Louisiana Transportation Research Center

Final Report 611

Evaluating the Effectiveness of Regulatory and Warning Signs on Driver Behavior near Highway/Rail Crossings

by

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16. Abstract

There are approximately 211,893 highway-rail grade crossings nationwide with approximately 5,200 in Louisiana. The number of fatalities and injuries at highway-rail grade crossings have proceeded to increase since 2014. Signage has been a choice solution for reducing crashes at highway-rail grade crossings. This study therefore evaluates the effectiveness of regulatory signage in reducing instances of stopped vehicles within the Dynamic Envelope Zone (DEZ) at highway-rail grade crossings. Data was collected prior to signage installation, and after a first novelty period after signage installation (Post-Installation 1) and a second set of data was collected after a longer novelty period (Post-Installation 2). After Post-Installation 1, four sites experienced an average decrease of 36% in major violations and four sites experienced a 66% increase in major violations. After Post-Installation 2, major violations decreased at six sites by an average of 43% and increased by 9% at two sites. Post-Installation 1 data revealed that seven sites experienced decreases in minor violations by an average of 27% and one site recorded an increase in minor violations at 39%. Post-Installation 2 data indicated that the proportions of minor violations increased at four sites by an average of 31% and decreased at the other four by an average of 50%. The proportion of safe maneuvers (Post-Installation 1), increased at six sites at an average increase of 25%, while two sites experienced a decrease in safe driving behavior at an average of 14%. After Post-Installation 2, the proportion of safe maneuvers increased on an average of 45% at five sites and decreased by 24% at the other three sites. The chi-squared test conducted showed mixed effects of the signage. The MBA analysis affirmed the results obtained from the chi-square analysis. Level of Compliance can be defined as the extents to which vehicles undertake a safe maneuver, or engage in a minor or major violation. Overall, the installation of signage did not have strong associations with Level of Compliance. Researchers recommended that in addition to regulatory signage, other methods like using pavement markings, flashing lights/bells and in-vehicle auditory warnings should be employed in order to improve safety at highway-rail grade crossings near roadway intersections with history of crashes.

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ABSTRACT

There are approximately 211,893 highway-rail grade crossings nationwide with approximately 5,200 in Louisiana. The number of fatalities and injuries at highway-rail grade crossings have proceeded to increase since 2014. Signage has been a choice solution for reducing crashes at highway-rail grade crossings. This study therefore evaluates the effectiveness of regulatory signage in reducing instances of stopped vehicles within the Dynamic Envelope Zone (DEZ) at eight highway-rail grade crossings. Data was collected prior to signage installation, and after a first novelty period after signage installation (Post-Installation 1) and a second set of data was collected after a longer novelty period (Post-Installation 2). After Post-Installation 1, four sites experienced an average decrease of 36% in major violations and four sites experienced a 66% increase in major violations on average. After Post-Installation 2, the proportions of major violations decreased at six sites by an average of 43% and increased by 9% at two sites. Post-Installation one data revealed that seven sites experienced decreases in minor violations after the first novelty period by an average of 27% and the remaining site recorded an increase in minor violations at 39%. Post-Installation two data indicated that the proportions of minor violations increased at four sites by an average of 31% and decreased at the other four by an average of 50%. The proportion of safe maneuvers after Post-Installation 1, increased at six sites by an average increase of 25% and 2 sites experienced a decrease in safe driving behavior at an average of 14%. After Post-Installation 2, the proportion of safe maneuvers increased by an average of 45% at five sites and decreased by 24% at three sites. The chi-squared test conducted showed mixed effects of the signage. The MBA analysis affirmed the results obtained from the chi-square analysis. Level of Compliance can be defined as the extents to which vehicles undertake a safe maneuver, or engage in a minor or major violation. Overall, the installation of signage did not have strong associations with LOC. Researchers recommended that in addition to regulatory signage, other methods like using pavement markings, flashing lights/bells and in-vehicle auditory warnings should be employed in order to improve safety at highway-rail grade crossings near roadway intersections with history of crashes.

ACKNOWLEDGEMENTS

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IMPLEMENTATION STATEMENT

The purpose of this project was to evaluate the effectiveness of regulatory signage on driver behavior near highway-rail grade crossings that are in close proximity to roadway intersections and have a history of crashes. Since the signage was not found to be effective all of the time, it was recommended that additional research be undertaken on other forms of enhancements that may encourage drivers to cease stopping within the dynamic envelope zone of railroad crossings. This study does not recommend statewide signage installation at railroad crossings for these reasons. The research team will present and publish these findings, which will contribute to literature in this field of study.

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INTRODUCTION

Nationwide, there are approximately 211,893 highway-rail grade crossings with about 5,262 in Louisiana, of which about 2,837 are publicly owned. Apart from 2015, when there was a slight decrease from the previous year, the number of crashes at highway-grade crossings in Louisiana has been steadily rising for the past five years. Preliminary statistics show that for 2017, there were 2,108 highway-rail incidents resulting in 827 injuries and 307 fatalities nationwide. In the state of Louisiana, 2017 recorded 87 collisions resulting in 32 injuries and six fatalities *[1]*. In addition to presenting safety concerns, there is a liability issue for the state, railroad companies, and private owners, depending on whether the highway-rail incidents occur at a roadway crossing that is open to public or private use. Liability also becomes an issue through the statutory obligations of the parties involved in an incident, regardless of whether the crossing is private or public. These issues can be costly and tend to hamper railroad operations and efficiency by diverting much needed resources towards litigation and compensation efforts.

In 2010, Louisiana was identified as one of the top 10 states with the highest number of reported highway-rail incidents. This led to the state being mandated by the Federal Railroad Administration (FRA) to develop a State Action Plan to improve safety at highway-rail grade crossings (49 CFR 234. 11) *[2]*. In 2017, Louisiana ranked seventh among the states with the highest number of reported highway-rail incidents. In the same year, approximately 64% of all such incidents across the US occurred in the top 10 states *[3]*. This shows that incidents at highway-rail grade crossings still present a challenge for Louisiana and there is a need for identifying measures that will increase safety at Louisiana's highway-rail grade crossings.

For decades, preemption and signage have been used in efforts to reduce incidents at highway-rail grade crossings. According to the Louisiana Department of Transportation and Development (DOTD), in areas with a high crossing density, preemption has been an expensive option due to the need to upgrade adjacent crossings. Where adjacent crossings have not been upgraded, the traffic signal controlling the roadway intersection may not be able to accept the preemption signal. It is also not DOTD's policy to add signals solely for the purpose of preemption, as this has the potential to cause additional problems related to safety at intersections. Warning and regulatory signs are alternatives to preemption. Warning signs, as the name suggests, alert road users of impending danger or unusual conditions ahead that might not be immediately apparent. Regulatory signs influence driver behavior by giving instructions on the appropriate action to take depending on the situation. This type of signage guides vehicles safely and attempts to maintain a steady traffic flow.

This study seeks to evaluate the effectiveness of regulatory signage on driver behavior, specifically within the dynamic envelope of a train. The study reviews the standard "Do Not Stop on Tracks" (R8-8) sign, a variant of this sign, "Stop Here until Stop Sign is Clear," as well as the "Look" (R8-15) sign. The goal of the signage is to draw attention to the need for the train's dynamic envelope to be clear of vehicles and thereby influence driver behavior at such locations.

To achieve the study's objectives, video data was collected for a set period before and after the installation of the signage at eight sites where drivers tend to stop on the tracks. After manually observing driver behavior from the video footage, the types and frequency of vehicle encroachments within the train's dynamic envelope were used to develop safety parameters that analyzed the level of compliance. The level of compliance, before and after installation of the signage, were compared to evaluate the effectiveness of the signs. The level of compliance is defined as the extents to which vehicles undertake a safe maneuver, or engage in a minor or major violation. Additional data, long after the installation of the signs, was collected and analyzed to verify if the observations made were sustained over time. It is anticipated that the research will be able to recommend whether appropriate signage may reduce instances of stopped vehicles within the DEZ of highway-grade crossings. If effective, signage will offer a less expensive alternative to preemption signals to improve safety at problematic locations.

OBJECTIVES

The primary objective of this study is to evaluate the effectiveness of regulatory signage on driver behavior in reducing instances of stopped vehicles, within the dynamic envelope of highway-rail grade crossings near roadway intersections with a history of crashes.

Specifically, the main objectives are:

1. Conduct a literature review of completed and ongoing studies that relate to using signage to improve safety.

2. Confirm with DOTD the list of locations with known problems of stopped vehicles within the dynamic envelope of crossings.

3. Equip the selected locations with traffic data collection devices and collect “Pre-Installation” data.

4. Install accompanying signage at selected locations.

5. Collect “Post-Installation” traffic data.

6. Determine the effectiveness of the signage through comparative analysis of the “Pre-Installation” and “Post-Installation” data.

If effective, it is anticipated that the signage will be widely used at problematic locations statewide to increase safety at grade crossings.

SCOPE

The list of sites to be studied was confirmed with DOTD and eight locations were selected. The research team and DOTD district traffic operations engineers undertook the mounting of video surveillance systems, along with installation of the signage. The research team relied on DOTD to obtain any special permits, if and where necessary, prior to any installations.

METHODOLOGY

The first section of the Methodology provides background information on the dynamic envelope zone (DEZ) and a literature review on studies pertaining to driver behavior in reaction to signage. The second section of the Methodology provides site characteristics and discusses the process for acquiring the regulatory signage. Subsequent sections document the video surveillance systems used in this study and the data processing procedure. The parameters used in this study are then outlined, including the manner in which they were observed and their purposes for understanding driver behavior at the grade crossings. The goal is to identify parameters that analyze driver behavior associated, specifically, with stopping behavior at the stop line and within the DEZ. The rest of this section discusses the comparative analysis using percentage change of the proportions of vehicles in a safe maneuver before and after the sign installation, the chi-squared test to determine whether the percentage changes were statistically significant, and a novel "Market Basket Analysis" (MBA) tool in identifying important associations between driver behavior and site characteristics.

Background and Literature Review

The dynamic envelope is the area a train occupies as it passes through a grade crossing as shown in Figure 1. Therefore, the DEZ includes the track as well as the clearance required for a train's cargo overhang due to any combination of loading, lateral motion, or suspension failure *[4]*. When a grade crossing is within 200 ft. of a roadway intersection, or on roads with high traffic volume, and when vehicles on the road with the crossing must stop due to a traffic signal, stop sign, or yield sign, the vehicle queue may extend over the railroad tracks. By law, drivers are not to stop on the tracks but must wait prior to the stop line whenever a queue is present. However, due to driver distraction, lack of education, and/or other factors, there is a nation-wide problem of drivers stopping within the DEZ when in queue. The *Manual on Uniform Traffic Control Devices* (MUTCD) states that regulatory signage should be installed at these types of intersections and wherever an engineering study determines the potential for highway vehicles stopping on the tracks at a grade crossing to be significant *[4]*.

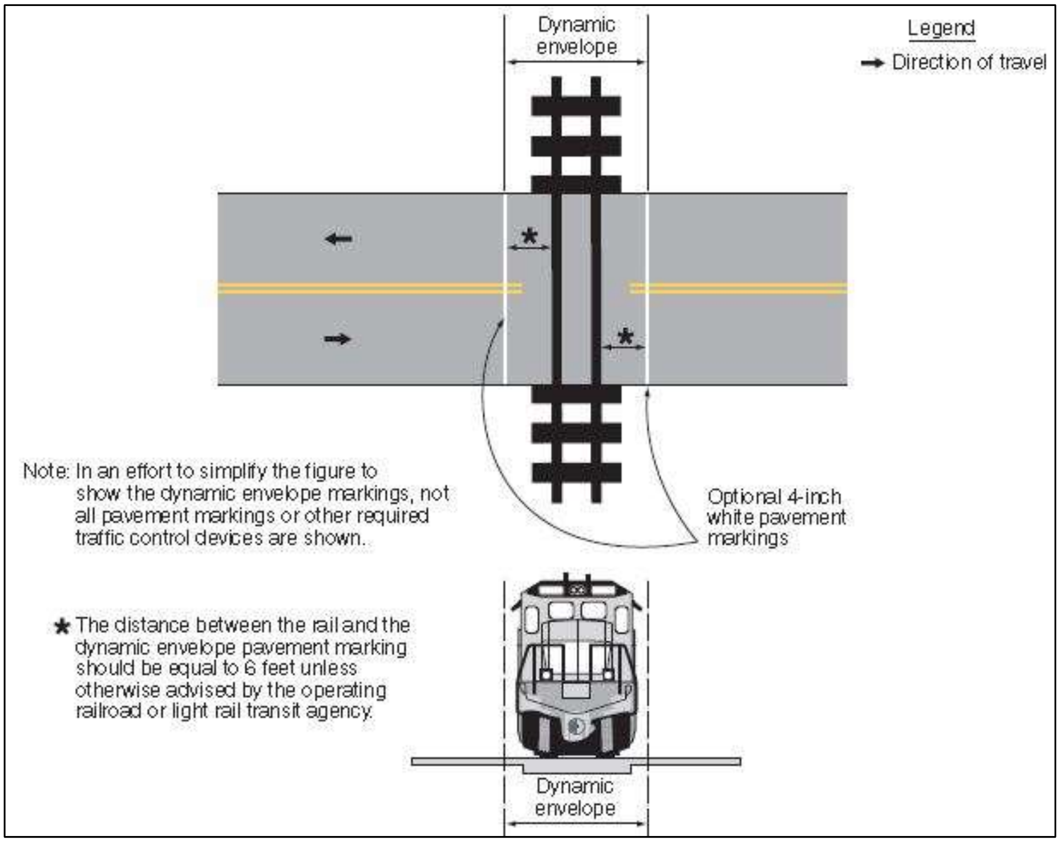

Figure 1
Schematic diagram of dynamic envelope zone

For decades, preemption and signage have been used in efforts to reduce incidents at highway-rail grade crossings. In preemption, the traffic signal controlling the intersection connects to warning devices such as flashing light signals and gates that inform the road users of the approach or presence of rail traffic at grade crossings. The FRA also refers to crossings with gate arms and such devices as active grade crossings, and although these are often more expensive to implement, they are usually much safer than passive grade crossings, which only contain passive signage specified by the MUTCD. When the warning devices are activated by a train's approach, the traffic signal is alerted and put into a special sequence. In this sequence, the approach with the crossing is given priority for a green light in order to move any vehicles away from the tracks. Warning signs and regulatory signs are alternatives to preemption. Warning signs, as the name suggests, alert road users of impending danger or unusual conditions ahead that might not be immediately apparent. Regulatory signs influence driver behavior by giving instructions on the appropriate action to take depending on the situation. This type of signage guides vehicles safely and attempts to maintain a steady traffic flow. Driver behavior is defined here as the manner in which the driver reacts to their surroundings and other influences on the road.

A study on supplemental pavement markings by Stephens and Long identified two critical judgments that drivers make in a matter of seconds when approaching railroad crossings: stopping prior to the tracks and, if not required, determining if there is sufficient unobstructed space to accommodate the vehicle beyond the tracks *[5]*. While stopped in the DEZ, panicked drivers may accelerate or reverse in an attempt to avoid collisions with oncoming trains but by doing so may cause collisions with other vehicles. Drivers in vehicles that have already crossed over the tracks are sometimes unaware that the back end of the vehicle is still within the DEZ. This misperception may also cause fatal crashes with oncoming trains. It is not only imperative to discourage and prohibit this kind of behavior but also to improve the understanding of interactions between violating vehicles and grade crossings.

Various researchers have studied how the presence of regulatory signage influence driver behavior. The parameter for testing driver behavior and quantifying the effectiveness of signage has primarily been drivers' safe maneuvers. For instance, a study in Australia by Tey et al. used an advanced driving simulator to study driver behavior at grade crossings *[6]*. These crossings were equipped with either active or passive warning devices including stop signs, rumble strips, flashing lights/bells, and in-vehicle auditory warnings. Twenty-four volunteers from ages 17 to 66 years were recruited for this experiment. They were instructed to drive as they normally would in a real vehicle. The nature of the experiment was not made known to the volunteers in order to avoid producing artificially high levels of vigilance and a safe maneuver. The results from the experiment indicated that the a safe maneuver rate for stop signs was 74% and these results were then compared to a field study conducted by Li-Sian Tey and Luis Ferreira in 2010 *[7]*. The comparison showed that a safe maneuver for the simulated experiment was higher than a safe maneuver in the field experiment by 33%. This was to be expected since the simulation experiment occurred in a more controlled environment as compared to that of the field experiment.

In 2010, Lenné et al. also used a driving simulator to compare driver behavior at grade crossings with active controls versus driving behavior at standard passive grade crossings *[8]*. Each of the participants who drove the advanced driving simulator was exposed to three level crossing scenarios. The first scenario consisted of two pre-warning signs, a "Stop-Sign Ahead" sign and a composite sign that included a railroad crossbuck stop sign and the text "Look for Trains." The second scenario comprised sets of flashing lights, a composite sign, and pre-warning sign. Lastly, the third scenario chosen for the experiment consisted of traffic signals, a composite sign, and pavement markings. Driver safe maneuvers with the crossing controls were determined by examining minimum speeds on approach to the level crossing. If the minimum speed on approach was less than approximately 6.21 mph, then the driver was considered to have stopped before that particular crossing and constituted compliant behavior in this study. The results indicated that driver safe maneuvers at grade crossings were lowest for passive crossings controlled with stop signs only, and highest for active crossings controlled with flashing red lights. In addition, a comparison between stop signs at active grade crossings and passive grade crossings indicated that drivers stopped completely 3% more at active grade crossings with stop signs than at passive grade crossings. The results obtained from these studies and others led to varying conclusions. In summary, although some of the studies concluded, at a 99% confidence level, that driver safe maneuvers were significantly influenced by the signs used, Tey et al. and Tey and Ferreira concluded that overall, the signs did not change driver behavior *[6], [7]*. The study by Lenné and Kim concluded that driver speed was significantly lowered when approaching passive crossings (especially those equipped with stop signs) as compared to active crossings *[8], [9]*.

Attempts made to promote a safe maneuver at crossings include Intelligent Transportation Systems (ITS) interventions and application of locally-based education and enforcement programs *[10]*. It is important to note that most of these studies were conducted at crossings near intersections where the distances of the crossings from the roadway varied. For instance, in the study conducted by Tey et al, two of the study sites used were at distances of 400 m and 500 m from adjacent T-intersections *[6]*. Some drivers in the simulations may have had an unnatural heightened sense of alertness due to their awareness of being tested in a controlled environment. Naturalistic data on driver behavior may be obtained by observing drivers in the field using video surveillance. This data is often more reliable when compared to data from simulated experiments and can provide much more realistic results.

Several studies have utilized video surveillance to evaluate the effectiveness of various safety measures at grade crossings. The impact of these safety measures on driving behavior was analyzed by monitoring several parameters including site conditions and vehicle characteristics. A field study in Kansas by Rys et al. measured driver stopping behavior at grade crossings by determining whether the vehicle stopped, did not stop, or performed a rolling stop at the stop line *[11]*. Different combinations of the stop sign, yield sign, and the crossbuck sign were used at two active and seven passive grade crossings. Using the “pooled estimate” of population variance, the study evaluated the percentage of vehicles performing each action and determined that the overwhelming majority of drivers did not perform any type of stopping motion, rolling or complete, before or after stop signs were installed. In a re-publication of these findings, Rys et al. determined that only 9% (398) of the vehicles stopped completely, 15% (651) did a rolling stop, and 76% (3,269) did not stop at all *[12]*. In addition, drivers stopped completely 2% more at grade crossings at night as compared to daytime.

In addition to studying the driver behavior at the stop line, researchers have also analyzed the behavior within the DEZ. Another field study by Gabree used a chi-squared test to evaluate the stopping behavior at grade crossings before and after the implementation of dynamic envelope pavement markings and supplemental signage *[13]*. In this study, four actions were defined: stopping behind the stop line and gate arm, stopping past the stop line but before the tracks, stopping directly on the tracks, and stopping immediately after the tracks. For the researchers, stopping on the tracks was considered the most dangerous behavior that a driver could perform, while stopping at the stop line and waiting for the intersection to be clear was considered the safest. The result of the pavement markings was a significant reduction in DEZ stopping behavior. The number of vehicles that stopped on the tracks was reduced by 59%, while the number of vehicles correctly stopping at the stop line increased by 15%. In addition, fewer vehicles stopped within the DEZ before and after the tracks.

In summary, these studies and others conducted on the interactions between drivers and safety systems at grade crossings were limited to evaluating traffic warning devices, signage and specific pavement markings *[14], [15]*. The results supported previous research that highlighted and affirmed the general ineffectiveness of stop signs at grade crossings. Despite the conclusions from the simulated experiments, Rys et al. suggested that supplementary signage with specific language tends to be more effective than other forms of signage in reducing crashes at grade crossings *[11]*. This study therefore analyzes the effectiveness of regulatory signage, with specific language. Due to the expected low safe maneuver rate at passive crossings, the site selection for this study was based solely on active grade crossings.

Site Selection and Characteristics

Eight active highway-rail grade crossings with varying characteristic, comprising five rural sites and three urban sites, were selected to give a general overview of crossings in Louisiana. These sites had known problems of drivers stopping within the DEZ. Initially, the investigation of DEZ infringements at these sites was divided into Stage A and Stage B. Stage A included five sites and Stage B reported on the remaining three sites. Stage A included the rural sites LA 182 at LA 88 (Site A) near New Iberia, LA 3089 at LA 70 (Site B) near Donaldsonville, and LA 1 at LA 1148 (Site C) near Plaquemine. The urban sites for Stage A were LA 30 at Brightside Drive (Site D) and LA 30 at Bob Petit Boulevard (Site E). The remaining three sites for Stage B included the rural sites LA 3051 at LA 138 near Bastrop (Site F), US 51 at LA 10 near Roseland (Site G), and the urban site LA 77 at LA 1 also near Plaquemine (Site H). The majority of the rural sites experienced low traffic volumes except for Site B, which is located near factories and experienced high traffic volumes during peak hours. The urban sites experienced high traffic volumes especially Site

D because it was situated near neighborhoods populated by university students. All sites were located on railroads with trains carrying freight.

In July 2016, the DOTD District 3 office conducted a Road Safety Assessment on Site A which involved an extensive study of the site including crash analysis and alternative solutions for reducing the amount of crashes at the grade crossing *[16]*. This site experienced several fatalities and was subject to legal issues. The study resulted in the recommendation of additional regulatory signage. It was therefore equipped with the R15-8 "Look" sign attached to the gate as well as the less conventional variant of the R8-8, "STOP HERE UNTIL STOP SIGN IS CLEAR" as seen in Figure 2.

The research team worked with DOTD's Highway/Railway Safety Unit and the respective district offices in establishing that the candidate test sites were suitable for study. The proximity of crossings to roadway intersections, volume of vehicles, and crash history of the locations were used to confirm the suitability of the test sites. DOTD District Traffic Operations Engineers/Staff agreed with DOTD's Highway/Railway Safety Unit on the exact location of the signs, requested the signage from the respective sign shops, and submitted utility locate tickets to ensure no utilities would be affected. Railroad coordinators were also present where installation was close to the railroad right of way.

The site characteristics and existing conditions are summarized in the following sections. These characteristics include locality and type of intersection, functional classifications of the roadways parallel to and intersecting the tracks, angle of encroachment of the vehicle, number of tracks, and location of crashes. Only Site C and Site H had two sets of tracks. Each site's characteristics were described in Tables 1 through 8, and the crash data was visually depicted in Figures 4 through 11.

Figure 2
Regulatory signage installed at Site A

Sites B to H were equipped with the standard R8-8, "DO NOT STOP ON TRACKS" sign as seen in Figure 3, in both directions of the approaches to the railroad. All sites were initially without any signage.

Figure 3
Regulatory signage installed at Sites B-H

Site A New Iberia

Table 1
Site A characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Rural Three-way Junction (Stop Sign)	Minor Arterial	Major Collector	89	1	BNSF

Figure 4
Aerial view and crashes at Site A

Site B Donaldsonville

Table 2
Site B characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Rural Three-way Junction (Stop Sign)	Principal Arterial	Minor Arterial	79	1	Union Pacific

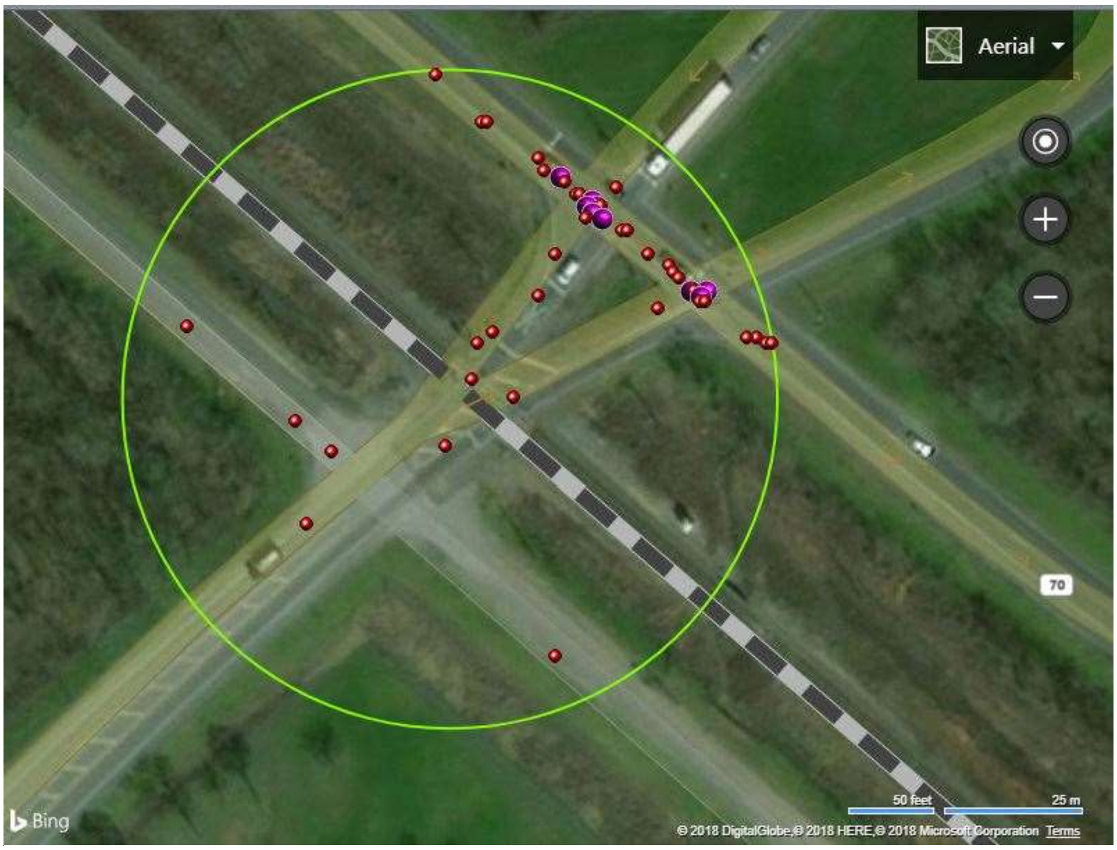

Figure 5
Aerial view and crashes at Site B

Site C Plaquemine I

Table 3
Site C characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Rural Three-way Junction (Stop Sign)	Principal Arterial	Minor Collector	42	2	Union Pacific

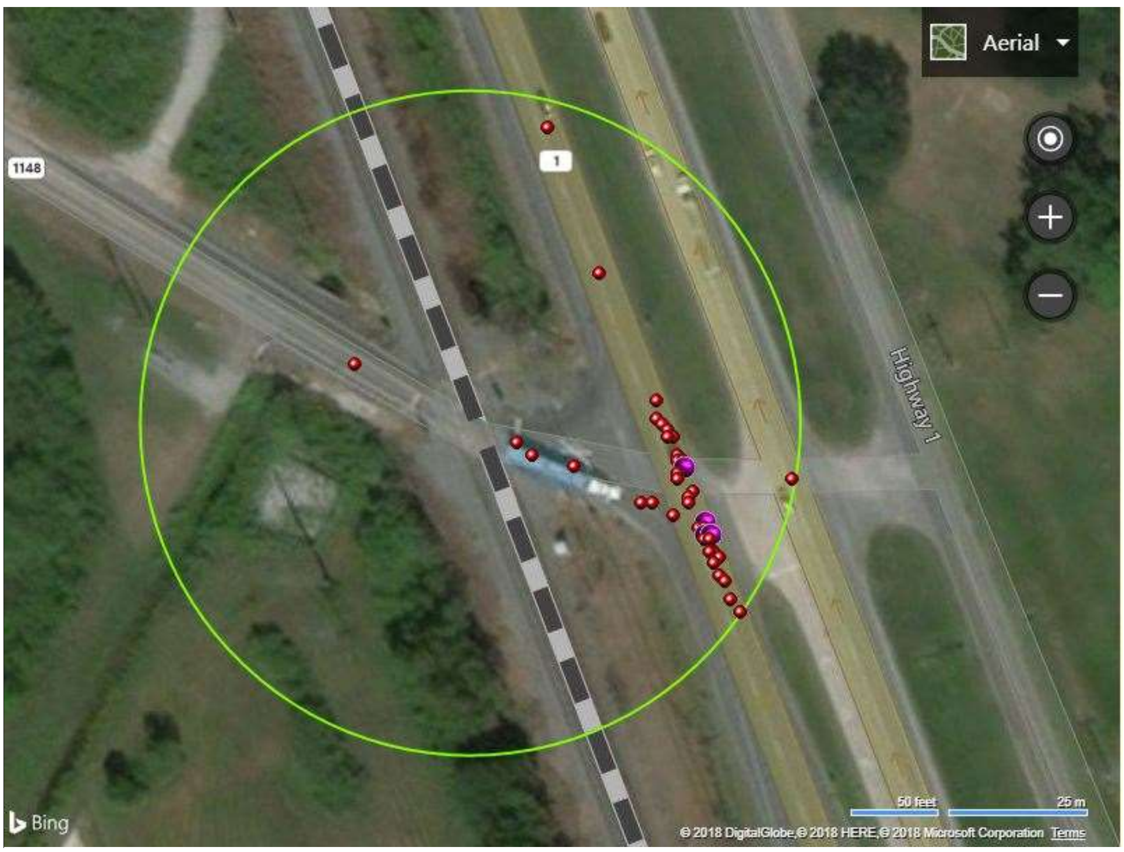

Figure 6
Aerial view and crashes at Site C

Site D Brightside

Table 4
Site D characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Urban Four-way Junction (Traffic Signal)	Principal Arterial	Minor Collector	85	1	Canadian National

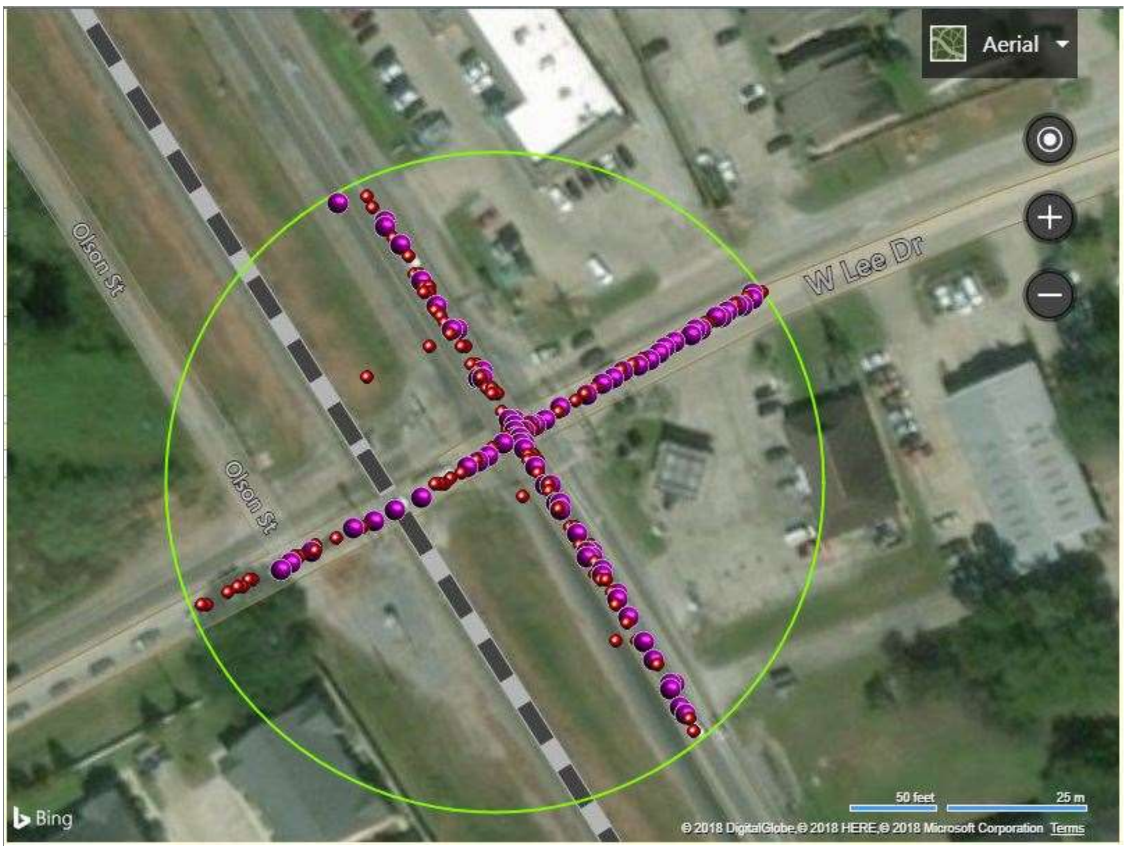

Figure 7
Aerial view and crashes at Site D

Site E Bob Petit

Table 5
Site E characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Urban Four-way Junction (Traffic Signal)	Principal Arterial	Local	91	1	Canadian National

Figure 8
Aerial view and crashes at Site E

Site F Bastrop

Table 6
Site F characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Rural Four-way Junction (Stop Sign)	Major Collector	Major Collector	62	1	Union Pacific

Figure 9
Aerial view and crashes at Site F

Site G Roseland

Table 7
Site G characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Rural Three-way Junction (Stop Sign)	Minor Arterial	Major Collector	88	1	Canadian National

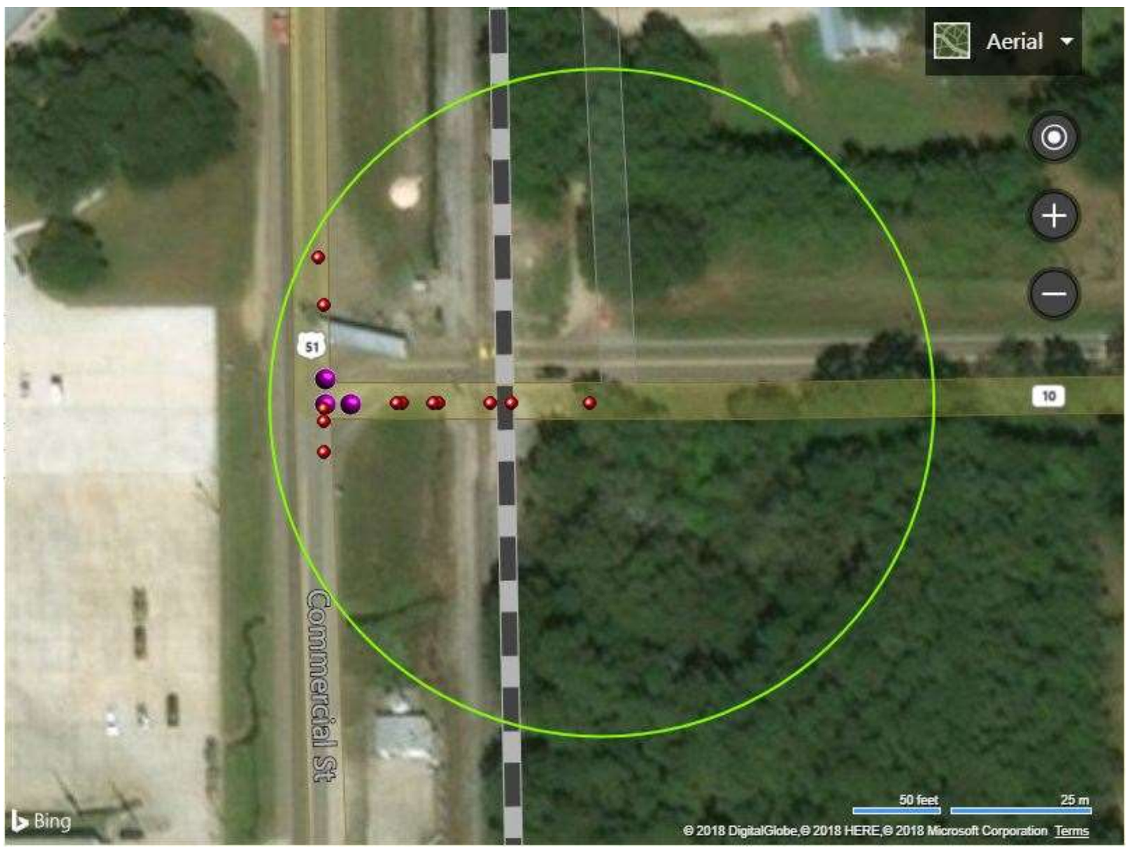

Figure 10
Aerial view and crashes at Site G

Site H Plaquemine II

Table 8
Site H characteristics

Locality	Functional Classification of Roadway (Parallel)	Functional Classification of Roadway (Intersecting)	Angle of Roadway (Degrees)	Number of Tracks	Railroad Company
Urban Three-way Junction (Stop Sign)	Minor Arterial	Major Collector	105	2	Union Pacific

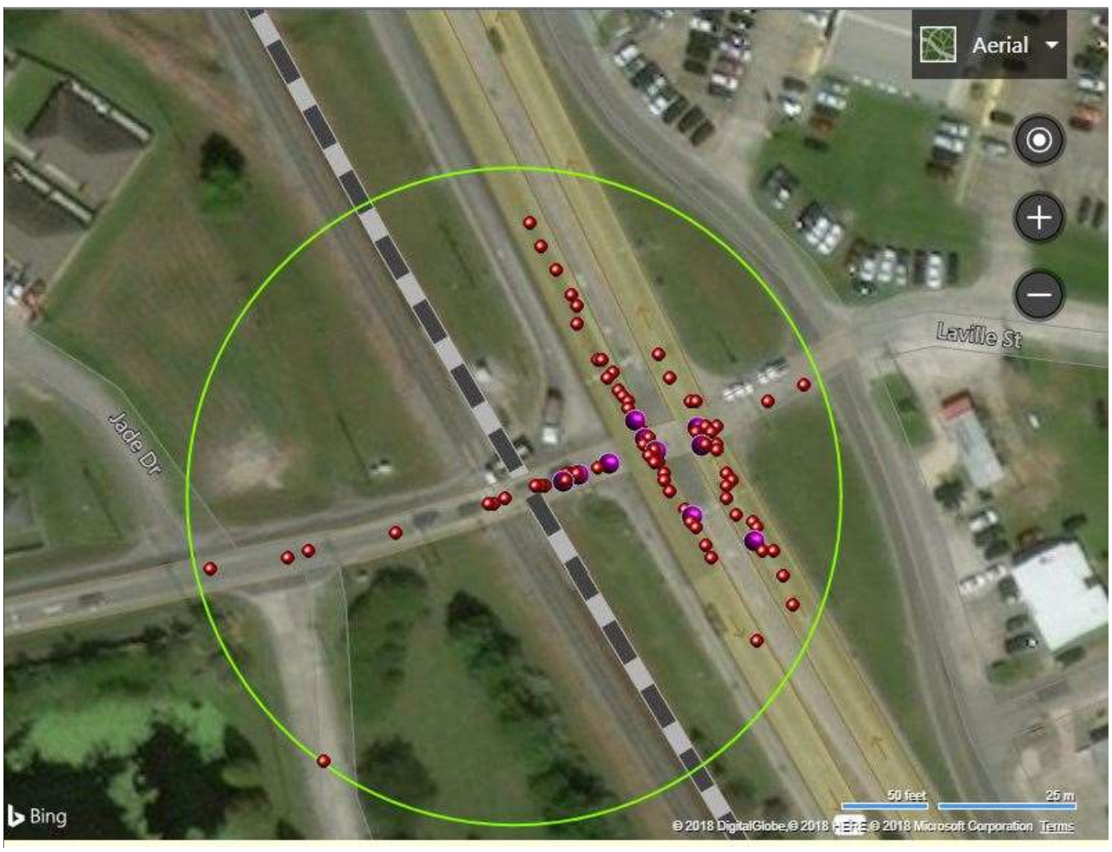

Figure 11
Aerial view and crashes at Site H

The research team compiled the crash data from 2013 to 2017, including vehicle-to-vehicle and vehicle-to-train collisions. The crashes were recorded on both roadways parallel to and crossing over the tracks as well as within a 200 ft. radius from the grade crossing. The crash data for the intersections chosen for this study is presented in Table 9.

Table 9
Crash history for all sites

Site	Total Incidents (2013-2017)	Injuries and Fatalities (2013-2017)
A	35	12 injuries and 5 fatalities
B	68	28 injuries and 1 fatality
C	48	46 injuries
D	531	106 injuries
E	198	51 injuries and 1 fatality
F	52	28 injuries
G	19	8 injuries
H	95	63 injuries

The following sections document the video surveillance systems used in this study, explain the data processing procedure, and discuss the parameters chosen for the analyses.

Video Surveillance Systems and Site Maintenance

The video detection systems used for this study were acquired from four companies: DETEL, Miovision, JAMAR Technologies, Inc., and Counting Cars. While achieving the objectives outlined for this research project, the various systems were documented with the purpose of providing the ITS lab at LTRC with a wide range of tools for future studies. The following sections provide brief summaries of the camera systems.

DETEL

Collectively, DETEL Computer Solutions and DETEL Communications is a Louisiana-based company that provides technological products and services for a wide range of businesses *[17]*. The camera systems from DETEL are typically used for security purposes and this was the first time that the company's products were used for a traffic study as specific as this one. As a result, the system required extra work for adaptation to continuous filming and traffic monitoring. Installation required DOTD district personnel and effort by professionals, including an electrician with an elevated bucket. The camera system is powered by a 200 W solar panel. Figure 12 shows the equipment used for the system, which was attached to a nearby utility pole.

Figure 12
DETEL apparatus

The camera is a 2 megapixels (MP) Starlight IP Intelligent Bullet Camera that can record in both daytime and nighttime conditions. The footage is recorded in a high resolution and compatible with image processing software. Hardware storage requires more space due to excess equipment. Despite these challenges, hardly any maintenance is required once installed. The system can record over four months of data continuously and the footage is compatible with SmartICRSS Player for viewing.

Miovision

Miovision is a well-known Canadian company in transportation engineering that focuses on traffic operations, traffic data, and smart cities solutions *[18]*. The installation for the system is easy and does not require professional installation or special software to review the footage. Minimal space is necessary to store the equipment shown in Figure 13.

Figure 13
Miovision apparatus

The system utilizes the Scout camera which records at 30 fps and at a 720 x 480 resolution. The video footage is saved in MP4 format and can be viewed in most media players such as Windows Media Player or VLC. The camera stores two SD cards (max of 64 gigabytes (GB) each) worth of data and the battery lasts up to seven days. The system requires minimal maintenance; a site visit should be done every three days for replacing storage and seven days for replacing the battery.

JAMAR Technologies, Inc.

JAMAR Technologies, Inc. offers a large selection of products for traffic data collection *[19]*. The JAMAR Portable Video Camera System installation does not require professional effort and can be set up with two workers at most. The camera has built in Wi-Fi for remote setup and viewing wirelessly. The system, shown in Figure 14, also includes the TDC-Ultra, a turning movement counter, and the companion data processing software PetraPro.

Figure 14
Jamar Technologies apparatus

The system has a 64GB memory capacity for each filming period and can capture approximately two days of continuous footage with a standard resolution of 640 x 480 pixels and four to nine hours with highest resolution at 1920 x 1080 pixels. The footage is saved in an MP4 format onto a micro SD card (max 64 GB), making data transfer easy. The PetraPro allows for exporting data into an excel format along with a number of other formats. Minimal space is needed for storage and minimal maintenance is required. The camera is battery operated with the option to add an external battery for increased recording time. A battery and a 64 GB SD card will last two days at most when continuously filming with a standard resolution. This system also includes settings for a filming schedule to prolong the battery life.

Counting Cars

Counting Cars is an American manufacturer and maintains an online store for transportation data collection equipment *[20]*. Installation is easy, but does require some tools and hardware. As shown in Figure 15, the camera angle and footage can be viewed on site. In addition, the system uses a 64 GB SD card which makes data transferring the data efficient.

Figure 15
Counting Cars apparatus

The quality of footage is a lower compared to the other systems in terms of standard resolution, which is 640 x 480 pixels, and might not be compatible with image processing data. "COUNTpro" software exports data directly to Excel and Petra Pro file formats and generates its own detailed PDF reports. "COUNTpad2" allows for easy interaction with footage. Minimal parts make storage easy and the maintenance involves storage and battery exchange approximately every 12 days.

Data Extraction and Filtering

The amount of footage acquired through this study was approximately 5 terabytes (TB), including initial novelty periods ranging from 13 to 70 days for the first stage and between 54 and 646 days for the second stage of data collection. While the idea of the novelty period was to allow motorists time to familiarize themselves with the new signage and not capture a 'novelty' effect, the varying durations were also influenced by logistics in signage installation at the sites. Three stages of data collection were undertaken: pre-installation data to observe driving behavior prior to signage installation; Post-Installation 1 data to observe driving behavior after signage installation and an initial novelty period; and, lastly, Post-Installation 2 data to observe driving behavior after a lengthier novelty period. Table 10 shows the range of dates used for counting at each site, the dates of the regulatory signage installation, and the novelty periods allowed in between.

Despite the variability in the novelty periods, the amount of data processed for each site was the same. Before and after the signage installation at each site, the researchers manually counted six individual hours throughout an entire day, from each day of the week, and over the period of approximately a month to two months. By taking this sample of days and times, 84 counting hours were obtained for each site. In addition, the Post-Installation 2 data consisted of 8 hour counts for each day and 3 consecutive days for each of the 8 sites, resulting in 24 counting hours for each site. The goal was to give as much of an accurate representation of the drivers passing through these sites as possible. For instance, it could be that drivers tend to behave differently on the weekend as opposed to the weekdays as well as at different times of the day. To ensure the collection of only naturalistic variables the videos were manually inspected and relevant features were observed and recorded. Figure 16 shows a screenshot of the SmartICRSS video player that was used to playback the video footage while relevant features were observed and recorded.

Table 10
Filming and novelty period dates

Site	Pre-Installation	Signage Installation	1st Novelty Period	Post-Installation 1	2nd Novelty Period	Post-Installation 2
A	06/20/2016 to 7/16/2016 **27 days**	08/22/2016	08/22/2016 to 10/30/2016 **70 days**	10/31/2016 to 12/02/2016 **33 days**	08/22/2016 to 05/29/2018 **646 days**	05/30/2018 to 06/1/2018 **3 days**
B	04/01/2017 to 04/30/2017 **30 days**	05/24/2017	05/24/2017 to 06/12/2017 **20 days**	06/13/2017 to 06/29/2017 **17 days**	05/24/2017 to 05/21/2018 **363 days**	05/22/2018 to 05/24/2018 **3 days**
C	04/03/2017 to 05/23/2017 **51 days**	05/24/2017	05/24/2017 to 06/12/2017 **20 days**	06/13/2017 to 07/02/2017 **20 days**	05/24/2017 to 05/10/2018 **352 days**	05/11/2018 to 05/13/2018 **3 days**
D	03/30/2017 to 05/08/2017 **40 days**	05/24/2017	05/24/2017 to 06/12/2017 **20 days**	06/13/2017 to 07/01/2017 **19 days**	05/24/2017 to 05/14/2018 **356 days**	05/15/2018 to 05/17/2018 **3 days**
E	04/18/2017 to 05/18/2017 **31 days**	05/24/2017	05/24/2017 to 06/12/2017 **20 days**	06/13/2017 to 07/02/2017 **20 days**	05/24/2017 to 05/17/2018 **359 days**	05/18/2018 to 05/20/2018 **3 days**
F	11/22/2017 to 12/22/2017 **31 days**	1/30/2018	01/30/2018 to 03/06/2018 **36 days**	03/07/2018 to 03/30/2018 **24 days**	01/30/2018 to 06/07/2018 **129 days**	06/8/2018 to 06/10/2018 **3 days**
G	11/06/2017 to 11/23/2017 **18 days**	1/09/2018	01/09/2018 to 02/07/2018 **30 days**	02/08/2018 to 02/28/2018 **21 days**	01/09/2018 to 05/24/2018 **136 days**	05/25/2018 to 05/27/2018 **3 days**
H	11/19/2017 to 12/28/2017 **40 days**	3/15/2018	03/15/2018 to 03/27/2018 **13 days**	03/28/2018 to 04/21/2018 **25 days**	03/15/2018 to 05/07/2018 **54 days**	05/8/2018 to 05/10/2018 **3 days**

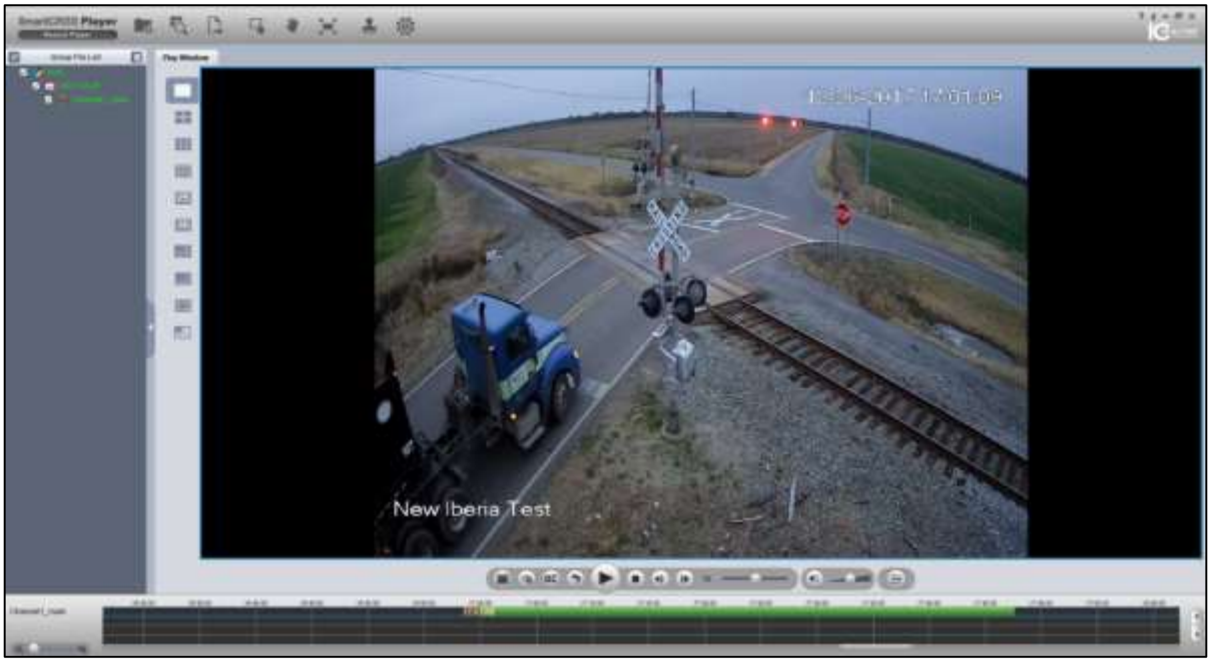

Figure 16
Screenshot of SmartICRSS player (Site F)

Student workers manually observed each vehicle passing over the tracks using an interactive counter developed with the parameters for analysis. The students were supervised in order to minimize human error. The most common mistakes documented were counting incorrect dates and failure to select an appropriate parameter. The quality control exercise revealed that the amount of error from these mistakes accounted for 4.9% of the total counts, subsequently leading to the removal of this data. Figure 17 shows the interactive counter which was developed for analyzing the video footage.

Figure 17
Interactive counter

Table 11
Observed driver behavior

Parameter	Category
Presence of a Vehicle Queue	Queue
	No Queue
Driver Behavior at Stop Line	Stop
	Doesn't Stop
	Rolling Stop
Driver Behavior within DEZ	Prior to Tracks
	On Tracks
	After Tracks
	None

Table 11 summarizes the categories of possible driver maneuvers at the grade crossings with or without the presence of a vehicle queue. The driver maneuvers at grade crossings were used to develop a safety parameter noted as level of compliance (LOC). There are three categories for defining LOC, including two violations and safe maneuver that were observed and documented as undertaken in several previous studies *[5]*, *[11]*, *[13]*. Any form of stopping within the DEZ was considered to be a major violation and observed as "Prior to Tracks," "On Tracks," or "After Tracks." Minor violations occurred if a vehicle did not stop at the stop line or performed a rolling stop with the presence of a vehicle queue. The driver behavior at the stop line was observed as "Stop," "Doesn't Stop," and "Rolling Stop." Table 12 summarizes each category of the LOC parameter and Figures 18 to 22 show visual examples of each LOC category. A safe maneuver occurred when the vehicle stopped before the stop line with a queue and waited for the area between the intersection and the tracks to become clear. If there were no queue present then it was not necessary for the vehicle to stop at the stop line, therefore a "Doesn't Stop" or "Rolling Stop" with no vehicle queue was observed as a safe maneuver. The following section discusses the parameters that were used for the analysis of factors that correlate to unsafe driver behavior and to better understand the sites that experienced an increase in unsafe driving behavior.

Table 12
Categories for defining level of compliance (LOC)

Category	Description	
Major Violation	Vehicle stops completely within the DEZ.	Before Tracks
		On Tracks
		After Tracks
Minor Violation	Vehicle does not stop within the DEZ, or does not stop at the stop line, or performs a rolling stop with a vehicle queue.	Stop
		Doesn't Stop
		Rolling Stop
Safe Maneuver	Vehicle stops before the stop line with a queue and waits for the area between the intersection and the tracks to become clear. (If there was no queue present then it was not necessary for the vehicle to stop at the stop line, therefore a "Doesn't Stop" or "Rolling Stop" with no vehicle queue was observed as a safe maneuver)	

Figure 18
Major violation before tracks

Figure 19
Major violation on tracks

Figure 20
Major violation after tracks

Figure 21
Minor violation

Figure 22
Safe maneuver

Comprehensive Parameter Discussion

The impact of regulatory signage was evaluated at all sites during both peak and non-peak hours as well as under various weather and lighting conditions. The video footage was manually inspected to extract the following information: weather, lighting condition, vehicle type, vehicle routing, and traffic volume. Moreover, this study utilized the site characteristics and traffic volume (as vehicles per hour (VPH)) as parameters of interest. In order to study the driver's awareness of the grade crossing and regulatory signage, the parameters were chosen to analyze the visibility, perception, and maneuverability that the driver experiences. Each parameter was categorized as to delineate the varying conditions attributing to driver behavior. Table 13 summarizes these parameters and categorizes them by each influence.

The parameter 'weather' was recorded as "Clear Weather," "Fog," or "Rain" to analyze the influence of site visibility. The United States Naval Observatory (USNO) serves as the official source of time for the U.S. Department of Defense and as a standard of time for the entire United States *[21]*. The database includes the calculated times for the beginning and end of civil twilight for every day of the year. The research team examined the footage of each specific counting date to verify that these times were accurate. Similarly, to account for the influence of site visibility, the parameter lighting condition was categorized into Daytime, Nighttime, Dawn, and Dusk. If the times for the beginning of morning civil twilight (BMCT) and the end of evening civil twilight (EECT) were within the observed counting hour, then that hour was categorized as Dawn or Dusk, respectively.

The parameters “vehicle type” and “vehicle routing” were chosen to study how the driver’s perception of the grade crossing and signage affect their behavior. The type of vehicle was categorized into “Small Passenger Vehicle,” “Passenger Truck/SUV,” and “Heavy Vehicle” (18-wheeler’s, buses, utility vans, etc.). These categories represent varying heights of the driver’s vantage point and varying levels of the driver’s skill. Professionals normally operate utility vans, buses, and large road vehicles making them more sensitive and adept when engaging grade crossings *[5]*. Vehicles passing through the intersection were recorded as turning left, right or as going straight.

The parameters in regards to the site maneuverability were used to study the associations between driver behavior and certain conditions experienced through the grade crossing. Locality was categorized into Urban and Rural with two different types of intersections; urban junctions with traffic signals and rural junctions with stop signs.

Traffic volume, as VPH, was categorized as being less than 100, equal to or greater than 100 but less than 300, and greater than 300. Lastly, the number of tracks was recorded as one or two sets of tracks for the sites. Among the other inspected parameters are LOC, signage installation period, site code, and the day of the week in which the counting took place for each site. Monday through Thursday was coded as “Weekday” while Friday through Sunday were coded as “Weekend” for this parameter. The following section provides the technical background for the comparative and associative analyses performed in this study, namely, the percentage change, the chi-squared test, and the MBA.

Table 13
Parameters for analyzing driver behavior

Type of Influence	Parameter	Category
Visibility	Weather	Clear Weather
		Rain
		Fog
	Lighting Condition	Daytime
		Nighttime
		Dawn
		Dusk
Perception	Vehicle Type	Small Passenger
		Passenger Truck/SUV
		Heavy Vehicle
	Vehicle Routing	Right
		Straight
		Left
Maneuverability	Locality	Urban
		Rural
	Angle of Encroachment	Perpendicular
		Angled
	Traffic Volume	VPH < 100
		100 ≤ VPH ≤ 300
		VPH > 300
	Number of Tracks	1
		2
Site Conditions	Site Code	A, B, C, D, E, F, G, and H
	Signage Installation	Pre-Installation
		Post-Installation
	Day of Week	Weekday
		Weekend

Percentage Change

After level of compliance was manually observed from driver behavior at all sites, percentage change calculations of the proportion of vehicles counted were used for the comparative analysis in evaluating the impact of regulatory signage on driver behavior before and after installation. The number of major violations, minor violations, and instances of safe maneuvers were totaled for each signage installation period and noted as "Total Counts." Using proportions calculated from these totals, the formula for calculating the percentage change is:

$$\text{Percentage Change} = -\left(\frac{\text{Pre-Installation LOC} \;-\; \text{Post-Installation LOC }(1,2)}{\text{Pre-Installation LOC}}\right)*100 \qquad (1)$$

where,

$$\text{Pre-Installation LOC}= \frac{\text{LOC before signage installation}}{\text{Total counts before signage installation}} \qquad (2)$$

and

$$\text{Post-Installation LOC 1,2}= \frac{\text{LOC for post installation 1 and 2 data}}{\text{Total counts for post installation 1 and 2 data}} \qquad (3)$$

Proportions were used to account for variations in total vehicle counts between the different periods after signage installation. LOC referred to the separate counts for major violations, minor violations, and instances of safe maneuvers. The post-installation LOC was done separately for the two different post-installation data sets; Post-Installation 1 and Post-Installation 2 data.

The percentage change of the major violations, minor violations, and safe maneuvers between the pre and post-installation periods identifies the extent to which the regulatory signage installation affected driver behavior. Percentage change was chosen to give a simple and concise calculation for evaluating the effectiveness of the regulatory signage.

Chi-squared Test

A chi-squared test was performed to verify the percentage change calculations and test any statistically significant changes in LOC due to the regulatory signage. The chi-square test is a statistical analysis tool that measures the significance of association between two variables summarized in a contingency table and reports a significance value or p-value. The p-value is then compared to a critical value to determine whether the null hypothesis is rejected. The hypotheses for the chi-squared analysis is:

Null Hypothesis (H0): There is no significant association between signage installation and LOC.

Alternative Hypothesis (H1): There is a significant association between signage installation and LOC.

This was a one-tailed test that measured change in one direction. Consequently, if the p-value is less than the critical significance value α (0.05 in this study), the null hypothesis is rejected and the conclusion is that there is a significant association between signage installation and LOC.

Market Basket Analysis

As the dimensionality or number of variables in data increases, tracking associations between parameters using contingency tables becomes overwhelmingly tedious and inefficient. The MBA extracts rules that identify associations among a set of variables within given data and is a more generalized tool for looking through all the possible associations in order to identify those that are meaningful. Marketers normally use this type of analysis for identifying the items or set of goods a customer prefers to buy jointly and more frequently through the investigation of transactions. The "A Priori" algorithm is most commonly used for this analysis and comes from the concept that the frequency of subsets of any item set is dependent on the frequency of that set *[22]*. The algorithm implements this concept in the form of a pruning technique that trims the exponential search space for candidate rules. In general, the MBA implements three metrics to evaluate the item sets of extracted rules, namely, the "Support," "Confidence," and "Lift." These metrics are presented in the Venn diagram illustrated in Figure 23, where the area of the rectangle N is the set of all observations.

The three metrics represent the frequency, strength, and interest of a particular association rule. A rule of length two is defined as "$X \rightarrow Y$" consisting of an antecedent (LHS) and a consequent (RHS). The length of the rule can also be three or more, as in "$X_1, X_2, X_i \rightarrow Y$." It is important to note that the MBA does not indicate a cause and effect relationship, but simply investigates associations between specific parameters or combinations of parameters. Accordingly, the rule "$X \rightarrow Y$" is assumed to have the same meaning in reversed order *[23]*. Since the MBA does not suggest this type of relationship, both rules including parameter "X" in the LHS or the RHS are useful. Therefore, many useful rules are repeated with reversed LHS and RHS.

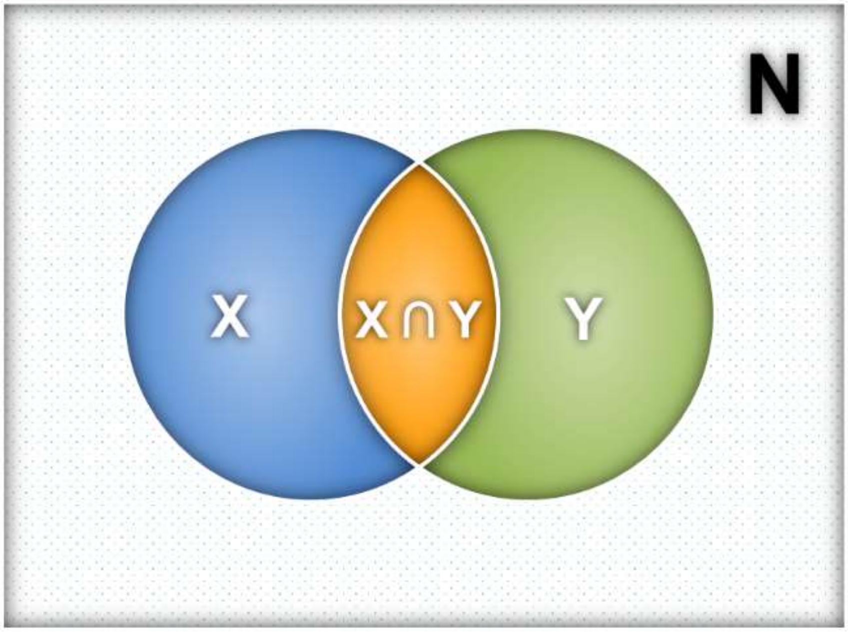

Figure 23
Venn-diagram representing MBA metrics

The Support represents how frequently an association rule occurs. It is determined by taking the number observations of parameters X and Y occurring together and dividing that value by the number of total observations. It essentially represents the percentage of a specific rule occurring and is represented as the orange area in Figure 23 divided by the area of the rectangle. The higher the support value, the more frequently a rule of the LHS and RHS occurs. The following equation defines the Support:

$$\text{Support } (X \rightarrow Y) = \frac{\sigma\,(X \rightarrow Y)}{N} \tag{4}$$

The Confidence acts as the strength or reliability measure of a specific association rule by representing its conditional probability. As seen in Figure 23, the Confidence of a rule is represented as the percentage of summing both the blue and orange areas. It determines how often a rule occurs when parameter X occurs. The Confidence is calculated by equation (5):

$$\text{Confidence } (X \rightarrow Y) = \frac{\sigma\,(X \rightarrow Y)}{\sigma(X)} \tag{5}$$

It is to be noted that the symbol "σ" in equations (4) and (5) does not represent "standard deviation." Rather, it only represents the number of observations of parameters X and Y occurring together.

Finally, the Lift of a rule is the interest of an association between parameters and represents its statistical dependence. The Lift is the ratio between the rule's Confidence and the Support of the RHS. It is represented as the Confidence divided by the percentage of the green and orange areas from the total area of N. A Lift with a value greater than 1 suggests that the presence of the either the LHS or RHS increases the probability that the other also occurs; the larger the Lift, the greater the link between the two parameters. Equation (6) calculates the Lift value:

$$\text{Lift } (X \rightarrow Y) = \frac{\text{Confidence } (X \rightarrow Y)}{\text{Support } (Y)} \quad (6)$$

A Lift value of 1 implies that the probability of each the LHS and the RHS are independent of each other. When the LHS and RHS are independent of each other, irrespective of the Confidence value, no useful rule can be drawn involving the two sides. Consequently, Lift values much greater than 1 were used in this study for evaluating strong associations among the extracted rules. Lift values less than one imply negative associations, meaning that the presence of the LHS reduces the probability of the RHS and vice versa.

To allow for the extraction of only reliable rules which are easily interpreted, this study utilized a threshold value of 5% for the Support to extract as many rules of length 2 and 3 as possible and to account for expected rare conditions. An association rule, "X→Y" is considered redundant if a more general rule with equal or higher Confidence exists, in other words if "X*→Y" where the X* is similar to or a subset of X *[23]*. All non-redundant rules were investigated further to identify those that were meaningful and the research team manually removed those that were intuitive or were considered not useful. In addition, rules that were repeated with reversed RHS and LHS had similar Lift values but different Confidence values. This study implemented the MBA as to improve and extrapolate on the results of the chi-squared test, while providing the research with a more advanced technique for analyzing parameters pertaining to driver behavior at grade crossings.

DISCUSSION OF RESULTS

There were two post-installation data sets collected. The first dataset, labelled Post-Installation 1, was collected after the first novelty period and Post-Installation 2 was collected after a second, lengthier novelty period. A chi-square test was then performed to determine if there was a significant difference between the pre- and post-installation LOC. Table 14 contains the counts collected at each site (Pre-Installation, Post-Installation 1, and Post-Installation 2). Furthermore, MBA was undertaken to explore any associations between the LOC categories and any site-specific observations made, ultimately to attempt to explain the results obtained. All counts have been separated based on LOC categories discussed in the methodology section, i.e., major violations, minor violations, and safe maneuvers. This study obtained 116,171 individual vehicle counts for analysis.

Table 14
Level of compliance for all sites

Site	Pre-Installation			Post-Installation 1			Post-Installation 2		
	Major Violations	Minor Violations	Safe Maneuvers	Major Violations	Minor Violations	Safe maneuvers	Major Violations	Minor Violations	Safe Maneuvers
A	959	385	1,053	883	381	1,173	483	11	1,030
B	436	4,036	4,675	53	4,968	3,065	64	4,738	1,183
C	52	367	1,469	37	288	1,572	37	288	865
D	1,474	9,160	4,358	1,861	6,693	4,515	620	2,966	5,024
E	1,860	3,151	3,520	1,299	2,397	3,494	464	1,550	1,870
F	37	245	1,247	54	110	1,042	18	73	617
G	165	974	1,995	333	940	2,079	47	468	803
H	613	2,569	2,078	571	262	2,541	281	1,989	3,193
Sum	**5,596**	**20,887**	**20,395**	**5,091**	**16,039**	**19,481**	**2,014**	**12,083**	**14,585**
Total Counts				**116,171**					

Percentage Change Results

Because this study focuses on identifying problematic DEZ stopping behavior, observing Major Violations was an important aspect of the research. The results obtained from percentage change calculations after the first novelty period showed that the signage decreased major violations in four out of the eight sites studied. The exact decreases in major violations were 9.4%, 86.2%, 29.2%, and 17.1% for Sites A, B, C, and E, respectively. This translated to the fact that four of the eight sites experienced an average 36% decrease in Major Violations, while the remaining four sites experienced a 66% increase in Major Violations on average. Site B experienced the highest decrease in major violations at 86.2%, while Site G experienced the highest increase in major violations at 88.7%. Results are displayed in Table 15.

After the second, lengthier novelty period (Post-Installation 2), an important observation was that the proportions of major violations decreased at 6 sites by an average of 43%. The exact decreases in major violations were 20.8%, 77.6%, 26.8%, 45.2%, 32.3% and 55.9% at Sites A, B, D, E, G, and H. The average increase in major violations was 9% at the remaining two sites. Site B experienced the highest reduction in major violations (77.6%) and Site C recorded the highest increase in major violations (12.9%). Again, results are displayed in Table 15.

Table 15
Percentage change for major violations

Site	Pre-Installation			Post-Installation 1				Post-Installation 2			
	Major Violations	Total Counts	Proportion	Major Violations	Total Counts	Proportion	Percentage Change	Major Violations	Total Counts	Proportion	Percentage Change
A	959	2,397	0.40	883	2,437	0.36	-9.4	483	1,524	0.32	-20.8
B	436	9,147	0.05	53	8,086	0.01	-86.2	64	5,985	0.01	-77.6
C	52	1,888	0.03	37	1,897	0.02	-29.2	37	1,190	0.03	12.9
D	1,474	14,992	0.10	1,861	13,069	0.14	44.8	620	8,610	0.07	-26.8
E	1,860	8,531	0.22	1,299	7,190	0.18	-17.1	464	3,884	0.12	-45.2
F	37	1,529	0.02	54	1,206	0.04	85.0	18	708	0.03	5.1
G	165	3,134	0.05	333	3,352	0.10	88.7	47	1,318	0.04	-32.3
H	613	5,260	0.12	571	3,374	0.17	45.2	281	5,463	0.05	-55.9

The results for minor violations in relation to Post-Installation 1 showed that seven out of eight sites experienced decreases in minor violations after the first novelty period by an average of 27%. The individual percentages associated with the decrease in minor violations were 2.7%, 21.9%, 16.2%, 9.7%, 43.1%, 9.8%, and 84.1% at Sites A, C, D, E, F, G, and H, respectively. Site B was the only site that exhibited an increase in minor violations at 39%. These results are displayed in Table 16.

The results for minor violations (Post-Installation 2) indicated that the proportions of these violations increased at half of the sites by an average of 31% and decreased at the other half by an average of 50% after the second lengthier novelty period. The percentages associated with the decrease in minor violations after the second novelty period were 95.5%, 43.6%, 35.7%, and 25.5% at Sites A, D, F, and H. The percentages associated with the increase in minor violations were 79.4%, 24.5%, 8%, and 14.3% at Sites B, C, E, and G. Again, Table 16 summarizes the results.

Table 16
Percentage change for minor violations

Site	Pre-Installation			Post-Installation 1				Post-Installation 2			
	Minor Violations	Total Counts	Proportion	Minor Violations	Total Counts	Proportion	Percentage Change	Minor Violations	Total Counts	Proportion	Percentage Change
A	385	2,397	0.16	381	2,437	0.16	-2.7	11	1,524	0.01	-95.5
B	4,036	9,147	0.44	4,968	8,086	0.61	39.2	4,738	5,985	0.79	79.4
C	367	1,888	0.19	288	1,897	0.15	-21.9	288	1,190	0.24	24.5
D	9,160	14,992	0.61	6,693	13,069	0.51	-16.2	2,966	8,610	0.34	-43.6
E	3,151	8,531	0.37	2,397	7,190	0.33	-9.7	1,550	3,884	0.40	8.0
F	245	1,529	0.16	110	1,206	0.09	-43.1	73	708	0.10	-35.7
G	974	3,134	0.31	940	3,352	0.28	-9.8	468	1,318	0.36	14.3
H	2,569	5,260	0.49	262	3,374	0.08	-84.1	1,989	5,463	0.36	-25.5

After Post-Installation 1, the proportion of safe maneuvers increased at six sites at an average increase of 25%, while the remaining two sites experienced a decrease in safe driving behavior at an average of 14.2%. The individual percentages associated with the decrease in safe maneuvers were 25.8% and 2.6% at Sites B and G, respectively. Sites A, C, D, E, F, and H experienced 9.6%, 6.5%, 18.8%, 17.8%, 5.9%, and 90.6% increases in safe maneuvers.

After Post-Installation 2, the proportion of safe maneuvers increased on an average of 45.2% at five of the sites and decreased by 24% at the other three sites. The percentages associated with the increase in safe maneuvers were 53.8%, 100.7% 16.7%, 6.9%, and 47.9% at Sites A, D, E, F, and H, respectively. The decreases in safe maneuvers at Sites B, C and G were 61.3%, 6.6%, and 4.3% respectively. The results obtained at each site have been presented in Table 17.

Table 17
Percentage change for instances of safe maneuvers

Site	Pre-Installation			Post-Installation 1				Post-Installation 2			
	Safe maneuvers	Total Counts	Proportion	Safe maneuvers	Total Counts	Proportion	Percentage Change	Safe maneuvers	Total Counts	Proportion	Percentage Change
A	1,053	2,397	0.44	1,173	2,437	0.48	9.6	1,030	1,524	0.68	53.8
B	4,675	9,147	0.51	3,065	8,086	0.38	-25.8	1,183	5,985	0.20	-61.3
C	1,469	1,888	0.78	1,572	1,897	0.83	6.5	865	1,190	0.73	-6.6
D	4,358	14,992	0.29	4,515	13,069	0.35	18.8	5,024	8,610	0.58	100.7
E	3,520	8,531	0.41	3,494	7,190	0.49	17.8	1,870	3,884	0.48	16.7
F	1,247	1,529	0.82	1,042	1,206	0.86	5.9	617	708	0.87	6.9
G	1,995	3,134	0.64	2,079	3,352	0.62	-2.6	803	1,318	0.61	-4.3
H	2,078	5,260	0.40	2,541	3,374	0.75	90.6	3,193	5,463	0.58	47.9

These results indicated that signage installation was not able to produce a consistent result across all sites. For instance, Site B was one the sites that showed the highest decrease in the number of safe maneuvers. At the same time at Site B, while drivers were less likely to stop within the DEZ, there was also a marked decrease in the number of major violations, which explained the decrease in the proportions of safe maneuvers. There was no clear-cut site that could be pinpointed as being the most problematic when considering the entirety of the results.

Analysis of the data showed that there were no consistent trends in the effect of the signage in improving driver behavior at the DEZ over time. For instance, after the first novelty period, four out of the eight sites (A, B, C, and E) showed reduced instances of major violations. However, after the second novelty period, three of these sites (A, B, and E) continued to show reduced instances of major violations as well as three other sites (D, G, and H). All remaining sites showed increased instances of major violations. For minor violations, all sites apart from Site B showed an initial reduction in minor violations after the first novelty period. However, after the second novelty period, only four sites (A, D, F, and H) continued to show this trend. Only instances of safe maneuvers showed a consistent trend across the two novelty periods with both Sites B and G showing decreased proportions of safe maneuvers, and the remaining sites showing increased proportions over time. Table 18 shows a summary of changes in LOC between Post-Installation 1 (corresponding to the first novelty period) and Post-Installation 2 (corresponding to the second novelty period).

Table 18
Summary of changes in LOC between Post-Installation 1 and Post-Installation 2

Site	Major Violations			Minor Violations			Safe Maneuvers		
	Post-Installation 1	Post-Installation 2	Difference	Post-Installation 1	Post-Installation 2	Difference	Post-Installation 1	Post-Installation 2	Difference
A	-9.4	-20.8	11.3	-2.7	-95.5	92.8	9.6	53.8	-44.3
B	-86.2	-77.6	-8.7	39.2	79.4	-40.2	-25.8	-61.3	35.5
C	-29.2	12.9	-42.1	-21.9	24.5	-46.4	6.5	-6.6	13.1
D	44.8	-26.8	71.6	-16.2	-43.6	27.4	18.8	100.7	-81.9
E	-17.1	-45.2	28.1	-9.7	8.0	-17.8	17.8	16.7	1.1
F	85.0	5.1	80.0	-43.1	-35.7	-7.4	5.9	6.9	-0.9
G	88.7	-32.3	121.0	-9.8	14.3	-24.0	-2.6	-4.3	1.7
H	45.2	-55.9	101.1	-84.1	-25.5	-58.6	90.6	47.9	42.7

Chi-squared Test Results

To reiterate, the LOC was coded as the following: a major violation was any form of stopping within the DEZ and a minor violation occurred when the driver did not stop within the DEZ nor at the stop line or performed a rolling stop. A safe maneuver occurred when the vehicle stopped at the stop line and did not stop within the DEZ. Chi-squared tests were used next to determine if there was a significant association between the two variables, LOC and signage installation. This test can determine if there is a significance in the association between variables, but not its strength. In effect, it will show whether the percentage changes observed for all the LOC categories were statistically significant. If the percentage is greater than 20% then the assumption has been violated and another statistical tool must be used. Two counts are presented in the cross tabulation of the variables, the observed and expected counts. The expected counts are the expected number of observations if there is no significant association between signage installation and LOC as calculated by the IBM SPSS software used for the analysis. The asymptotic significance is the p-value, or significance value. The critical significance value, α, for this study was chosen to be 5% or 0.05.

Tables 19 through 26 present the Chi-squared tests for the eight individual sites. Each individual Chi-squared test compares Pre-Installation to Post-Installation 1 and Pre-Installation to Post-Installation 2 for major violations, minor violations and safe maneuvers with the specific site being the constant.

Table 19
Chi-squared test results for Site A

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	959	883	1,842	959	483	1,442
	Expected	913.4	928.6	1,842	881.5	560.5	1,442
Minor Violations	Observed	385	381	766	385	11	396
	Expected	379.8	386.2	766	242.1	153.9	396
Safe Maneuvers	Observed	1,053	1,173	2,226	1,053	1,030	2,083
	Expected	1,103.8	1,122.2	2,226	1,273.4	809.6	2,083
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		9.295	2	0.010	332.725	2	0.000

Table 20
Chi-squared test results for Site B

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	436	53	489	436	64	500
	Expected	259.6	229.4	489	302.2	197.8	500
Minor Violations	Observed	4,036	4,968	9,004	4,036	4,738	8,774
	Expected	4,779.2	4,224.8	9,004	5303.7	3,470.3	8,774
Safe Maneuvers	Observed	4,675	3,065	7,740	4,675	1,183	5,858
	Expected	4,108.3	3,631.7	7,740	3541.0	2,317.0	5,858
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		668.556	2	0.000	1833.884	2	0.000

Table 21
Chi-squared test results for Site C

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	52	37	89	52	37	89
	Expected	44.4	44.6	89	54.6	34.4	89
Minor Violations	Observed	367	288	655	367	288	655
	Expected	326.7	328.3	655	401.8	253.2	655
Safe Maneuvers	Observed	1,469	1,572	3041	1469	865	2334
	Expected	1516.9	1524.1	3041	1431.6	902.4	2334
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		15.524	2	0.000	10.622	2	0.005

Table 22
Chi-squared test results for Site D

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	1,474	1,861	3335	1,474	620	2094
	Expected	1781.8	1553.2	3335	1330.1	763.9	2094
Minor Violations	Observed	9,160	6,693	15853	9,160	2,966	12126
	Expected	8469.7	7383.3	15853	7702.4	4423.6	12126
Safe Maneuvers	Observed	4,358	4,515	8873	4,358	5,024	9382
	Expected	4740.5	4132.5	8873	5959.5	3422.5	9382
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		301.227	2	0.000	1978.440	2	0.000

Table 23
Chi-squared test results for Site E

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	1,860	1,299	3159	1,860	464	2324
	Expected	1714.2	1444.8	3159	1596.9	727.1	2324
Minor Violations	Observed	3,151	2,397	5548	3,151	1,550	4701
	Expected	3010.6	2537.4	5548	3230.3	1470.7	4701
Safe Maneuvers	Observed	3,520	3,494	7014	3,520	1,870	5390
	Expected	3806.1	3207.9	7014	3703.8	1686.2	5390
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		88.452	2	0.000	173.873	2	0.000

Table 24
Chi-squared test results for Site F

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	37	54	91	37	18	55
	Expected	50.9	40.1	91	37.6	17.4	55
Minor Violations	Observed	245	110	355	245	73	318
	Expected	198.5	156.5	355	217.4	100.6	318
Safe Maneuvers	Observed	1,247	1,042	2289	1,247	617	1864
	Expected	1279.7	1009.3	2289	1274.1	589.9	1864
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		35.219	2	0.000	12.954	2	0.002

Table 25
Chi-squared test results for Site G

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	165	333	498	165	47	212
	Expected	240.6	257.4	498	149.2	62.8	212
Minor Violations	Observed	974	940	1914	974	468	1442
	Expected	924.8	989.2	1914	1015.1	426.9	1442
Safe Maneuvers	Observed	1,995	2,079	4074	1,995	803	2798
	Expected	1968.5	2105.5	4074	1969.7	828.3	2798
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		51.742	2	0.000	12.345	2	0.002

Table 26
Chi-squared test results for Site H

Level of Compliance		Signage Installation					
		Pre-Install	**Post-Install 1**	**Total 1**	**Pre-Install**	**Post-Install 2**	**Total 2**
Major Violations	Observed	613	571	1184	613	281	894
	Expected	721.3	462.7	1184	438.5	455.5	894
Minor Violations	Observed	2,569	262	2831	2,569	1,989	4558
	Expected	1724.7	1106.3	2831	2235.9	2322.1	4558
Safe Maneuvers	Observed	2,078	2,541	4619	2,078	3,193	5271
	Expected	2814.0	1805.0	4619	2585.6	2685.4	5271
Parameter	-	**Value**	**Degrees of Freedom**	**P-value 1**	**Value**	**Degrees of Freedom**	**P-value 2**
Pearson Chi-Square		1591.871	2	0.000	429.269	2	0.000

The chi-squared test for each site in the study indicates that the percentage change recorded for major violations, minor violations, and safe maneuvers were all statistically significant. However, considering that both positive and negative percentage changes were recorded, no correlation between sign installation and driver behavior can be made. For example, when considering major violations, it is expected that sign installation would cause a negative percentage change meaning that less major violations had occurred after sign installation. The same would be expected for minor violations and the opposite for safe maneuvers. However, this was not seen in the results of the percentage change analysis. Specified in Table 15, Sites D, G, and H all reported an increase in major violations after Post-Installation 1 followed by a decrease after Post-Installation 2. Also, Site C reported a decrease in major violations after Post-Installation 1 followed by an increase after Post-Installation 2. Site F recorded an increase in major violations after both installation periods. The reported results for minor violations and safe maneuvers are varied in the same manner, implying that no defined correlation exists between signage installation and LOC even though all percentage changes were considered to be statistically significant per a chi-squared test.

Market Basket Analysis

The MBA was performed to evaluate the effectiveness of the R8-8 further and had the potential to identify associations contributing to the anomalies at some of the sites, where unsafe driving behavior increased. Initially, the MBA used only the variables Site Code, Signage Installation, and LOC generating 13 association rules of length 2 and 3. Table 27 shows the generated rules for the preliminary MBA along with their corresponding Support, Confidence, and Lift values. Lift values greater than 1 imply a higher probability of the LHS and the RHS occurring together. The comprehensive parameters were only recording using the data from Post-Installation one, therefore the introduction of the MBA will only include this data in addition to the Pre-Installation data.

Inspecting Rules 1 and 2 jointly shows a slight decrease in Lift value with the change in the LHS category from “Pre-Installation” to “Post-Installation,” indicating a negative but potentially weak association present between signage installation and Safe Maneuvers. Likewise, Rules 3 and 4 as well as 5 and 6 indicate that the signage installation may have minimal associations with Major and Minor Violations. Lift values equal to and nearly equal to 1 can also indicate that the LHS and RHS may be independent of each other. These interpretations can confirm the results of the safety analysis in that there was only a slight increase in overall safe driving behavior, 15% on average. The interpretations that signage installation has no association with Major Violations also reflects the safety analysis in that there was an average of 15% increase in these violations with the Post-Installation Data.

Table 27
Preliminary MBA

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
1	Signage Installation: Pre-Installation → LOC: Safe	0.245	0.471	1.007
2	Signage Installation: Post-Installation → LOC: Safe	0.223	0.464	0.992
3	Signage Installation: Pre-Installation → LOC: Major Violation	0.063	0.121	1.000
4	Signage Installation: Post-Installation → LOC: Major Violation	0.058	0.121	1.000
5	Signage Installation: Pre-Installation → LOC: Minor Violation	0.212	0.407	0.992
6	Signage Installation: Post-Installation → LOC: Minor Violation	0.199	0.414	1.009
7	Site Code: B → LOC: Safe	0.088	0.449	0.959
8	Site Code: B → LOC: Minor Violation	0.103	0.522	1.273
9	Site Code: B, Signage Installation: Post-Installation → LOC: Minor Violation	0.057	0.614	1.497
10	Site Code: D → LOC: Minor Violation	0.181	0.565	1.376
11	Site Code: D → LOC: Safe	0.101	0.316	0.675
12	Site Code: H → LOC: Safe	0.065	0.643	1.375
13	Site Code: E → LOC: Minor Violation	0.063	0.353	0.860

The inspection of Rules 7, 8, and 9 demonstrates an increase in Lift value with the introduction of Minor Violations and the category "Post-Installation," indicating a strong association between Site B and Minor Violations particularly during the post-installation period. This result confirms that Site B experienced an increase in this type of violation. Similarly, Rule 10 shows a very strong association between Site D and Minor Violations. Though no rule was generated specifically between Site D and the category "Post-Installation," Rule 11 shows a negative association between Site D and Safe Maneuvers. In other words, the consideration of Site D reduces the overall chance of Safe Maneuvers at this site.

The MBA can also provide important associations for other sites. For instance, Site H has a very strong association with Safe Maneuvers while Site Code E has a negative association with Minor Violations. Based on the safety analysis results Site H experienced the highest increase in Safe Maneuvers at 90.6% reflecting this association. Site E had the second to lowest at -9.7 next to Site A. Since Site E was an urban site and had a much higher volume than the rural Site A, this association was generated due to a higher Support value. The same reasoning is given for why the other rural sites, (Site F, G, and H), did not show up in generated rules.

This study implemented the MBA in order to improve and extrapolate on the results of the safety analysis, while providing the research with a more advanced tool for analyzing variables pertaining to driver behavior at grade crossings. Due to the weak association between LOC and signage installation determined by the preliminary MBA, a comprehensive MBA was conducted for identifying important associations between the 11 variables listed in Table 13 and LOC. The R software used for the analysis removed the redundant rules and a final set of 179 non-redundant rules of length 2 and 3 were extracted. These rules were thoroughly examined to extract a condensed set of 50 rules containing the most meaningful associations for discussion. Since the Lift is a function of the Support, variables with low frequencies often did not appear in the generated rules. Tables 28 to 38 summarize these rules and organize them by the identifying variable including the corresponding Support, Confidence, and Lift values.

Table 28

MBA Results for weather

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
1	Weather: **Clear Weather** → LOC: **Safe Maneuver**	0.137	0.675	1.443
2	Weather: **Clear Weather** → LOC: **Major Violation**	0.095	0.127	1.046
3	Weather: **Clear Weather**, Site Code: **B** → LOC: **Safe Maneuver**	0.090	0.450	0.960

Rules 1 and 2 show that Safe Maneuvers hold a much stronger association with the category “Clear Weather” than “Major Violation.” This is interpreted from the decrease in Lift value corresponding to the RHS changing from “Safe Maneuver” to “Major Violation.” Another method for interpretation involves introducing a new variable on the LHS and observing the change in Lift value. By inspecting Rules 1 and 3 simultaneously, it is observed that the consideration of Site B decreases the Lift value and is indicative of the fact that this site experienced an overall increase in unsafe driving behavior compared to the average of all sites.

Table 29

MBA Results for lighting condition

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
4	Lighting Condition: **Nighttime** → LOC: **Safe Maneuver**	0.089	0.691	1.476
5	Lighting Condition: **Daytime** → LOC: **Safe Maneuver**	0.311	0.420	0.896
6	Lighting Condition: **Daytime**, Site Code: **B** → LOC: **Minor Violation**	0.098	0.556	1.355
7	Lighting Condition: **Daytime** → LOC: **Minor Violation**	0.342	0.462	1.126
8	Lighting Condition: **Daytime** → LOC: **Major Violation**	0.088	0.118	0.975
9	Lighting Condition: **Daytime**, Site Code: **D** → LOC: **Minor Violation**	0.155	0.608	1.480

The MBA generated rules indicating a much stronger association between Safe Maneuvers and the nighttime counting hours than daytime ones as shown by the significant difference in Lift values in Rules 4 and 5. By considering only Site B (in Rule 6) and Site D (in Rule 9), the association between Minor Violations and the category "Daytime" is much stronger compared to Rule 7 when all sites were considered at once. Rule 8 shows that Major Violations had an overall negative associated with Daytime. Overall, the safety violations appear to be less associated with the daytime counting hours.

Table 30

MBA results for vehicle type

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
10	Vehicle Type: **Small Passenger** → LOC: **Major Violation**	0.057	0.130	1.069
11	Vehicle Type: **Truck/SUV** → LOC: **Major Violation**	0.061	0.115	0.944
12	Vehicle Type: **Truck/SUV** → LOC: **Minor Violation**	0.220	0.414	1.009
13	Vehicle Type: **Small Passenger** → LOC: **Minor Violation**	0.184	0.419	1.021
14	Vehicle Type: **Truck/SUV**, Site Code: **B** → LOC: **Minor Violation**	0.063	0.532	1.297

Rules 10 and 11 show that the category “Small Passenger” was slightly more associated with Major Violations than larger vehicles classified as “Truck/ SUV” and that these vehicles had a negative association with this type of safety violation. Rule 12 implies almost no association with “Truck/SUV” and Minor Violations, while Rule 13 implies a slightly positive association between “Small Passenger” and Minor Violations. Rule 14 shows that in regards to Minor Violations, the Lift value increases dramatically when Site B is considered. An inference that can be made from these results is that since larger vehicles are situated higher off the ground, there is a better view and the DEZ is more easily identified, but the larger size may cause these vehicles to encroach upon the stop line more often. These results may also be attributed to the fact that the smaller size of certain vehicles allows them to fit more easily in the DEZ and these drivers may perceive to have space that is more available. It was said that possible reasons for the increase in unsafe driving behavior could be attributed to the location of Site B by factories and the location of Site D by collegiate neighborhoods. These results also correlate with Sites B and D having higher Minor and Major Violations respectively and that the frequency of “Small Passenger” vehicles at Site D was 16.2% higher than Site B.

Rules 15 and 16 for the variable Vehicle Routing indicated that there was a much stronger association between Major Violations and left turn movements than Safe Maneuvers. Rules 17 and 18 show that Minor Violations had an overall weak association with right turn movements except when Site B is considered. Rules 19 to 21 show that going straight at the intersections was much more associated with the safety violations, especially at Site D, including a negative association with Safe Maneuvers. It is stipulated that since the intersections did not have left turn signals, left turning vehicles paid more attention to oncoming traffic than to the grade crossings while vehicles going straight tended to pay less attention to the stop line. Overall, it can be inferred that right turning vehicles were more compliant.

Table 31

MBA results for vehicle routing

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
15	Vehicle Routing: **Left** → LOC: **Major Violation**	0.058	0.183	1.504
16	Vehicle Routing: **Left** → LOC: **Safe Maneuver**	0.172	0.541	1.155
17	Vehicle Routing: **Right** → LOC: **Minor Violation**	0.177	0.443	1.079
18	Vehicle Routing: **Right**, Site Code: **B** → LOC: **Minor Violation**	0.094	0.524	1.276
19	Vehicle Routing: **Straight** → LOC: **Minor Violation**	0.145	0.515	1.254
20	Vehicle Routing: **Straight**, Site Code: **D** → LOC: **Minor Violation**	0.122	0.639	1.558
21	Vehicle Routing: **Straight** → LOC: **Safe Maneuver**	0.107	0.379	0.809

Table 32

MBA results for locality

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
22	Locality: **Rural** → LOC: **Safe Maneuver**	0.221	0.556	1.188
23	Locality: **Urban** → LOC: **Safe Maneuver**	0.247	0.410	0.876
24	Locality: **Urban** → LOC: **Major Violation**	0.087	0.145	1.191
25	Locality: **Urban** → LOC: **Minor Violation**	0.268	0.445	1.085
26	Locality: **Urban**, Vehicle Routing: **Right** → LOC: **Minor Violation**	0.062	0.476	1.159

Rules 22, 23, 24, and 25 indicate that Safe Maneuvers overall tended to be much more associated with the rural sites and that the safety violations were more associated with urban sites. No useful rules were generated relating the safety violations to the category "Rural." Referring back to the previous discussion, the category "Right" alone was not strongly associated with Minor Violations (Rule 17, Table 31), but the introduction of the category "Urban" as seen in Rule 26, increases the Lift value from 1.079 to 1.159.

Table 33

MBA results for angle of encroachment

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
27	Angle of Encroachment: **Angled** → LOC: **Safe Maneuver**	0.149	0.556	1.187
28	Angle of Encroachment: **Angled** → LOC: **Minor Violation**	0.112	0.416	1.013
29	Angle of Encroachment: **Perpendicular** → LOC: **Safe Maneuver**	0.319	0.436	0.931
30	Angle of Encroachment: **Perpendicular** → LOC: **Major Violation**	0.114	0.156	1.282

Considering the variable angle of encroachment, Rules 27 to 30 indicate that Safe Maneuvers were more associated with sites having larger angled roadways and that Major Violations were associated more with approximately perpendicular roadways. This interpretation could have been synonymous to that of locality, since the two urban sites had almost perpendicular intersections and all rural sites had large angled roadways apart from Site A, which had an almost perpendicular roadway resulting in the changes to the Lift values. For example, Rule 24 (Table 32) has a Lift value of 1.191 and Rule 30 has a Lift value of 1.282. If all urban sites were perfectly perpendicular, these two rules would have the same Lift value.

Results for the variable Traffic Volume indicate that as traffic volume increased, there was a tremendous reduction in the likelihood of Safe Maneuvers because the Lift values decreases for Safe Maneuvers. Rules 33 and 34 indicate that Minor Violations were strongly associated to high traffic volumes, VPH > 300 and that Major Violations were more associated with medium traffic volumes, $100 \leq \text{VPH} \leq 300$. These associations support the fact that vehicles tend to queue more often over the tracks during peak hours, yet when considering high traffic volume, VPH > 300, there was no useful rule associated with Major Violations. It can be inferred that as traffic volume increased even more, vehicles begin to pay more attention to the DEZ but less attention to the stop line.

Table 34
MBA results for traffic volume

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
31	Traffic Volume: **VPH < 100** → LOC: **Safe Maneuver**	0.128	0.754	1.611
32	Traffic Volume: **VPH > 300** → LOC: **Safe Maneuver**	0.118	0.291	0.621

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
33	Traffic Volume: **VPH > 300** → LOC: **Minor Violation**	0.248	0.611	1.489
34	Traffic Volume: **100 ≤ VPH ≤ 300** → LOC: **Major Violation**	0.063	0.148	1.218

Table 35
MBA results for number of tracks

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
35	Number of Tracks: **2** → LOC: Safe	0.100	0.691	1.477
36	Number of Tracks: **1** → LOC: Safe	0.368	0.430	0.920
37	Traffic Volume: **100 ≤ VPH ≤ 300**, Number of Tracks: **1** → LOC: **Major Violation**	0.052	0.151	1.245

Rules 35 and 36 demonstrate that Safe Maneuvers were much more associated with sites with two sets of tracks as opposed to sites with only one. A site having two sets encompasses a larger DEZ area and driver may be more aware of behavior within and around it. The two sites which had two sets of tracks were the rural Site C and the urban Site H. Site C experience a consistent increase in safe driving behavior with a decrease in Major Violations by 29.2% and increase in Safe Maneuvers by 6.5% after signage installation. Though Site H experienced an increase in Major Violations, this was the site that experienced the largest increase in Safe Maneuvers after the installation of the signs. There is an observed increase in Lift value when comparing Rule 34 (Table 34) to Rule 37. The introduction of the parameter Number of Tracks indicates that there exist a stronger association with Major violations and site with one set of tracks.

Table 36
MBA results for day of week

Rule	Description X_1, $X_2 \rightarrow Y$	Support	Confidence	Lift
38	Day of Week: **Weekday** → LOC: **Minor Violation**	0.241	0.418	1.018
39	Day of Week: **Weekend** → LOC: **Minor Violation**	0.169	0.400	0.975
40	Day of Week: **Weekend** → LOC: **Major Violation**	0.052	0.124	1.021
41	Day of Week: **Weekday**, Site Code: **B** →LOC: **Minor Violation**	0.064	0.541	1.319
42	Day of Week: **Weekday**, Site Code: **D** →LOC: **Minor Violation**	0.109	0.578	1.407

Inspecting Rules 38 and 39 shows that the category "Weekday," despite having a weak association with Minor Violations, has a higher association with this safety violation than the category "Weekend" which has a negative association. Likewise, Rule 40 shows a weak association between the category "Weekend" and Major Violations and no useful rule was generated with Major Violations and "Weekday." Based on the results it can be inferred that Minor Violations occurred more frequently on weekdays and Major Violations on weekends. Furthermore, the consideration of Sites B and D in Rules 41 and 42 increases the Lift values for each safety violation. This knowledge is very useful for identifying days at which the violations occurred more frequently.

Table 37
MBA results for signage installation

Rule	Description X_1, $X_2 \rightarrow Y$	Support	Confidence	Lift
43	Signage Installation: **Post-Installation** Traffic Volume: **VPH < 100** → LOC: **Safe Maneuver**	0.062	0.756	1.615
44	Signage Installation **Pre-Installation**, Traffic Volume: **100 ≤ VPH ≤300** → LOC: **Safe Maneuver**	0.115	0.551	1.176
45	Signage Installation: **Post-Installation**, Angle of Encroachment: **Perpendicular** → LOC: **Major Violation**	0.057	0.161	1.325

The preliminary MBA provided weak associations between LOC and signage installation altogether. Rules 43, 44, and 45 can help identify other variables that were affected more by the installation of the R8-8. Rules 43 and 44 indicate that Safe Maneuvers after the signage installation became more associated with low traffic volumes. If Rule 45 is compared to Rule 30 (Table 33), the introduction of the category “Post-Installation” increases the Lift value from 1.282 to 1.325. The increase in Major Violations at Site D most likely contributed to the slightly higher association with this safety violation and sites with perpendicular roadways during the post-installation period.

Table 38
MBA results for site code

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
46	Site Code: **B**, Traffic Volume: **VPH >300** → LOC: **Minor Violation**	0.064	0.619	1.509
47	Site Code: **B**, Lighting Condition: **Daytime** → LOC: **Minor Violation**	0.098	0.556	1.355
48	Site Code: **B**, Day of Week: **Weekday** → “LOC: **Minor Violation**	0.064	0.541	1.319
49	Site Code: **B**, Vehicle Routing: **Right** → LOC: **Minor Violation**	0.094	0.524	1.276
50	Site Code: **B**, Vehicle Type: **Truck/SUV** → LOC: **Minor Violation**	0.063	0.532	1.297

The safety analysis and the preliminary MBA confirmed that Minor Violations increased at Site B. Collectively inspecting rules containing Site B in Rules 46 to 50 can assist in determining specifically what other variables are associated with Minor Violations. Based these rules, it is shown that most of the Minor Violations at Site B occurred at very high traffic volumes, during the daytime, and on weekdays when “Truck/SUV” vehicles were making right turn movements.

CONCLUSIONS

This study evaluated the effectiveness of regulatory signage on driver behavior in reducing instances of stopped vehicles within the DEZ at highway-rail grade crossings near roadway intersections with histories of crashes. The methodology presented in this study can be easily repeated and applied to a wide range of research. The parameters obtained from data collection were chosen such that preprocessing the data from this study will be relevant in the future and could be used with Intelligent Transportation System (ITS) technology as well as other advanced traffic modeling techniques. Image processing software may be used to automatically account for parameters and avoid manually observing footage.

Data was collected after a first novelty period after signage installation (Post-Installation 1) and a second set of data was collected after a longer novelty period (Post-Installation 2). After Post-Installation 1, four of the eight sites experienced an average decrease of 36% in major violations, while the remaining sites experienced a 66% increase in major violations on average. After Post-Installation 2, the proportions of major violations decreased at all six sites by an average of 43% and increased by 9% at the other sites. Post-Installation 1 data revealed that seven out of eight sites experienced decreases in minor violations after the first novelty period by an average of 27% and the remaining site recorded an increase in minor violations at 39%. Post-Installation 2 data indicated that the proportions of minor violations increased at half of the sites by an average of 31% and decreased at the other half by an average of 50%. The proportion of safe maneuvers after Post-Installation 1, increased at six of the sites at an average increase of 25%, while the remaining sites experienced a decrease in safe driving behavior at an average of 14%. After Post-Installation 2, the proportion of safe maneuvers increased by an average of 45% at five of the sites and decreased by 24% at the other sites. The comparative safety analysis concluded that installation of the signage produced mixed effects and the overall positive effect of regulatory signage on DEZ stopping behavior was minimal.

The chi-squared test conducted for Post-Installation 1 data and Post-Installation 2 data from the eight sites showed variability between the observed and expected counts, which indicated a potential correlation between sign installation and driver behavior. The collective tests showed that there was no significant association between signage installation and LOC for Post-Installation 1 data. A significant association between signage installation and LOC was observed for Post-Installation 2. This was a one-tailed test and the significant association between the two variables could either mean there was an improvement or otherwise. This was why the percentage differences were calculated to quantify improvements and worsened conditions. The chi-square test for Post-Installation 1 and Post-Installation 2 further showed the mixed effects of the signage.

The preliminary MBA resulted in weak associations overall between the LOC parameter and the installation of the R8-8. When the anomalies at Sites B and D were considered, there were much stronger associations between these sites and the safety violations. It was also determined that Site E and Site H had the strongest association with safe driving behavior. When considering the percentage change calculations as well, it was concluded that safety improvement was the most associated with these sites. The comprehensive MBA developed these results further by identifying important associations between site conditions and driver compliance. Some of non-redundant rules examined were more intuitive than others were and affirmed assumptions about driver behavior. For example, the results showed that Safe Maneuvers decreased as traffic volume increased, left turning vehicles tended to pay less attention to the DEZ than right turning vehicles, and safety violations occurred more often at the urban sites than the rural ones and even stronger associations with the perpendicular sites. Other associations were not as direct and helped broaden the understanding of interactions at grade crossings. Some notable associations were that Safe Maneuvers were more associated with nighttime counting hours than daytime, Minor Violations were more associated with high traffic volumes while Major Violations with medium traffic volumes, and that Safe Maneuvers improved the most during medium traffic volumes after the signage installation. Since there was no useful rule correlating high traffic volumes with Major Violations, it was inferred that as traffic volume increased even further, vehicles began to pay more attention to the DEZ but less attention to the stop line.

Many associations provided knowledge that is useful in identifying specific instances that contribute to unsafe driving behavior. The results showed that Minor Violations occurred more often on weekdays and Major Violations occurred more often on weekends, especially at the urban sites. Most of the Minor Violations at Site B occurred at very high traffic volumes, during the daytime, and on weekdays when vehicles recorded as Truck/SUV were making right turn movements. The results also suggested that Major Violations were more associated with Small Passenger Vehicles and Minor Violations with Truck/SUV vehicles.

In conclusion, the comparative safety analysis validated the findings of previous studies and the results showed that the R8-8 had a positive but minimal effect on driver behavior at the grade crossings. The MBA successfully demonstrated its value by confirming the safety analysis and increasing the number of variables that can be analyzed simultaneously. The methodology presented in this study can easily be repeated, can be applied to a wide range of research, and offers the scientific community an innovative approach to analyzing driver behavior. The results identify important variables for developing preventive measures, which will ultimately help reduce safety violations at grade crossings. The MBA can provide practical insight for transportation engineers when determining problematic intersections and can be used to improve the education on grade crossing interactions. The study was able to observe the effect of signage but could not record consistent improvement of driving behavior across all sites. The insights obtained from this study provide information to transportation engineers on the actual effects of providing signage at crossings where vehicles tend to queue within the DEZ in Louisiana. It also offers DOTD an engineering study upon which it can further study other preventive measures such as using pavement markings, rumble strips, flashing lights/bells, or in-vehicle auditory warnings, which may ultimately help reduce crashes at grade crossings.

RECOMMENDATIONS

The research team cannot recommend the use of regulatory signage to reduce instances of stopped vehicles within the DEZ at highway-rail grade crossings near roadway intersections with history of crashes due to the mixed results obtained in this study. Researchers recommend that other regulatory signs, as well as other methods such as using pavement markings, rumble strips, flashing lights/bells, and in-vehicle auditory warnings should be investigated, and subsequently employed, in order to improve safety at highway-rail grade crossings near roadway intersections with history of crashes.

ACRONYMS, ABREVIATIONS, AND SYMBOLS

BMCT	Beginning of Morning Civil Twilight
BNSF	Burlington Northern Santa Fe
DEZ	Dynamic Envelope Zone
DOTD	Louisiana Department of Transportation and Development
EECT	End of evening Civil Twilight
FRA	Federal Railroad Administration
GB	Gigabyte
ITS	Intelligent Transportation Systems
LHS	Left-Hand Side of Rule or Antecedent
LOC	Level of compliance
LTRC	Louisiana Transportation Research Center
MP	Megapixel
MBA	Market Basket Analysis
MUTCD	Manual on Uniform Traffic Control Devices
PRC	Project Review Committee
RHS	Right Hand Side of Rule or Consequent
TB	Terabyte
USNO	The United States Naval Observatory
VPH	Vehicles per Hour

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APPENDIX A

Complete List of MBA Rules

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
1	Traffic Volume: VPH < 100, Angle of Encroachment: Angled → LOC: Safe	0.07	0.84	1.80
2	Traffic Volume: VPH < 100, Lighting Condition: Nighttime → LOC: Safe	0.05	0.80	1.72
3	Vehicle Routing: Straight, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.12	0.68	1.66
4	Vehicle Routing: Left, Angle of Encroachment: Perpendicular → LOC: Major Violation	0.06	0.20	1.64
5	Number of Tracks: 2, Signage Installation: Pre-Installation → LOC: Safe	0.05	0.77	1.64
6	Day of Week: Weekend, Traffic Volume: VPH < 100 → LOC: Safe	0.06	0.76	1.63
7	Vehicle Type: Passenger Truck/SUV, Traffic Volume: VPH < 100 → LOC: Safe	0.07	0.76	1.62
8	Traffic Volume: VPH < 100, Signage Installation: Post-Installation → LOC: Safe	0.06	0.76	1.61
9	Vehicle Type: Small Passenger, Traffic Volume: VPH < 100 → LOC: Safe	0.05	0.76	1.61
10	Traffic Volume: VPH < 100 → LOC: Safe	0.13	0.75	1.61
11	Weather: Clear Weather, Signage Installation: Pre-Installation → LOC: Safe	0.07	0.75	1.59
12	Vehicle Routing: Right, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.11	0.65	1.58
13	Vehicle Routing: Straight, Site Code: D → LOC: Minor Violation	0.12	0.64	1.56
14	Day of Week: Weekday, Number of Tracks: 2 → LOC: Safe	0.06	0.73	1.56
15	Vehicle Type: Passenger Truck/SUV, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.14	0.62	1.52
16	Traffic Volume: VPH > 300, Signage Installation: Pre-Installation → LOC: Minor Violation	0.14	0.62	1.52
17	Weather: Clear Weather, Locality: Rural	0.07	0.71	1.51

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
	→ LOC: Safe			
18	Weather: Clear Weather, Number of Tracks: 1 → LOC: Safe	0.07	0.71	1.51
19	Site Code: B, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.06	0.62	1.51
20	Traffic Volume: VPH > 300, Angle of Encroachment: Angled → LOC: Minor Violation	0.06	0.62	1.51
21	Locality: Rural, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.06	0.62	1.51
22	Site Code: D, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.17	0.62	1.51
23	Weather: Clear Weather, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.23	0.62	1.51
24	Vehicle Routing: Left → LOC: Major Violation	0.06	0.18	1.50
25	Day of Week: Weekend, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.10	0.62	1.50
26	Traffic Volume: VPH > 300, Lighting Condition: Daytime → LOC: Minor Violation	0.23	0.62	1.50
27	Weather: Clear Weather, Day of Week: Weekday → LOC: Safe	0.08	0.70	1.50
28	Traffic Volume: VPH > 300, Number of Tracks: 1 → LOC: Minor Violation	0.24	0.61	1.50
29	Site Code: B, Signage Installation: Post-Installation → LOC: Minor Violation	0.06	0.61	1.50
30	Vehicle Type: Small Passenger, Traffic Volume: VPH > 300 → LOC: Minor Violation	0.11	0.61	1.49
31	Traffic Volume: VPH > 300 → LOC: Minor Violation	0.25	0.61	1.49
32	Site Code: D, Signage Installation: Pre-Installation → LOC: Minor Violation	0.10	0.61	1.49
33	Traffic Volume: 100 ≤ VPH ≤ 300, Angle of Encroachment: Perpendicular → LOC: Major Violation	0.06	0.18	1.48
34	Vehicle Type: Passenger Truck/SUV, Number of Tracks: 2 → LOC: Safe	0.06	0.69	1.48
35	Site Code: D, Lighting Condition: Daytime → LOC: Minor Violation	0.16	0.61	1.48
36	Number of Tracks: 2 → LOC: Safe	0.10	0.69	1.48
37	Lighting Condition: Nighttime → LOC: Safe	0.09	0.69	1.48
38	Vehicle Type: Passenger Truck/SUV, Site Code: D	0.09	0.59	1.45

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
	→ LOC: Minor Violation			
39	Weather: Clear Weather → LOC: Safe	0.14	0.68	1.44
40	Site Code: D, Day of Week: Weekday → LOC: Minor Violation	0.11	0.58	1.41
41	Weather: Clear Weather, Angle of Encroachment: Perpendicular → LOC: Major Violation	0.09	0.17	1.40
42	Weather: Clear Weather, Vehicle Routing: Straight → LOC: Minor Violation	0.13	0.57	1.40
43	Vehicle Routing: Straight, Lighting Condition: Daytime → LOC: Minor Violation	0.12	0.57	1.39
44	Weather: Clear Weather, Site Code: D → LOC: Minor Violation	0.17	0.57	1.38
45	Site Code: H, Traffic Volume: 100 ≤ VPH ≤ 300 → LOC: Safe	0.05	0.65	1.38
46	Vehicle Routing: Straight, Locality: Urban → LOC: Minor Violation	0.14	0.57	1.38
47	Vehicle Routing: Straight, Angle of Encroachment: Perpendicular → LOC: Minor Violation	0.14	0.57	1.38
48	Site Code: D → LOC: Minor Violation	0.18	0.56	1.38
49	Site Code: H → LOC: Safe	0.07	0.64	1.37
50	Vehicle Routing: Left, Locality: Rural → LOC: Safe	0.05	0.64	1.36
51	Site Code: B, Lighting Condition: Daytime → LOC: Minor Violation	0.10	0.56	1.35
52	Angle of Encroachment: Perpendicular, Signage Installation: Post-Installation → LOC: Major Violation	0.06	0.16	1.32
53	Number of Tracks: 1, Angle of Encroachment: Perpendicular → LOC: Major Violation	0.10	0.16	1.32
54	Site Code: B, Day of Week: Weekday → LOC: Minor Violation	0.06	0.54	1.32
55	Vehicle Routing: Straight, Signage Installation: Pre-Installation → LOC: Minor Violation	0.07	0.54	1.32
56	Lighting Condition: Daytime, Angle of Encroachment: Perpendicular → LOC: Major Violation	0.08	0.16	1.30
57	Vehicle Type: Passenger Truck/SUV, Site Code: B → LOC: Minor Violation	0.06	0.53	1.30

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
58	Angle of Encroachment: Perpendicular → LOC: Major Violation	0.11	0.16	1.28
59	Angle of Encroachment: Angled, Signage Installation: Pre-Installation → LOC: Safe	0.08	0.60	1.28
60	Vehicle Type: Passenger Truck/SUV, Vehicle Routing: Straight → LOC: Minor Violation	0.08	0.52	1.28
61	Vehicle Routing: Straight, Day of Week: Weekday → LOC: Minor Violation	0.09	0.52	1.28
62	Vehicle Routing: Right, Site Code: B → LOC: Minor Violation	0.09	0.52	1.28
63	Vehicle Routing: Straight, Number of Tracks: 1 → LOC: Minor Violation	0.14	0.52	1.27
64	Site Code: B → LOC: Minor Violation	0.10	0.52	1.27
65	Vehicle Routing: Straight → LOC: Minor Violation	0.15	0.51	1.25
66	Locality: Rural, Day of Week: Weekend → LOC: Safe	0.10	0.59	1.25
67	Locality: Rural, Signage Installation: Pre-Installation → LOC: Safe	0.12	0.58	1.25
68	Day of Week: Weekend, Angle of Encroachment: Angled → LOC: Safe	0.06	0.58	1.25
69	Traffic Volume: $100 \leq VPH \leq 300$, Number of Tracks: 1 → LOC: Major Violation	0.05	0.15	1.25
70	Locality: Urban, Lighting Condition: Daytime → LOC: Minor Violation	0.22	0.50	1.23
71	Weather: Clear Weather, Locality: Urban → LOC: Major Violation	0.07	0.15	1.22
72	Locality: Urban, Number of Tracks: 1 → LOC: Major Violation	0.07	0.15	1.22
73	Weather: Clear Weather, Lighting Condition: Daytime → LOC: Minor Violation	0.29	0.50	1.22
74	Traffic Volume: $100 \leq VPH \leq 300$ → LOC: Major Violation	0.06	0.15	1.22
75	Vehicle Routing: Right, Lighting Condition: Daytime → LOC: Minor Violation	0.15	0.50	1.22
76	Lighting Condition: Daytime, Number of Tracks: 1 → LOC: Minor Violation	0.32	0.50	1.21
77	Vehicle Routing: Right, Angle of Encroachment: Angled → LOC: Minor Violation	0.10	0.49	1.20
78	Vehicle Type: Passenger Truck/SUV, Vehicle Routing: Left → LOC: Safe	0.09	0.56	1.20

Rule	Description X_1, $X_2 \rightarrow Y$	Support	Confidence	Lift
79	Weather: Clear Weather, Locality: Urban → LOC: Minor Violation	0.23	0.49	1.19
80	Vehicle Type: Passenger Truck/SUV, Angle of Encroachment: Angled → LOC: Safe	0.09	0.56	1.19
81	Locality: Urban → LOC: Major Violation	0.09	0.14	1.19
82	Locality: Urban, Number of Tracks: 1 → LOC: Minor Violation	0.24	0.49	1.19
83	Locality: Rural, Angle of Encroachment: Perpendicular → LOC: Safe	0.07	0.56	1.19
84	Locality: Rural → LOC: Safe	0.22	0.56	1.19
85	Vehicle Routing: Right, Traffic Volume: $100 \leq VPH \leq 300$ → LOC: Safe	0.09	0.56	1.19
86	Angle of Encroachment: Angled → LOC: Safe	0.15	0.56	1.19
87	Vehicle Routing: Left, Signage Installation: Post-Installation → LOC: Safe	0.09	0.55	1.18
88	Weather: Clear Weather, Vehicle Routing: Right → LOC: Minor Violation	0.15	0.48	1.18
89	Traffic Volume: $100 \leq VPH \leq 300$, Signage Installation: Pre-Installation → LOC: Safe	0.11	0.55	1.18
90	Vehicle Type: Small Passenger, Lighting Condition: Daytime → LOC: Minor Violation	0.15	0.48	1.17
91	Angle of Encroachment: Angled, Signage Installation: Post-Installation → LOC: Minor Violation	0.06	0.48	1.17
92	Vehicle Routing: Right, Signage Installation: Post-Installation → LOC: Minor Violation	0.09	0.48	1.17
93	Vehicle Routing: Right, Locality: Urban → LOC: Minor Violation	0.06	0.48	1.16
94	Vehicle Routing: Right, Number of Tracks: 1 → LOC: Minor Violation	0.17	0.48	1.16
95	Vehicle Routing: Left, Day of Week: Weekday → LOC: Safe	0.10	0.54	1.16
96	Vehicle Routing: Left → LOC: Safe	0.17	0.54	1.16
97	Weather: Clear Weather, Number of Tracks: 1 → LOC: Minor Violation	0.34	0.47	1.15

Rule	Description X_1, $X_2 \rightarrow Y$	Support	Confidence	Lift
98	Lighting Condition: Daytime, Signage Installation: Post-Installation → LOC: Minor Violation	0.17	0.47	1.15
99	Weather: Clear Weather, Vehicle Type: Passenger Truck/SUV → LOC: Minor Violation	0.18	0.47	1.15
100	Day of Week: Weekday, Lighting Condition: Daytime → LOC: Minor Violation	0.20	0.47	1.15
101	Weather: Clear Weather, Day of Week: Weekday → LOC: Minor Violation	0.20	0.47	1.14
102	Vehicle Type: Passenger Truck/SUV, Traffic Volume: 100 ≤ VPH ≤ 300 → LOC: Safe	0.12	0.53	1.14
103	Weather: Clear Weather, Signage Installation: Pre-Installation → LOC: Minor Violation	0.19	0.47	1.14
104	Lighting Condition: Daytime, Angle of Encroachment: Perpendicular → LOC: Minor Violation	0.24	0.46	1.13
105	Number of Tracks: 1, Angle of Encroachment: Angled → LOC: Minor Violation	0.10	0.46	1.13
106	Lighting Condition: Daytime → LOC: Minor Violation	0.34	0.46	1.13
107	Locality: Urban, Signage Installation: Pre-Installation → LOC: Minor Violation	0.15	0.46	1.12
108	Day of Week: Weekend, Traffic Volume: 100 ≤ VPH ≤ 300 → LOC: Safe	0.10	0.52	1.12
109	Traffic Volume: 100 ≤ VPH ≤ 300 → LOC: Safe	0.22	0.52	1.12
110	Weather: Clear Weather, Angle of Encroachment: Perpendicular → LOC: Minor Violation	0.24	0.46	1.12
111	Weather: Clear Weather → LOC: Minor Violation	0.34	0.46	1.11
112	Vehicle Type: Passenger Truck/SUV, Locality: Urban → LOC: Minor Violation	0.13	0.46	1.11
113	Vehicle Type: Passenger Truck/SUV, Number of Tracks: 1 → LOC: Minor Violation	0.20	0.46	1.11
114	Day of Week: Weekday, Number of Tracks: 1 → LOC: Minor Violation	0.23	0.46	1.11
115	Vehicle Type: Small Passenger, Vehicle Routing: Right → LOC: Minor Violation	0.07	0.46	1.11
116	Vehicle Routing: Right, Day of Week: Weekday → LOC: Minor Violation	0.11	0.45	1.11
117	Vehicle Type: Small Passenger, Number of Tracks: 1	0.05	0.13	1.10

Rule	Description X_1, X_2 → Y	Support	Confidence	Lift
	→ LOC: Major Violation			
118	Locality: Urban, Day of Week: Weekday → LOC: Minor Violation	0.15	0.45	1.10
119	Weather: Clear Weather, Number of Tracks: 1 → LOC: Major Violation	0.09	0.13	1.10
120	Number of Tracks: 1, Signage Installation: Pre-Installation → LOC: Minor Violation	0.20	0.45	1.09
121	Site Code: B, Signage Installation: Pre-Installation → LOC: Safe	0.05	0.51	1.09
122	Vehicle Type: Passenger Truck/SUV, Vehicle Routing: Right → LOC: Minor Violation	0.10	0.45	1.09
123	Locality: Urban → LOC: Minor Violation	0.27	0.45	1.09
124	Vehicle Type: Small Passenger, Number of Tracks: 1 → LOC: Minor Violation	0.17	0.44	1.08
125	Number of Tracks: 1 → LOC: Minor Violation	0.38	0.44	1.08
126	Vehicle Routing: Right → LOC: Minor Violation	0.18	0.44	1.08
127	Vehicle Routing: Right, Signage Installation: Pre-Installation → LOC: Safe	0.11	0.50	1.07
128	Vehicle Type: Small Passenger → LOC: Major Violation	0.06	0.13	1.07
129	Day of Week: Weekday, Angle of Encroachment: Angled → LOC: Minor Violation	0.07	0.43	1.05
130	Vehicle Routing: Right, Day of Week: Weekend → LOC: Safe	0.08	0.49	1.05
131	Vehicle Type: Small Passenger, Day of Week: Weekday → LOC: Minor Violation	0.11	0.43	1.05
132	Weather: Clear Weather → LOC: Major Violation	0.10	0.13	1.05
133	Number of Tracks: 1, Signage Installation: Post-Installation → LOC: Major Violation	0.05	0.13	1.04
134	Vehicle Type: Small Passenger, Signage Installation: Pre-Installation → LOC: Minor Violation	0.10	0.43	1.04
135	Number of Tracks: 1 → LOC: Major Violation	0.11	0.13	1.04
136	Angle of Encroachment: Perpendicular, Signage Installation: Pre-Installation → LOC: Minor Violation	0.16	0.43	1.04
137	Day of Week: Weekday, Signage Installation: Post-Installation	0.12	0.43	1.04

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
	→ LOC: Minor Violation			
138	Vehicle Type: Passenger Truck/SUV, Signage Installation: Post-Installation → LOC: Minor Violation	0.11	0.42	1.03
139	Vehicle Type: Passenger Truck/SUV, Day of Week: Weekend → LOC: Safe	0.11	0.48	1.03
140	Vehicle Type: Passenger Truck/SUV, Day of Week: Weekday → LOC: Minor Violation	0.13	0.42	1.03
141	Day of Week: Weekend, Signage Installation: Post-Installation → LOC: Safe	0.10	0.48	1.03
142	Vehicle Type: Small Passenger → LOC: Minor Violation	0.18	0.42	1.02
143	Vehicle Type: Passenger Truck/SUV, Signage Installation: Pre-Installation → LOC: Safe	0.13	0.48	1.02
144	Day of Week: Weekend → LOC: Major Violation	0.05	0.12	1.02
145	Day of Week: Weekday → LOC: Minor Violation	0.24	0.42	1.02
146	Day of Week: Weekend → LOC: Safe	0.20	0.48	1.02
147	Angle of Encroachment: Angled → LOC: Minor Violation	0.11	0.42	1.01
148	Vehicle Routing: Right → LOC: Safe	0.19	0.47	1.01
149	Signage Installation: Post-Installation → LOC: Minor Violation	0.20	0.41	1.01
150	Vehicle Type: Passenger Truck/SUV → LOC: Minor Violation	0.22	0.41	1.01
151	Signage Installation: Pre-Installation → LOC: Safe	0.25	0.47	1.01
152	Vehicle Type: Passenger Truck/SUV → LOC: Safe	0.25	0.47	1.01
153	Signage Installation: Pre-Installation → LOC: Major Violation	0.06	0.12	1.00
154	Signage Installation: Post-Installation → LOC: Major Violation	0.06	0.12	1.00
155	Angle of Encroachment: Perpendicular → LOC: Minor Violation	0.30	0.41	1.00
156	Signage Installation: Post-Installation → LOC: Safe	0.22	0.46	0.99

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
157	Signage Installation: Pre-Installation → LOC: Minor Violation	0.21	0.41	0.99
158	Day of Week: Weekday → LOC: Safe	0.27	0.46	0.99
159	Day of Week: Weekday → LOC: Major Violation	0.07	0.12	0.98
160	Day of Week: Weekend → LOC: Minor Violation	0.17	0.40	0.98
161	Lighting Condition: Daytime → LOC: Major Violation	0.09	0.12	0.97
162	Weather: Clear Weather, Site Code: B → LOC: Safe	0.09	0.45	0.96
163	Vehicle Type: Small Passenger → LOC: Safe	0.20	0.45	0.96
164	Site Code: B → LOC: Safe	0.09	0.45	0.96
165	Site Code: E → LOC: Safe	0.08	0.45	0.95
166	Vehicle Type: Passenger Truck/SUV → LOC: Major Violation	0.06	0.11	0.94
167	Locality: Rural, Traffic Volume: $100 \leq VPH \leq 300$ → LOC: Minor Violation	0.06	0.38	0.93
168	Angle of Encroachment: Perpendicular → LOC: Safe	0.32	0.44	0.93
169	Number of Tracks: 1 → LOC: Safe	0.37	0.43	0.92
170	Lighting Condition: Daytime → LOC: Safe	0.31	0.42	0.90
171	Weather: Clear Weather → LOC: Safe	0.31	0.42	0.89
172	Locality: Urban → LOC: Safe	0.25	0.41	0.88
173	Locality: Rural → LOC: Minor Violation	0.14	0.36	0.87
174	Site Code: E → LOC: Minor Violation	0.06	0.35	0.86
175	Vehicle Routing: Straight → LOC: Safe	0.11	0.38	0.81
176	Traffic Volume: $100 \leq VPH \leq 300$ → LOC: Minor Violation	0.14	0.33	0.80
177	Site Code: D → LOC: Safe	0.10	0.32	0.68
178	Vehicle Routing: Left → LOC: Minor Violation	0.09	0.28	0.67
179	Traffic Volume: $VPH > 300$	0.12	0.29	0.62

Rule	Description $X_1, X_2 \rightarrow Y$	Support	Confidence	Lift
	$\rightarrow$ LOC: Safe			

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