT	0.000425	0.0259	0.0002
Daily Train Volume	0.47	0.0008	0.13
Constant	-3.45	0.2915	3.23
Number of Observations	49		
Adjusted R-Squared	0.3124		

The model shown in Table 6-8 does not appear to predict FL violations as well as the model produced earlier (i.e., the model developed with the original 16 sites). However, the second model encompasses a wider range of data and, therefore, can be applied to more gated crossings without suffering the consequences of using data outside of the range of the data used to produce the model. The model shown here is very similar to the original model. In the original model, exposure was the only independent variable. However, exposure is a function of ADT and daily train volume, the two independent variables used herein.

TEVs at All Sites and Periods

As with the previous efforts, the first attempt to identify useful variables for multiple regression was to create a correlation matrix. Table 6-9 presents those variables that resulted in significant correlations with TEVs. Interestingly, the results show that as train speed increases, fewer TEVs can be expected. Typically, many traffic and railroad engineers argue that the motorists who violate crossing arms do so without regard to train speed. This statement is made because the train is such a large object and almost directly approaching the motorist with respect to the motorist's line of sight, it is very difficult, if not impossible, to judge the speed of the train. This argument might have some truth to it; however, the results included herein indicate that the motorists' decision to violate is influenced by the speed of the train. As suspected, violations increase as the other variables (daily train volume, warning time, and number of lanes) increase.

Table 6-9. Pearson's Correlation Coefficient with Respect to TEVs.

Variable	Daily Train Volume	Train Speed (km/h)	Warning Time	Number of Highway Lanes
Pearson's Coefficient	0.32057	-0.33753	0.30941	0.29391
p-value	0.0247	0.0177	0.0305	0.0404

In selecting variables for the model, several approaches were taken. Rather than discussing the details of these statistical procedures, the results of one variable selection method are shown in Figure 6-13. The method shown refers to Mallow's C(p) statistic. The statistic is a measure of total squared error for a subset model containing p independent variables. The total squared error is a measure of the error variance plus the bias introduced by not including important variables in a model. It may, therefore, indicate when variable selection is deleting too many variables.

When using Mallow's statistic, one looks for values of C(p) close to the number of independent variables in the model plus one. A plot usually indicates where the optimum cut-off point falls. However, from the partial output shown above, it is evident that the best model for predicting TEVs will contain three or four main effect variables.

Initially, the best model appeared to be a four-variable model that included daily train volume, exposure, warning time, and pavement width. The adjusted R-squared associated with this model was 0.33. All four variables were significant with p-values smaller than 0.001. However, this model suffered from two sites with unusually high numbers of TEVs. Lawndale and Telephone Road sites had 69 and 56 TEVs, respectively. These two data points were analyzed using several techniques; based on the results, a decision was made to discard the sites from the analysis.

Discarding the two outlying sites resulted in a slight change in the independent variables that were deemed statistically significant. The model was basically reduced from a four-variable model to a two-variable model. Warning time and exposure were the only two significant variables (see Figures 6-14 and 6-15). However, the adjusted R-squared value dropped to 0.194. Residual plots were created which identified other problems. The residual plots generally had a curve associated with them, and the error terms did not have equal variance. To correct for the curved trends in the residual plots, quadratic terms were introduced to the model. Weighted least squares were used to handle the non-variance of the error terms. Table 6-10 shows the final model.

```
Number in    R-square        C(p)      Variables in Model
  Model

    1      0.18658802      9.52874    TRNVOL
    1      0.13621621     11.29543    TRNSPDKM
 --------------------------------------------
    2      0.33621481      6.28089    TRNVOL PVMTWIDM
    2      0.30918534      7.22890    TRNVOL LANE
 -----------------------------------------------
    3      0.45436343      4.13707    TRNVOL WARNTIME PVMTWIDM
    3      0.43930243      4.66531    TRNVOL WARNTIME LANE
 --------------------------------------------------------
    4      0.47658792      5.35760    TRNVOL EXPOS_T WARNTIME PVMTWIDM
    4      0.47629385      5.36791    ADT_TTI TRNVOL WARNTIME PVMTWIDM
 --------------------------------------------------------------------
    5      0.56411946      4.28761    ADT_TTI TRNVOL WARNTIME LANE ADT_LN_T
    5      0.55861193      4.48077    ADT_TTI TRNVOL WARNTIME PVMTWIDM ADT_LN_T
```

Figure 6-13. C(p) Variable Selection Results.

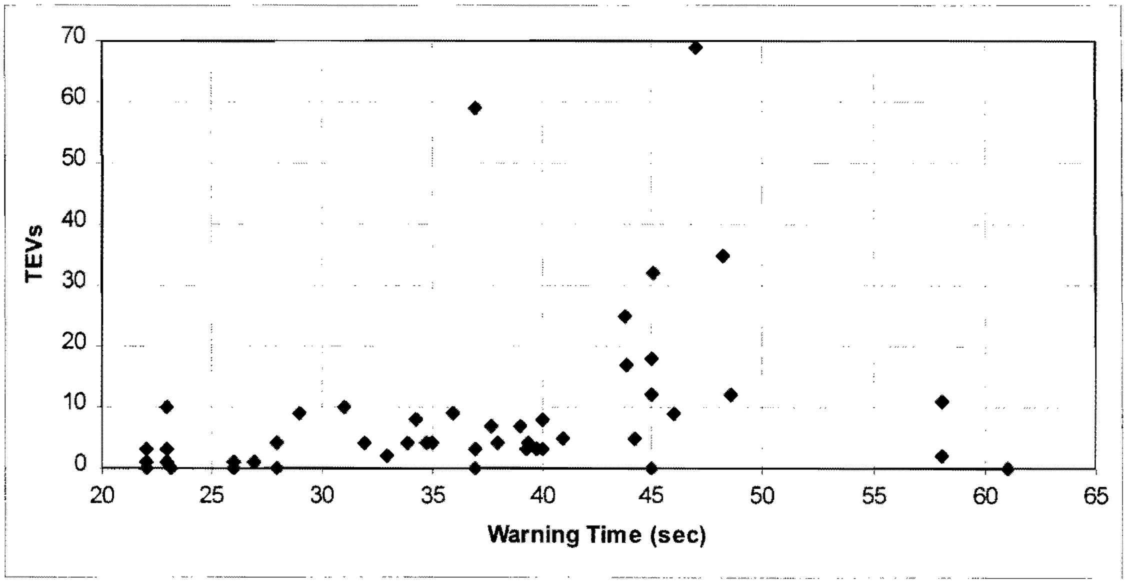

Figure 6-14. Scatter Plot of Warning Time and TEVs.

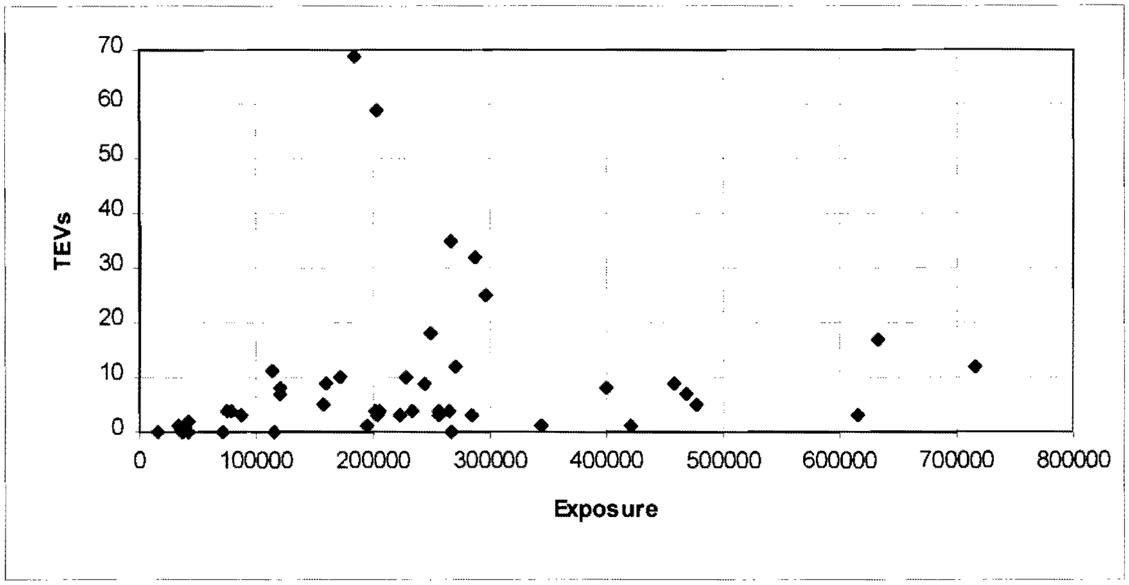

Figure 6-15. Scatter Plot of Exposure and TEVs.

Table 6-10. Regression Statistics for TEVs Prediction Model Using All Data.

Statistic	**Parameter Value**	**p-value**	**Standard Error**
Intercept	-7.815	0.0391	3.662
Exposure	5.260×10^{-5}	0.0001	1.167×10^{-5}
Warning Time (sec)	0.1894	0.0539	0.095
Exposure Squared	-6.470×10^{-11}	0.0094	0.00
Number of Observations	47		
Adjusted R-Squared	0.496		

The final model developed for TEVs is quite different from the original model developed using the initial 19 sites. In that original model, train speed and warning time were the statistically significant independent variables. Logically, that made sense. The original model had an adjusted R-squared of 0.461. With the introduction of the additional variables, the model changed somewhat. Although warning time (measured in seconds) remained a statistically significant variable, train speed dropped out of the model and exposure was added. Furthermore, exposure squared was also determined to be statistically significant. Also different with this final model is the use of weighted least squares to account for the unequal variance associated with the model. The adjusted R-squared, reported as 0.496, indicates a slight improvement over the original TEV model.

AT Violations

As previously, the after-train violations were not modeled because they are rare events. From field observations conducted when collecting and reducing the data, it appears that the best predictor of these violations would be whether the active traffic control devices were working properly. If the gate arms remained lowered for an extended period of time, the motorist assumed they were malfunctioning and would drive around the gate. Another situation where these violations appear more frequently are when trains just cross the highway and stop within a short distance of the crossing. When there is only one track present, the danger to the motorist is not as great as when there are multiple tracks. When multiple tracks exist, the stopped train could restrict the line of sight to an approaching train (depending on the sight distance available and the approach direction of the train relative to the stopped train). Albeit, the number of tracks are displayed at each approach to an at-grade crossing; however, the driver may not appropriately consider the number of tracks when deciding whether or not to violate the gate arms after the train has passed.

ARRIVAL-SPECIFIC ANALYSIS

An arrival-specific analysis of the data was conducted to evaluate the effect of geometric and operational characteristics on an individual arrival-specific basis, as described in Chapter 5. This analysis considers data from the 19 crossings as one sample data set composed of 1008 observations. Each observation constitutes a potential opportunity to comply or violate the traffic laws associated with active traffic control devices at gated highway-railroad grade crossings. Of these 1008 potential opportunities, 868 actual opportunities to commit a violation arose. The difference (140) is the number of times the flashing lights and/or gate arms were activated and no vehicles approached the crossing. However, the 868 opportunities to commit a violation include activations when no trains arrived at the crossings (i.e., false activations). Table 6-11 summarizes the noncompliance rates for FL violations and TEVs. Approximately 69 and 34 percent of the motorists who had the opportunity to violate the warning lights or the gate arm, respectively, at active highway-railroad grade crossings did so.

Flashing light violations are defined as those violations that occur after the activation of the flashing lights and two seconds into the gate arms' descent. Of the data set, 47 percent of the violations were of this type. Drivers may consider this action as analogous to the behavior at an at-grade highway-highway intersection in which the drivers proceed through the yellow phase prior to the red signal. The TEVs are those violations that occur after the gates have been descending for two seconds or when the gates are in the horizontal position and prior to the arrival of the train. These violations are considered to be very hazardous actions. Approximately 47 percent of the violations observed were of this type. Violations occurring after the train traverses the crossing were the most infrequent type of violation. Furthermore, one site accounted for 17 of the 28 AT violations. Without these 17 violations, AT violations would account for only about 2 percent of all violations.

Table 6-11. Noncompliance Rates.

	FL	TEV
Number of Violations	217	216
Opportunities	313	637
Percent Violating Traffic Control Devices (%)	69	34
Number of Activations	454	454
Average Number of Violations per Activations	0.48	0.48

Similar to the site-specific or aggregate analysis, several variables were analyzed for their effect on the motorists' decision to comply or violate. The difference is that in the aggregate analysis, each site was considered an observation so that comparisons could be made between the 19 sites and their average values for the variables. In the arrival-specific analysis, each driver's decision is considered separately based on the exact variable value during that specific activation (i.e., warning time of the specific activation rather than average warning time at that particular site). This analysis will help to identify the relationships between several variables and the number of violations witnessed by accounting for the variability occurring from violation to violation within each site as well as within the range of sites. A limitation of the analysis is that a violation that occurred during a false activation was not considered since no train-related data, such as train speed or warning time, is available. The variables considered for this analysis are:

- train speed;
- warning time;
- adequacy of sight distance;
- ADT;
- pavement width;
- train volume;
- presence of single or multiple tracks;
- number of highway lanes; and
- ADT per lane.

Individual Variable Effects on Each Arrival

To provide an appreciation of the variation within key variables, the frequency of violations was grouped according to categories or intervals across the range of operational characteristics. The frequencies at each interval or category cannot be directly compared without some bias given to those intervals in which more actual opportunities to violate occurred. Therefore, the percent choosing to violate per interval was determined. Figures illustrate the distributions of these percentages by type of violation.

Train Speed

Three figures show the distribution of noncompliance by violation type for train speeds grouped in intervals of 10 km/h. Figure 6-16 shows the percentage of all violations by train speed. The figure shows that there is no trend in the percent of motorists who violate at different train speeds. Based on Figure 6-16, it appears that train speed may have no correlation with arrival-specific violations.

However, presenting only the FL opportunities and violations (Figure 6-17) provides a different view. A pattern is presented here which surprisingly indicates that as the speed of trains increases, the chance that a motorist will drive through the flashing lights also increases. The positive relationship is fairly uniform over the range of train speeds. The results of the site-specific FL violation analysis, however, resulted in significant independent variables of daily train volume and ADT. Therefore, there appears to be a discrepancy in the results between the site-specific and arrival-specific analyses. However, this difference can be explained by investigating the relationship between train speed and the two site-specific significant variables—daily train volume and ADT. Correlation coefficients were calculated for these relationships and are shown in Table 6-12.

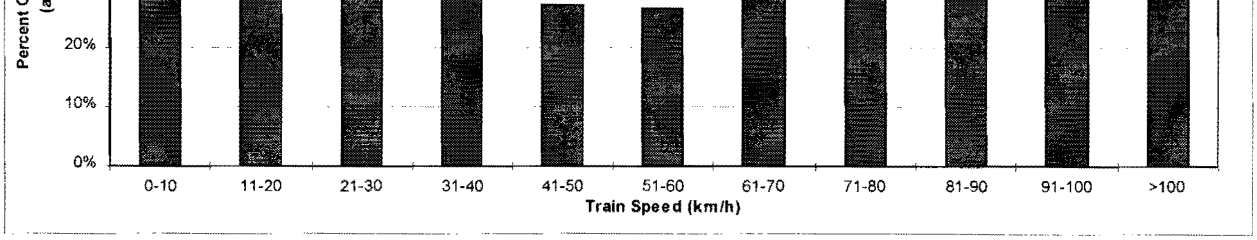

Figure 6-16. Distribution Percentage of All Violations Over Train Speed.

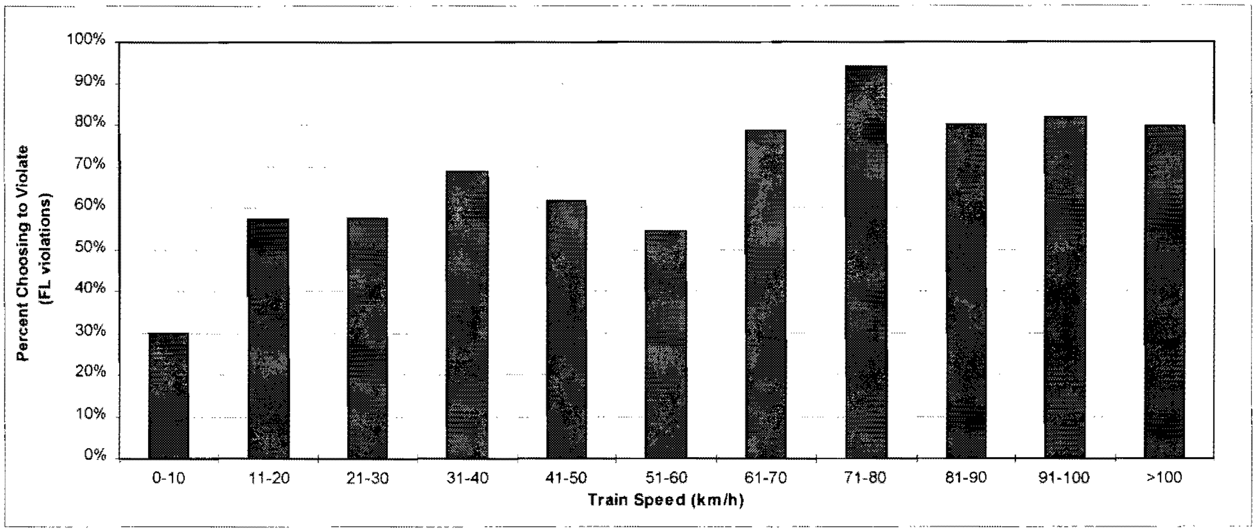

Figure 6-17. Distribution Percentage of FL Violations Over Train Speed.

Table 6-12. Pearson's Correlation Coefficient with Respect to Train Speed (km/h).

Variable	**ADT**	**Daily Train Volume**
Pearson's Coefficient	0.6368	-0.2360
p-value	0.0001	0.0001

The p-values show that the variables are significantly related to train speed. Furthermore, the relationship between daily train volume and train speed shows that as the number of trains per day increases, the speeds tend to decrease. The relationship between ADT and train speed is positive. That is, as the ADT increases, so does the train speed. Therefore, as the train speeds increase, there tend to be fewer trains and more highway vehicles. This, in turn, leads to higher percentages of violations (from those motorists who have an opportunity to violate) as train speeds increase. This significant relationship between train speed and the other two variables deemed significant in the site-specific analysis (daily train volume and ADT) is the reason why train speed did not show up as significant in the site-specific analysis. By incorporating daily train volume and ADT, the variability in train speed is mostly accounted for before it is even introduced into the model.

Figure 6-18 incorporates only TEVs. As train speed increases, the percentage of those who drive around the gate arms decreases until train speeds are over 80 km/h. At speeds over 80 km/h, over half of the drivers presented with an opportunity to violate do so. At low train speeds, motorists may be more comfortable judging their available time to drive through the flashing lights or around the gate arms. Another explanation for the increased number of TEVs during lower train speeds is the fact that when crossings are equipped with fixed-distance warning time devices, the devices are designed to provide at least the minimum warning time (i.e., 20 seconds). Therefore, the railroad must use the highest speed that a train will achieve approaching the crossings. Consequently, when

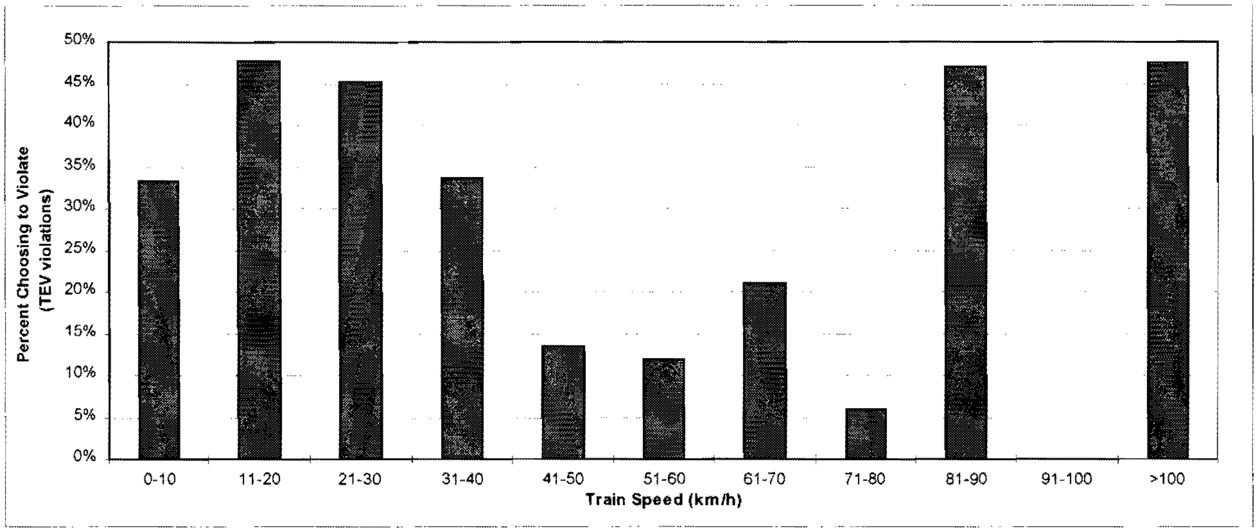

Figure 6-18. Distribution Percentage of TEVs Over Train Speed.

trains of lower speeds approach the crossings, they trigger the FDWT at the same point the faster trains do. Ultimately, this results in longer warning times and more opportunity for a motorist to become impatient and violate the gate arms.

Warning Time

The distribution of violation types was plotted versus warning time (in intervals of 10 seconds). Figures 6-19 through 6-21 show the results. Figure 6-19 includes all violation types. As indicated by the positive slope, as warning time increases, the percent of violations also increases up to 90 seconds of warning time. So the more time the motorist has between when the lights begin to flash and when the train actually arrives at the crossing may be a good explanatory variable when considering violations. Figure 6-20 includes only FL opportunities and violations. No significant pattern can be discerned from the figure.

Figure 6-21 includes only TEVs and their associated opportunities. In this figure, the trend is similar to Figure 6-19. Logically, this is what one might expect. In other words, the more time motorists have to wait at the crossing without the arrival of a train, the more likely they are to drive through the lights or around the gate arms. This finding also validates the results of the site-specific TEV analysis which resulted in one of the independent variables being warning time. Furthermore, this result is consistent with previous literature pertaining to relationships between violations (and accidents) and warning times. It is expected that warning time will be significant in predicting TEVs using the arrival-specific data.

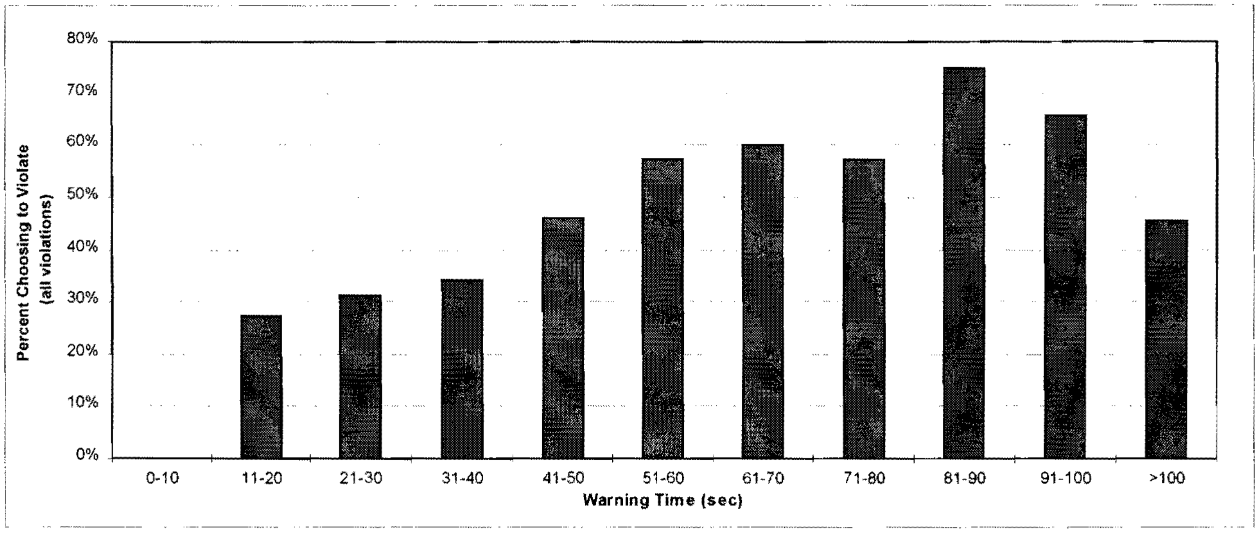

Figure 6-19. Distribution Percentage of All Violations Over Warning Time.

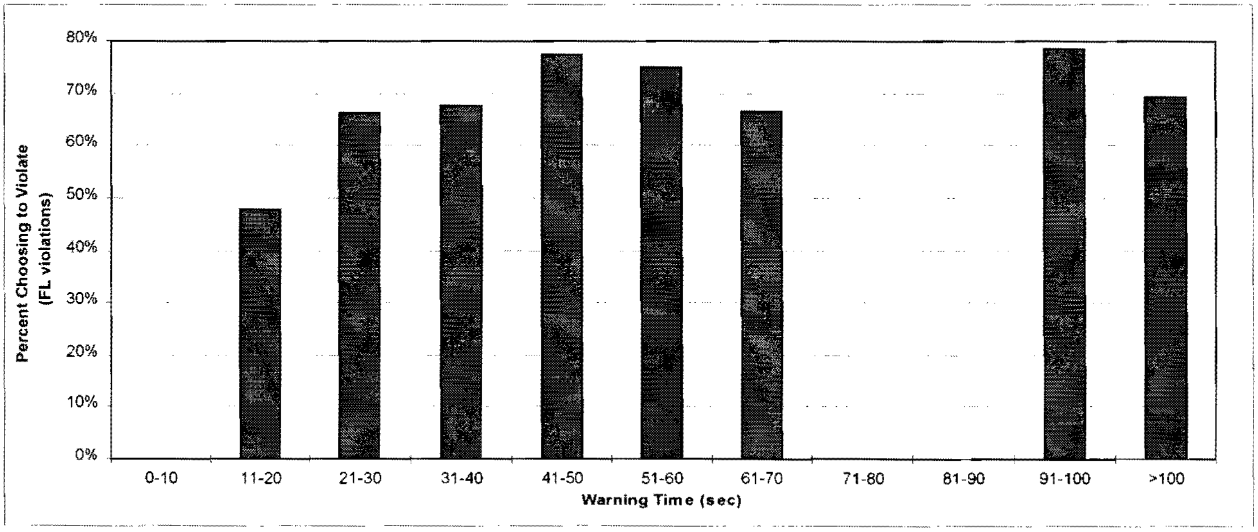

Figure 6-20. Distribution Percentage of FL Violations Over Warning Time.

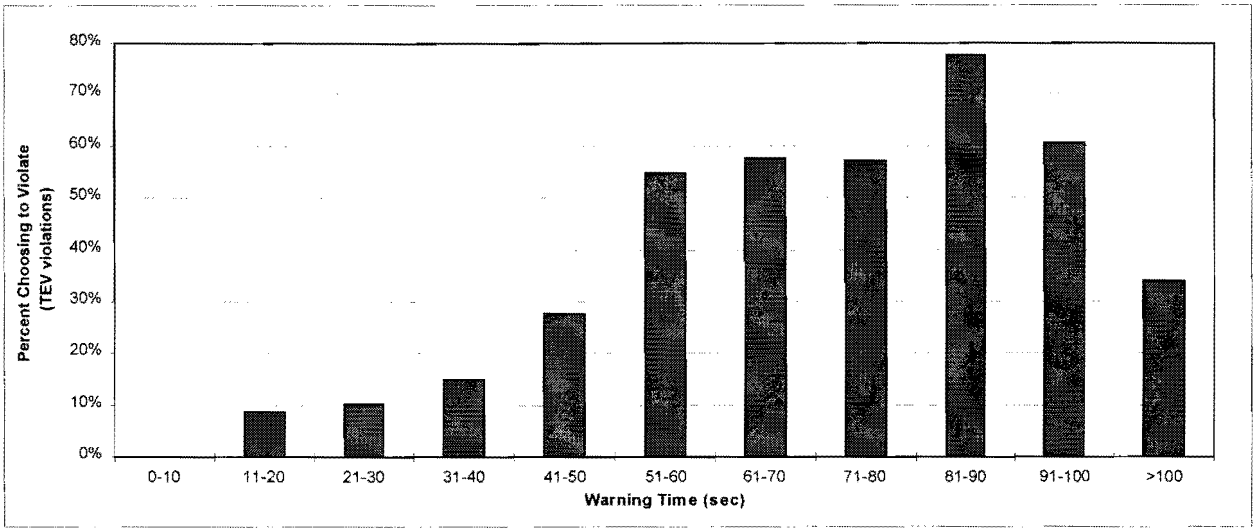

Figure 6-21. Distribution Percentage of TEVs Over Warning Time.

Development of a Logistic Regression Model

As previously discussed, the site-specific analysis used daily averages of each variable in an attempt to predict the number of violations that one may expect per day. One caveat to this approach is that by averaging all the variables, the daily variation that occurs within each site is neglected. Although statistically significant models can result in this averaging technique, the variation between trains and drivers is not included. Therefore, an arrival-specific analysis was chosen to account for the variability that is associated with each opportunity to violate at a site.

Because in the arrival-specific analysis an "event" occurs (i.e., either the motorist violates or complies with the traffic laws associated with active traffic control devices), the dependent variable is binary. In other words, there are only two possible events that can occur — a complying act or a violation. To model this situation, logistic regression was used. Logistic regression is a statistical procedure for developing relationships that predict the probability that a particular event will occur rather than the number of events that will occur (as in the site-specific analysis when the number of violations were modeled). Consequently, the results will predict the probability of certain violation types occurring, given an opportunity. More specifically, the result will be the probability that a violation type (either FL or TEV) will occur for a given opportunity. Once again, the AT violation type was not modeled because of such few occurrences (28) and the fact that 17 (68 percent) of these violations occurred at one site.

FL Analysis Results

Logistic regression analysis was applied to the FL opportunities. A stepwise analysis was performed using PROC LOGISTIC in SAS to identify those parameters that significantly contributed to predicting the probability of a FL violation occurring for each opportunity. The confidence levels were set at 95 percent. The same set of independent variables previously selected for use in the site-specific analyses were also used for the arrival-specific analyses. Table 6-13 shows the final results and model diagnostics of the logistic regression analysis for FL violations.

Table 6-13. Logistic Regression Statistics for FL Violations Prediction Model.

Statistic	Parameter Value	Chi-Square Statistic	p-value	Odds Ratio[1]
Intercept	0.5924	3.033	0.0816	
Train Speed (km/h)	0.00936	3.893	0.0485	1.009
Number of Tracks	-0.1881	5.914	0.0150	0.829
Number of Observations	Number of Opportunities			313
	Number of Discarded Observations[2]			96
	Number of Opportunities with trains			217
	Number of Violations (% of opportunities)			170 (78%)
R_L-Squared	0.348			

[1] Odds ratio equals exp(coefficient). It indicates the amount by which the odds of a FL violation occurring increase for each unit increase in the variable.

[2] Discarded observations were caused by the absence of train-related data associated with the observation. Situations when this occurred include: opportunities with no violations and no trains (12); opportunities with FL violations but no train (47).

The model produced here has a slightly higher coefficient of determination than the site-specific multiple regression model using 49 sites. Two variables were deemed significant in the arrival-specific analysis (train speed and number of tracks). Daily train volume and ADT were found to be significant in the 49 period site-specific model. Consequently, the models have their differences. In general, the logistic model appears to fit the data relatively well and, in general, slightly better than the multiple regression model developed for the 49 site-specific analysis.

The 19 site-specific model which only includes exposure as an independent variable appears to fit that data considerably better than the two previously discussed FL violation models (with an adjusted R-squared of 76 percent). With only one independent variable, this model could be considered the most appropriate. However, this model was developed using 19 very aggregated observations (i.e., all the variables were reduced to daily averages) and the independent variable is actually an interaction variable that requires ADT and daily train volume to compute.

TEV Analysis Results

Using the same procedure as described above, TEVs were also analyzed using stepwise logistic regression. The confidence levels were set at 95 percent, and the same set of independent variables were used. Table 6-14 shows the final results and model diagnostics of the logistic regression analysis for TEV violations.

Table 6-14. Logistic Regression Statistics for TEVs Prediction Model.

Statistic	**Parameter Value**	**Chi-Square Statistic**	**p-value**	**Odds Ratio**[1]
Intercept	-5.4882	86.19	0.0001	
Warning Time (sec)	0.0526	64.45	0.0001	54
Adequate Sight Distance[2]	1.6865	29.43	0.0001	5.401
Number of Tracks	-0.4288	10.79	0.0010	0.651
Number of Lanes	0.5469	13.03	0.0003	1.728
Number of Observations	Number of Opportunities			637
	Number of Discarded Observations[3]			127
	Number of Opportunities with Trains			510
	Number of Violations (% of opportunities)			147 (29%)
R_L-Squared	0.789			

[1] Odds ratio equals exp(coefficient). It indicates the amount by which the odds of a FL violation occurring increase for each unit increase in the variable.

[2] 0 if adequate, 1 otherwise

[3] Discarded observations were caused by the absence of train-related data associated with each discarded observation. Situations when this occurred include: opportunities with no violations and no trains (58); and opportunities with a TEV and no train (69).

The statistical results summarized in Table 6-14 are somewhat surprising. A logistic coefficient of determination equal to 79 percent indicates that over three-quarters of the variability in TEVs is explained by the independent variables. This value is also considerably higher than that of the site-specific analysis. The averaging that was conducted for the site-specific analysis is likely the culprit for this difference. After the averages were calculated for each site, the number of observations were not great enough to account for the variability in the averages. With the arrival-specific analysis, which incorporates over 500 observations in the analysis, more data are available to explain the variability.

Interpretation of the independent variables appears to be reasonable. As warning time increases, the probability of a TEV occurring also increases. Furthermore, if sight distance is adequate, then the assigned coefficient is zero. When sight distance is inadequate, however, a one is assigned to the estimated sight distance variable, and the probability of a TEV increases. Except for sight distance, all relationships are what one could logically expect.

In addition to the appropriate signs of the independent variables, the model also produces a surprisingly high coefficient of determination (R-squared) of 79 percent. This indicates that 79 percent of the variation is explained by the independent variables. Generally, this model appears to be more reasonable than the previous two multiple regression models developed to predict TEVs. This logistic model has a considerably higher R-squared value than the previous models.

SUMMARY OF THE DEVELOPED MODELS

Two types of models were developed from the data collected in this study: (1) regression models that can be used to predict for a site the number of expected flashing light violations and typically enforced violations and (2) logistic models that can be used to predict whether a driver will commit a flashing light violation or a typically enforced violation. All models were based upon data collected at 19 different sites. The format and quantity of the data varied between the different efforts. For the regression modeling efforts, two data sets were used. One data set contained data for one day at each of the 19 sites. The other data set contained multiple days for six of the sites and one day for the remaining 13 sites. Models were developed using the different data sets because of concerns with not having multiple days for all sites. Not using the data for the multiple days at the six sites, however, could have resulted in a lost opportunity to more fully explore how operational and geometric elements influenced violations.

The logistic models related the data present during each opportunity to violate with the action of the driver. The models only considered when a train crossed during the activation, i.e., no false activations. This approach allows the model to use the warning time present during the violation rather than an average warning time for the 24-hour period, which is what is used in the regression models. All models are limited in that they do not account for any specific driver characteristics. This would be a very difficult variable to quantify; however, it is recognized that the characteristics of the drivers using a crossing can impact the frequency of violations experienced. In summary, the following models were determined:

Predict number of violations (Regression)

19 sites, 19 24-hour periods:

$$\text{FLV} = -1.397 + 0.0000787\,(\text{exposure}) \qquad R^2 = 0.76 \tag{6-1}$$

$$\text{TEV} = -11.540 - 0.4102\,(\text{train speed}) + 1.283\,(\text{warning time}) \qquad R^2 = 0.46 \tag{6-2}$$

Regression at 19 sites, 49 24-hour periods:

$$\text{FLV} = -3.45 + 0.000425\,(\text{ADT}) + 0.47\,(\text{daily train volume}) \qquad (6\text{-}3)$$
$$R^2 = 0.31$$

$$\text{TEV} = -7.815 + 0.1894\,(\text{warning time}) + 5.26\times10^{-5}\,(\text{exposure}) - 6.47\times10^{-11}(\text{exposure})^2 \qquad (6\text{-}4)$$
$$R^2 = 0.50$$

Where:

FLV = number of predicted flashing light violations
TEV = number of typically enforced violations
Exposure = Average daily traffic at the crossing multiplied by daily train volume
Train Speed = Average train speed at the crossing (km/h)
Warning Time = Time between when the lights begin to flash and the train arrives at the crossing (sec), average for all trains in 24-hour period
ADT = Average daily traffic at crossing
Daily Train Volume = Number of trains at the crossing in a 24-hour period

Predict Probability that a Violation will Occur (Logistic Models)

$$Prob(FLV) = \frac{e^{0.5924 + 0.00936(TS) - 0.1881(TR)}}{1 + e^{0.5924 + 0.00936(TS) - 0.1881(TR)}} \qquad (6\text{-}5)$$

$$R^2_L = 0.348$$

$$Prob(TEV) = \frac{e^{-5.4882 + 0.526(WT) + 1.6865(SD) - 0.4288(TR) + 0.5469(LA)}}{1 + e^{-5.4882 + 0.0526(WT) + 1.6865(SD) - 0.4288(TR) + 0.5469(LA)}} \qquad (6\text{-}6)$$

$$R^2_L = 0.789$$

Where:

TS = Train Speed, Train speed at the crossing (km/h)
WT = Warning Time, Time between when the lights begin to flash and the train arrives at the crossing (sec)
SD = Adequacy of Sight Distance, 0 if adequate, 1 otherwise
TR = Number of Tracks
LA = Number of Lanes on Approach

APPLICATION OF THE DEVELOPED MODELS

The logistic models (6-5 and 6-6) were developed using a much greater number of data points than the linear regression models (6-1 through 6-4), and the regression models used averages over the 24-hour period for the independent variables rather than the specific value present during the compliance or violation at the crossing. **Therefore, the logistic models are recommended for comparing the relative safety at different sites.** For example, model 6-5 could be used to identify which sites would have a greater likelihood of a typically enforced violation occurring than other sites. Furthermore, model 6-4 could be used to predict the number of violations expected at a site; however, one would need to assume average or typical values for the input variables and assume the number of opportunities present at the site. Number of typically enforced violations could then be calculated by determining the probability of a typically enforced violation occurring using model 6-4 and then multiplying that number by the expected number of opportunities present.

Because the expected number of opportunities present is not an easy value to determine or measure, the logistic models are not recommended if the number of violations is the desired result. In addition, the logistic models did not account for violations that occurred when the gates were activated but no train arrived. These observations were discarded in the model development efforts. **Therefore, the models developed using linear regression are recommended for predicting number of violations.**

Potential uses for the above equations are the ranking of crossings for additional enforcement or for safety improvements. A site with a high number of violations is assumed to also have the potential of having a large number of accidents. The above equations could be used to target particular sites for additional enforcement to decrease the hazardous behavior. Another potential use of the equations is having them incorporated in the procedure used by TxDOT to rank sites for safety improvements. Chapter 3 summarizes the procedure currently used to rank all sites (not just sites with active crossings). The equations developed in this research could be used to identify those sites with active crossings that are expected to have higher violation rates than other sites which also have active crossings. The current formula used by TxDOT includes the number of train-vehicle collisions in the previous five years. Because the number of train-vehicle collisions is small, even over a five year period, and the number of violations is much greater, the above equations could provide better sensitivity to the level of hazardous behavior occurring at a site.

CHAPTER 7
BEFORE-AND-AFTER STUDY RESULTS

The objective of the before-and-after study was to determine the impact of installing and operating an automated enforcement system on violations at highway-railroad grade crossings. Use of automated enforcement in other areas has shown that a significant reduction in violations occurs as the result of photographing violators and mailing citations. The Texas Demonstration Project differs from other studies in two significant areas: type of correspondence mailed and public relation campaigns.

Rather than mailing citations, the Texas project sent an "education letter" and educational materials to the owner of vehicles recorded as violating the gate arms at the three sites. The letter emphasized that the owner was not being cited or fined and that the letter was being mailed as a public service, to remind the driver of the law and to encourage safe driving behavior at all railroad crossings. These letters were accompanied by copies of the photographs showing the violation and educational materials. The educational materials contained safe driving tips at highway-railroad grade crossings and information on safety at crossings.

An extensive public information campaign employing multiple types of media (e.g., print, TV, radio, safety and educational brochures, etc.) is an essential component of an effective and credible automated enforcement program. Due to the constraints of time and budget resources for the Texas Demonstration Project, a large-scale public information campaign was not conducted as part of the demonstration project. A public information campaign was judged to be desirable, but optional, for the purposes of this short-term demonstration project. The demonstration project was the subject of media attention on at least one occasion. During Texas Operation Lifesaver's Highway-Rail Safety Week, television news stories discussed the demonstration project as part of a story that covered highway-rail safety in Texas. The stories were reportedly broadcast during the evening newscast on at least two Austin television stations and on at least one Houston television station during May 1997.

STUDY SITE DESCRIPTION

The study was conducted at three locations—two in Austin and one in Crosby. These locations had a minimum of three accidents in the previous five years, traffic volume of 7500 vehicles per day, and train volume of 16 trains per day.

West Mary and Oltorf Sites

Two sites were selected in Austin. The West Mary site is a two-lane residential collector roadway with approximately 7500 vehicles per day. The crossing has one track and approximately 17 trains per day. Figure 7-1 illustrates the crossing. The Oltorf site is a four-lane roadway located about one km from the West Mary crossing. It is an arterial street with an average daily traffic of approximately 16,600 vehicles per day. The crossing has one track and approximately 17 trains per day. Figures 7-2 illustrates the crossing.

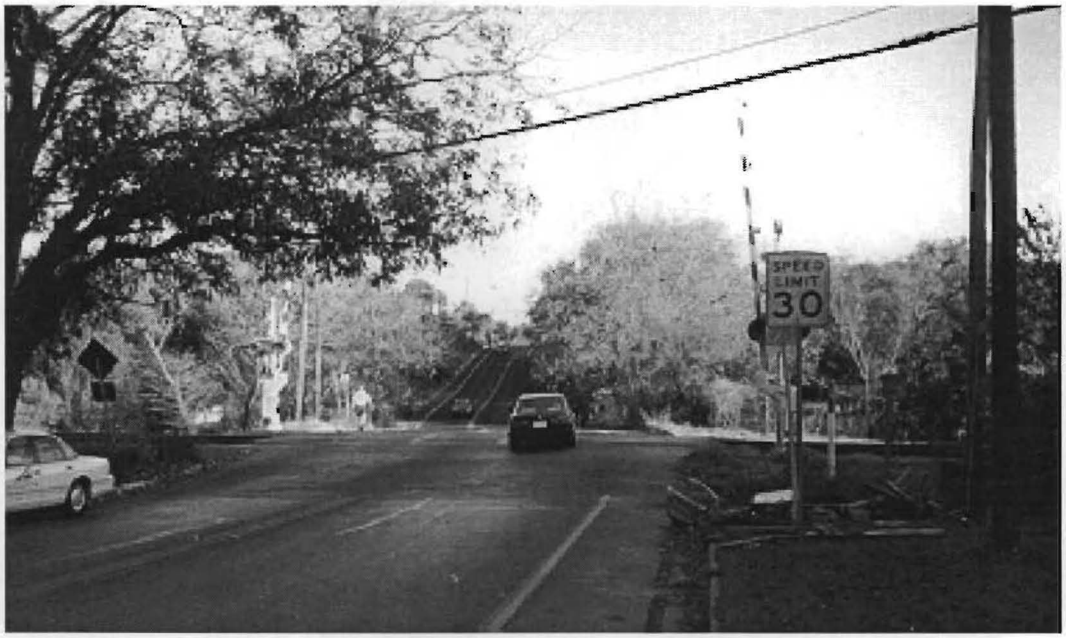

Figure 7-1. Photograph of West Mary Site.

Figure 7-2. Photograph of Oltorf Site.

The vendor for the Austin sites used an automated enforcement system designed and developed for the specific purpose of detecting and recording violators at highway-railroad grade crossings. Figure 7-3 summarizes the process used to detect and record violations and to identify and inform alleged violators of their actions. The automated enforcement system field equipment consisted of two cameras located in environmental housings. The housings were mounted on a pole approximately 3 to 4.6 m high. AC power and video cable were run from a conduit in the pole to a junction box that housed a computer and modem that recorded images of the violators and transmitted the high-resolution pictures to a data processing workstation. Figure 7-4 shows photographs of the equipment at the Austin sites.

Grade crossing warning system is activated (flashing signals followed by gate closure);
loop detectors are ready to detect violations.

↓

Digital violation images are saved to a hard disk in a computer located on site.

↓

Digital images are transmitted via modem and voice-grade phone line
to the central office after the train has cleared the tracks.

↓

Clerk reviews violation images. Records information about the violator,
such as the license plate number and type of vehicle, into the computer database.
In addition, information on why the license plate is not readable is recorded.

↓

The electronic file of license plate numbers is submitted to the TxDOT motor vehicle
registration database via a modem. TxDOT provides registered owner's name and address and
type of vehicle.

↓

Clerk verifies the type of vehicle and the license plate number matches with the information
provided by TxDOT. After a successful match, the picture of the violation is printed.

↓

The following is then sent by overnight mail to the Austin Police Department:
information about the violation such as the registered owner of the
license plate number and pictures of the violation.

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The Austin Police Department generates, signs, and mails the education letters.

Figure 7-3. Process Used at Austin Sites.

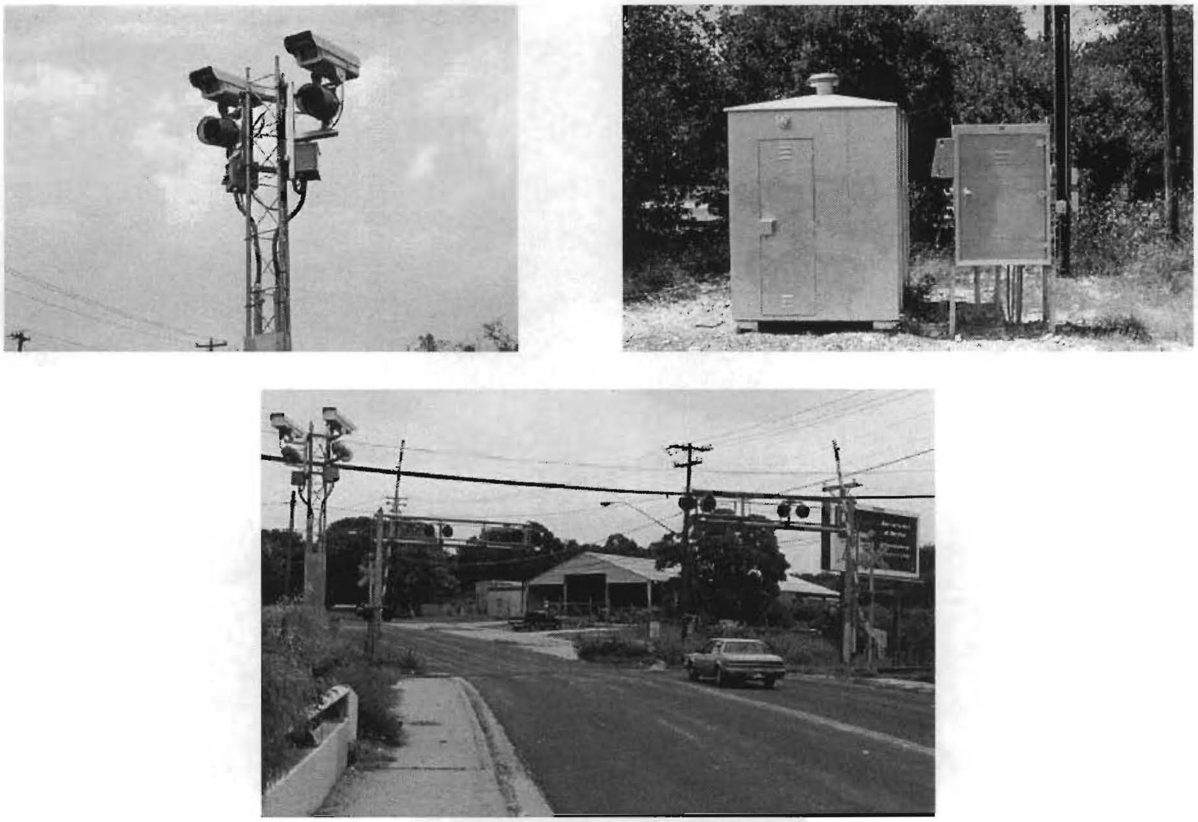

Figure 7-4. Photographs of Equipment at Austin Sites.

Specific site experiences at West Mary and Oltorf are reported elsewhere (1). Based on the observations made concerning the process used at the sites, the following conclusions were made:

1. The automated enforcement system vendor successfully demonstrated the ability to detect and record violations at highway-railroad grade crossings.

2. Based on the available evidence, the process employed by the vendor, working with local law enforcement officials, to identify and contact suspected crossing gate arm violators appears to have also been successful.

3. On at least one occasion, a citizen who did not violate the crossing gate arms received an educational letter. This situation occurred because the vehicle was sold before the violation. Such events were anticipated and are generally beyond the control of the automated enforcement system vendor.

FM 2100

The FM 2100 site has one track crossing a four-lane state highway with an average daily traffic of 19,000 vehicles per day. The track handles approximately 16 trains per day. Figure 7-5 illustrates the crossing. The vendor for the FM 2100 site used an automated enforcement system designed and developed for multi-purpose traffic enforcement applications (e.g., red-light enforcement, speed enforcement, etc.). Figure 7-6 summarizes the automated enforcement process used at the FM 2100 site.

The system consisted of a camera, a computer, and detection loops. The camera was located in a housing unit mounted atop a hinged pole. Each photograph had a superimposed data box that contained the time, date, and location of the violation, along with how many seconds after the flashing red lights were activated that the vehicle entered the grade crossing. Figure 7-7 is a photograph of the equipment at the site.

Figure 7-5. Photograph of FM 2100 Site.

Grade crossing warning system is activated (flashing signals followed by gate closure); loop detectors are ready to detect violations

↓

Violation images are recorded on film.

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Film canister and memory card are removed from the camera twice weekly and over-nighted to the processing office.

↓

Clerk reviews film and memory card simultaneously. Records information about the violator, such as the license plate number and type of vehicle, into the computer. In addition, information on why the license plate is not readable is recorded.

↓

The electronic file of license plate numbers is submitted to the TxDOT motor vehicle registration database via a modem. TxDOT provides registered owner's name and address and type of vehicle.

↓

Clerk verifies the type of vehicle and the license plate number matches with the information provided by TxDOT. After a successful match, the picture of the violation is printed.

↓

The vendor representative generates, signs, and mails the education letters. In addition, prepared educational materials are inserted with the letter.

Figure 7-6. Process Used at FM 2100.

Discussions on the site experience at FM 2100 are contained elsewhere (1). The following conclusions were developed based on the observation made at the site:

1. The automated enforcement system vendor for FM 2100 demonstrated the ability of its equipment to detect and photograph vehicles violating the gate arms at a highway-railroad grade crossing.

2. The vendor successfully demonstrated the ability to identify and contact suspected violators.

3. Several times, a citizen who did not violate the crossing gate arms received an educational letter. Such events were anticipated and are generally outside the control of the automated enforcement system vendor. The experience at FM 2100, however, emphasizes that all involved parties must clearly agree upon and understand the operational definition of a violation at the highway-railroad grade crossing. (The vendor initially had set the system to record two seconds after the warning lights began flashing, rather than two seconds after the gates began descending, as was specified.) Such an understanding can only result from effective communication between the project sponsor, the railroad company, the automated enforcement system vendor, and the law enforcement agency.

Figure 7-7. Photograph of Equipment at FM 2100 Site.

VIOLATIONS OBSERVED AT STUDY SITES

The automated enforcement equipment operated for three to four and one half months depending on the site. Violation characteristics were obtained at the sites according to the data collection and reduction approach presented in Chapter 5. Table 7-1 summarizes study site milestones.

Table 7-1. Study Sites Milestones.

Street/Highway Name	Collect Before Data	Operation Begins	Collect After Data
FM 2100	May 19-24, 1996	April 29, 1997	July 21-25, 1997
West Mary St. and Oltorf St.	April 28- May 3, 1996	March 13, 1997	July 7-11, 1997

The observed violations were divided into two groups—violations (which include all violations) and typically enforced violations (abbreviated as TEV within this report). The Texas Motor Vehicle Law about gated railroad crossings (Article XI, Section 86 of the Uniform Act, Subsection C) states:

> A person who is the driver of a vehicle commits an offense if the person drives the vehicle around, under, or through a crossing gate or barrier at a railroad crossing while the gate or barrier is closed, being closed, or being opened.

Consequently, when the video data collected in the field were reduced and entered in a spreadsheet, all vehicles driving under (as they were closing or opening) or around the gates, or while the lights were flashing, were classified as violators of the gated arms. However, discussions with law enforcement personnel and TxDOT led to an understanding that officers tend to only enforce violations that occur two or more seconds after the gate arms begin to move. One reason given for allowing the two second "grace period" so that motorists would not be cited if they decided clearing the tracks at the existing speed was safer rather than attempting to stop at a high deceleration rate and risk stopping too close to the tracks. For traffic signals, this situation is termed the "dilemma zone," and the yellow clearance interval is designed to avoid its occurrence. At highway-railroad grade crossings, the gate arm might begin its descent after a motorist has committed to driving across the tracks. Officers contacted for this study said they would not want to cite these motorists, who made a decision based on what they felt was the safest approach to the situation, with a moving violation.

Considering the above discussion, an early consensus was reached with TxDOT and the local law enforcement agencies involved with the demonstration project to allow a two-second grace period from the time the gates started their descent until a violation that typically would be enforced occurred. Therefore, the difference between the number of violations and the number of TEVs is the number of violations that occurred when (1) the warning lights were flashing, (2) during the initial two seconds of the gates descending, and (3) after the train passes the crossing. Warning/educational letters were only to be sent to those vehicles classified as a TEV. Figure 7-8 illustrates the number of violations and the number of TEVs for each study site.

EFFECTS OF AUTOMATED ENFORCEMENT INSTALLATIONS ON VIOLATIONS

Table 7-2 shows the violations or TEVs that occurred per train, activation, or hour. Overall, all rates measured increased between the before-and-after period. Violations per train, perhaps the most useful information, almost doubled, while TEVs increased by 25 percent.

Using trains per day for each site, a randomized complete block design (RCBD) was implemented to statistically test the variability in violations between the before-and-after periods. The data were blocked by sites, thus yielding a three by two RCBD with four replications (violations per day) per cell. The statistical procedure, called analysis of variance (ANOVA), was used along

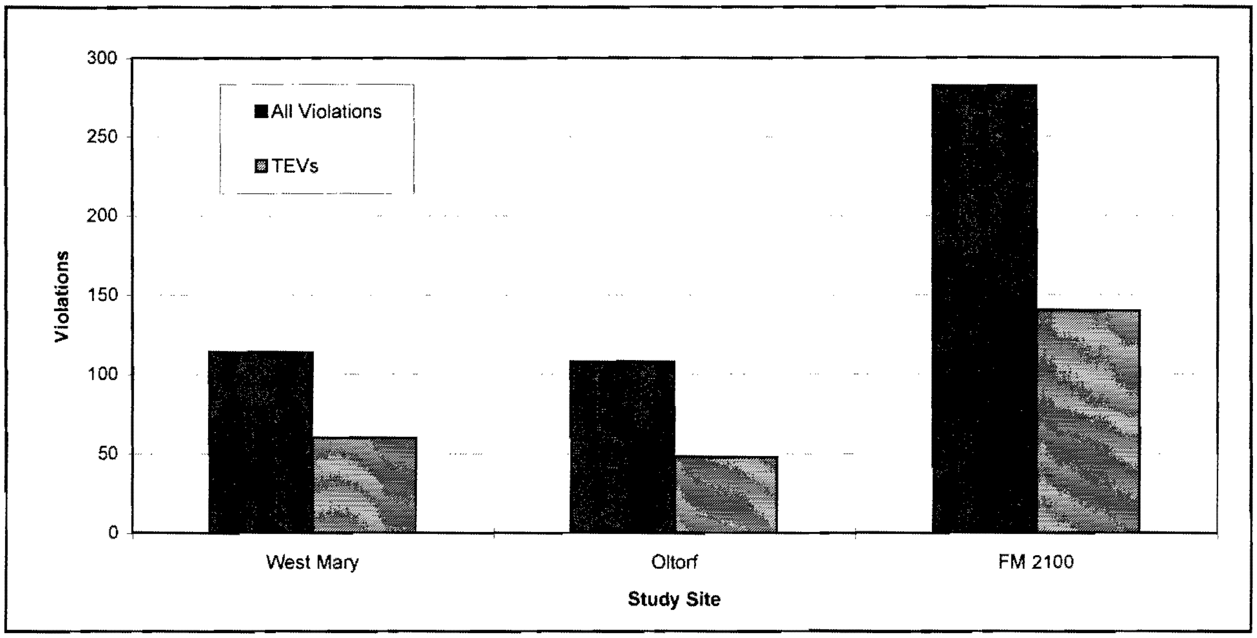

Figure 7-8. Number of Violations and TEVs for the Study Sites.

Table 7-2. Summary of Before-and-After Rates.

Location	Period	Violations per			TEV per		
		Train	Activation	Hour	Train	Activation	Hour
West Mary	Before	0.67	0.67	0.54	0.21	0.21	0.17
	After	0.77	0.78	0.54	0.18	0.18	0.12
	Percent Change	14.9	16.4	0.0	-14.3	-14.3	-29.4
Oltorf	Before	0.46	0.47	0.40	0.09	0.09	0.08
	After	0.86	0.86	0.62	0.25	0.25	0.18
	Percent Change	87.0	83.0	55.0	177.8	177.8	-77.5
FM 2100	Before	1.08	1.02	0.85	0.43	0.41	0.34
	After	1.94	1.91	1.39	0.43	0.43	0.31
	Percent Change	79.6	87.3	63.5	0.0	4.9	-8.8
All Sites	Before	0.72	0.71	0.59	0.24	0.23	0.19
	After	1.23	1.23	0.88	0.30	0.30	0.21
	Percent Change	70.8	73.2	49.2	25.0	30.4	10.5

with Tukey's Studentized Range (Honest Significant Difference) test to analyze the data. Table 7-3 shows results of the analysis.

The results indicate that statistically, no significant difference exists among the violations per day between the before-and-after periods (measured at the 95th percentile confidence level). Consequently, the results summarized in Tables 7-2 and 7-3 are not as disappointing as they might first appear. Basically, the variability in violations is so great that the differences witnessed and shown in Tables 7-2 and 7-3 can be considered statistically the same.

A similar test was conducted using enforceable violations instead of violations. The results indicated that, again, the difference was not statistically significant at the 95th percentile confidence level. Therefore, the differences in enforceable violations between the before-and-after periods can again be explained by the large amount of variability in the data.

Table 7-3. Variability of Violations per Day.

Period	**Average Number of Violations per Day**	**Observations**
Before	20.333	12
After	14.833	12
α =0.05 df = 18		
Minimum HSD = 6.2637		

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

The objective of this effort was to identify operational and geometric relationships that may influence violations at gated highway-railroad grade crossings (violation study), and to determine the effects of sending education letters to motorists recorded as violating the gate arms (before-and-after study). Based on the work performed, the following conclusions and recommendations are made.

CONCLUSIONS

Violation Study

- Three types of violations were observed at the study sites: flashing light (which occurred when the warning lights were flashing and the gate arms were vertical or during the initial two seconds of the gate arm descending), typically enforced violations (which occurred after the gate arms had been in motion for two seconds or when the arms were in the horizontal position prior to the train arrival), and after train violations (which occurred after the train departed the site but before the gates were completely raised).

- Approximately 47 percent of the violations were in the typically enforced violation category. The flashing light category represented 47 percent of observed violations. The after train category contained 5 percent of the observed violations, with most of the violations at one site. Had that site not been included, the after train category would have had only about 2 percent of the observed violations.

- On average, one violation occurs for each gate activation at a gated crossing. For typically enforced violations only, approximately one violation occurs for every two gate activations at an active crossing.

- For the data collected in this study, 69 percent of the drivers arriving when the lights are flashing before or during the initial two seconds of the gates moving committed a violation. For those drivers with an opportunity to commit a typically enforced violation, 34 percent did so.

- Exposure, which is the product of average daily traffic and train volume, can be used to predict flashing light violations, and with warning time to predict typically enforced violations.

- Warning time is correlated with the number of typically enforced violations. Minimum variation in number of violations and low violation numbers are observed when the warning time is less than 35 seconds; however, when the warning time is greater than 35 seconds, considerable variability exists and higher numbers of violations occur. Modifying how warning time is set at a crossing could have a notable influence on the number of violations at the crossing.

- Two types of models were developed from the data collected in this study: (1) regression models that can be used to predict the number of expected flashing light violations and typically enforced violations at a site and (2) logistic models that can be used to predict whether a driver will commit a flashing light violation or a typically enforced violation.

- Given that the logistic models were developed using a much greater number of data points than the linear regression models, and that the regression models used averages over the 24-hour period for the independent variables rather than the specific value present during the compliance or violation at the crossing, the logistic models are recommended for comparing the relative safety at different sites. If the expected number of violations is desired, the multiple regression equations should be used.

Before-and-After Study

- Although violations and TEVs both increased between the before-and-after periods, the increase was not statistically significant at the 95th percentile confidence level.

- The results of the before-and-after study indicate that the effects of sending educational materials to motorists recorded as violating the gate arms do not affect the violation rate. However, the project limitations included not fining the violator and minimal public education. Given a more permanent automated enforcement program with appropriate public education and fine value, the violation rates would have likely decreased, as found in other studies.

RECOMMENDATIONS

- The logistic models developed here should be considered when prioritizing highway-railroad grade crossing improvements as a supplement to accident prediction models and indices and to identify locations that could benefit from additional enforcement efforts. The models can be used to predict the likelihood of a violation, given the operational and geometric characteristics of the crossing, and thus be a reflection of the degree of hazard present at the crossing.

- Warning time has a significant influence on the number of violations at highway-railroad grade crossings. How warning time is set at a specific crossing depends upon many different variables and may not be constant from one crossing to another within an area. Additional research is needed regarding how warning time is set and how it could be improved to decrease violation rates at highway-railroad grade crossings.

- If an automated enforcement program is to be implemented at highway-railroad grade crossings, public education and an appropriate fine value should be considered priorities. Proper education of the public should produce a reduction in violations.

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