Highway-Rail Crossing Safety Improvements by Diverting Motorist to Alternate Routes

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16. Abstract

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Abstract

Integration of an advanced train detection system with a highway traveler information system is needed at highway rail grade crossings (HRGCs) to improve operational efficiency and safety. Diversion of highway traffic to alternate routes that use grade-separated crossings may reduce crash exposure at HRGCs and thereby improve safety. However, research on specific applications and effects of such technologies at HRGCs has not fully been explored. Train Occupancy Time Estimation System (TOTES) was developed in this study to detect train movements, estimate its speed and size, calculate the amount of expected delay that motorists may likely experience, and inform the motorists of the delay. Detailed system components, relevant equations for required variables, and system information logic flow are presented. With a field test of the modified version for the originally developed system, it was revealed that the system significantly improved the safety at a study HRGC by reducing unsafe motorist maneuvers such as crossing the solid white line and illegal left turns. Furthermore, the use of a variable message sign was found to affect the motorists' decision to take an alternate route to avoid delay due to the presence of a train at a crossing. This study provides evidence that safety may be improved at HRGCs by deploying systems such as TOTES.

Chapter 1 Introduction

1.1 Background

Railway transportation is a vital land transportation mode in the United States (US) due to its ability to transport large quantities of freight reliably. Although it has physical and spatial constraints, a broad range of heavy industries traditionally has relied on it for transportation of raw materials and finished goods. Another dominant land transportation mode in the US is the highway, which facilitates the movement of freight and people. A key component in the rail and highway networks is the at-grade junction of these two modes—the highway-rail at-grade crossing (HRGC).

Correctly setting right-of-way is crucial to avoid conflicts between the two modes and to operate them safely at HRGCs. Since train mass and operational characteristics make the braking distance of a train much longer than that of a vehicle, a right-of-way is given to trains. That is, highway traffic must be operated with some type of traffic controllers during train crossing events. There are active and passive warning devices to control highway traffic at HRGCs. The former includes bells, flashing lights, and gates while the latter contains crossbucks, yield or stop signs, and pavement markings. While actively-controlled HRGCs utilize both types of warning devices, passively-controlled HRGCs do not have electronically controlled warning devices and often only contain crossbucks and pavement markings (Federal Highway Administration 2009).

According to Federal Railroad Administration (FRA) Office of Safety Analysis (OSA) (assessed on February 2, 2018), there were 130,724 public and 80,706 private HRGCs in the U. S. in 2016 (Federal Railroad Administration Office of Safety Analysis 2017). At these HRGCs, traffic conflicts involving trains, motor vehicles, bicyclists and pedestrians often make traffic control a challenge. Due to numerous conflicts amongst different transportation modes, collisions are more likely to occur at these locations, and the consequences usually result in significant societal costs due to the nature of train-involved accidents. During 2016, there were 11,257 rail-associated accidents, and these accidents caused 777 fatalities and 8,485 non-fatal injuries. Of these 11,257 total accidents, 2,041 involved an HRGC, accounting for approximately 20 percent of all reported accidents. Total fatalities and non-fatal injuries at HRGCs were 260 and 842 respectively, amounting to 30 and 10 percent of the totals during 2016. Figures 1.1 through 1.3 show the past accident trends in the total number of annual incidents, non-fatal injuries, and fatalities at HRGCs in the U.S. from 2005 to 2016. Even though the number of total accidents had a decreasing trend from 2005 to 2009, an upward tendency appears after 2009. Moreover, the combined number of fatalities and non-fatal injuries at HRGCs has reached over one thousand casualties each year during the period.

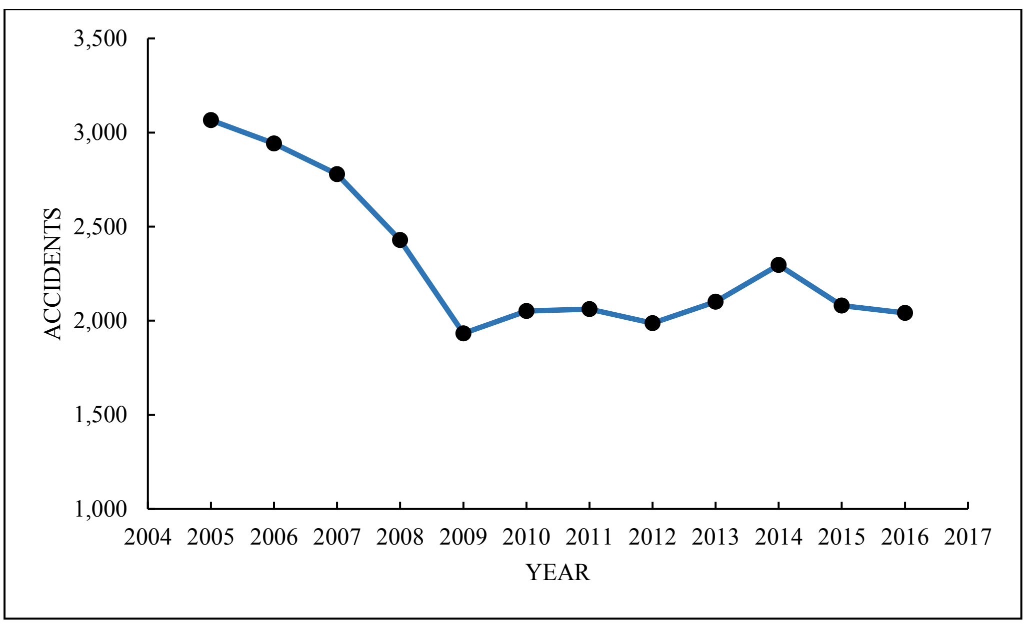


Figure 1.1 National HRGC total accidents from 2005 to 2016

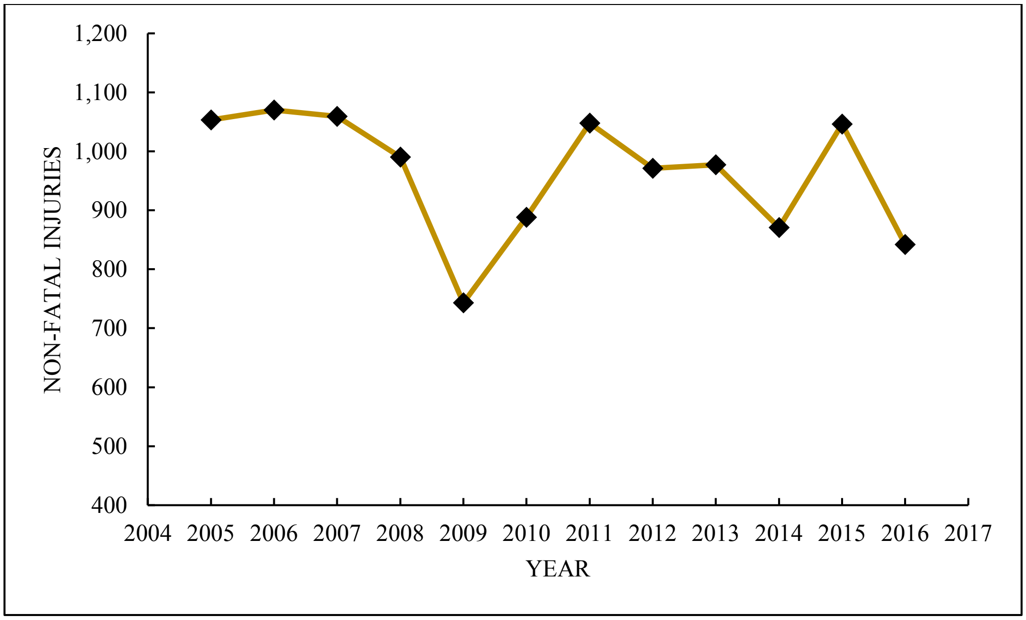


Figure 1.2 National HRGC non-fatal injuries from 2005 to 2016

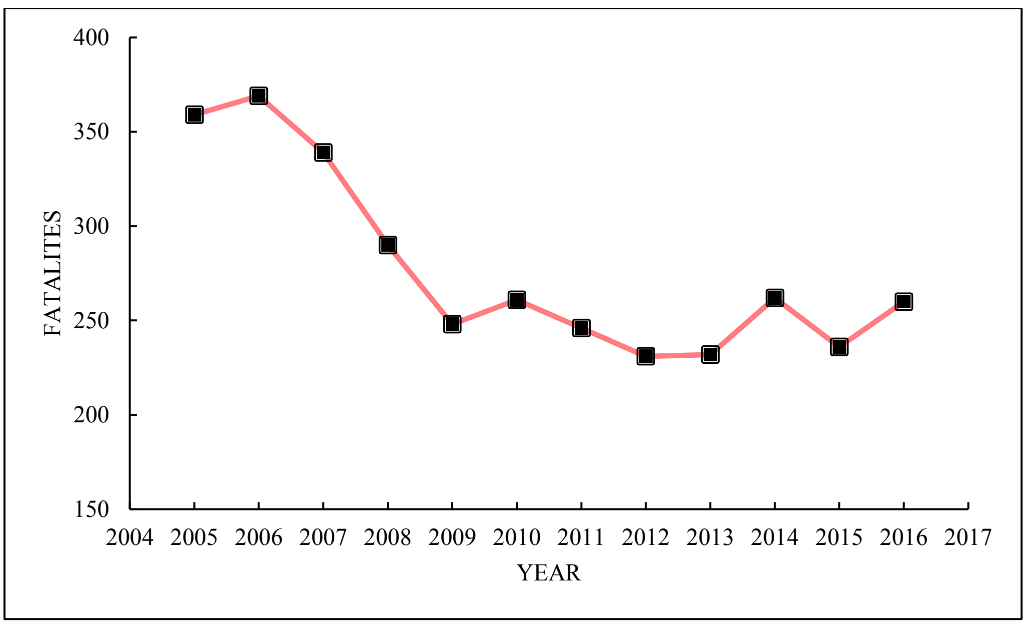


Figure 1.3 National HRGC fatalities from 2005 to 2016

Safety issues at HRGCs are mainly associated with operational controls of the at-grade junction for two different transportation modes. Inefficient train blockages at HRGCs result in lengthy motor vehicle queues causing traffic congestion and queue spillback (Schulz and Smadi

1998; Sivanandan et al. 2003). In particular, crossings near freeway ramps aggravate the problem by hindering traffic from entering and exiting freeways (Sivanandan et al. 2003). Besides, train blockage of HRGCs incurs unknown wait times of highway motor vehicles. These unexpected wait times at HRGCs encourage motorists to make unsafe maneuvers before trains arrive at the HRGCs, such as crossing an HRGC while gates are still moving, or driving around closed gates to pass without delay (Appiah and Rilett 2008; Khattak 2014).

Numerous motor vehicle-train collision prediction models are available to assess the safety of HRGCs (e.g., NCHRP Hazard Index, the USDOT Accident Prediction Formula). A staple of these models is motor vehicle traffic at the crossing—the idea being greater motor vehicle traffic results in a higher number of collisions. That is, the presence of motor vehicles at crossings when trains are at or near crossings creates potential for crashes. A possible solution is grade separation (e.g., overpasses and underpasses) at crossings to provide right-of-ways for both train and motor vehicle movements at all times. However, construction of grade-separated crossing structures is often not feasible due to high costs and physical and spatial constraints (Anandarao and Martland 1998; Krahn and Smadi 1999; Leibowitz 1985; Sivanandan et al. 2003). Another possible solution is to reduce motor vehicle traffic at HRGCs through dissemination of train crossing information. Advanced information on train arrival time and expected delay at an HRGC, and detour route options would provide nearby motorists in their decision-making process with alternate routes. This will be more likely to improve safety and operational efficiency of the transportation network near crossings with a relatively low implementation cost compared to grade-separation. Also, route planning of emergency vehicles will be more efficient with predicted arrival times and estimated crossing times of oncoming trains at HRGCs.

The literature review presented in Chapter 2 shows that there are gaps in HRGC safety literature with respect to motorist diversion behavior near train-occupied HRGCs. This research will assess the feasibility of having an appropriate system aimed to detect train movements and estimate occupancy time at HRGCs. Using preliminary data collected as a case study from the system, this research will investigate driver behavior according to the estimated train delay information. This will reveal specific driving patterns as well as the diversion rate of motorists with varying levels of train-induced delays. The findings from this research are expected to lay the foundation for the implementation of more advanced driver information systems at HRGCs. The hope is to identify potential pitfalls involved in setting up a motor vehicle driver information system at HRGCs and open the door for filling gaps in the knowledge of HRGC safety.

1.2 Problem Statement

To provide better operational efficiency and safety at HRGCs, they need an integrated environment that includes an advanced train detection system and a traveler information system. These systems inform motor vehicle drivers of the presence of a train and the estimated train occupancy time at the crossing so they may optionally divert to alternate routes to avoid possible delay. Any diverted motor vehicle traffic potentially improves the overall highway network efficiency and HRGC safety by reducing the exposure of motor vehicle traffic to trains. In addition, the disseminated train occupancy information may be helpful for emergency vehicle operations as they may avoid train-blocked crossings.

Currently, integrated train detection technologies and their information delivery applications are in developing stages. Much research work has been undertaken on train detection systems to sense the presence of trains and has revealed high network efficiency from using Advanced Traveler Information Systems (ATIS). Despite evolution of train detection techniques and the proven capabilities of ATIS, no research has fully explored the effects of traveler information systems integrated with advanced detection techniques at HRGCs. Additionally, the diversion rate of motor vehicle drivers under varying levels of predicted train-induced delays has not been well researched.

In response to the aforementioned issues, this study proposes to assess the feasibility of developing a prototype system for train detection and a traveler information system for deployment at an HRGC. This system intends to estimate train occupancy time at an HRGC during a crossing event and provide the time to nearby drivers so they may divert to an alternate route. Using preliminary data collected as a case study from such a system, this study will investigate driver-route-diversion behavior when estimated train delay information at an HRGC is supplied. This research will lay the foundation for the implementation of more advanced ATIS at HRGCs. This study will also identify potential pitfalls involved in setting up an ATIS at a HRGC.

1.3 Research Objectives

The goal of this research is to lay the foundation for implementation of ATIS at HRGCs for improving the efficiency of the highway system as well as enhancing safety at HRGCs by diverting motor vehicle traffic to alternate routes when a train is present at an HRGC.

Specifically, there are three objectives to achieve the goal in this study:

1. To design, field-test, and implement a prototype system that provides information to motor vehicle drivers on HRGC delays due to crossing trains. The system is expected to enable motor vehicle drivers to divert to alternate routes in response to train-induced delays at HRGCs. The design process will include defining software architecture and hardware modules and representing the flow of processed data. Based on the design

criteria, a prototype will be built and field-tested. Finally, the developed system will be installed at an HRGC with established guidelines to collect data.

2. To verify effects of the implemented system near an HRGC. Motor vehicle traffic will be measured while the system is disseminating information on the oncoming train and the estimated delay due to the train occupying the crossing. To identify the traffic pattern changes, the number of motor vehicle traffic will be measured before and after the system disseminating train information.
3. To identify the association between the diversion rate and varying levels of train delay information. With a focus on different amounts of estimated train occupancy time, the diversion rate of motorists will be measured to identify factors that contribute to current driving patterns near HRGCs.

The research hypothesis is that the train delay information given to drivers would affect their route diversion behavior. The expectation is that greater diversion will result with longer predicted delays. A before and after study will enable investigation of motor vehicle drivers' diversion behavior. The statistical analytic procedure measures diversion rate along with knowledge of the average delay at two time points as shown in Figure 1.4. The first-time point is before the installation of the developed system disseminating train delay information at an HRGC to nearby drivers. The second-time point is after the system has been installed and initiated. With obtained data at the two time points, statistical analyses will be made to examine if the installation of the system and different amount of delay information have affected drivers' decision making to divert to alternate routes.

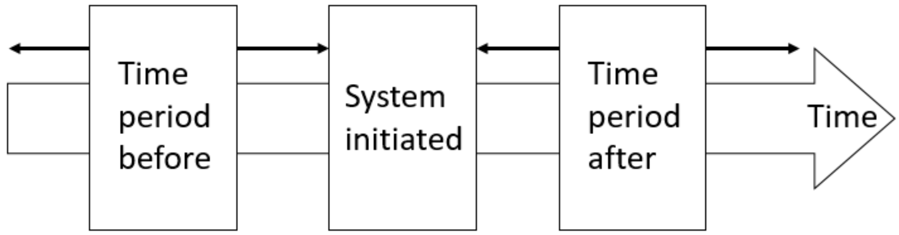


Figure 1.4 Before and after study scheme

1.4 Project Report Organization

This report is composed of six chapters. The present chapter, Chapter 1 provides the study background, includes the research problem and objectives, and outlines the structure of the report. Chapter 2 presents a complete review of literature relevant to the topic of HRGC safety improvement by diverting motorists to alternate routes. This chapter explicates diverse theoretical perspectives of studies in terms of general information of train-occupied HRGC, historical developments of train detection technologies, and traveler information systems applied to HRGCs. This chapter also includes a critical summary of reviewed literature to show the limitations of conducted research work to resolve safety and network efficiency issues of train-occupied HRGC. Chapter 3 describes the process of developing a prototype system to detect oncoming trains, to estimate the occupancy times at HRGCs, and to inform motorists of the estimated train delay. This chapter also describes a complete system check on both hardware and software components to remove possible mechanical and programming errors. Chapter 4 discusses data collection details including data collection scheme, design standards of equipment installation, summary statistics of collected data, and challenges in data collection. Chapter 5 describes analyses of collected data, including detailed explanations of adopted research methods and findings from the results. Chapter 6 discusses results of data analyses and draws conclusions of the project report. The chapter also includes information on the limitations and challenges of this research to adduce future directions of related studies.

Chapter 2 Literature Review

This chapter presents a review of literature on the highway-rail at-grade crossing (HRGC) safety improvement by diverting motorists to alternate routes. This chapter consists of four sections: 1) Train-occupied HRGC, 2) train detection technologies at HRGCs, 3) traveler information systems at HRGCs, and 4) summary of the presented literature review.

2.1 Train-Occupied HRGC

Railroads often run through major cities because cities grow alongside transportation lines such as railways or highways. Thus, many HRGCs exist within cities, causing frequent delays of highway traffic and safety issues when trains occupy those crossings (Schulz and Smadi 1998; Sivanandan et al. 2003). Since train blockage of HRGCs incurs unknown wait times of highway motor vehicles, motorists are more likely to make unsafe maneuvers before train arrival at the HRGCs, such as crossing while gates are still moving, or driving around closed gates to pass through to avoid delays (Appiah and Rilett 2008; Khattak 2014).

2.1.1 Duration of Train-Occupied HRGC

The duration of train-occupied HRGCs is mainly determined by the combination of length and speed of operating trains. A long train takes a significant time to clear and prevents motorists from crossing and overtaking in a network region (Toletti et al. 2015). Typical freight trains can measure approximately 2,000 meters (6,500 feet) in the U.S. (Joiner 2010). However, lengths of three or four times the average train length are possible due to the technological development of the distributed power unit (DPU). The DPUs are placed in the middle or at the end of railcars and remotely controlled by a leading locomotive that generates extra power. This additional power reduces stress on couplers between railcars; subsequently, the number of railcars can be increased significantly (McCarthy 2000).

With the length of a crossing train, another main factor that affects the crossing occupancy time is the speed of a train. The faster a train crosses an HRGC, the less the train occupancy time is at the crossing. It is known that the speed of a crossing train varies based on diverse factors such as the curvature, superelevation, and a different acceleration or deceleration rate applied at HRGCs (Gitelman et al. 2006; Khattak 2014). In the U.S., the FRA has categorized all tracks in nine speed classes based on the track quality as shown in Table 2.1 (Federal Railroad Administration 2014a; b). Each category has the maximum possible running speed limit and the ability to run passenger trains. Generally, passenger trains operate with a faster speed limit due to their lighter weight and shorter length compared to the physical characteristics of freight trains. However, the speed limits for both freight and passenger trains become equal in class 6 or above classes which are designed for high-speed trains.

It is also reported that deployed warning devices at HRGCs affect the duration of train-occupied HRGC (Gitelman et al. 2006; Khattak 2014). This is because the total delay of motorists at an HRGC includes not only the occupancy time of a crossing train, but the operation time of deployed warning devices at the crossing, such as moving gates and visible or audible signals.

Table 2.1 FRA Track Classification by the Maximum Allowable Train Speed

Track class	Freight train	Passenger train
Excepted*	<10 mph (16 km/h)	not allowed
Class 1	10 mph (16 km/h)	15 mph (24km/h)
Class 2	25 mph (40 km/h)	30 mph (48 km/h)
Class 3	40 mph (64 km/h)	60 mph (97 km/h)
Class 4	60 mph (97 km/h)	80 mph (129 km/h)
Class 5	80 mph (129 km/h)	90 mph (145 km/h)
Class 6	110 mph (177 km/h)	110 mph (177 km/h)
Class 7	125 mph (201 km/h)	125 mph (201 km/h)
Class 8	160 mph (257 km/h)	160 mph (257 km/h)
Class 9	220 mph (354 km/h)	220 mph (354 km/h)

* Track type that carries a 10-mph speed limit for freight and cannot be used by revenue passenger trains

2.1.2 Regulations of Train-Occupied HRGC

The “2013 Compilation of State Laws and Regulations Affecting Highway-Rail Grade Crossings” includes a full list of statutory and regulatory provisions regarding blocking of crossings by railroads, legal exemptions, and the infringement penalties of the statutory provisions. According to the document, most states have regulations on the amount of allowable blockage time by a train at an HRGC. Most states generally allow no longer than 20 minutes for a train to block an HRGC. However, a great number of states include an exception for emergencies or circumstances beyond the control of the railroad company in their legal documents (Deborja and Hamilton 2013). Appendix A presents all the detailed provisions provided by each state.

2.1.3 Efforts to Mitigate Issues of Train-Occupied HRGC

The FRA argued that the role of communities and railroads is of the utmost importance to resolve the issues of train-occupied HRGCs. Specifically, the organization suggested possible solutions that can be divided into operational strategies, systematic strategies, and communication among stakeholders (Federal Railroad Administration Office of Public Affairs 2008).

Several operational strategies that a railroad may adopt include: 1) making a train wait at the outskirt area until it can pass through the HRGC without stopping; 2) improving rail yard traffic management to make train operations more efficient; 3) working with customers to establish pick-up and delivery times that minimize impact on HRGCs; 4) limiting the length of trains; 5) relocating train stops for a crew change; and 6) decoupling a long train into two trains before crossing the HRGC to allow the resumption of highway traffic. These strategies directly involve required actions by railroad companies and require their active participation.

The FRA also provided systematic strategies that include using public and/or private investments and developing technologies to mitigate the blocked grade crossing issues. Investing public and/or private funds include: 1) improvement of rail infrastructure such as the addition of more rail tracks or lengthening sidings; 2) construction of grade separations to provide independent right-of-ways for both highway and railway traffic; 3) closure of problematic crossings to improve highway traffic flow; and 4) relocation of a rail line to a completely new right-of-way. These strategies result in the inevitable compilation of a massive budget to achieve effectiveness. However, systematic strategies that use developing technologies are more feasible to implement since they can be installed in a short time at relatively low cost. These strategies may involve: 1) establishing systems using communication-based train controls with GPS; 2) applying Electronically Controlled Pneumatic (ECP) brakes to reduce frequency and the time it takes to perform federally required air brake tests; and 3) utilization of Intelligent Transportation Systems (ITS) to inform drivers and emergency responders of advance information about blocked grade crossings so they can take alternate routes.

Close communication between stakeholders is another option to mitigate the issue. Railroads, local communities, state agencies, and emergency responders discuss and understand the issue, and establish how each can contribute to the issue to improve safety and efficiency of HRGC operations. For instance, local governments can hold public hearings on planning or operating HRGCs, gather the opinions of the residents and the people engaged in business, and have a better plan to minimize impacts of HRGCs on the communities.

2.2 Train Detection Technologies at HRGCs

Most of the research conducted on train detection technologies at HRGCs focused on providing reliable information on arrival of approaching trains. With knowledge of train arrival times, HRGCs can be managed in a safer and more efficient manner to control motorists, pedestrians, and bicyclists. Types of train detection techniques have evolved and can be divided into three levels: first, second, and third generation (Cho and Rilett 2003; Forsberg 2012).

2.2.1 First Generation

First generation train detection systems rely on detectors connected to railroad track circuits. Approaching trains are detected using electric signals from the rail track circuits. A change in the electric signal wave pattern due to a passing train on the rail track activates warning devices installed at the HRGC (Cho and Rilett 2003). The first generation of train detection technology is widely used around the world due to its simplicity and reliability.

2.2.1.1 Fixed-Distance Warning Time (FDWT) System

Figure 2.1 presents the working of the fixed-distance warning time (FDWT) system. This system consists of a train detector placed a fixed distance away from the HRGC. The distance is long enough so that the fastest train is detected with a warning time of at least 20 seconds (Forsberg 2012; Halkias and Eck 1985). The 20 seconds warning time is the specified minimum standard in the Manual on Uniform Traffic Control Devices (MUTCD). Since the distance is set with the fastest train arriving at the HRGC with the minimum required warning time, oncoming trains at slower speeds may cause excessively long warnings at an HRGC. As the amount of warning time varies for each train having a different speed, drivers may make poor decisions to cross the HRGC (Cho and Rilett 2003).

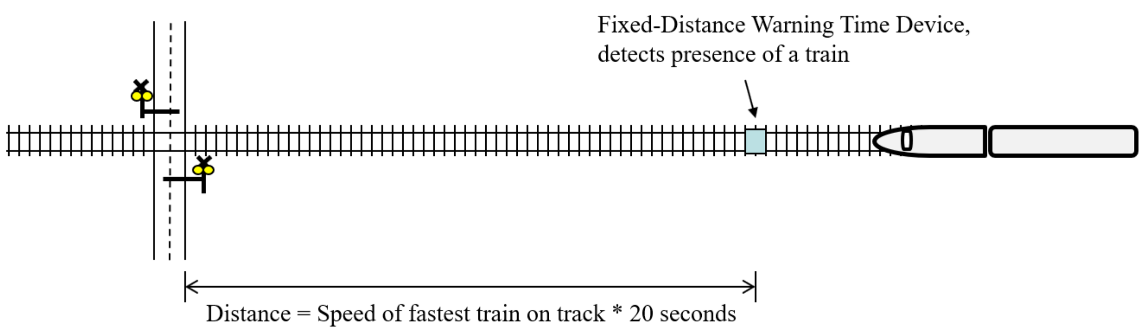


Figure 2.1 Diagram of fixed-distance warning time device (Forsberg 2012)

2.2.1.2 Constant Warning Time (CWT) System

Another application of the first generation train detection is the constant warning time (CWT) system (Fig. 2.2). This system improved the FDWT system by taking into account train speed at the detector location. Similar to the FDWT system, a detector is placed from the HRGC at a distance that will provide a 20 second warning with the fastest train expected on the tracks. The system estimates the arrival time based on the measured speed along with distance from the crossing and provides a constant warning time for each train regardless of its approaching speed (Forsberg 2012; Halkias and Eck 1985). However, the system assumes constant train speed (i.e., no acceleration or deceleration).

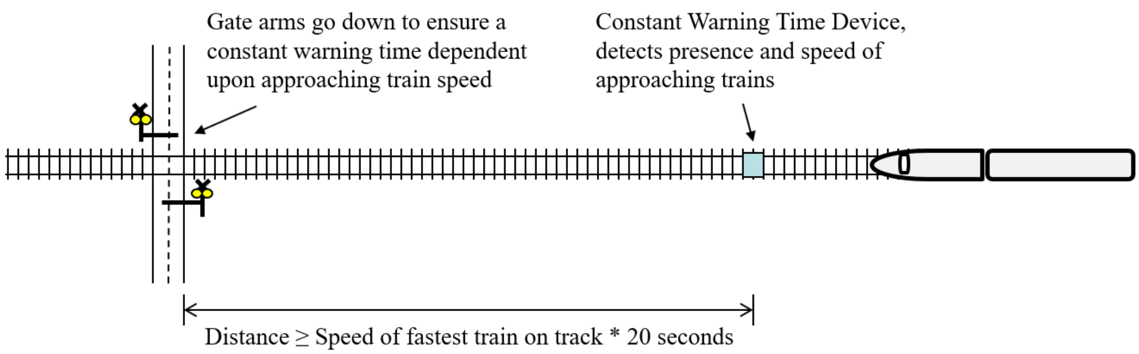


Figure 2.2 Diagram of constant warning time device (Forsberg 2012)

2.2.1.3 Measures of Effectiveness (MOE)

To determine the influence of FDWT and CWT systems, a study developed measures of effectiveness (MOE) under several different conditions including road classification (freeway, principal arterial, minor arterial, collector, and local), angle of crossing (0°-29°, 30°-59°, and 60°-90°), and train speed (Halkias and Eck 1985). With respect to the influence of train speed, the authors examined three different measures: speed difference, speed ratio, and maximum speed. The speed difference approach was the algebraic difference between maximum timetable speed and typical minimum speed. The speed ratio approach was the ratio of maximum timetable speed to typical minimum speed. The maximum speed approach was the maximum timetable speed. Using data acquired from the U.S. Department of Transportation-Association of American Railroads Crossing Inventory File and the FRA Accident/Incident Reporting System, the authors used a formula developed by Morrissey (1980) to calculate the effectiveness of the warning device systems. The used MOE equation is as below.

$$\mathrm{E} = \left(\frac{A_b}{Y_b} - \frac{A_a}{Y_a}\right) / \frac{A_b}{Y_b} \tag{2.1}$$

Where,

E = effectiveness of a particular warning device system (%),

A_b = total number of accidents before warning device installation,

Y_b = total number of crossing years before warning device installation,

A_a = total number of accidents after warning device installation, and

Y_a = total number of crossing years after warning device installation

The results showed that the FDWT and CWT systems were similarly more effective than passive warning systems such as crossbucks, yield or stop signs, and pavement markings. CWT systems displayed a 3 percent greater level of effectiveness than FDWT systems. However, the effectiveness value was 26 percent when CWT systems replaced FDWT systems, confirming CWT systems had greater reliability than FDWT systems. Meanwhile, the functional class of the roadway did not show significant impact on the calculation of effectiveness when FDWT systems were replaced with CWT systems. The authors noted that the effectiveness value of upgrading from a FDWT to a CWT was the greatest for the crossing angle category of 0 to 29 degrees (68 percent). The authors also argued that the effectiveness value of CWT systems increased as variation of train speed increased. The concepts of speed ratio and speed difference did not show apparent influence in calculating effectiveness values for both FDWT and CWT systems (Halkias and Eck 1985).

2.2.1.4 Effects of CWT at HRGC

Using a video detection camera and a before and after field study design, Richards et al. (1990) investigated effects of CWT systems in terms of crossing safety and driver response measures. The utilized CWT system was an advanced detector that can provide a fixed CWT at crossings with variable speed trains or switching operations. The subject HRGC consisted of a single-track and flashing light signals. The field data obtained for a two-month period without providing CWT was compared to another two-month data with the CWT detector. There were a total of 139 trains involved in the study – 89 trains during the before study and 50 trains during the after study. Before the CWT detector was installed, it was found that the crossing warning times were highly variable, and frequent long warning times were observed. After the installation of the CWT detector at the HRGC, the warning times were more consistent. The research also revealed that the average length of train warning times was reduced, and fewer excessively long warning times occurred with the detector installed. In addition, the average number of vehicles crossing during the flashing light signal activated were significantly reduced. Based on the results, the authors concluded that the installation of CWT detectors at HRGCs improved crossing safety and traffic operations, and recommended the system be installed at active crossings that have highly variable and long train warning times.

2.2.1.5 Time Domain Reflectometry (TDR)

A more advanced system of the first generation technology was developed and tested by Turner (Turner 2009). The author developed a system using a concept called Time Domain

Reflectometry (TDR) to detect oncoming trains and estimate their arrival times at HRGCs. The proposed method used rails as a two-wire differential transmission line. The system transmits electrical coded pulses through the railways at a known speed. When the train's axles reflect these pulses, control systems detect the variation of the pulses. The distance from the control systems to the detected train axel is then identified based on the reflected time. A field test was conducted to ensure the feasibility of the system after properties of the electrical transmission line were determined based on variations for tie type, track ballast quality, and moisture content. Findings revealed that trains could be detected at theoretical distances of up to 5 miles under ideal conditions. However, poor conductance on railways was found when rail tracks were covered with dirt and mud. Moisture accumulation on rail tracks also significantly affected the detection range by deteriorating the quality of electric pulses transmitted.

2.2.2 Second Generation

Train detection equipment has evolved by using more advanced detection technologies to produce, process, and communicate required data. The quality of the data obtained with second generation technologies is generally better than that obtained using first generation because it provides more detailed train information. Besides, the deployment cost to install the second generation systems is relatively inexpensive compared to the first generation (Estes and Rilett 2000). The second generation train detection systems also involved the concept of avoiding the use of rails or minimize the use of areas near HRGCs for communication between the train and infrastructure (Morar 2012). Much of the research has been conducted using second generation technologies including radar, acoustic sensors, anisotropic magneto-resistive magnetometers, and video image detection cameras (Santos et al. 2013).

2.2.2.1 Radar Detection Technology

Train detection systems using radar technology is the most popular second generation technique. A radar detection system uses electric signals beamed to surrounding areas at known propagation speed, and measures reflected time of the signals from a moving target object to identify information such as speed and direction. In analyzing low-cost active warning devices, a study was conducted using a radar detector (Roop et al. 2007). The study used Doppler radars located 0.5 miles away from the target HRGC to activate train-warning devices automatically. The radar system was installed for both directions so the departures and arrivals of trains could be detected in advance. The obtained data of the tested system was compared to the data from a track circuit-based device, which provides reliable detection. The result showed that even though the radar system successfully detected crossing trains at 100 percent accuracy, it produced many false positive detections, recognizing some non-train objects as the presence of a train. The use of radar at HRGCs can also be found in many other research papers (Chen 2015; Cho and Rilett 2003; Estes and Rilett 2000; Goolsby et al. 2003). These studies used Doppler radar in similar ways to collect train detection data at HRGCs.

2.2.2.2 Acoustic Detection Technology

Roop et al. (2007) conducted a study using an acoustic train detection system, which utilizes sound generated from train operation. The authors investigated frequencies of existing train horns and used frequency ranges to identify the presence of a train. The developed system was comprised of a power supply, an analog microphone, an analog amplifier, an analog-to-digital converter, a digital microprocessor, a logic controller, and a digital electrically programmable read-only memory (ROM). The equipped microphone was omnidirectional to detect trains at both directions by distinguishing the frequency ranges from peripheral noise. The authors conducted a field study to reveal the effectiveness of the acoustic detection system by comparing it with a track circuit-based detector. The result showed that the total activated number of the acoustic system was 26,094 during the field research period, 1,486 of which were correct detections of train presence. From the result, the authors indicated that the false alarm rate of the system was too high (94.3 percent) even though the system did not make any true negative detections. With the high degree of false positive detections rate, the authors concluded that advanced technical updates should be added to be applicable at HRGCs.

2.2.2.3 Magnetic Detection Technology

A research effort was made to examine the applicability of using Anisotropic Magneto-Resistive (AMR) magnetometers to determine when to activate warning devices at HRGCs (Brawner and Mueller 2006). The developed idea is based on the earth's magnetic field, which is locally formed as parallel lines. When a large metallic object such as a vehicle or a train changes the regularly arrayed magnetic parallel lines, magnetometers detect the transformed traits of the lines. The proposed AMR sensors were not only able to detect train presence by recognizing the transformed array of earth's magnetic field but also to differentiate the unique magnetic signature of each moving object. This unique signature of a metallic object can also be used to determine the moving direction since the wavelength is a mirrored image, as shown in Figure 2.3. The authors concluded that the 3-axis measurement capability of the AMR magnetometers is feasible to detect moving vehicles successfully and to remove noise signatures to obtain correct vehicle signatures. However, they argued that future research work and sufficient funds on this technology will be necessary to deploy this new train detection technology at HRGCs as an alternate train warning system.

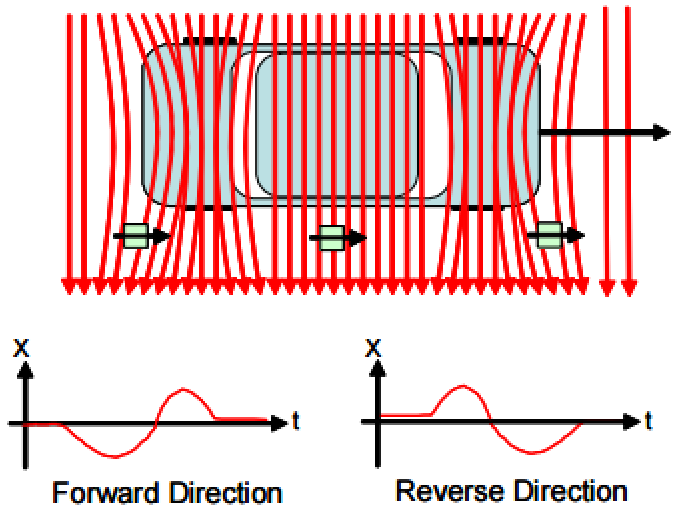


Figure 2.3 Directional signature of vehicle (Application Note – AN218 2005)

2.2.2.4 Video Image Detection Technology

Video image detection techniques have been used at HRGCs to detect train movements (Appiah and Rilett 2008; Chen 2015; Forsberg 2012; Martin et al. 2004; Tian 2003). Video image detection technologies involve an image processor, which extracts necessary information from a video footage. These detection devices have capabilities to obtain speed, occupancy, count, and the presence or absence of vehicular objects. To have information of vehicles or trains at a specified area, the system sets one or several detection boundaries within the image range of the camera. Using real-time image processing algorithms, the system detects any changes within the boundaries for desired objectives. A common operational issue of this technology is occlusion, which results in missed detections, false detections, and increased detector presence time (Tian 2003). Occlusion takes place because of the parallax effect in video detection systems, as shown in Figure 2.4. As two different objects are overlapped at one detection zone, the video detection system may not correctly identify the two as separate objects due to the overlapping (e.g., one behind the other cannot be recognized by the detector). To remove fallacious detections, the position of detection cameras should be high enough to secure both rail tracks in a detection zone (Tian 2003).

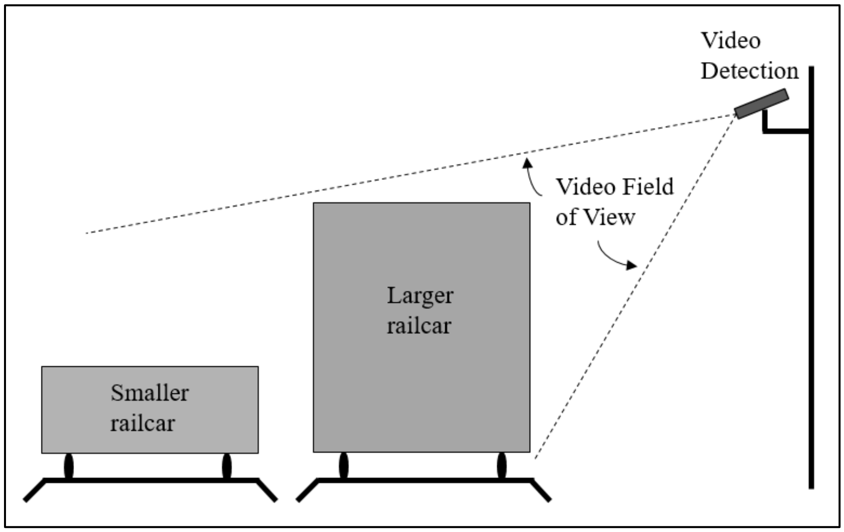


Figure 2.4 Illustration of Occlusion (Forsberg 2012)

A study investigated various environmental factors that may affect the performance of the accuracy of the video detection system in eight locations in Utah (Martin et al. 2004). Data were obtained under different weather (clear, snow, rain, and fog), and light conditions (day, night, and dusk). The study found that the detection accuracy was the highest during day and dusk conditions, having approximately 87 percent of the correct detection rate. The rate, however, was reduced during the nighttime (73.4 percent) and under severe weather conditions (81.3 percent). The study recommended that the detailed installation information of video detection equipment be carefully reviewed before deploying. Such information includes proper placement of cameras, enough background lighting acquisition, camera focus settings, and field of view calibration to minimize false detections.

2.2.2.5 Multiple Detectors in a System

Several detection technologies can be combined to provide additional information on trains as well as highway vehicle status. Multiple detectors combined in a system have significant potential of generating more detailed and accurate train information that may be a source of future traffic control systems (Reiff et al. 2001, 2003). The FRA, Transportation Technology Center, Inc. (TTCI), and the John A. Volpe National Transportation Systems Center (Volpe Center) conducted a study to evaluate five combined systems identified as System 1, 2, 3, 4, and 6 (Reiff et al. 2003). Table 2.2 summarizes the combined detection technologies evaluated in the study. System 5 was not included since the equipment installation was not complete at the time the report was prepared. System 1, 2, 3, and 4 detect trains only or trains and highway vehicles simultaneously while System 6 only detects highway vehicles and obstacles around an HRGC, thus the system should be integrated with another form of detection targeting trains to be operational at HRGCs.

Table 2.2 Non-Track Circuit Based Detection Technologies at HRGCs

Prototype system	Detection methods	Target(s) detected
System 1	Magnetic anomaly and vibration detectors	Train
System 2	Double wheel, laser, and video imagery detectors	Train, vehicle and obstacle
System 3	Vibration and magnetic anomaly detectors	Train
System 4	Inductive loop and radar detectors	Train and vehicle
System 6	Passive infrared and ultrasonic detectors	Vehicle and obstacle

*System 5 was not included as installation was not complete at the time of the report.

With respect to system architecture, System 1 sensor module consisted of magnetic anomaly and vibration detectors. When a train is approaching, two detectors sense the magnetic field changes and vibrations caused by the train. These two detectors operate independently of each other. The obtained information from the detectors is transmitted and stored in a control module located near the HRGC. System 2 consisted of a track circuit (Fig. 2.5, left) and a non-track circuit detector for train and highway vehicle detection (Fig. 2.5, right). The system used a double wheel sensor and each sensor had a pair of resonant circuits intended to detect the approach and departure of trains. The detector counts the axles of a train passing the detection point and sends the information to the controller located near the HRGC via electric wires. In addition, low power laser and video imaging detectors were integrated to the system to detect highway vehicles and other obstacles.

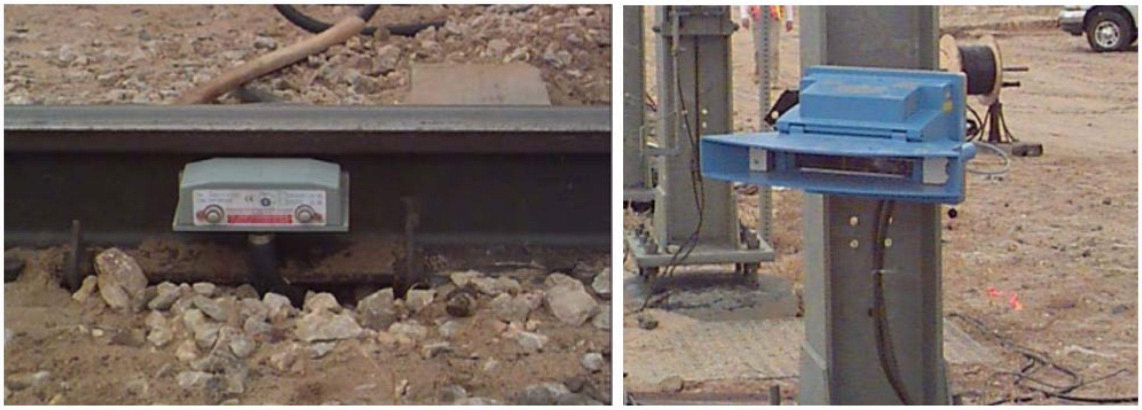


Figure 2.5 System 2 Wheel sensor (left) and vehicle/obstacle detection sensor (right) (Reiff et al. 2003)

System 3 was evaluated as a train detection system only. This system consisted of vibration and magnetic anomaly sensors to detect the moving trains at/near HRGCs. The detectors were connected to the control module at the HRGC via radio frequency transmitters. System 4 was evaluated as an integrated train and vehicle detection system. This system included inductive loops buried under the rail tracks to detect the movements of trains (Fig. 2.6, left). These loops were hardwired to a control unit to transmit train presence information. With respect to vehicle detection, the system utilized a single radar unit placed on one side of the HRGC (Fig. 2.6, right).

Figure 2.6 System 4 Inductive loop sensors (left) and radar detector for vehicle (right) (Reiff et al. 2003)

Lastly, System 6 was evaluated as a vehicle/obstacle detection system. This system consisted of passive infrared and ultrasonic detectors to sense vehicles or obstacles near the target HRGC. To install this system, the detectors should be situated above the target HRGC facing downward to secure a clear vertical view of the crossing surface area. During the evaluation period, 12 sensors were arranged above the HRGC and suspended with the catenary wire. Figure 2.7 represents the actual installation of the sensors at the study site and their perspective drawing of the installation to display detection areas. Although brief explanations of each evaluated system are addressed in this literature review, detailed technical information of each system, as provided by the system vendors, appears in the original report (Reiff et al. 2001, 2003) and thus will not be documented in this chapter.

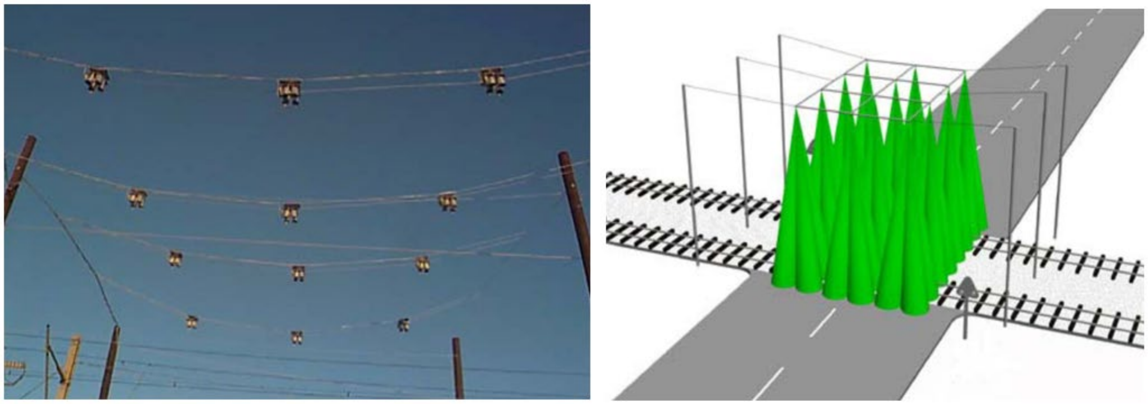


Figure 2.7 System 6 vehicle/obstacle detection sensors (left) and perspective drawing of the installation at a HRGC (right) (Reiff et al. 2003)

The evaluations were conducted for these five systems with the criteria including successful detections, critical failures, missed detections, and nuisance and/or false alarms. The results showed that System 2 did not make any train approaches nor train island area failures. It also did not include any missed detection, nuisance, or false alarms showing a 100 percent detection rate. System 4 made nine critical failures and 17 nuisance or false alarms during the evaluation, accounting for 22 percent and 41 percent of detection error rates, respectively. Systems 2, 4, and 6 detected static pedestrians and vehicles with reasonably low detection failure rates in the target HRGC. System 2 and 6 made no mistakes in detecting dynamic obstacles while only System 6 properly detected dropped loads. Using Intelligent Transportation Systems (ITS) information, the technologies' capability to identify train direction, train speed, and train length were also evaluated. Results showed that System 2 was able to provide train direction and train speed information, and System 4 was able to provide train direction information. The authors concluded that the evaluated prototype systems did not always provide satisfactory train and highway vehicle detection and recommended future studies on these technologies for improved performance (Reiff et al. 2003).

2.2.3 Third Generation

This generation is the most sophisticated technological development phase in which real-time train information on the train and highway network is shared by central operation centers or roadway users immediately. Technologies in this generation are generally referred to as communication-based control systems. All trains are equipped with wireless communication systems to exchange necessary information with the central operation center. In addition, the developed sensor technologies in the first and the second generation can also be integrated with advanced communication equipment and provide a more advanced control system environment. (Cho and Rilett 2003; Morar 2012).

Since mid-1990 the U.S. DOT and FRA had sponsored research conducted by the John A. Volpe National Transportation Systems Center of the U.S. DOT Research and Innovative Technology Administration (RITA) (Federal Railroad Administration 2007). This research had focused on integrating Intelligent Transportation Systems (ITS) technologies with Positive Train Control (PTC), which is a communication-based/processor-based train control technology intended to provide capabilities to control trains reliably and functionally. Figure 2.8 represents the configuration of PTC integrated with ITS technologies in the research. A part of the study's research objectives was to conduct technological assessment of vehicle proximity alerting systems (VPAS) in different scenarios to improve safety and efficiency at HRGCs.

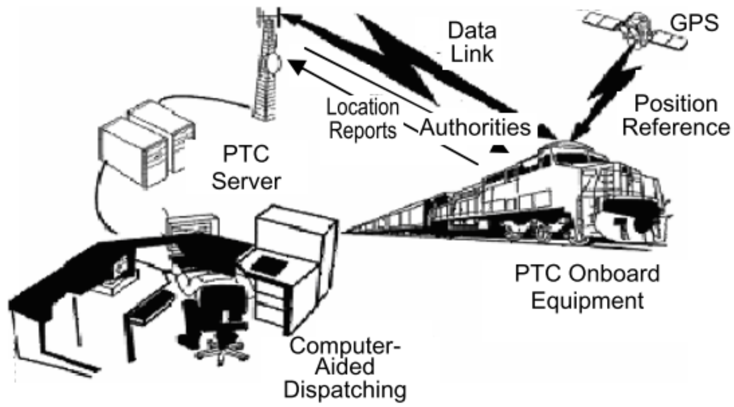


Figure 2.8 System configuration of PTC integrated with ITS (Federal Railroad Administration 2007)

To evaluate VPAS, three prototypes were tested in the controlled environment of the Transportation Technology Center (TTC), Pueblo, Colorado (Fig. 2.9): 1) a three-point radio frequency (RF) system, which has a wayside transceiver between a locomotive transmitter and a vehicle receiver; 2) a two-point RF system to deliver information from a locomotive transmitter to a vehicle receiver directly; and 3) a one-point onboard acoustic system in vehicles to detect the horn of the approaching train and alert the drivers (Carroll et al. 2001). All prototype systems were tested with four different phases. One of the main test phases was that the systems were actuated repeatedly for more than 500 train runs under the same conditions. During the test, the RF or horn signals of test trains were activated with a certain distance before the target crossing and deactivated after the crossing. The stationary test vehicles were located 500 ft (150m) from the HRGC. The results showed that the three tested VPAS prototypes were feasible and thus able to be installed at HRGCs. Also, RF systems were more suitable to communicate than acoustic devices at HRGCs.

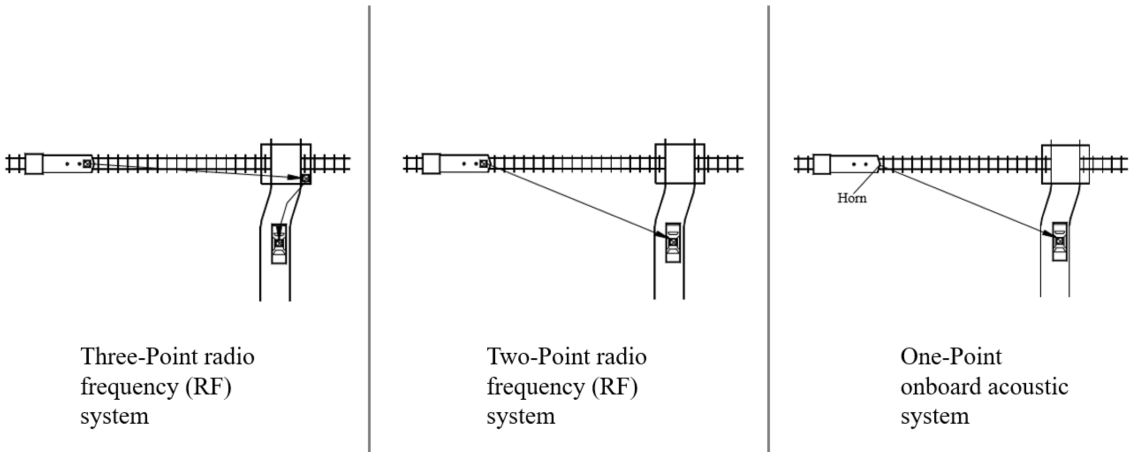


Figure 2.9 Three VPAS prototype designs (Federal Railroad Administration 2007)

Similarly, in-vehicle warning systems using the third generation technology were also tested by the Raytheon Company (Sikaras et al. 2001). The purpose of the systems was to warn vehicles equipped with the communication receiver when an oncoming train is approaching. The tested systems included different modes such as visual, audible, or visual/audible. The authors argued that the installation of the systems made drivers more attentive at HRGCs.

Using third generation technology, the San Antonio Metropolitan Model Deployment Initiative (MMDI) developed the Advanced Warnings for Railroad Delays (AWARD) project to provide oncoming train information to nearby drivers. The authors integrated second generation train detection techniques (Doppler radar and acoustic detectors) with advanced communication devices to obtain and utilize oncoming train information. The information was transmitted to the master computer located in the Transguide Operation Center (TOC) to provide proper network operation strategies (Carter et al. 2000). Figure 2.10 represents the designed communication-based system used to obtain information from HRGCs and disseminate it to nearby drivers.

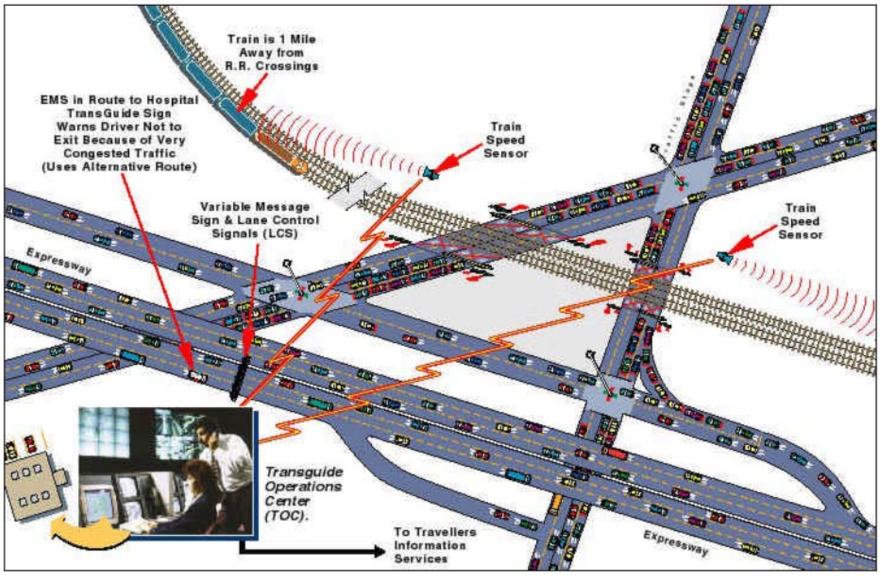


Figure 2.10 Communication based AWARD system for railroad crossing (Carter et al. 2000)

2.3 Traveler Information Systems

At HRGCs, traveler information systems can provide train information such as presence of train or expected delay derived from crossing trains. Given the information, motorists may take alternate routes to avoid delay from a blocked crossing. The reduced traffic at an HRGC may alleviate potential conflicts at crossings and improve crossing safety as well as network efficiency. Providing accurate traveler information such as Advanced Traveler Information Systems (ATIS) in a timely manner has already indicated an improvement in highway network efficiency (Chatterjee et al. 2002; Mcdonald et al. 1998; Peeta et al. 2000; Peeta and Gedela 2001).

2.3.1 Variable Message Signs (VMS)

Variable message signs (VMS), or changeable message signs (CMS), are a typical form of presenting information to assist roadway users in the ATIS. A VMS is a type of electronic traffic control device that disseminates network traffic information to drivers nearby. VMS are used for a variety of purposes including parking guidance, control of high-occupancy-vehicle

(HOV) lanes, safety warnings, traffic flow diversion in work zones, etc. However, it is particularly useful under incidents by providing information and influencing driver routing decisions, and hence enhance transportation network efficiency (Chatterjee et al. 2002; Peeta et al. 2000; Peeta and Gedela 2001). VMS messages are divided into two main groups according to their displaying contents: passive and active messages. A passive message refers to simple explanations of the situation such as accident type and location, expected delay, etc. On the other hand, an active message contains recommended action or required activities that exposed drivers should follow such as route guidance or available alternate routes (Peeta et al. 2000).

Driver response rates may provide an assessment of VMS effectiveness in traffic operations. A study investigated drivers' responses to VMS by estimating a logistic regression model with data collected via a questionnaire. Considering the probability of route diversion, and journey and message characteristics, the study concluded that the location of the incident and message contents were main indicators affecting driver diversion rate (Chatterjee et al. 2002). The research of Peeta et al. (2000) aimed to reveal the relationship between the VMS message contents and driver route diversion rates. The authors hypothesized that drivers would react differently to various representations of the same message content, and if so, the contents of the message could be used as a control factor in VMS design. After conducting an on-site survey, the authors concluded that the level of detail in the VMS contents significantly affected drivers' decision about diverting.

More recently, a study by Majumder et al. (2013) argued that drivers' rerouting tendency was significantly affected by several factors connected to drivers at locations with VMS. Focusing on the frequent drivers at the study site, the authors of the study developed a generalized ordered logit (GOLOGIT) model and generalized regression model to reveal the relationship between the diversion tendency and other explanatory variables including socioeconomic characteristics, route familiarity, VMS information accessibility, and trip characteristics. The authors reported that trip perceptions including travel time sensitivity, trip flexibility, and trip safety perception affected drivers' decisions to reroute.

Another study also conducted a survey to unveil driver response tendencies with the provided information from VMSs in Beijing, China. When it comes to personal socioeconomic characteristics, females, more experienced, private vehicles, or calm drivers were more likely to divert to an alternate route via VMS. In association with trip characteristics, commuter drivers and drivers with familiarity of alternate routes were more likely to reroute to an alternate road. The authors stated that VMS perception will be increased by providing more specified message contents and reduced lags for real-time message displaying (Ma et al. 2014).

2.3.2 Traveler Information Systems for HRGCs

Although deployment of advanced information systems can potentially improve safety and operational efficiency, relatively little attention has been paid to using it at HRGCs. A study investigated the application of advanced detection systems (ADS), advanced traveler information systems (ATIS), and advanced signal control systems (ASCS) to provide drivers with information about oncoming trains (Schulz and Smadi 1998). In analyzing drivers' diversion, the authors used a traffic simulation program, TRAF-CORSIM to reveal the effectiveness of the ITS systems. The four simulated scenarios included one base case reflecting the current condition and the three ITS alternative cases (ADS, ATIS, and ASCS), which reflected varying driver response rates. The four measures of effectiveness used in the study were: 1) total travel time, 2) total delay time, 3) Level-Of-Service (LOS), and 4) queue lengths. Findings revealed that the three scenarios using ITS systems showed reduced travel time, delay, and queue lengths as well as improved LOS in the simulation program.

In the course of investigating integration of HRGCs with traveler information systems, the San Antonio Metropolitan Model Deployment Initiative (MMDI) proposed the Advanced Warnings for Railroad Delays (AWARD) project by using VMS for freeway traffic. The system was designed to provide motorists and emergency response vehicles on Interstate 10 (I-10) in San Antonio, Texas with train blockage information near exit ramps. When a train approaches an HRGC, the system detects the presence, speed, and length of the train by Doppler radar and acoustic sensors located along the railways (Fig. 2.11). Then, the obtained information is transmitted to the master computer in the operation center. The computer calculates the expected train arrival time at the HRGC and sends the information to VMS installed on the freeway.

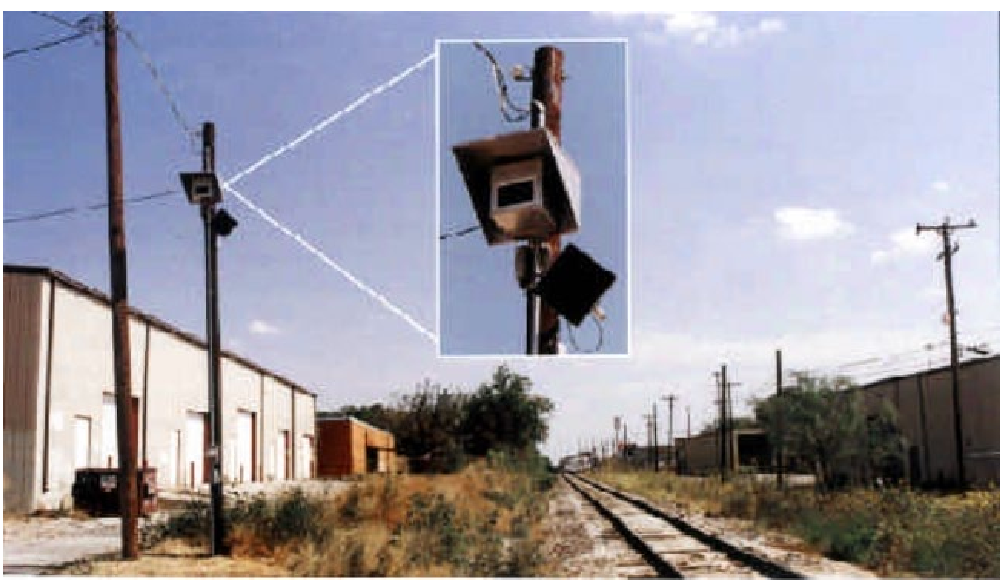


Figure 2.11 AWARD site installation to collect train information (Carter et al. 2000)

The evaluation of the highway-rail information system in the AWARD project was conducted in two ways: field interviews and a micro-simulation model (INTEGRATION). The major findings of the AWARD project are summarized as follows:

- The deployment of the system is feasible as an integrated HRGC traveler information system due to its non-intrusive feature which represents the rapid and immediate integration with the current system;
- The system did not provide substantial immediate benefits as expected at the three study sites because train delays and traffic demands are not too high; and
- The system benefits depend on the driver compliance rate (Carter et al. 2000).

Using one of the three locations analyzed in the AWARD project, a study reviewed the conclusions made in the previous research conducted in the project. The authors discussed the potential use of VMS to disperse congested traffic to alternate routes at HRGCs near freeway exits. A case study was conducted using the INTEGRATION software to evaluate the impacts of VMS and train operations at the crossing. After simulating different scenarios based on various levels of train-crossing time, traffic demand, and the vehicle response rate to VMS, the authors obtained similar results by showing little network improvements with the use of VMS, with only a marginal decrease of total travel times in the simulated network (Sivanandan et al. 2003).

More recently, a research effort was made to examine the effectiveness of VMS to supplement railroad preemption operations at HRGCs. The authors evaluated changes of queue lengths and average intersection delay by simulating different train occupancy times and different levels of driver compliance to VMS. They used a microscopic simulation model, VISSM, where lengths of train were used as a surrogate measure of train occupancy times, and rerouted vehicle volume was used to refer diverted vehicles to alternate routes. The result showed that the queue formed during the train blockage at the HRGC was reduced after VMS effects were included. Also, the diverted traffic did not aggravate the traffic on nearby signalized intersections (Appiah and Rilett 2008).

2.4 Summary

Highway traffic blockage by trains occupying crossings is an issue and a cost-effective solution is to introduce systematic strategies at HRGCs by deploying train detection technologies and traveler information systems to divert motor vehicle drivers to alternate routes. Train detection technologies have evolved to improve the safety and efficiency at HRGCs by detecting trains accurately. Various studies have been conducted using these technologies to detect trains efficiently and accurately. In particular, traveler information systems can be a vital part in disseminating information obtained from the train detection technologies. However, relatively limited literature has uncovered the use of the detection technologies along with traveler information systems applied at HRGCs. Although some studies investigated the effects of VMS to divert motorists to alternate routes during the train crossing events, effectiveness of the systems was not verified (Carter et al. 2000; Sivanandan et al. 2003). Previous research only used on-site surveys or simulation software to evaluate the network effect and diversion rate near HRGCs. Therefore, the review of literature shows that there is a need to: 1) investigate effects of traveler information systems integrated with an advanced train detection application at HRGCs, 2) reveal the types of driver behaviors given the train information via a traveler information system, and 3) measure the actual diversion rate after installation of the traveler information system at HRGCs.

Chapter 3 System Design

3.1 Train Occupancy Time Estimation System (TOTES)

Train Occupancy Time Estimation System (TOTES) is a system designed in this study that detects train movements, estimates its speed and size, calculates the amount of expected delay that motorists are likely to experience, and informs the motorists of the delay. The TOTES consists of three parts: the Train Detection System (TDS), Detection Control System (DCS), and Variable Message Signs (VMS) system. These sub-systems communicate with each other to obtain estimated train arriving time and crossing occupancy time. The estimated time information is given to motorists around the network to take an alternate route to avoid the delay derived from an oncoming train. The detailed information in the system is addressed in the following subchapters.

3.1.1 Train Detection System (TDS)

Train Detection system (TDS) includes six sets of Laser Beam Sensors (LBS) to detect train movements and direction, and a radio transmitter to communicate with the Detection Control System (DCS). One LBS consists of an infrared transmitter and a receiver installed across the rail track facing each other. Two parallel laser beams from a transmitter are delivered to a receiver. If the two are blocked by a train, the sensor detects the train's presence and records the time of the blockage. As the train completely crosses the detection point of the LBS, the beams from the transmitter reach the receiver again, and the sensor records the time of the train's complete leave at the point. In TOTES design, six total sets of LBSs are arranged along the train track as shown in Figure 3.1; four are located far enough from the target HRGC (LBS 1, 2, 5, and 6). The distance from the target HRGC to these LBSs should be enough to measure the length of an oncoming train before it reaches the crossing. This will be discussed in Chapter

3.2.1.2 with details. The other two (LBS 3 and 4) are situated on both sides of the HRGC at a certain distance.

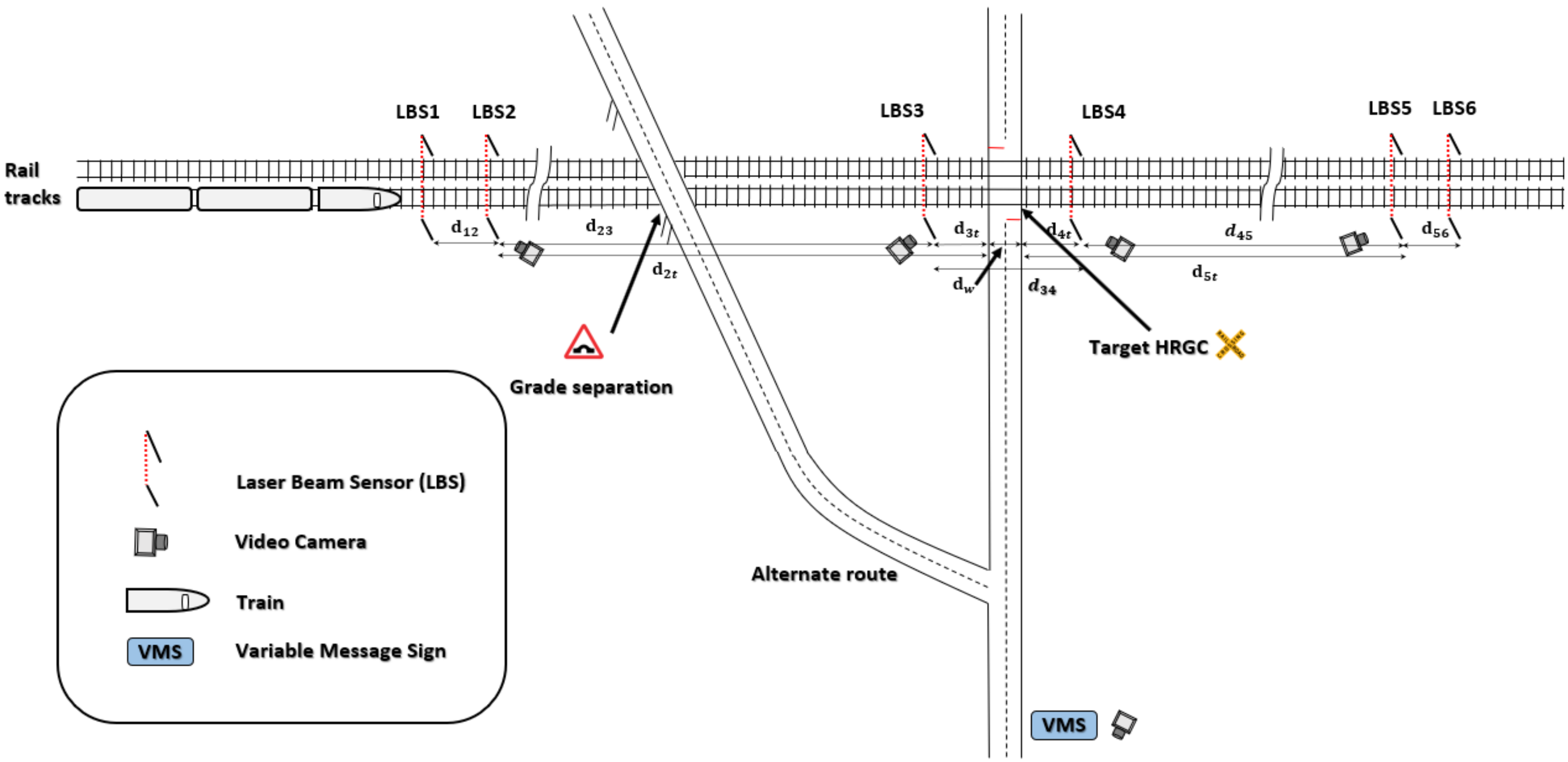


Figure 3.1 Illustration of TOTES components at an HRGC

As a train crosses each LBS detection point, head and tail check-in times of the train are recorded and sent to the DCS via a radio transmitter to obtain train length, speed, and direction. Table 3.1 shows the sample time log information stored in the TDS when a train is in a rightward direction in Figure 3.1. There is a small gap between railcars or a railcar and a locomotive; these gaps in a train may be recorded by the laser beam sensor causing an incorrect time log of the train. Although the gap is very small, the laser beams from the transmitter can reach the receiver through each empty space. To prevent the sensor from detecting these small gaps, a marginal limit will be programmed in the system to sense a series of railcars and locomotives as one train.

Table 3.1 Sample Time Log Information For a Train Crossing in TDS

Train Detection System (TDS): Train in a rightward direction							
LBS1		LBS2		LBS3		LBS4	
ON (t_{h1})	OFF (t_{t1})	ON (t_{h2})	OFF (t_{t2})	ON (t_{h3})	OFF (t_{t3})	ON (t_{h4})	OFF (t_{t4})
.	.	.	.	.	.	.	.
10:47:28	10:52:36	10:47:32	10:52:40	10:57:17	10:59:36	10:57:37	11:01:10
.	.	.	.	.	.	.	.

* t_{hi} = train head check-in time at LBS *i*
* t_{ti} = train tail check-in time at LBS *i*

3.1.2 Detection Control System (DCS)

The DCS consists of a radio transmitter and a microprocessor-based computer to link up to LBSs and VMS to communicate back and forth while waiting for the train's arrival. Based on time log information from LBSs, the DCS determines the train's speed (v), length (L), estimated arrival time (t_a), and estimated crossing occupancy time (t_c). Table 3.2 shows the sample data processed by the DCS when a train is heading south. When a train crosses LBS 1 and LBS 2, the train's speed (v_0) between the two sensors is obtained using the distance between LBS 1 and

LBS 2 (d_{12}) and head check-in times at the two sensors ($t_{h1}$and t_{h2}). The calculated v_0 and the time gap between the ON and OFF of LBS 2 (t_{g2}) are used to obtain the train length (L_0). With the distance from LBS 2 to the target HRGC (d_{2t}) and v_0, the estimated train arrival time (t_{a0}) at the target HRGC is calculated and stored in the DCS. This information will not be displayed on VMS since the advance information on the expected train arrival times may encourage drivers to try to beat the train by speeding. On top of that, if the train stops before the crossing, the estimated arrival time would be incorrect and meaningless. Thus, this information will be saved in the data storage and reviewed for research purposes.

Table 3.2 Sample Data Information Processed by DCS

Detection Control System (DCS): Train in a rightward direction									
Time gap at LBS 2 (t_{g2})	Train speed (mph) (v_0)	Train length (Ft) (L_0)	Estimated arrival time at HRGC (min) (t_{a0})	Estimated crossing occupancy time (min) (t_{c0})	Adjusted train speed (v_0')	Adjusted estimated crossing occupancy time (min) (t_{c0}')	Long train mode	Estimated crossing occupancy time for long train (min) (t_{c0L})	Adjusted estimated crossing occupancy time for long train (min) (t_{c0L}')
.	.	.	.	.	.	.	.	.	.
4.0	46	5400	3	7	42	8	No	.	.
.	.	.	.	.	.	.	.	.	.

When LBS 3 detects the head of the train, the DCS determines the estimated crossing occupancy time (t_{c0}) based on the distance between LBS 3 and the target HRGC (d_{3t}), v_0, and L_0. The t_{c0} is sent to the VMS system to display the estimated delay for drivers. However, it is possible that the speed of the train at LBS 3 and LBS 4 is different from the initially calculated speed at the LBS 1 and LBS 2 (v_0). Applying an updated train speed will likely increase the accuracy in measuring the crossing occupancy time. Since v_0 is calculated far away from the target HRGC, the system calculates the adjusted train speed (v_0') based on the distance (d_{34}) and the head check-in times at LBS 3 and LBS 4 (t_{h3} and t_{h4}) when the train head reaches LBS 4, and sends the adjusted crossing occupancy time (t'_{c0}) to the VMS to provide drivers with more recent information.

There may be a case when a long train comes in the system occupying LBS 2 and LBS 3 simultaneously. On such an occasion, the train's estimated crossing time cannot be calculated since train length (L_0) is not obtained when the train reaches the detection point of LBS 3. Even though the distance between LBS 2 and LBS 3, or LBS 4 and LBS 5, are originally designed to be enough to contain a typically sized train, the presence of super-long trains must be taken into consideration. In this system, if both LBS 2 and LBS 3 are occupied by a train, the DCS enters long train mode and calculates the estimated crossing occupancy time for a long train ($\mathrm{t_{c0L}}$) based on the distance between LBS 2 and LBS 3 (d_{23}) instead of L_0. Since the train's length is longer than the distance between LBS 2 and LBS 3, the actual delay is greater than the calculated time, so the messages on VMS should include additional time information (e.g., "Expected Delay More than 9 Min").

The detailed equations used to calculate $\mathrm{v_0}$, $\mathrm{L_0}$, $\mathrm{t_{a0}}$, $\mathrm{t_{c0}}$, $\mathrm{v'_0}$, $\mathrm{t'_{c0}}$, $\mathrm{t_{c0L,}}$ and $\mathrm{t'_{c0L}}$ are shown in equations 3.1 through 3.9. When a train is in a leftward direction, $\mathrm{v_1}$, $\mathrm{L_1}$, $\mathrm{t_{a1}}$, $\mathrm{t_{c1}}$, $\mathrm{v'_1}$, $\mathrm{t'_{c1}}$, $\mathrm{t_{c1L}}$, and $\mathrm{t'_{c1L}}$ are calculated, respectively, with equations 3.10 through 3.18.

$$\mathrm{v_0} = \frac{\mathrm{d_{12}}}{\mathrm{t_{h2}} - \mathrm{t_{h1}}} \tag{3.1}$$

$$\mathrm{t_{g2}} = \ t_{h2} - t_{t2} \tag{3.2}$$

$$\mathrm{L_0} = \mathrm{v_0} \times \mathrm{t_{g2}} \tag{3.3}$$

$$t_{a0} = \frac{d_{2t}}{v_0} \tag{3.4}$$

$$t_{c0} = \frac{L_0 + d_w + d_{3t}}{v_0} \tag{3.5}$$

$$v'_0 = \frac{d_{34}}{t_{h4} - t_{h3}} \tag{3.6}$$

$$t'_{c0} = \frac{L_0 - d_{4t}}{v'_0} \tag{3.7}$$

$$t_{c0L} = \frac{d_{23} + d_w + d_{3t}}{v_0} \tag{3.8}$$

$$t'_{c0L} = \frac{d_{23} - d_{4t}}{v'_0} \tag{3.9}$$

$$v_1 = \frac{d_{56}}{t_{h5} - t_{h6}} \tag{3.10}$$

$$t_{g5} = t_{h5} - t_{t5} \tag{3.11}$$

$$L_1 = v_1 \times t_{g5} \tag{3.12}$$

$$t_{a1} = \frac{d_{5t}}{v_1} \tag{3.13}$$

$$t_{c1} = \frac{L_1 + d_w + d_{4t}}{v_0} \tag{3.14}$$

$$v'_1 = \frac{d_{34}}{t_{h3} - t_{h4}} \tag{3.15}$$

$$t'_{c1} = \frac{L_1 - d_{3t}}{v'_1} \tag{3.16}$$

$$t_{c1L} = \frac{d_{56} + d_w + d_{4t}}{v_1} \tag{3.17}$$

$$t'_{c1L} = \frac{d_{56} - d_{3t}}{v'_1} \tag{3.18}$$

Where,
v_0, v_1 = train speed at a rightward and leftward direction (fps)
v_0', v_1' = adjusted train speed at a rightward and leftward direction (fps)
L_0, L_1= train length at a rightward and leftward direction (feet)
d_{12}= distance between LBS 1 and LBS 2 (feet)
d_{23}= distance between LBS 2 and LBS 3 (feet)
d_{34}= distance between LBS 3 and LBS 4 (feet)
d_{45}= distance between LBS 4 and LBS 5 (feet)
d_{56}= distance between LBS 5 and LBS 6 (feet)
d_{2t}= distance between LBS 2 and target HRGC (feet)
d_{3t}= distance between LBS 3 and target HRGC (feet)
d_{4t}= distance between LBS 4 and target HRGC (feet)
d_{5t}= distance between LBS 5 and target HRGC (feet)
d_w= width of crossing roadway (feet)
t_{h1}~ t_{h6} = head check-in time at LBS 1~ LBS 6 (sec)
t_{t1}~ t_{t6} = tail check-in time at LBS 1~ LBS 6 (sec)
t_{g2}= time gap between ON and OFF of LBS 2 (sec)
t_{g5}= time gap between ON and OFF of LBS 5 (sec)
t_{a0}, t_{a1}= estimated train arrival time at HRGC at a rightward and leftward direction (sec)
$\mathrm{t_{c0}}$, $\mathrm{t_{c1}}$= estimated train crossing occupancy time at a rightward and leftward direction (sec)
$\mathrm{t'_{c0}}$, $\mathrm{t'_{c1}}$= adjusted train crossing occupancy time at a rightward and leftward direction (sec)
$\mathrm{t_{c0L}}$, $\mathrm{t_{c1L}}$= estimated train crossing occupancy time in long train mode at a rightward and leftward direction (sec)
$\mathrm{t'_{c0L}}$, $\mathrm{t'_{c1L}}$= adjusted train crossing occupancy time in long train mode at a rightward and leftward direction (sec)

The DCS also has video cameras to monitor rail crossing activities and detection sensors. The video camera locations for detection sensors are shown in Figure 3.1. These cameras are used to verify if the sensors correctly recognize train crossings and reveal causes of abnormal data collection including outliers or data errors.

3.1.3 Variable Message Signs (VMS) System

This is a typical VMS system with the addition of a radio linked to the DCS. When a train is not present, the VMS system is in standby mode, and general safety information will be provided on the screen or the screen will be blank, as shown in Figure 3.2 *(a)*. When a train arrives at the third LBS (LBS 3 with a train in a rightward direction or LBS 4 with a train in a leftward direction respectively), the VMS is in train arriving mode in which the VMS system controller receives data from the DCS and displays the estimated train crossing occupancy time (t_{c0} or t_{c1}). This information will be used for nearby motorists to know the expected delay in minutes and seconds format and to take an alternate route, as shown in Figure 3.2 *(b)*. The displayed crossing occupancy time is clocked down naturally at a one-minute unit (α) to be displayed on the VMS.

After the adjustment of the crossing occupancy time, an updated occupancy time (t'_{c0} or t'_{c1} for each direction) with a one-minute clock down is displayed on the message board of the VMS system. This will be active until the tail of the train completely passes the fourth LBS in each direction. After the train has completely left, the VMS system goes back to standby mode and waits for another train.

When a long train mode is applied in the DCS, the VMS enters long train mode and uses the same protocol with t_{c0L} or t_{c1L} instead of t_{c0} or t_{c1} with extra waiting time information since the train length would be longer than the distance between LBS 2 and LBS 3, or LBS 4 and LBS 5. In long train mode, the VMS system also displays t'_{c0L} or t'_{c1L} for the adjustment of the estimated crossing occupancy time as the train crosses the fourth LBS.

(a) Standby mode

(b) Train arriving mode

(c) Precaution mode

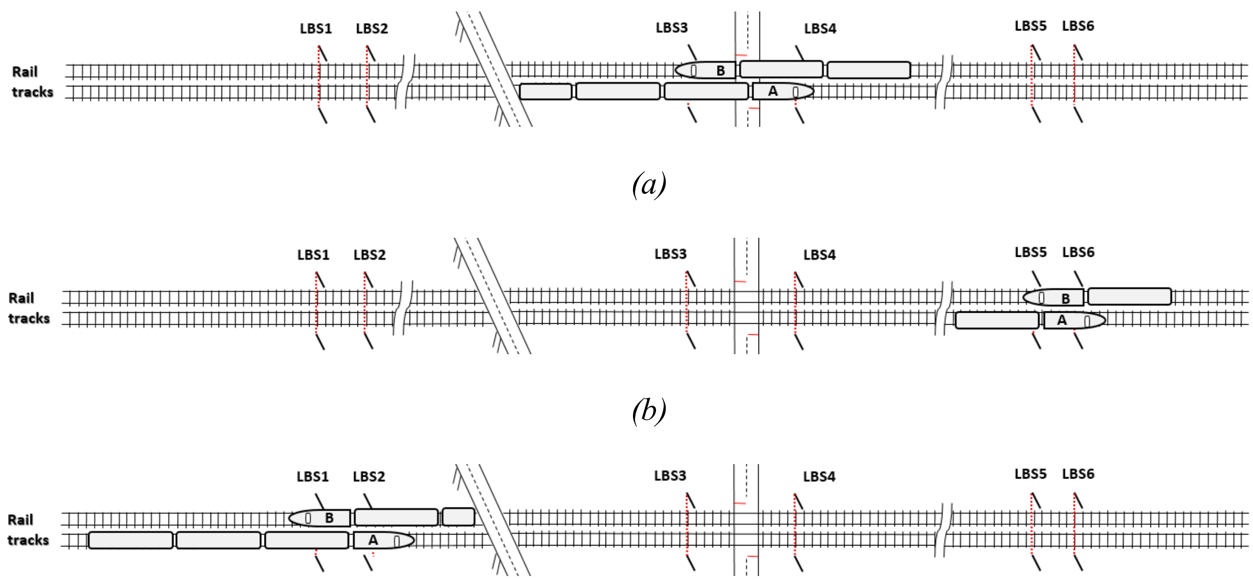
Figure 3.2 Variable Message Sign design for different modes

The VMS system may have a precaution mode with information on expected train arrival time when a train is detected at the first LBS as shown in Figure 3.2 *(c)*. However, this mode should be carefully reviewed since the advance information may encourage drivers to violate the speed limit to beat the train.

The VMS system will also be operated with a camera to monitor driver behavior and/or distractions. Using the displayed information (e.g., different amount of expected delay), drivers would be observed to see how they react to different delay information given and what types of traffic safety factors should be measured.

3.1.4 Multiple Trains in the System

This research takes into account times there are two trains approaching the target HRGC. At the outset, it is imperative to clarify what happens when multiple trains come in the system. Since each LBS is located along the two-way rail tracks, these LBSs are unable to detect trains coming from both directions simultaneously. That is, a laser-beam detection point occupied by a train cannot recognize the second train passing the same detection point. Figure 3.3 shows all the possible scenarios where detection blind spots are created by two overlapped trains.



(a)

(b)

(c)

Figure 3.3 Scenarios of overlapped trains in multiple train mode

Since distances between LBS 1 and LBS 2, LBS 3 and LBS4, and LBS5 and LBS6 are relatively small, the three locations are determined as blind spots instead of determining all six detector spots. In each spot, there is blindness of the detector to the rail track on the LBS receiver side due to the simultaneous occupation of two trains. If a train on the LBS transmitter side occupies the detection point first, the second train is unable to be detected. However, regardless of whichever comes first to the detection point, two trains in one detection point make the sensor unable to detect correct head or tail check-in times for both trains. This is because a train occupying the rail track on the receiver side can still be occupying the sensor after the prior train already passes the detection point. Therefore, the sensor may incorrectly record the first train's complete leave at the second train's leave. As a result, train occupancy times at the HRGC cannot be estimated accurately since the head and tail check-in times of the two trains would not be appropriately measured at the detection points.

Installing LBS separately for both rail tracks could be adopted to resolve the blindness issue of multiple trains. To implement this, an LBS receiver or a transmitter must be installed in the middle of two rail tracks to provide distinguishable detection on each track. However, the space between rail tracks is often limited, and installing detection structures between the tracks would interrupt the train passage, causing safety issues. Thus, TOTES design includes multiple train mode to resolve the detection blindness issues. To apply the multiple train mode, it is essential to clarify the possible train movement scenarios, as shown in Figure 3.3 (*a), (b),* and *(c)*.

In scenario *(a)*, Train A and Train B meet at LBS 2 and LBS 3, occupying the two sensors at the HRGC. No matter which train comes first to occupy the sensors, the presence of two trains can be detected by LBS 1 and LBS 6. That is, if LBS 1 is activated with Train A while LBS 6 senses the opposite train (Train B), the system enters the multiple train mode scenario *(a)*. The train occupancy time at the target HRGC will be calculated based on the longer train length and its speed. The system checks which train comes first. If a longer train arrives to the sensor first (LBS 3 with a train in a rightward direction or LBS 4 with a train in a leftward direction respectively), the occupancy time based on its length and speed will be displayed on the VMS system. When the shorter train arrives at the LBS near the HRGC first, the occupancy time is still calculated based on the longer train's length and speed, but the message board will show additional time information (e.g., "Expected Delay 8 min or more") because the longer train has not arrived yet.

There are several distinct features in the multiple train mode scenario *(a)* compared to the single train detection mode. First, the adjusted train occupancy time cannot be calculated since the two trains are occupying LBS 3 and LBS 4 concurrently. Thus, the VMS system will only show the initial train occupancy time without displaying the adjusted occupancy time. Second, in multiple train mode with a long train in the system, the distances between LBS 2 and LBS 3 or LBS 4 and LBS 5 will be used to calculate the occupancy time with additional time information on the VMS. If the long train is on LBS 2 and LBS 3, the distance between them will be used; otherwise, the distance between LBS 4 and 5 will be used. Third, when one of the trains stops moving before crossing the HRGC while the other train completely crosses the LBS point, the VMS system will enter standby mode and wait for the second train to pass the crossing. The occupancy time will be calculated based on the train that stopped before the crossing.

Scenario *(b)* and *(c)* are cases where two trains are overlapped at the first two LBSs; this makes the applying the multiple train mode process more complicated. Even though these two situations are not likely to occur often, they must be taken into consideration. To activate multiple train mode, it is necessary to know that there are two trains in the system. In scenario *(b)*, for example, if the train leaving the system (Train A) occupies LBS 5 and LBS 6 first before the approaching train (Train B) passes the two detection points, Train B will not be detected. The system does not know the presence of Train B until the undetected Train B at LBS 5 and LBS 6 are sensed at LBS 4. Train B is not recognized in the system without any information on its length and initial speed because it runs with Train A in LBS 5 and LBS 6. In this case, the accurate train occupancy time cannot be obtained and thus the VMS system will only show the train crossing information without the estimated crossing time information at the arrival of the train at LBS 4. In the case of Train B first touching LBS 5 and LBS 6, it is still unable to know the length of Train B since Train A may be still blocking LBS 5 and LBS 6 as the tail of Train A leaves LBS 5. This makes the train occupancy time impossible to estimate, so the VMS system will also show the train crossing activity without the occupancy time information.

3.1.5 System Logic Diagram

Detailed system logic diagrams are shown in Figure 3.4, Figure 3.5, Figure 3.6, and Figure 3.7. These diagrams include specific details of the communicated information flow within the subsystems.

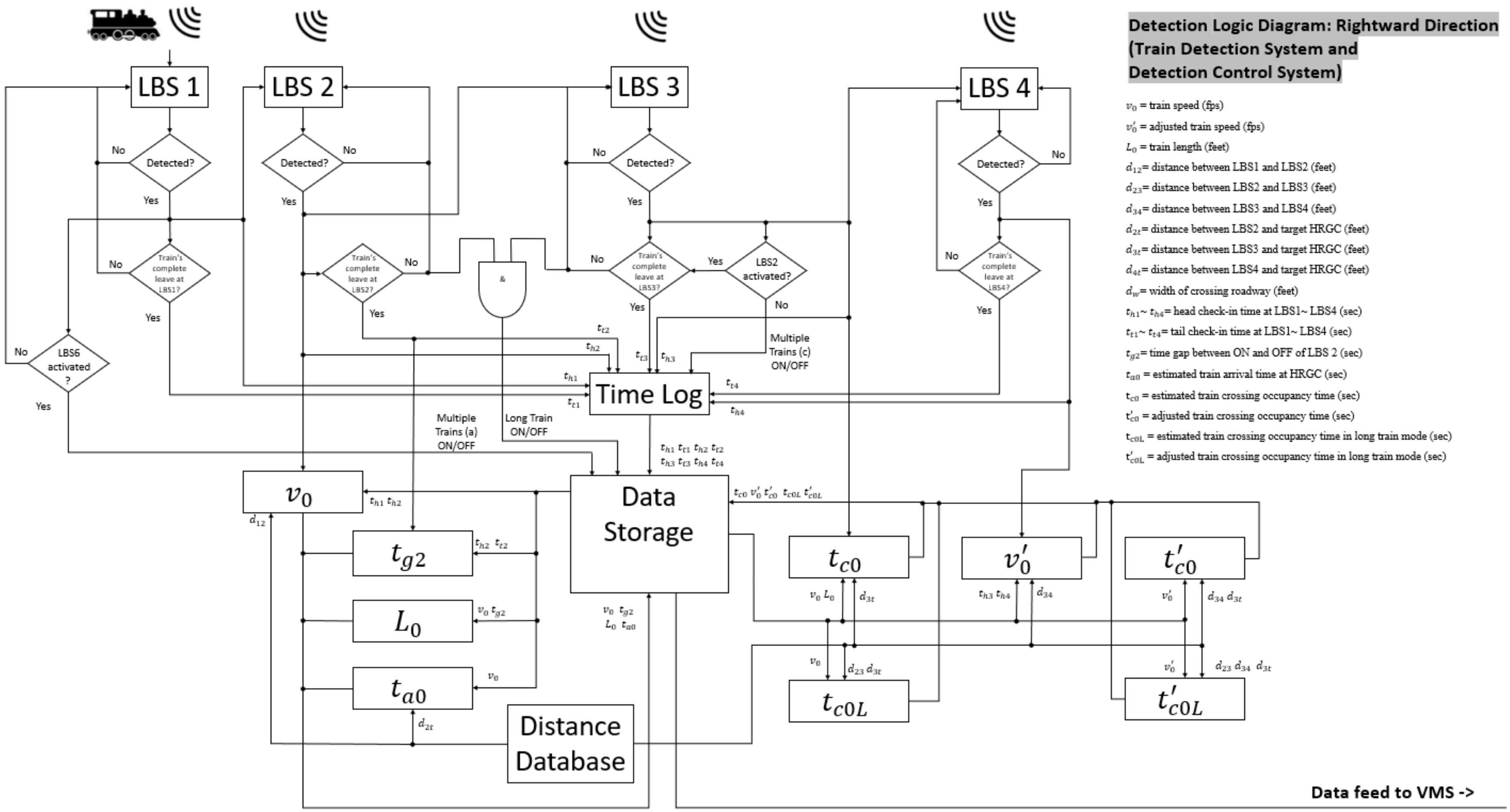


Figure 3.4 System logic diagram for a train coming from LBS 1 (TDS and DCS)

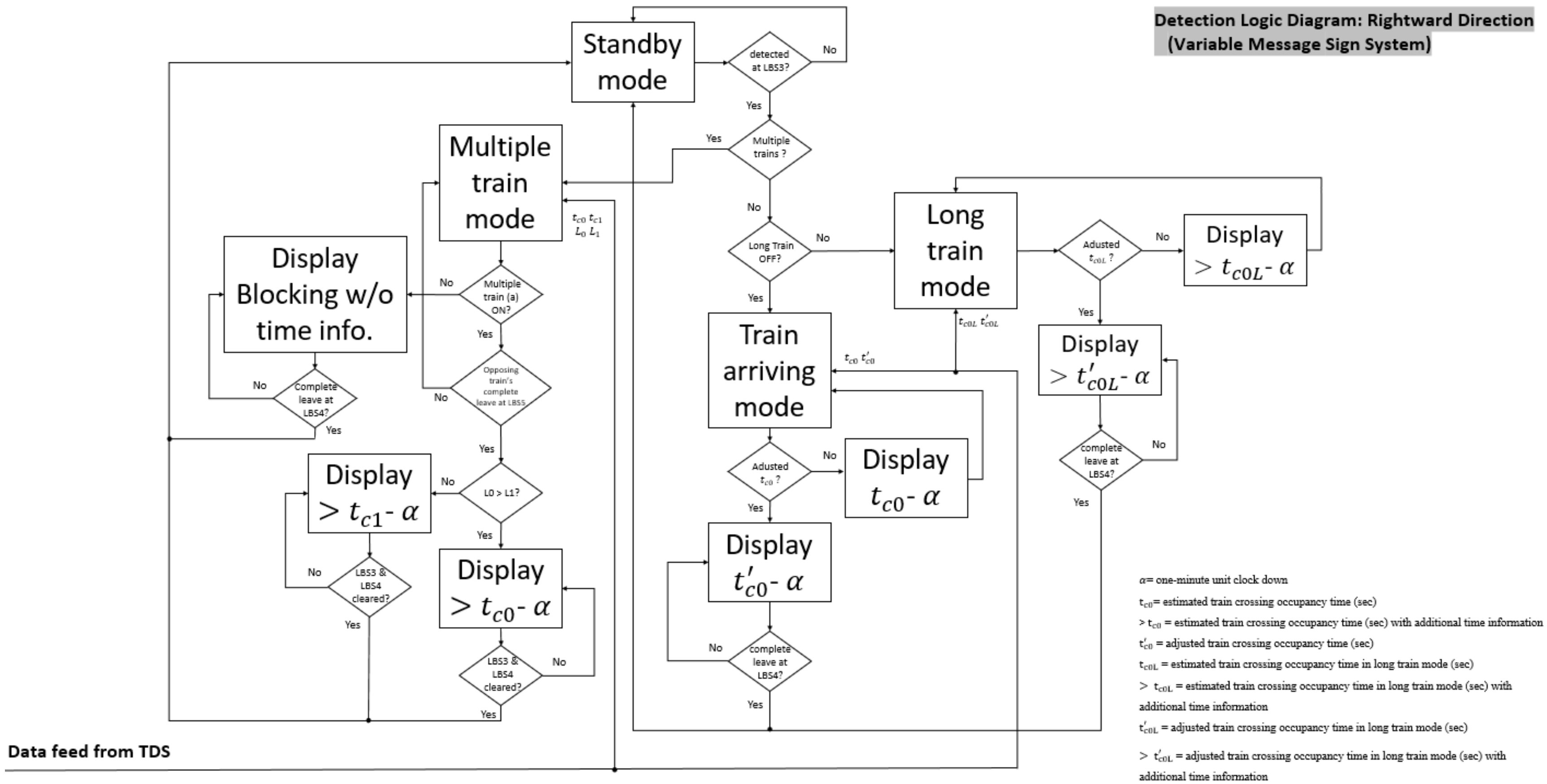


Figure 3.5 System logic diagram for a train coming from LBS 1 (VMS system)

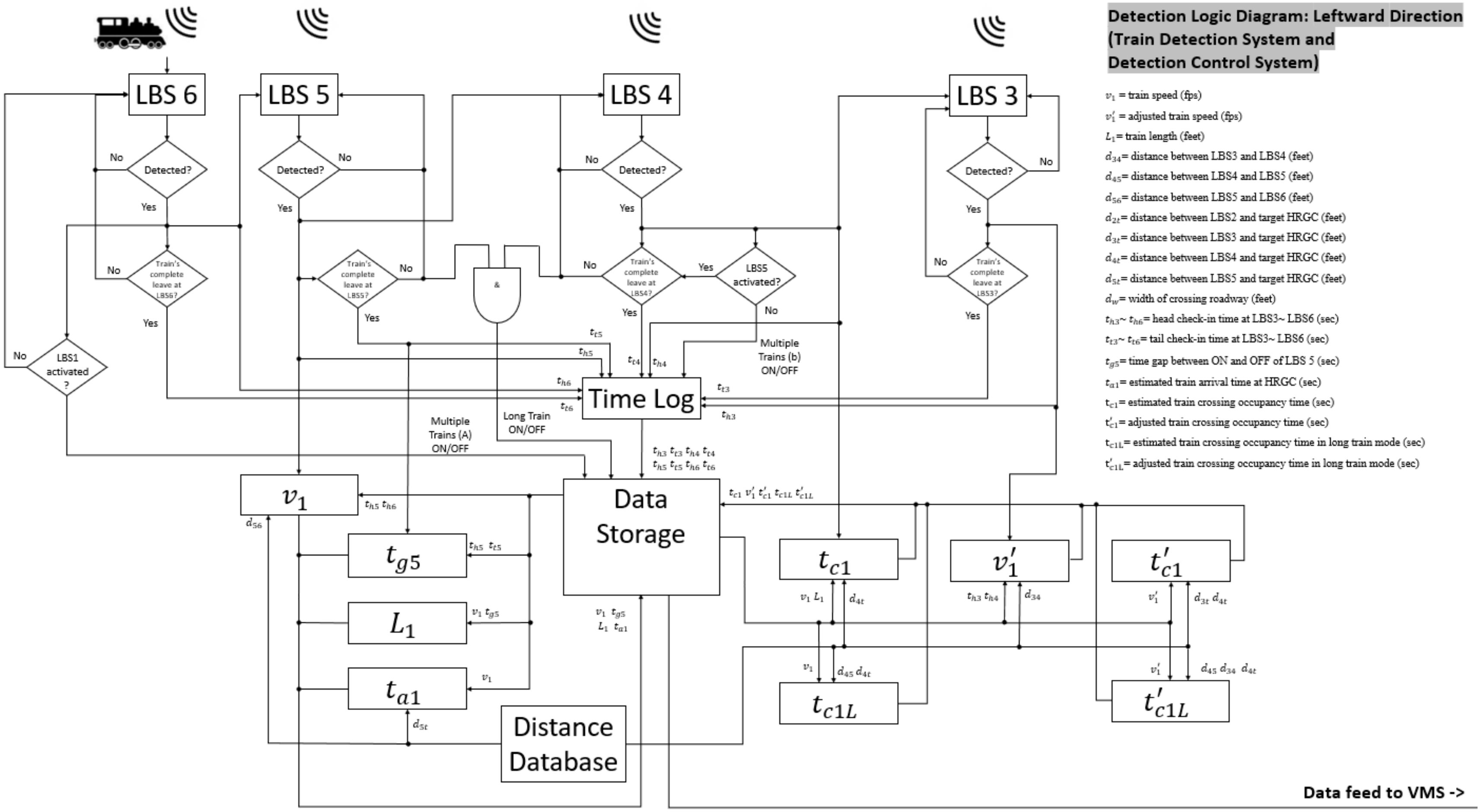


Figure 3.6 System logic diagram for a train coming from LBS 6 (TDS and DCS)

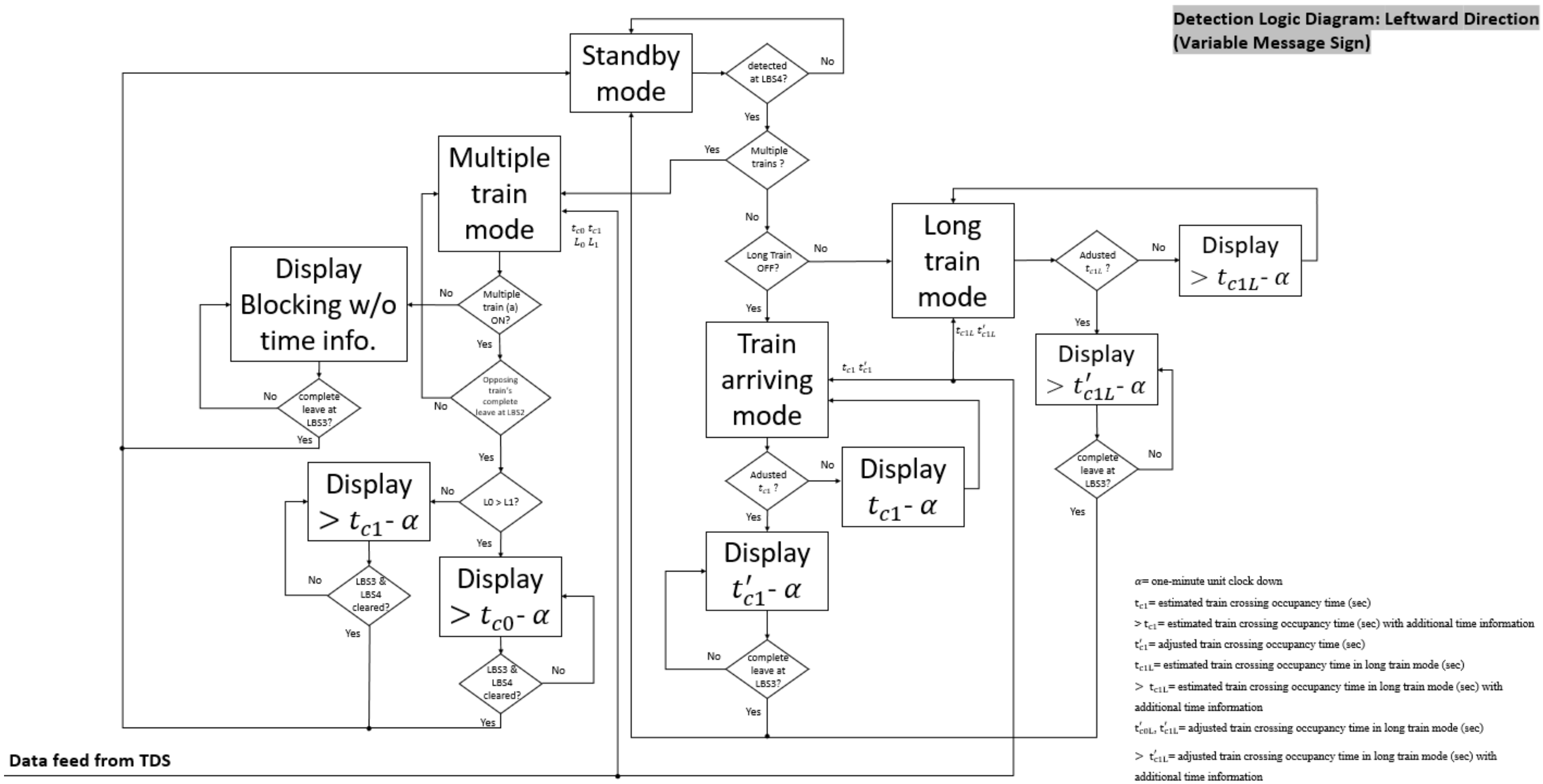


Figure 3.7 System logic diagram for a train coming from LBS 6 (VMS system)

3.2 Manual Input System of TOTES

Due to limited financial resources and time constraints, the TOTES design has been modified to a manual input system. Unlike the original TOTES design, which is a fully automated system, the modified system includes development of the VMS input system by field personnel to predict train occupancy time and trigger VMS manually. The manual input system simplifies the complicated coding processes required in the original TOTES design. It also decreases the detection error rate of the original system using several sets of laser-beam sensors. This is because field personnel are present at the study site to detect trains and operate the VMS system.

3.2.1 Field Personnel

In the manual input system of TOTES, field personnel observe train movements, measure train occupancy times, trigger the VMS system, and count number of vehicles in queues. There are four field survey positions (Position 1, Position 2, Position A, and Position B) as shown in Figure 3.8. All field personnel at their positions conduct allocated tasks. At Position 1 and Position 2 (the previous or the next crossing of a target HRGC), train speed, length, and occupancy times will be measured by the field personnel. In this research, the crossing occupancy times include the gate operation time (e.g. gate closing and opening time). As the train completely crosses the HRGC, and the gate is fully open, the train occupancy time information is sent to the field personnel at Position A. Using the crossing occupancy time from the previous or next HRGC (HRGC 1 or 2), the field personnel at Position A trigger the VMS system remotely as the train arrives at the target HRGC and the gate starts to lower. The field personnel at Position A also measure the queue lengths for both directions during the train blocking. While the VMS system is displaying train delay information, the field personnel at

Position B monitor the messages on VMS to ensure that they are displayed correctly and there are no mechanical issues. In this system design, there are four total survey positions and at least one person is needed at each position. However, experimental train data accumulated at Position A may make Position 1 and 2 unnecessary. If resources are limited, the pre-obtained train data will be used at Position A, and survey position 1 and 2 will be removed.

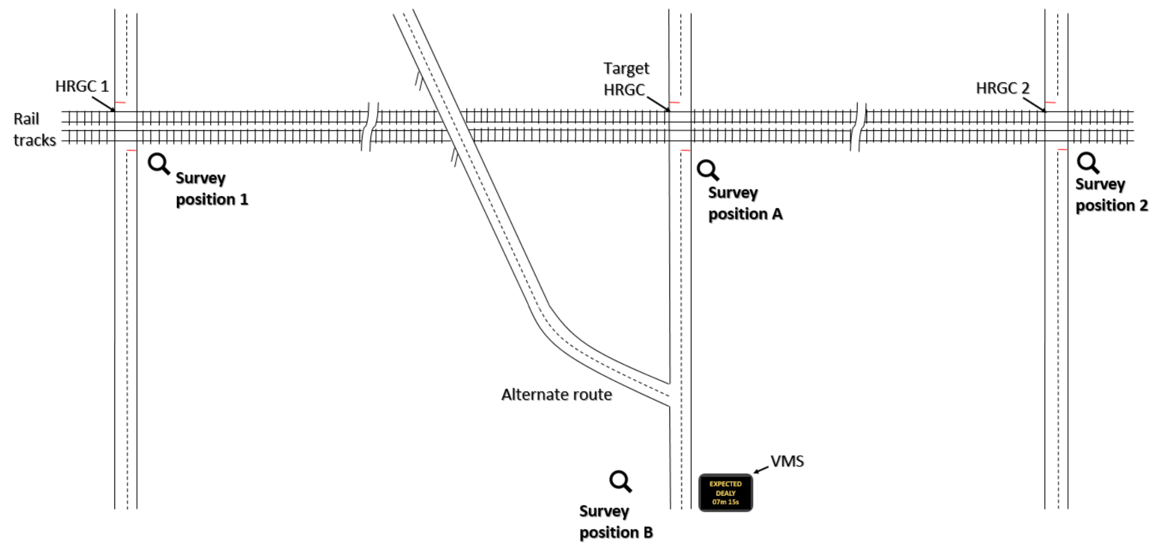


Figure 3.8 Illustration of manual input system design

3.2.2 VMS System Design

The basic components of the VMS system are the same as the original TOTES except for the input mechanism. In the manual input system, the VMS system is activated by a portable VMS controller carried by field personnel. When a train is not present, the VMS system is in standby mode, and general safety information or a blank will be provided on the screen as shown in Figure 3.9 *(a)*. When a train arrives at the HRGC, the field personnel at Position A trigger the VMS system to enter train arriving mode. In train arriving mode, "EST TRAIN DELAY

AHEAD 00m 00s" message will be displayed for 12 seconds, and the "TRAIN CROSSING AHEAD" message will be shown for 8 seconds as shown in Figure 3.9 *(b)*. The two messages will be displayed back and forth, and the estimated occupancy time will be clocked down naturally with a five-second interval while the train arriving mode is activated on the VMS system.

(a) Standby mode

(b) Train arriving mode

Figure 3.9 Message design for different modes in manual input system

In case the actual train occupancy time is less than the initially measured occupancy time at the previous or next HRGC, the field personnel at Position A adjust the message display by phasing out. That is, the currently displayed time reduces to zero, and the VMS system goes back to standby mode. On the contrary, if the actual crossing time is longer than the measured occupancy time, the field personnel would reprogram the occupancy time on the VMS system. When a long train appears and occupies both the target and the previous or next HRGC simultaneously, the field personnel put the longest train crossing time on the VMS system and adjust the time if necessary.

3.2.3 System Programming

System programming involves developing system software to control each hardware system and process obtained data. The system program was written with Python language and integrated with VMS control systems. The detailed developed software code is in Appendix B.

3.2.4 In-Lab Testing

In-lab testing of the developed system was needed to reduce errors and enhance system integrity. Testing of the developed system involved comprehensive system checks on all system hardware components as well as the developed software program. System hardware components consist of a VMS panel, VMS controller with a radio frequency receiver, hand-carry VMS remote controller with a radio frequency transmitter, and batteries for the VMS panel and the remote controller. To verify that each component operates as expected and to recognize possible mechanical errors that may occur, each item became modularized before they were integrated. The integrated system is composed of each module after the separated modules are tested individually. Meanwhile, a system program was finalized for implantation into the integrated hardware system. The program was also tested to reduce programming errors and improve the information throughput rate in the system. Finally, the integrated system with the embedded program was simulated under the lab environment before deploying in the study site.

Chapter 4 Data Collection

This chapter explains details about data collection for validation of the developed system (TOTES). The data collection is divided into two parts: 1) preliminary data collection of train activity, and 2) data collection of driver behavior on TOTES at an HRGC. The preliminary train activity data were collected before conducting driver behavior data collection to better understand the train activity at the study site and to carry out the driver behavior data collection efficiently and systematically. Also, employing preliminary data collection of train activities allowed the establishment of a proper period for driver behavior data acquisition.

4.1 Study Location

A suitable study location has been selected in consultation with the City of Lincoln traffic engineers. Figure 4.1 shows the chosen study site with the VMS location and the target rail crossing (FRA Crossing#074406N) on Old Cheney Road. Motorists at the intersection between Old Cheney and Warlick Boulevard that are westbound toward Highway 77 are provided with crossing closure information at the target HRGC so that they may access Highway 77 via Warlick Boulevard rather than Old Cheney Road. Motorists using the alternate route are not affected by trains due to its grade-separated structure over the railway. Although the travel distance using the Warlick Boulevard (alternate route) is about 1.25 km longer than using Old Cheney Road to reach the intersection between Old Cheney Road and Highway 77, the travel time difference between the two routes is about one minute when considering the travel speed limits on each roadway. Thus, it is likely that some motorists would be willing to use the alternate route to avoid train delay when they are notified of the rail crossing closure information. In this study location, it was also noticed that the motorists are not given any other major alternate routes after they cross the intersection between Old Cheney Road and Warlick

Boulevard. This closed network feature at this location allows more accurate measurements of vehicles taking the alternate route at the data collection site where video recording equipment is installed.

Figure 4.1 Study site in Lincoln, NE

4.2 Preliminary Data Collection of Train Activity

Train activity data were collected from the target HRGC to understand timely and weekly variations of train activity. The data collection included information on time and day of crossing trains, occupancy times of each train, and the number of vehicles queued for each train activity at the HRGC. This information was used to determine the main data collection period and time. In order to conduct the data collection, a trailer was configured with an Internet Protocol camera (IP camera), a network video recorder (NVR), four rechargeable batteries, and a solar panel as shown in Figure 4.2 (left). The trailer was located along the Old Cheney Road near the target HRGC to record train, vehicle, and gate movements. Sample video clips for the designated area of interest were shown in Figure 4.2 (right). The IP camera was programmed to record the site from 6:00 AM to 8:00 PM (14 hours a day) for seven days to obtain weekly and timely changes of train and vehicle activities. Train occupancy time was measured based on the gate operation time. The time when the gate starts moving up was recorded and regarded as the start time for the train blockage at the crossing, and the time when the gate is entirely up was used for the end time of the train blockage. The number of vehicles in the first platoon was counted and deemed as the queued vehicles during the train activity.

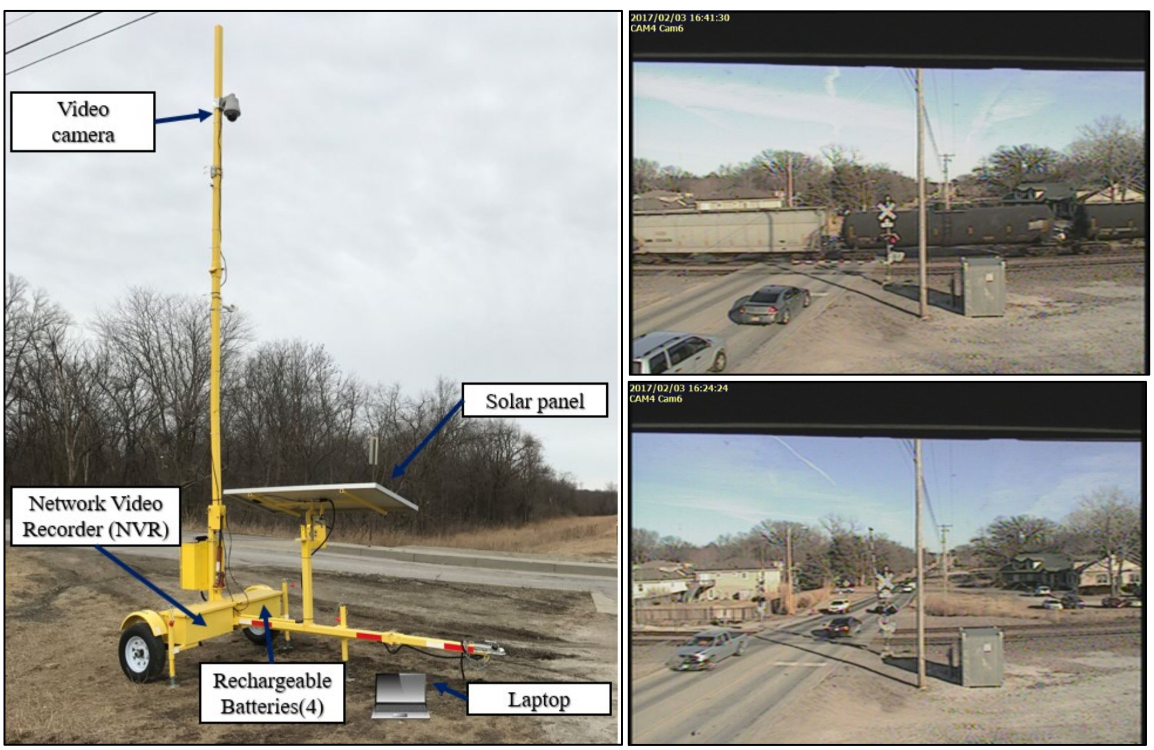


Figure 4.2 Configuration of data collection equipment for train activity data (left) and field-of-views from the installed IP camera (right above and below)

Video footage recorded at the rail crossing was coded by trained personnel using the network video player with a function of detecting screen pixel changes. Using image-processing algorithms, the function embedded in the player sets detection zones within the image range of the camera and allows investigators to identify the train appearance and moving gates automatically.

4.3 Data Collection of Driver Behavior on TOTES

Driver behavior data were collected using a City of Lincoln traffic-monitoring camera and the manual input system of TOTES stated in Chapter 3.2. The intersection had been recorded for two weeks before the VMS system was initiated and for another two weeks when motorists were exposed to the VMS system to verify the effect of the disseminated train information. The specific data collection period was in the morning (7 – 10 AM) and evening peak hours (4 – 7 PM) for Monday, Tuesday, Wednesday, and Thursday. Figure 4.3 shows the video footage from the traffic-monitoring camera that covers the intersection where drivers get to decide to take an alternate route by making a left turn or to drive straight to reach the rail crossing.

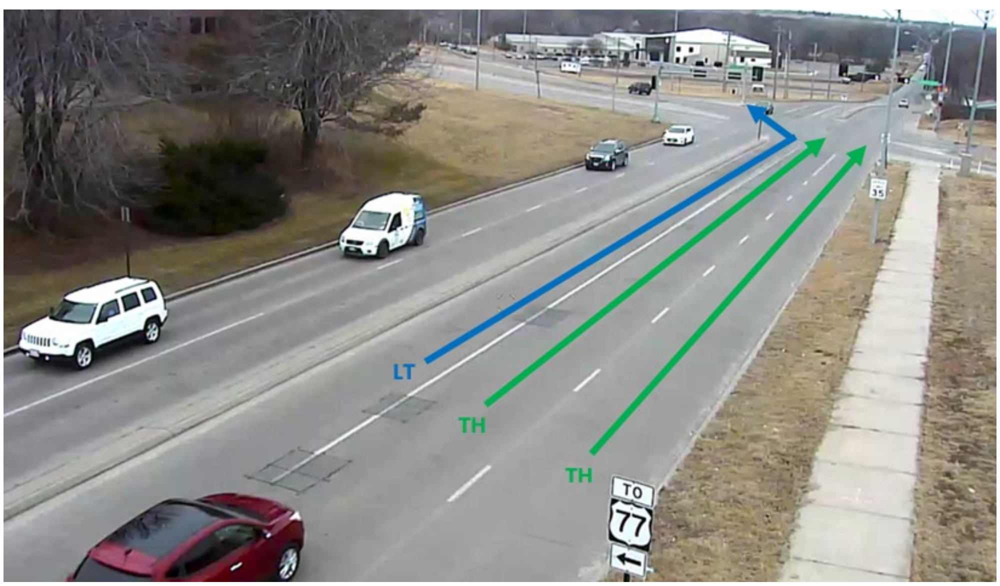


Figure 4.3 City of Lincoln traffic monitoring camera view

In the manual input system of TOTES, field personnel were present at the study location to record train activities and trigger the VMS system. Position 1 and Position 2 of the original manual input system were omitted due to prior knowledge about train occupancy times obtained from the preliminary data collection at the crossing. Thus, predicted train occupancy time was directly used by field personnel at Position B to activate the VMS system. The predicted average train occupancy time used in this study was five minutes, which is the 85^{th} percentile value from the preliminary data collection. Field personnel at Position A communicated with Position B via walkie-talkies to inform train arrivals and departures at the target crossing so that Position B knows when to trigger the system and make it back to the standby mode.

The essential components of the manual input system of TOTES consisted of a VMS panel, a VMS controller with a radio frequency receiver, and a hand-carry VMS remote controller with radio frequency transmitter as shown in Figure 4.4. All the components were tested in a lab environment to confirm whether they are fully operational. Subsequently, they were integrated with a solar panel connected to rechargeable batteries and mounted on a trailer to be employed in the study location.

Figure 4.4 VMS system hardware components: VMS panel (left), VMS controller with a radio frequency receiver (right above), and hand-carry VMS remote controller with radio frequency transmitter (right below)

4.3.1 VMS location

To determine the location of the VMS panel, the distance from the major decision point to the VMS should be taken into account. If the VMS is located too far in advance of the alternate route entrance, drivers would not recall the message well and the diverting rate would decrease. If the VMS is too close to the alternate route, drivers would not have enough time to take the left turn lane. The VMS location was determined using the decision sight distance criteria defined by AASHTO Green book (AASHTO 2011) as shown in Table 4.1.

Table 4.1 Decision Sight Distance (Source: AASHTO Greenbook, 2011)

Design Speed (mph)	Decision Sight Distance for Avoidable Maneuver, (ft.)					
	A		B	C	D	E
25	180	280	400	375	400	525
30	220	350	490	450	535	620
35	275	425	590	525	625	720
40	330	505	690	600	715	825
45	395	590	800	675	800	930
50	465	680	910	750	890	1030
55	535	775	1030	865	980	1135
60	610	875	1150	990	1125	1280
65	695	980	1275	1050	1220	1365
70	780	1090	1410	1105	1275	1445
75	875	1200	1545	1180	1365	1545
80	970	1320	1685	1260	1455	1650
	Rural	Suburban	Urban	Rural	Suburban	Urban

*Note: Avoidance Maneuvers

1. Avoidance maneuver A: Stop on rural road – t = 3.0s

1a. Stop on suburban road – Assume t =6.0s

2. Avoidance maneuver B: Stop on urban road – t = 9.1s

3. Avoidance maneuver C: Speed/path/direction change on rural road – t = 10.2 – 11.2s

4. Avoidance maneuver D: Speed/path/direction change on suburban road – t = 12.1 – 12.9s

5. Avoidance maneuver E: Speed/path/direction change on urban road – t = 14.0 – 14.5s

The study area was in suburban area and the posted speed limit of the Old Cheney Road (45 mph), though different from the design speed, was used to identify the appropriate decision sight distance of the VMS system for motorists. Based on the avoidance maneuver D for speed/path/direction change column, it was determined that drivers would need at least 800 feet to decide to either stay or change lanes to take the alternate route. Concerning the VMS legibility distance, it was revealed that an average driver could read the VMS within his/her area of vision at a distance of 35 ft for every inch of letter height (Garvey and Mace 1996). Since the current

VMS letter height was equal to 12 inches, it was thought that about 420 feet can be given back to the decision point. Thus, the VMS panel was located about 360 feet away from the Warlick Boulevard. Regarding the horizontal offset of the VMS, about 25 feet from the roadway sideline were given to avoid the safety issues of vehicles on the adjacent road.

4.3.2 Variables and Coding Scheme

Video footage recorded at the intersection was extracted and coded by trained safety researchers using a data recording spreadsheet. The spreadsheet incorporated information on weather, time, train activities, the number of vehicles for left-turn and though traffic, vehicle types, and any other unusual activities including traffic violations. The sampling unit was each green time given to the westbound traffic at the intersection between the Old Cheney Road and Warlick Boulevard. The green time period included a circular green indication along with a following yellow time during which left-turn and through traffic movements proceeded.

For each sampling unit, the train effect including the occupancy time were observed using the traffic-monitoring camera and field observation. For the first two weeks before the VMS system was initiated, the train movements were observed and collected by checking the circled area from the camera view as shown in Figure 4.5. Using video footage, the train movements were observable, but the observation of gate operations at the crossing was not available due to the crossing's location far from the camera and the limited quality of video image resolution. Thus, the estimated gate operation times were added using information collected from the field investigation at the crossing. It was found that the time between the gate starting to lower and train arrival at the crossing was about 30 seconds, and the time between the train completely departing the crossing and the gate being entirely up was about 17 seconds. For another two weeks during the VMS system activation, the train activity data were directly collected by field personnel located at the crossing, thus, the actual gate movements were recorded without estimation.

Figure 4.5 Observation of train movements using video footage

The number of vehicles making left turns or driving straight were recorded with vehicle types for each green time at the intersection. The adopted left-turn phasing scheme for the westbound traffic at the intersection was the leading protected-permissive which represents a unification of the permissive and protected left-turn phasing. Specifically, the westbound left-turn traffic is given the right-of-way during the protected left-turn arrow signal, which is served concurrently with the adjacent through movements. The left-turn traffic is also able to make the turn permissively during the circular green indication for the adjacent and opposite through traffic. The permissive left-turn becomes unallowable when the opposite left-turn traffic obtains the lagging permitted left-turn indication. This means the left-turn vehicles always proceed within the defined sampling unit, a circular green indication. The vehicle types of left-turning and through traffic were passenger car, sport utility vehicle (SUV), minivan/van, pickup truck, heavy truck, motor cycle, and bicycle as shown in Figure 4.6.

Composition of Left Turning Traffic								Composition of Through Traffic							
Passenger Car	SUV	Minivan & Van	Pickup Truck	Heavy Truck	Motor cycle	Bicycle	Left Total	Passenger Car	SUV	Minivan & Van	Pickup Truck	Heavy Truck	Motor cycle	Bicycle	Through Total
1	1	0	0	0	0	0	2	2	3	1	4	0	0	0	10
1	0	0	0	0	0	0	1	5	2	1	4	0	0	0	12
2	3	1	3	0	0	0	9	7	2	0	5	0	0	0	14
							0								0
							0								0
							0								0
							0								0
							0								0

Figure 4.6 Sample data-coding scheme for vehicle types

In addition, unusual activities including traffic violations at the intersection were recorded for each green time. There were two types of violations mainly recorded: 1) left turning from the straight lane, and 2) going straight from the dedicated left turning lane. Also, vehicles crossing solid white lines used for left turning lanes at the intersection were recorded (Fig. 4.7). This white solid line for the dedicated left turn lane exists to prevent lane changes near intersection and separate turning traffic from through traffic flow safely. Although crossing the solid line is not illegal in the State of Nebraska, it is deemed highly discouraged by drivers according to MUTCD. Except for the aforementined unusal activities, any other particular violations or activities detected from the data observation were recorded in the spreadsheet. The increase or decrease of the number of thsese activitities were used to explain the effect of developed system installed at the study location.

Figure 4.7 Vehicle crossing solid white line for dedicated left turn lane

Chapter 5 Data Analysis and Research Findings

This chapter describes the analysis of data followed by a discussion of the research findings. The findings relate to the research hypothesis and address research questions that guided the study. Train acitivty and driver behavior data were analyzed to identify, describe, and explore the effectivness of advanced traveler information systems applied at an HRGC.

5.1 Train Activity Data Analysis

Train activity data were obtained from the preliminary data collection conducted using a trailer equipped with an IP camera, a network video recorder, rechargeable batteries and a solar panel. The detailed train activity data from the video footage are shown in Appendix C. A total of 93 trains were observed during the one week data collection period (6:00 AM to 8:00 PM) and their occupancy times were estimated using the gate operation time. Road–rail vehicles for rail track inspection were identified during the data collection but excluded due to the extremly short gate closure time and a very small number of vehicles. It was revealed that the longest train occupancy time at the crossing was six minues and 52 seconds, and the shortest time was one minute and 11 seconds. The avearage train occupancy time was found to be three minuntes and 44 seconds at the crossing. From the data, it was also seen that about 90 percent of total trains (83 out of 93 trains) was heading southbound and only nine trains were heading northbound. There was one gate closure when two trains from north and south appeared and passed the crossing simultaneously.

The distribution of train activities through the time of day is shown in Figure 5.1. Although train traffic at the crossing is slightly more concentrated during the afternoon, the results of the analysis did not show any significant concentration of trains at a certain time of day. It was also noticed that there is a small number of trains during the time between 12:00 to

13:00. With respect to the distributional trend for a day of the week, the data analysis found that most train activities were allocated evenly with a small decrease during Tuesday and Wednesday.

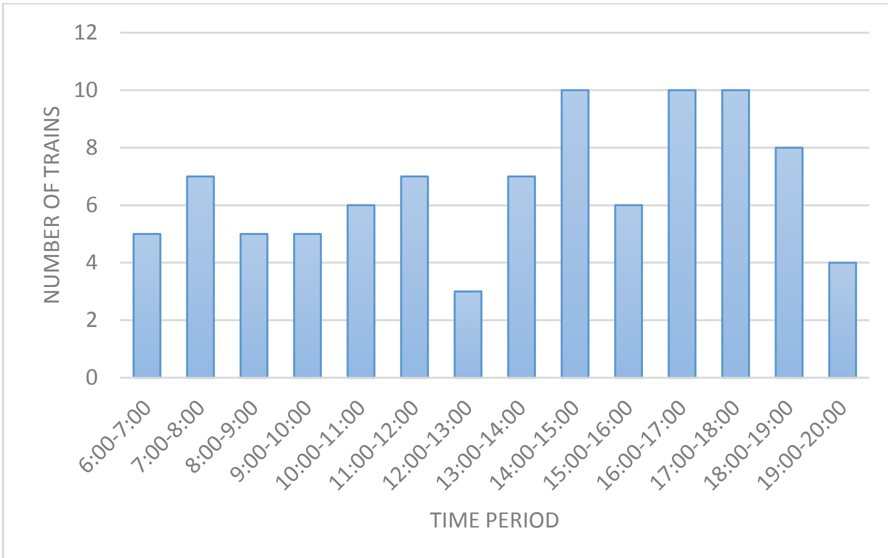


Figure 5.1 Distribution of train activities through the time of day

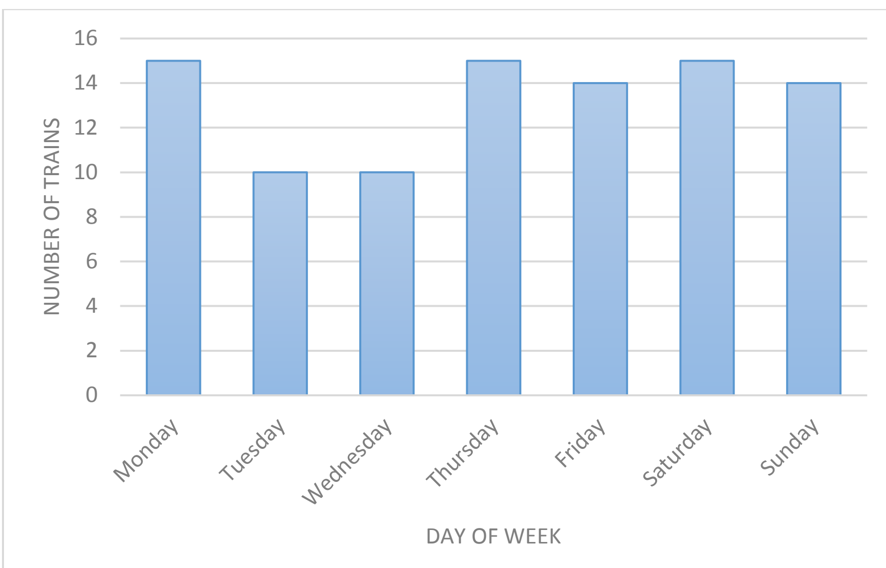


Figure 5.2 Distribution of train activities through the day of the week

5.2 Driver Behavior Data Analysis

Driver behavior data at the intersection near the target crossing were obtained using the manual input system and video footage from the City of Lincoln traffic monitoring camera. Several hypotheses were addressed and tested using the independent-samples t-test to compare means between two unrelated groups on the same continuous dependent variables. The first hypothesis suggested that motorists who were exposed to VMS would show less unsafe manuevers such as illegal left turns, illegal driving through, and crossing the solid white line. It was presumed that the VMS system showing a general safety and train occupancy information would make motoristis nearby drive more safely. As shown in Table 5.1, Table 5.2, and Table 5.3, statistically significant differences occurred for all three unsafe maneuvers after installation of VMS system. Specifically, the number of vehicles crossing the solid white line was signficantly reduced ($t(2396.845) = 5.896$, $p < .01$) when compared to the number before the VMS system was installed. This may be because of the general safety message during the stanby mode of the system or the train occupancy information in advance of motorists reaching the white solid line. The number of illegal left turns were marginally reudced with $t(2041.326) = 2.058$ and $p = 0.040$. The number of illegal driving through from the left turn lane decreased with $t(1956.820) = 2.353$ and $p = 0.019$.

The second hypothesis suggested that the VMS system would affect the motorists' decision making to take an alternate route to avoid the train delay. When it comes to the diverting rate when a train is present, the employment of the VMS system did not statistically show a significant difference with an alpha level of 0.05 ($p = 0.084$) as shown in Table 5.4. However, the VMS system with displaying train occupancy time information showed a statistically signficant increase of diverting rate when compared to the rate with displaying general safety information as shown in Table 5.5 ($t(1133) = -5.746$, $p = 0.000$).

Table 5.1 Difference of VMS Effect on the Number of Crossing a Solid Line

	VMS	N	Mean	SD	t	P-value
Number of crossing solid line	Not installed	1281	0.87	1.120	5.896	0.000
	Installed	1135	0.63	0.911		

*** p < .001.

Table 5.2 Difference of VMS Effect on the Number of Illegal Left Turning Vehicles

	VMS	N	Mean	SD	t	P-value
Number of illegal left turn	Not installed	1281	0.02	0.142	2.058	0.040*
	Installed	1135	0.01	0.078		

* p < .05.

Table 5.3 Difference of VMS Effect on the Number of Illegal Driving Through Vehicles

	VMS	N	Mean	SD	t	P-value
Number of illegal driving through	Not installed	1281	0.01	0.100	2.353	0.019*
	Installed	1135	0.00	0.051		

* p < .05.

Table 5.4 Difference of VMS Effect on Rate of Left Turning Vehicles when Train Presents

	VMS	N	Mean	SD	t	P-value
Rate of left turning vehicle	Not installed	120	0.404	0.175	1.738	0.084
	Installed	81	0.364	0.143		

Table 5.5 Difference of VMS Message Types on the Rate of Left Turning Vehicles

	VMS message type	N	Mean	SD	t	P-value
Rate of left turning vehicle	General Safety	1054	0.2758	0.1315	-5.746	0.000
	Train occupancy	81	0.3635	0.14343		

*** $p < .001$.

Chapter 6 Conclusions and Summary

Generally, it has been regarded that the integration of an advanced train detection system with a traveler information system is required at HRGCs to provide better operation efficiency and safety. These systems function to disseminate train information including arriving, departing, occupancy time, etc. at HRGCs to nearby motorists so that they can choose alternate routes to avoid possible train delay. Diverted motor vehicle traffic not only increases safety at HRGCs by reducing exposed traffic to trains, but improves network efficiency by distributing traffic to less congested routes when trains are present at HRGCs. Currently, even though related technologies eligible for application at HRGCs are being developed and proven, research on specific applications and effects of such technologies at HRGCs has not fully been explored. In order to fill the gap in the literature, this study proposed a prototype system design for train detection and information dissemination and assessed the effect of the developed system at an HRGC.

Train Occupancy Time Estimation System (TOTES) was developed in this study to detect train movements, estimate its speed and size, calculate the amount of expected delay that motorists are likely to experience, and inform the motorists of the delay. Detailed system components, relevant equations for required variables, and system information logic flow were presented. However, due to the limited resources, the system was built in a modified version, or the manual input system of TOTES to be deployed at an HRGC and tested for driver behaviors on the system. It was revealed that the developed system significantly improved the safety at the target HRGC by reducing unsafe maneuvers such as crossing the solid white line, illegal left turns, and illegal going through. Furthermore, the use of the VMS system was found to affect the motorists' decision making to take an alternate route to avoid the train delay.

Regarding diverting rate, it was found that the system displaying train occupancy time information showed a statistically signficant increase of diverting rate when compared to the rate of displaying general safety information. This represents the deployment of a VMS system at HRGCs will be likely to increase the network efficiency and rail crossing safety. It is interesting that the diverting rate did not change significantly when trains present at the crossing before and after the VMS system initiated even though it was assumed to change. In effect, the mean value of diverting rate decreased after the VMS system was introduced with the p-value of 0.084. Although the difference is not statistically significant at an alpha level of 0.05, this result may imply that some motorists would decide to go to the rail crossing to wait for trains finishing crossing. Since the train occupancy time information given to the VMS system was only five minutes for every train, the motorists may have decided the time was short enough to wait at the crossing. Thus, it is recommended to use the varying levels of train occupancy times for the VMS system to investigate driver behaviors based on different wait times in the future studies. In addition, the number of vehicles making left turns can be directly used in the analysis instead of using the diverting rate calculated by the total number of left turning vehicles divided by total number of vehicles going westbound. More sophisticated statistical analysis for count data can be used to analyze driver behaviors at intersections located near HRGCs. Notwithstanding these limitations, it is expected that the findings from this research can contribute to helping local governments increase the safety and efficiency of their jurisdictional roadway networks that contain HRGCs.

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Appendix A The U.S. States Regulations on Blocking a HRGC

Alabama
***§ 37-8-115. Blocking of traffic, crossings.**
No member of a train crew, yard crew or engine crew of a railroad, which is a common carrier, shall be held personally responsible or found guilty of violating any law of this state or any municipal ordinance regulating or intended to regulate the occupying or blocking of any street, road or highway crossing-at-grade by trains or passenger or freight cars upon reasonable proof that the occupying or blocking of said street, road or highway crossing-at-grade was necessary to comply with the orders or instructions either written or oral of his employer or its officers or supervisory officials; provided, that the provisions of this section shall not relieve the employer or railroad from any responsibility placed upon said employee or railroad by any such state laws or by such municipal ordinances; provided further, that nothing contained herein shall affect any civil tortious responsibility of the agent, servants, employees and the railroad itself.
Ala. Code § 37-8-115 (2012)

Alaska
No applicable statute related to this topic

Arizona
§ 40-852. Allowing engine or car to remain upon public crossing; classification
An engineer, conductor or other employee or officer of a railroad company who permits a locomotive or cars to be or remain upon the crossing of a public highway over such railway so as to obstruct travel over the crossing for a period exceeding fifteen minutes, except in cases of unavoidable accident, is guilty of a class 2 misdemeanor.
Ariz. Rev. Stat. § 40-852 (2012)

Arkansas
***23-12-1008. Unlawful delay -- Action on complaint.**
(a) (1) (A) Prior to any request by a state, municipal, or county official for sanctions against a railroad company for violation of this section and §§ 23-12-1006 and 23-12-1007, the state, 231 municipal, or county official shall state the claim or complaint in writing, by certified mail, to the registered agent of the railroad company in question.
(B) (i) Within forty-five (45) days after the receipt of the written claim or complaint by the railroad company, the railroad company shall respond to the claim or complaint stating with specificity the reasons for obstructing a crossing for an unlawful period of time.
(ii) This response shall be in writing to the complaining official by certified mail.
(2) (A) In the event the issue is not then resolved to the satisfaction of the complaining official, the official shall notify the State Highway Commission in writing and shall enclose a copy of the complaint and response.
(B) (i) Within sixty (60) days after receipt of the notice, the commission shall hold a hearing on the complaint.

(ii) Notice of the hearing shall be given the railroad and the complainant at least twenty (20) days before the hearing.
(C) The commission or its designated representative, after an appropriate notice and hearing on the complaint, shall determine whether the obstruction was for an unlawful period of time under the circumstances.
(3) (A) If the commission makes such a finding of unlawful delay based on information presented at a hearing before the commission or before its designated representative, the railroad company charged with the violation shall be subject to a penalty to be imposed by the commission of not less than two hundred dollars ($200) nor more than five hundred dollars ($500) per occurrence.
(B) (i) The decision of the commission may be appealed to the circuit court of the county in which the violation occurred at any time within thirty (30) days after the decision is rendered.
(ii) Provided, the decision of the commission shall be final unless appealed as authorized herein.
(b) After the initial ten-minute period or such other period as may be prescribed by regulation of the commission, each ten-minute period or other period as may be prescribed by regulation of the commission that the crossing is obstructed by a standing train shall constitute a separate offense, and penalties may be imposed accordingly.
(c) (1) If the crossing where a violation occurs is located within the boundaries of a city or town, one-half (1/2) of the moneys recovered under the provisions of this section and §§ 23-12-1006 and 23-12-1007 shall be placed in the general fund or street fund of the municipality and one-half (1/2) of the funds shall be placed in the State Highway and Transportation Department Fund.
(2) All other moneys recovered under the provisions of this section shall be divided equally between the State Highway and Transportation Department Fund and the general road fund of the county in which the violation occurred.
Ark. Code. Ann. § 23-12-1008 (2012)

California
No applicable statute related to this topic

Colorado
No applicable statute related to this topic

Connecticut
***Sec. 13b-339. (Formerly Sec. 16-155). Obstruction of highway at crossing.**
Any person traveling upon any public highway, which is crossed by the tracks of any railroad company, who is obstructed or prevented from crossing such tracks for a longer time than five minutes, by reason of any train, car or locomotive using or occupying such highway, or by any gate, may recover twenty-five dollars and costs from the corporation or person owning or operating such railroad, provided suit shall be brought within thirty days from the date of such obstruction. The person first filing notice with the Commissioner of Transportation of intention to bring suit under the provisions of this section shall be entitled to the only recovery for any such obstruction.

Conn. Gen. Stat. § 13b-339 (2012)
***Sec. 13b-342. (Formerly Sec. 16-158 General orders regarding crossings. Forfeiture.**
The Commissioner of Transportation may make orders for the regulation of the speed at which locomotives and cars shall cross highways and generally may make all orders which he deems necessary to prevent inconvenience to the public relating to the crossing or obstruction of highways by locomotives and cars. Any company which violates any such order shall forfeit to the state fifty dollars for each day of such violation.
Conn. Gen. Stat. § 13b-342 (2012)

Delaware
§ 701. Whistles at public highway crossings; blocking of crossings; penalty; jurisdiction
(c) Every corporation operating any line of railroad within the State shall cause its trains to cross a highway or road for the public use within 10 minutes so that the highway or road is not blocked for any longer period of time, unless an emergency is the cause of the delay.
(d) Any corporation violating subsection (c) of this section shall be fined not less than $ 500 and not more than $ 1000 for the first conviction and not less than $ 1000 and not more than $ 2000 for each subsequent conviction which occurs within 1 year after a previous conviction.
(e) Justices of the peace shall have jurisdiction of offenses under this section. There shall be a right of appeal to the Court of Common Pleas in every case.
Del. Code Ann. tit. 17, § 701 (c-e)(2012) Excerpt from applicable statute published.

District of Columbia
18-2211. STREETCARS, RAILROAD TRAINS, AND SAFETY ZONES.
2211.7 It shall be unlawful for the directing officer or operator of any railroad train or streetcar to direct the operation of or to operate the train or streetcar in such a manner as to prevent the use of any street for purposes of travel for a period of longer than five (5) minutes; Provided, that this subsection shall not apply to trains or cars in motion, other than those engaged in switching.
D.C. Mun. Regs. tit.18 § 2211 (2013) Excerpt from applicable regulation published.
24-120. Railroads and Railroad Crossings
120.7 No highway or railway crossing in the District of Columbia on which tracks of steam railroad are laid shall be obstructed by any train, locomotive, car, or crossing gates for a period longer than five (5) minutes; nor shall a train, locomotive, car, or cars be parked or stored on a street for an unreasonable time.
120.8 The supervisor of tracks or yardmaster shall be held liable and subject to prosecution for obstructions by crossing gates when, by his or her order, they are kept down for a longer time than is permitted by the rules of this chapter.
D.C. Mun. Regs. tit. 24 § 120 (2013) Excerpt from applicable regulation published.

Florida
§ 351.03. Railroad-highway grade-crossing warning signs and signals; audible warnings; exercise of reasonable care; blocking highways, roads, and streets during darkness
(5) (a) Whenever a railroad train engages in a switching operation or stops so as to block a public highway, street, or road at any time from one-half hour after sunset to one-half hour

before sunrise, the crew of the railroad train shall cause to be placed a lighted fusee or other visual warning device in both directions from the railroad train upon or at the edge of the pavement of the highway, street, or road to warn approaching motorists of the railroad train blocking the highway, street, or road. However, this subsection does not apply to railroad-highway grade crossings at which there are automatic warning devices properly functioning or at which there is adequate lighting.
(b) A person who violates any provision of paragraph (a) is guilty of a misdemeanor of the second degree, punishable as provided in s. 775.082 or s. 775.083.
Fla. Stat. Ann. § 351.03(5-a,b) (2012) Excerpt from applicable statute published.
§ 351.034. Railroad-highway grade crossings to be cleared for emergency vehicles
Except for trains or equipment stopped due to mechanical failure where separation or movement is not possible, any train or equipment that has come to a complete stop and is blocking a railroad-highway grade crossing must be cut, separated, or moved to clear the crossing upon the approach of any emergency vehicle, which for the purpose of this law shall be:
(1) An ambulance operated by public authority or by private persons;
(2) A fire engine; or an emergency vehicle operated by power or electric companies; or
(3) Any other vehicle when operated as an emergency vehicle, defined as one which is engaged in the saving of life, property, or responding to any other public peril; or
(4) Emergency vehicles used as such by the Government of the United States; when upon the approach of such emergency vehicle, such vehicle gives due warning of its approach to such crossing by the sounding of sirens, flashing of lights, waving of flag, or any other warning sufficient to attract attention to such emergency vehicle; and thereupon the said train or equipment shall be cut and said crossing shall be cleared with all possible dispatch to permit the crossing and passing through of said emergency vehicle.
Fla. Stat. Ann.§ 351.034 (2013)

Georgia
§ 46-8-197. Legal responsibility of member of train crew, yard crew, or engine crew for occupying or blocking street, road, or highway grade crossing pursuant to employer's order
No member of a train crew, yard crew, or engine crew of a railroad common carrier shall be held personally responsible under, or found guilty of violating, any state laws or municipal ordinances regulating or intended to regulate the occupying or blocking of any street, road, or highway grade crossing by engines or passenger or freight cars, upon reasonable proof by the crew member that the occupying or blocking of the grade crossing was necessary to comply with the orders or instructions, either written or oral, of his employer or of the officers or supervisory officials of the company owning the railroad over which the engine or cars are operated; provided, however, that this Code section shall not relieve the employer or railroad company from any responsibility placed upon such employee or railroad company by any such state laws or municipal ordinances.
Ga. Code Ann. § 46-8-197 (2012)

Hawaii

No applicable statute related to this topic

Idaho

§ 49-1425. Railroad trains not to unnecessarily block crossings

No person or government agency shall operate any train in a manner as to prevent vehicular use of any highway for a period of time in excess of fifteen (15) consecutive minutes except:
(1) When necessary to comply with signals affecting the safety of the movement of trains;
(2) When necessary to avoid striking any object or person on the track;
(3) When the train is stopped to comply with a governmental safety regulation;
(4) When the train is disabled;
(5) When the train is in motion except while engaged in switching operations;
(6) When there is no vehicular traffic waiting to use the crossing.
Idaho Code Ann. § 49-1425 (2012)

Illinois

§ 625 ILCS 5/18c-7402. Safety Requirements for Railroad Operations

Sec. 18c-7402. Safety Requirements for Railroad Operations. (1) Obstruction of Crossings.
(a) Obstruction of Emergency Vehicles. Every railroad shall be operated in such a manner as to minimize obstruction of emergency vehicles at crossings. Where such obstruction occurs and the train crew is aware of the obstruction, the train crew shall immediately take any action, consistent with safe operating procedure, necessary to remove the obstruction. In the Chicago and St. Louis switching districts, every railroad dispatcher or other person responsible for the movement of railroad equipment in a specific area who receives notification that railroad equipment is obstructing the movement of an emergency vehicle at anycrossing within such area shall immediately notify the train crew through use of existing communication facilities. Upon notification, the train crew shall take immediate action in accordance with this paragraph.
(b) Obstruction of Highway at Grade Crossing Prohibited. It is unlawful for a rail carrier to permit any train, railroad car or engine to obstruct public travel at a railroad-highway grade crossing for a period in excess of 10 minutes, except where such train or railroad car is continuously moving or cannot be moved by reason of circumstances over which the rail carrier has no reasonable control.
In a county with a population of greater than 1,000,000, as determined by the most recent federal census, during the hours of 7:00 a.m. through 9:00 a.m. and 4:00 p.m. through 6:00 p.m. it is unlawful for a rail carrier to permit any single train or railroad car to obstruct public travel at a railroad-highway gradecrossing in excess of a total of 10 minutes during a 30 minute period, except where the train or railroad car cannot be moved by reason or circumstances over which the rail carrier has no reasonable control. Under no circumstances will a moving train be stopped for the purposes of issuing a citation related to this Section. However, no employee acting under the rules or orders of the rail carrier or its supervisory personnel may be prosecuted for a violation of this subsection (b).
(c) Punishment for Obstruction of Grade Crossing. Any rail carrier violating paragraph (b) of this subsection shall be guilty of a petty offense and fined not less than $ 200 nor more than $ 500 if the duration of the obstruction is in excess of 10 minutes but no longer than 15

minutes. If the duration of the obstruction exceeds 15 minutes the violation shall be a business offense and the following fines shall be imposed: if the duration of the obstruction is in excess of 15 minutes but no longer than 20 minutes, the fine shall be $ 500; if the duration of the obstruction is in excess of 20 minutes but no longer than 25 minutes, the fine shall be $ 700; if the duration of the obstruction is in excess of 25 minutes, but no longer than 30 minutes, the fine shall be $ 900; if the duration of the obstruction is in excess of 30 minutes but no longer than 35 minutes, the fine shall be $ 1,000; if the duration of the obstruction is in excess of 35 minutes, the fine shall be $ 1,000 plus an additional $ 500 for each 5 minutes of obstruction in excess of 25 minutes of obstruction.
625 Ill. Comp. Stat. Ann. 5/18c-7402(a-b-c) (2012) Excerpt from applicable statute published.

Indiana
8-6-7.5-1. Blocking railroad crossings unlawful -- Exception.
It shall be unlawful for a railroad corporation to permit any train, railroad car or engine to obstruct public travel at a railroad-highway grade crossing for a period in excess of ten (10) minutes, except where such train, railroad car or engine cannot be moved by reason of circumstances over which the railroad corporation has no control.
Ind. Code Ann. § 8-6-7.5-1 (2012)
8-6-7.5-2. Obstructing vehicular movement unlawful.
It shall be unlawful for a railroad corporation to permit successive train movements to obstruct vehicular traffic at a railroad-highway grade crossing until all vehicular traffic previously delayed by such train movements has been cleared or a period of five (5) minutes has elapsed between train movements.
Ind. Code Ann. § 8-6-7.5-2 (2012)
8-6-7.5-3. Violations -- Penalty.
A railroad corporation, conductor, or engineer who violates this chapter commits a Class C infraction. However, no conductor or engineer acting under the rules or orders of the railroad corporation or its supervisory personnel may be prosecuted for such a violation.
Ind. Code Ann. § 8-6-7.5-3 (2012)

Iowa
327G.32. Blocking highway crossing.
1. A railroad corporation or its employees shall not operate a train in such a manner as to prevent vehicular use of a highway, street, or alley for a period of time in excess of ten minutes except in any of the following circumstances:
a. When necessary to comply with signals affecting the safety of the movement of trains.
b. When necessary to avoid striking an object or person on the track.
c. When the train is disabled.
d. When necessary to comply with governmental safety regulations including but not limited to speed ordinances and speed regulations.
2. a. An officer or employee of a railroad corporation violating a provision of this section is, upon conviction, subject to the penalty provided in section 327G.14.

b. An employee is not guilty of a violation if the employee's action was necessary to comply with the direct order or instructions of a railroad corporation or its supervisors. Guilt is then with the railroad corporation.

3. Other portions of this section notwithstanding, a political subdivision may pass an ordinance regulating the length of time a specific crossing may be blocked if the political subdivision demonstrates that an ordinance is necessary for public safety or convenience. If an ordinance is passed, the political subdivision shall, within thirty days of the effective date of the ordinance, notify the department and the railroad corporation using the crossing affected by the ordinance. The ordinance does not become effective unless the department and the railroad corporation are notified within thirty days. The ordinance becomes effective thirty days after notification unless a person files an objection to the ordinance with the department. If an objection is filed the department shall notify the department of inspections and appeals which shall hold a hearing. After a hearing by the department of inspections and appeals, the state department of transportation may disapprove the ordinance if public safety or convenience does not require the ordinance. The decision of the state department of transportation is final agency action. The ordinance approved by the political subdivision is prima facie evidence that the ordinance is adopted to preserve public safety or convenience.

4. The department of inspections and appeals when considering rebuttal evidence shall weigh the benefits accruing to the political subdivision as they affect the general public use compared to the burden placed on the railroad operation. Public safety or convenience may include, but is not limited to, high traffic density at a specific crossing of a main artery or interference with the flow of authorized emergency vehicles.

5. A resolution regulating the length of time a specific crossing may be blocked, which was adopted before July 1, 1989, is an ordinance for the purposes of this section.

Iowa Code § 327G.32 (2012)

Kansas

66-273. Permitting trains, engines or cars to stand on public highway.

Each and every railroad company or any corporation leasing or otherwise operating a railroad in Kansas is hereby prohibited from allowing its trains, engines or cars to stand upon any public road within one half mile of any incorporated or unincorporated city or town, station or flag station, or upon any crossing or street, to exceed ten minutes at any one time without leaving an opening in the traveled portion of the public road, street or crossing of at least thirty feet in width.

Kan. Stat. Ann. § 66-273 (2011)

66-274. Same; penalty; exemption of railroad employees from certain penalties.

Any railroad company or corporation operating a line of railroad in Kansas failing or neglecting to comply with K.S.A. 66-273, and amendments thereto, shall be guilty of a misdemeanor, and upon conviction shall be punished by a fine as follows: One hundred dollars if the blocking is for more than 10 minutes but less than 20 minutes; $ 300 if the blocking is for more than 20 minutes but less than 30 minutes; $ 600 if the blocking is for 30 minutes and $ 600 for each additional 30 minutes if the blocking is for more than 30 minutes. No member of a railroad train, yard, or engine crew shall be held personally responsible or found guilty of violating any state laws or any municipal ordinances regulating or intended to regulate the

occupying or blocking of any street, road or highway crossing-at-grade by trains or passenger or freight cars upon reasonable proof that such person's action was necessary due to circumstances beyond such person's control, or to comply with the order or instructions, either written or verbal, of the person's employer or officers or supervisory officials. Nothing in this section shall relieve the employer or railroad from any responsibility placed upon such employer or railroad by any such state law or any municipal ordinance.
Kan. Stat. Ann. § 66-274 (2011)

Kentucky
277.200. Period of obstructing highway, street or navigable stream limited.
(1) No railroad company shall obstruct any public highway or street, or the navigation of any stream, by stopping and permitting trains, engines or cars to stand upon a public grade crossing or upon a drawbridge for more than five (5) minutes at any one time, unless such stopping and standing is caused by circumstances beyond control of the railroad company.
(2) No member of a railroad train crew shall be held personally guilty of violating a municipal ordinance regulating the blocking of public grade crossings by trains, engines or cars, on proof that his action was necessary to comply with the orders or instructions of the railroad company or its officers; provided that nothing in this section shall relieve the railroad company from any responsibility placed upon it by said ordinance.
Ky. Rev. Stat. Ann. § 277.200 (2012)
277.990. Penalties.
(6) Any railroad company that violates the provisions of KRS 277.200 shall be fined not less than twenty-five dollars ($25) nor more than one hundred dollars ($100) for each offense. If a grade crossing or drawbridge is obstructed by two (2) or more trains stopping and standing thereon in succession without allowing accumulated highway or water traffic to pass, the obstruction by each such successive train shall constitute a separate offense.
Ky. Rev. Stat. Ann. § 277.990 (2012) Excerpt from applicable statute published.

Louisiana
§ 48:391. Obstruction of railroad grade crossings
A. (1) It shall be unlawful for any train, railroad car or equipment, or engine to obstruct vehicular traffic at a public highway railroad grade crossing for a period in excess of twenty consecutive minutes, except when such train, railroad car or equipment, or engine is moving or when such movement is prevented by any of the following:
(a) A power brake failure or other mechanical failure.
(b) Enforcement of the Hours of Service Act.
(c) Derailment or other accident.
(d) A directive of the Federal Railway Administration.
(e) Circumstances over which the railroad company or carrier has no reasonable control, such as a natural disaster or acts of third parties.
(2) No employee performing his duties under the operating rules or orders of the railroad company or carrier or its supervisory personnel shall be prosecuted for any violation of this Section.

(3) Any rail carrier violating the provisions of Paragraph (1) of this Subsection shall be fined as follows:
(a) If the duration of the obstruction is in excess of twenty minutes, but not longer than twenty-five minutes, the fine shall be not less than two hundred dollars nor more than five hundred dollars.
(b) If the duration of the obstruction is in excess of twenty-five minutes, but not longer than thirty minutes, the fine shall be five hundred dollars.
(c) If the duration of the obstruction is in excess of thirty minutes, but not longer than thirty-five minutes, the fine shall be seven hundred dollars.
(d) If the duration of the obstruction is in excess of thirty-five minutes, but not longer than forty minutes, the fine shall be nine hundred dollars.
(e) If the duration of the obstruction is in excess of forty minutes, but not longer than forty-five minutes, the fine shall be one thousand dollars.
(f) If the duration of the obstruction is in excess of forty-five minutes, the fine shall be one thousand dollars plus an additional five hundred dollars for each five minutes of obstruction in excess of forty-five minutes. However, the maximum fine shall not exceed five thousand dollars for an obstruction which occurs within a twenty-four hour period.
B. (1) Every railroad shall be operated in such a manner as to minimize obstruction of emergency vehicles at public highway grade crossings.
(2) Upon receiving notification from a law enforcement officer, member of a fire department, operator of an emergency vehicle, or a member of an emergency services provider that emergency circumstances require the clearing of a public highway railroad grade crossing, the members of the train crew of the train, railroad car or equipment, or engine blocking such crossing shall immediately notify the appropriate railroad dispatcher of the pending emergency situation and request the clearing of such crossing, consistent with the safe operation of the train.
(3) Every railroad dispatcher or other person responsible for the movement of a train, railroad car or equipment, or engine in a specific area who receives notification that a train, railroad car or equipment, or engine is obstructing the movement of an emergency vehicle at any crossing within such area shall immediately notify the train crew through use of existing communication facilities. Upon notification, the train crew shall take immediate action in accordance with this Subsection.
C. (1) Any person riding upon a train, railroad car or equipment, or engine which is running through or within this state who is accountable for the movement of the train, car or equipment, or engine shall keep on his person or upon the train, railroad car or equipment, or engine written identification of the person, corporation, firm, or agent by whom he is employed.
(2) It shall be the responsibility of any railroad company or carrier operating any railroad, engine, or train within this state to inform the chief law enforcement officer of each parish or municipality in which it operates of the telephone numbers of the railroad dispatch center having jurisdiction over such railroad, engine, or train in the parish or municipality. The information shall be updated within forty-eight hours of any change, but no less than once every six months.

D. (1) Any railroad or public agency may, by formal application to the Department of Transportation and Development, request a variance from the requirements of this Section or have different regulations provided in connection with operation over a specific crossing where local conditions so require. The application shall list any public agencies within the geographic area or any railroads which may be affected by the variance and shall detail any previous steps which may have been taken in an attempt to reach an agreement on or alternative to the proposed variance.
(2) The department shall promulgate rules and regulations for the implementation and administration of the application process provided in this Subsection.
La. Rev. Stat. Ann. §48:391 (2012)
***§ 48:392. Obstruction of railroad grade crossings; moving or nonmoving trains**
A. (1) It shall be unlawful for any moving or non-moving train, railroad car or equipment, or engine to obstruct vehicular traffic at a public highway railroad grade crossing for a period in excess of twenty consecutive minutes.
(2) No employee performing his duties under the operating rules or orders of the railroad company or carrier or its supervisory personnel shall be prosecuted for any violation of this Section.
(3) Any rail carrier violating the provisions of Paragraph (1) of this Subsection shall be fined as provided for in R.S. 48:391(A) (3).
B. (1) Any railroad or public agency may, by formal application to the department, request a variance from the requirements of this Section or have different regulations provided in connection with operation over a specificcrossing where local conditions so require. The application shall list any public agencies within the geographic area or any railroads which may be affected by the variance and shall detail any previous steps which may have been taken in an attempt to reach an agreement on or alternative to the proposed variance.
(2) The department shall promulgate rules and regulations for the implementation and administration of the application process provided in this Subsection.
La. Rev. Stat. Ann. § 48:392 (2012)

Maine
§ 7220. Speed limit at highway grade crossings
The department is authorized to fix a maximum speed limit at which trains may be run over any grade crossing of a highway or other way and, when the limit has been fixed by the department, no engine or train may be run over the crossings at a greater speed than that fixed by the department and no way may be unreasonably and negligently obstructed by engines, tenders or cars. Any railroad corporation forfeits not more than $ 100 for every violation of this section.
Me. Rev. Stat. Ann. tit. 23, § 7220 (2012)

Maryland
No applicable statute related to this topic

Massachusetts
§ 151. Obstruction of Public Way by railroad; penalty

A railroad corporation, or receiver or assignee thereof, or its or his servant or agent, shall not wilfully or negligently obstruct or unnecessarily or unreasonably use or occupy a public way, or in any case wilfully, obstruct, use or occupy it with cars or engines for more than five minutes at one time; and if a public way has been thus used or occupied with cars or engines, the railroad corporation, or receiver or assignee thereof, shall not again use or occupy it with the cars or engines of a freight train, until a sufficient time, not less than three minutes, has been allowed for the passage across the railroad of such travelers as were ready and waiting to cross when the former occupation ceased. A railroad corporation, receiver or assignee thereof, who violates this section, shall forfeit not less than two hundred nor more than five hundred dollars.
Mass. Gen. Laws Ann. ch. 160, § 151 (West 2012)

Michigan
§ 462.391. Obstruction of vehicular traffic by trains; offenses as separate violations; penalty; allocation of fines.
Sec. 391. (1) A railroad shall not permit a train to obstruct vehicular traffic on a public street or highway for longer than 5 minutes at any 1 time, except the obstruction shall not be considered a violation under the following circumstances:
(a) If the train is continuously moving in the same direction at not less than 10 miles per hour for not longer than 7 minutes.
(b) If the railroad can show that the incident occurred as a result of a verifiable accident, mechanical failure, or unsafe condition.

(2) A railroad shall not permit successive train movements to obstruct vehicular traffic on a public street or highway until all vehicular traffic previously delayed by such train movements has been cleared.
(3) A railroad company shall not permit its employees to allow the activation of active traffic control devices at a railroad grade crossing for more than 2 minutes if there is no intention to move a train or track equipment through the crossing within 20 seconds to 60 seconds after the activation of the devices.
(4) Each offense under this section shall be a separate violation punishable by a fine of not more than $500.00 unless the railroad is willfully, deliberately, and negligently blocking vehicular traffic and then the fine shall be not more than $1,000.00 and the costs of prosecution.
(5) All fines civil or otherwise collected by a local unit of government in excess of $10,000.00 annually from the enforcement of a local ordinance substantially similar to this section shall be allocated as follows:
(a) Fifteen percent shall be retained by each local unit of government for costs of enforcement of the ordinance.
(b) Eighty-five percent shall be deposited in a railroad grade crossing safety fund. The revenue collected in this fund shall be used solely for railroad grade crossing safety projects in these local units of government.
Mich. Comp. Laws Serv. § 462.391 (LexisNexis 2012)

Minnesota

219.383 SAFE OPERATION OF TRAIN OVER ROAD; PENALTY

Subdivision 1. Speed fixed. --The commissioner of transportation, on petition of a city council or a railway corporation, may fix and determine after a hearing a reasonable speed for the operation of an engine or train on and over a railroad crossing of a public highway or street in that city.

Subd. 2. Maximum speed. --Where the commissioner has fixed the speed of an engine or train over a public highway or street crossing in a city as provided in this section, the fixed speed is the lawful maximum speed at which an engine or train may be operated on and over that public highway or street crossing, until changed by subsequent order of the commissioner.

Subd. 3. Not to block public road or street. --No railway corporation shall permit a public road or streetcrossing a railroad track to be closed for traffic by a standing car, train, engine, or other railroad equipment, or by a switching movement which continuously blocks a crossing for longer than ten minutes. This subdivision does not apply to cities of the first class which regulate obstruction of streets by ordinance.

Subd. 4. Penalty. --A railway corporation violating this section is guilty of a petty misdemeanor. A corporation that commits a second or subsequent violation of this section is guilty of a misdemeanor.

Minn. Stat. § 219.383 (2012)

Mississippi

§ 77-9-235 Obstructing highways and streets; penalty

Every railroad company, upon stopping any train at a place where such railroad shall cross a highway, shall so uncouple its cars as not to obstruct travel upon such highway for a longer period than five (5) minutes. Every railroad company shall, upon stopping a train at a place where the railroad is crossed by a street, so uncouple the cars as not to obstruct travel thereon for a longer period than shall be prescribed by ordinance of the city, town or village. A failure to observe this section shall cause a railroad company to be liable to a fine of Fifty Dollars ($ 50.00) for each offense. The conductor in charge of any train so violating the provisions of this section shall be liable to a fine of not less than Twenty-five Dollars ($ 25.00) nor more than Fifty Dollars ($ 50.00), on conviction thereof.

The provisions of this section shall be enforced by the Mississippi Department of Transportation.

Miss. Code Ann. § 77-9-235 (2012)

§ 77-9-236. Obstructing highways and streets; criminal responsibility of crew complying with orders of employer

No member of a train crew, yard crew or engine crew of a railroad which is a common carrier shall be held criminally responsible or found guilty of violating any state laws or of any municipal ordinances regulating or intended to regulate the blocking of any street, road or highway grade crossings by trains or passenger or freight cars upon reasonable proof that the blocking of said street, road or highway grade crossings was necessary to comply with the orders or instructions, either written or oral, of his employer or its officers or supervisory officials; provided, however, that the provisions of this section shall not relieve the employer or railroad from any responsibility placed upon said employee or railroad by any such state

laws or by such municipal ordinances; and provided further, that the employer or railroad shall stand in the place of the member of the train crew, yard crew or engine crew in such circumstances and shall be responsible for the violation of any such state laws or municipal ordinances and any criminal fines resulting therefrom.
The provisions of this section shall be enforced by the Mississippi Department of Transportation.
Miss. Code Ann. § 77-9-236 (2012)
***§ 97-25-37. Railroads; stopping or standing at crossing**
It shall be unlawful for any locomotive or train of cars to be stopped or left standing on any railroad crossing, unless done under regulations adopted by those having the right to control such matter. Any person violating this section shall, on conviction be fined not less than one hundred dollars, nor more than one thousand dollars, or be imprisoned in the county jail for one year, or both; and if, in consequence of such violation, any person shall be killed or injured, the guilty party shall be imprisoned in the penitentiary not exceeding fifteen years.
Miss. Code Ann. § 97-25-37 (2012)

Missouri
§ 71.013. Train crewman not to be personally liable under city ordinance or state statute for blocking crossing, when
1. No member of a railroad train or yard crew shall be held criminally guilty of any responsibility of violating a state law or any municipal ordinance regulating the occupying or blocking of any street or highway railroad crossing-at-grade by trains or cars, upon reasonable proof that his action was necessary to comply with the order or instructions, either written or verbal, of his employer or its officers or supervisory officials; and provided, that nothing in this section shall relieve the employer or railroad from any responsibility placed upon said employer or railroad by any such state law or any municipal ordinance.
2. Every person, firm, company, or corporation, operating a railroad as a common carrier in the state of Missouri and violating the provisions of this section, shall be fined not less than fifty dollars for each separate offense.
Mo. Rev. Stat. § 71.013 (2012)

Montana
69-14-626 Prohibition on extended obstruction of highway crossings.
(1) It shall be unlawful for any corporation, association, or company to willfully obstruct, blockade, interfere with, or prevent the free use of any public highway within the state where such highway crosses any railroad track outside of incorporated cities and towns by stopping any railroad train, car, engine, or locomotive for more than 15 minutes at any one time or by placing, depositing, or leaving any article or thing whatsoever on any railroad track at the point where any public highway crosses such track outside of incorporated cities and towns.
(2) Any corporation, association, or company so obstructing, blockading, or interfering with the free use of any such highway shall be deemed guilty of a misdemeanor and upon conviction thereof shall be punished by a fine of not less than $ 25 or more than $ 100. This section shall not be construed as repealing any existing laws prohibiting encroachments upon or obstruction of public highways.

Mont. Code Ann., § 69-14-626 (2012)

Nebraska

***§ 17-225. Railroads; blocking crossings; penalty**

It shall be unlawful for any railroad company or for any of its officers, agents, servants or employees to obstruct with car or cars, engine or engines, or with any other rolling stock, for more than ten minutes at a time, any public highway, street or alley in any unincorporated town or village in the State of Nebraska. Any corporation, person, firm or individual violating any provision of this section shall, upon conviction thereof, be fined in any sum not less than ten dollars nor more than one hundred dollars.

Neb. Rev. Stat. Ann. § 17-225 (2012)

***§ 74-594. Train, yard, or engine crew; blocking street or highway; liability; exempt**

No member of a train crew, yard crew, or engine crew of a railroad shall be held personally responsible or found guilty of violating any state laws or any municipal ordinances regulating or intended to regulate the occupying or blocking of any street, road, or highway crossing-at-grade by trains or passenger or freight cars upon reasonable proof that the occupying or blocking of the street, road, or highway crossing-at-grade was necessary to comply with orders or instructions either written or oral of his or her employer or its officers or supervisory officials. This section shall not relieve the employer or railroad from any responsibility placed upon the employer or railroad by any such state laws or by such municipal ordinances. This section shall be supplemental to any other law.

Neb. Rev. Stat. Ann. § 74-594 (2012)

§ 74-1323. Railroad car; obstructing view at crossing; violation; penalty

(1) Unless otherwise provided by city or village ordinance, the Public Service Commission, upon complaint or on its own motion, as to the crossing which is the subject of the complaint or motion, may direct that at suchcrossing any railroad car that is stored or parked on a railroad track which may be obstructing or obscuring the traveling public's view of any oncoming train be stored or parked at a minimum distance from the crossing of such railroad and public road. The minimum distance shall be that deemed by the commission to be reasonable and necessary to provide a sight distance at the crossing adequate to protect the safety of the traveling public, but in no instance shall any person who is authorized to control the movement of such railroad car or cars within such distance be prevented from reasonably conducting his or her business.

(2) Any company, its officers, agents, or employees, or any other person subject to subsection (1) of this section who fails, neglects, or refuses to promptly comply with an order of the commission issued under this section shall be guilty of a Class IV misdemeanor, but shall be fined not more than two hundred dollars for each offense. Each day of such neglect, refusal, or failure shall constitute a separate offense.

Neb. Rev. Stat. Ann. § 74-1323 (2012)

Nevada

No applicable statute related to this topic

New Hampshire

373:15 Occupancy of Crossing by Engines or Cars.

A railroad shall not occupy a grade crossing over a highway by its engines and cars more than 5 minutes at one time without authority from the department of transportation.
N.H. Rev. Stat. Ann. § 373:15 (2012)

373:16 Exceptions to 5 Minute Occupations.

I. The department of transportation, upon petition, notice and hearing, may fix the maximum time for the occupancy of a railroad on a grade crossing over a highway. The maximum time shall not exceed 9 minutes.

II. The commissioner may adopt rules, pursuant to RSA 541-A, relative to the time of maximum occupancy of a grade crossing.
N.H. Rev. Stat. Ann. § 373:16 (2012)

373:17 Penalty.

Any person who violates the provisions of any of the preceding sections, or of any order of the department of transportation made hereunder, shall be guilty of a violation if a natural person, or guilty of a misdemeanor if any other person, unless otherwise specifically.
N.H. Rev. Stat. Ann. § 373:17 (2012)

New Jersey

§ 39:4-94. Railroad blocking highway

No employee of a steam or electric railroad company shall operate a locomotive, train or crossing gate in such a manner as to unnecessarily prevent or interfere with the use of a highway for the purpose of travel.
N.J. Rev. Stat. Ann. § 39:4-94 (2012)

New Mexico

No applicable statute related to this topic

New York

§ 53-c. Obstructing farm and highway crossings

Any officer or employee of a railroad corporation who shall intentionally obstruct, and any owner, officer or employee of a railroad corporation who shall intentionally cause to be obstructed any farm or highway crossing with any locomotive, train or car for a longer period than five consecutive minutes is guilty of a violation which shall be punishable by a fine of not more than one hundred dollars or imprisonment for not more than fifteen days or by both such fine and imprisonment. Notwithstanding the foregoing provisions of this section or any local ordinance to the contrary, no owner, officer or employee of a railroad corporation who obstructs, or causes to be obstructed, any farm or highway crossing shall be subject to any civil, criminal or other penalty where such person has no control over the situation causing the obstruction or where the locomotive, train or car cannot be moved without endangering the safety of the passengers, the public or freight.
N.Y. R. R. Law § 53-c (Consol. 2012)

North Carolina

No applicable statute related to this topic

North Dakota

***49-11-01. Obstruction of crossing by railroad -- Provision for temporary way.**

Every railroad corporation while engaged in raising or lowering any railroad track or in making any other alterations, by means of which a railroad crossing may be obstructed, shall provide and keep in good order a suitable temporary way and crossing with adequate protection to enable travelers to avoid or pass such obstruction.

N.D. Cent. Code, § 49-11-01 (2012)

49-11-19. Blocking or obstructing crossing with train -- Penalty.

1. A person may not operate any train in a manner as to prevent vehicular use of any roadway for a period of time in excess of ten consecutive minutes except:

a. When necessary to comply with safety signals affecting the safety of the movement of trains;

b. When necessary to avoid striking any object or person on the track;

c. When the train is disabled, by accident or otherwise;

d. When the train is in motion except when engaged in switching operations or loading or unloading operations;

e. When vehicular traffic is not waiting to use the crossing;

f. When necessary to comply with a government statute or regulation; or

g. When allowed by written agreement between the governmental entity that controls the roadway and the interested commercial entities. The agreement must indicate which party is responsible for the timely notification of local emergency service providers regarding the crossing that will be blocked and the period of time the crossing will be blocked.

2. A person that violates this section is guilty of a class B misdemeanor. This section does not apply to a city that has an ordinance covering the same subject matter.

N.D. Cent. Code, § 49-11-19 (2012)

49-11-19.1. Blocking or obstructing alternative crossings -- Penalty.

Any person operating a train who shall block or obstruct a public railroad crossing and who has the alternative of blocking or obstructing a crossing with active grade crossing traffic control devices or a crossing without such device shall, where feasible, and subject to the exception set forth in section 49-11-19, leave open the crossing with active grade crossing control devices. Any person who violates this section is guilty of an infraction.

N.D. Cent. Code, § 49-11-19.1 (2012)

Ohio

§ 5589.21. Obstruction of roads by railroads

(A) No railroad company shall obstruct, or permit or cause to be obstructed a public street, road, or highway, by permitting a railroad car, locomotive, or other obstruction to remain upon or across it for longer than five minutes, to the hindrance or inconvenience of travelers or a person passing along or upon such street, road, or highway.

(B) At the end of each five minute period of obstruction of a public street, road, or highway, each railroad company shall cause such railroad car, locomotive, or other obstruction to be removed for sufficient time, not less than three minutes, to allow the passage of persons and vehicles waiting to cross.

(C) This section does not apply to obstruction of a public street, road, or highway by a continuously moving through train or caused by circumstances wholly beyond the control of the railroad company, but does apply to other obstructions, including without limitation those caused by stopped trains and trains engaged in switching, loading, or unloading operations.
(D) If a railroad car, locomotive, or other obstruction is obstructing a public street, road, or highway in violation of division (A) of this section and the violation occurs in the unincorporated area of one or more counties, or in one or more municipal corporations, the officers and employees of each affected county or municipal corporation may charge the railroad company with only one violation of the law arising from the same facts and circumstances and the same act.
(E) Upon the filing of an affidavit or complaint for violation of division (A) of this section, summons shall be issued to the railroad company pursuant to division (B) of section 2935.10 of the Revised Code, which summons shall be served on the regular ticket or freight agent of the company in the county where the offense occurred.
Ohio Rev. Code Ann. § 5589.21 (2013)

§ 5589.24. Fines paid to railroad grade crossing improvement fund

(A) All fines collected for a violation of division (A) of section 5589.21 or 5589.211 [5589.21.1] of the Revised Code shall be paid as follows:
(1) To the railroad grade crossing improvement fund of the county if the violation occurred in an unincorporated area of the county;
(2) To the railroad grade crossing improvement fund of the municipal corporation in which the violation occurred if the violation occurred in a municipal corporation.
(B) The board of county commissioners of each county and the legislative authority of each municipal corporation shall establish a railroad grade crossing improvement fund. The fund shall consist of fines paid to the county or municipal corporation under division (A) of this section and any other moneys allocated to the fund by the county or municipal corporation. Except as otherwise provided in this division, a county or municipal corporation shall use its railroad grade crossing improvement fund to pay any part of the cost assigned by the public utilities commission to the county or municipal corporation under section 4907.471 [4907.47.1] of the Revised Code. The county or municipal corporation also may use its railroad grade crossing improvement fund for other improvements to railroad grade crossings, including signs, signals, gates, or other protective devices, as the board of county commissioners or legislative authority of a municipal corporation determines to be appropriate.
If, during any fiscal year, the fines a county collects for violations of division (A) of section 5589.21 and section 5589.211 [5589.21.1] of the Revised Code equal three thousand dollars or less, during the subsequent fiscal year the county may use that amount of money in its railroad grade crossing improvement fund for any purpose that the board of county commissioners determines to be appropriate. If, during any fiscal year, the fines a county collects for violations of division (A) of section 5589.21 and section 5589.211 [5589.21.1] of the Revised Code exceed three thousand dollars, during the subsequent two fiscal years the county shall use all the money in its railroad grade crossing improvement fund only for those purposes described in this division. In such a case, the amount of money the county collects for violations of division (A) of section 5589.21 and section 5589.211 [5589.21.1] of the Revised

Code during the fiscal year immediately following the second of those two fiscal years shall determine the disposition under this division of the money the county collects during that fiscal year.
Ohio Rev. Code Ann. § 5589.24 (2013)

§ 5589.211. Obstructing street, road or highway by abandoning locomotive

No railroad company shall obstruct, or permit or cause to be obstructed, a public street, road, or highway, by permitting any part of a train whose crew has abandoned the locomotive to remain across it for longer than five minutes to the hindrance or inconvenience of travelers or a person passing along or upon the street, road, or highway, unless the safety of the train crew requires them to abandon the locomotive.

Upon the filing of an affidavit or complaint for violation of this section, summons shall be issued to the railroad company pursuant to division (B) of section 2935.10 of the Revised Code, which summons shall be served on the regular ticket or freight agent of the company in the county where the offense occurred.

Ohio Rev. Code Ann. § 5589.211 (2013)

Oklahoma

No applicable statute related to this topic

Oregon

***811.475 Obstructing rail crossing; penalty.**

(1) A person commits the offense of obstructing a rail crossing if the person is operating a vehicle and the person does either of the following: (a) Drives onto any railroad or rail fixed guideway system grade crossing when there is not sufficient space on the other side of the railroad or rail fixed guideway system grade crossing to accommodate the vehicle the person is operating without obstructing the passage of other vehicles, pedestrians, railroad trains or rail fixed guideway system vehicles; or (b) While driving a commercial motor vehicle, fails to negotiate the rail crossing because of insufficient undercarriage clearance. (2) The offense described in this section is applicable whether or not a traffic control device indicates to proceed. (3) The offense described in this section, obstructing rail crossings, is a Class B traffic violation.

Or. Rev. Stat. § 811.475 (2011)

824.222 Authority over duration that grade crossing may be blocked; penalty.

(1) The power to fix and regulate the length of time a public railroad-highway grade crossing may be blocked by railroad equipment is vested exclusively in the state.

(2)(a) Upon petition of the public authority in interest, or of any railroad or upon the Department of Transportation's own motion, the department shall, after due investigation and hearing, unless hearing is not required under ORS 824.214, enter an order fixing and regulating the length of time a public railroad-highway grade crossing may be blocked by railroad equipment.

(b) Upon petition of a person, the department shall investigate and may hold a hearing and, following a hearing, may enter an order fixing and regulating the length of time a public railroad-highway grade crossing may be blocked by railroad equipment.

(3) The time limits fixed by the department shall be maximum time limits and shall be commensurate with reasonable requirements of train and vehicular traffic operations.
(4) Violation of a time limit fixed by the department under this section is punishable by a civil penalty of not less than $ 100 nor more than $ 3,000 for each offense.
Or. Rev. Stat. § 824.222 (2011)
***824.223 Authority to regulate distance from grade crossing at which railroad may stop or park equipment; penalty.**
(1) The power to regulate the distance from a public railroad-highway grade crossing at which a railroad may stop or park equipment is vested exclusively in the state.
(2)(a) Upon petition of the public authority in interest, or of any railroad or upon the Department of Transportation's own motion, the department shall, after due investigation and hearing, unless hearing is not required under ORS 824.214, enter an order establishing a safe distance from a public railroad-highway grade crossing at which a railroad may stop or park equipment.
(b) Upon petition of a person, the department shall investigate and may hold a hearing and, following a hearing, may enter an order establishing a safe distance from a public railroad-highway grade crossing at which a railroad may stop or park equipment.
(3) In determining what constitutes a safe distance under subsection (2) of this section, the department shall consider issues including, but not limited to, hazards associated with public railroad-highway grade crossings that do not have active protective devices.
(4) Violation of an order issued under subsection (2) of this section is punishable by a civil penalty of not less than $ 100 nor more than $ 3,000 for each offense.
Or. Rev. Stat. § 824.223 (2011)

Pennsylvania
***§ 3713. Railroad trains not to block crossings.**
No person or government agency shall operate any train in such a manner as to prevent vehicular use of any roadway for a period of time in excess of five consecutive minutes except under any of the following circumstances:
(1) When necessary to comply with signals affecting the safety of the movement of trains.
(2) When necessary to avoid striking any object or person on the track.
(3) When the train is disabled.
(4) When the train is in motion except while engaged in switching operations.
(5) When there is no vehicular traffic waiting to use the crossings.
(6) When necessary to comply with a governmental safety regulation.
75 Pa. Cons. Stat. § 3713 (2012)
§ 6907. Obstructing public crossings.
It shall be a summary offense for any railroad to obstruct or block up the passage of any crossings of a highway, or obstruct such crossings, with its rolling stock. If any engineer, or any member of the train crew, or other agent of any such railroad, shall obstruct or block up such crossings, he shall be guilty of a summary offense.
18 Pa. Cons. Stat. § 6907 (2012)
§ 6908. Obstructing private crossings.

It shall be a summary offense for any railroad to continue to obstruct or block up the passage of any private crossing, wherever any private road or crossing-place may be necessary to enable the occupant or occupants of land or farms to pass over the railroad with livestock, wagons and implements of husbandry, after the railroad shall have received at least 15 minutes verbal notice to remove its rolling stock, or other obstructions from any such private road or crossing-place.
18 Pa. Cons. Stat. § 6908 (2012)

Rhode Island
§ 39-8-4. Obstruction of highway crossings
No railroad corporation, nor its servants or agents, shall willfully or negligently obstruct or unnecessarily use or occupy a highway, city or town way, or street, nor in any case at a street or highway grade crossing, with cars or engines for more than five (5) minutes at one time; and whenever a highway, city or town way or street has been thus used or occupied with cars or engines, no railroad corporation shall again use or occupy the same with cars or engines until a sufficient time, not less than three (3) minutes, has been allowed for the passage across the railroad of such travelers as were ready and waiting to cross when the former occupation ceased. For every violation of the provisions of this section, the corporation shall be fined not less than twenty-five dollars ($ 25.00) nor more than one hundred dollars ($ 100)
R.I. Gen. Laws § 39-8-4 (2012)

South Carolina
§ 57-7-240. Obstruction of roads by railroad cars and other obstacles.
If any person shall obstruct unnecessarily any street, public road or highway by permitting any railroad car or locomotive to be or remain upon or across any street, public road or highway for a longer period than five minutes, after notice to remove such car or locomotive has been given to the conductor, engineer, agent or other person in charge of such car or locomotive or shall permit any timber, wood or other obstruction to remain upon or across any such street, road or highway to the hindrance or inconvenience of travelers or any person passing along or upon such street, road or highway, such person so offending shall forfeit and pay for every such offense a sum not exceeding twenty nor less than five dollars and shall be liable for all damages arising to any highway, to be recovered by an action at the suit of the county in which such offense shall have been committed or any person suing for the same, before any magistrate within the county in which such offense shall have been committed or by indictment in the court of general sessions or suit in the court of common pleas. All fines so accruing under the provisions of this section, when collected, shall be paid over by the magistrate to the county treasurer for the district in which such offense was committed. Every twenty-four hours such person, after being notified, shall suffer such obstruction to remain, to the hindrance or inconvenience of travelers or any person going along or upon such road or highway, shall be deemed an additional offense against the provisions of this section.
S.C. Code Ann. § 57-7-240 (2011)
§ 58-17-4080. Penalty and damages for obstruction of highway by railroad car, locomotive or other object.

If any person, including any conductor of any train of railroad cars or any other agent or servant of any railroad company, shall obstruct unnecessarily any public road or highway by permitting any railroad car or locomotive to be or remain upon or across any street, public road or highway for a longer period than five minutes, after notice to remove such cars has been given to the conductor, engineer, agent or other such person in charge of such train or shall permit any timber, wood or other obstruction to remain upon or across any such street, road or highway to the hindrance or inconvenience of travelers or any person passing along or upon such street, road or highway, every such person so offending shall forfeit and pay for every such offense any sum not exceeding twenty nor less than five dollars and shall be liable for all damages arising to any highway, to be recovered by an action at the suit of the governing body of the county in which such offense shall have been committed or any person suing therefor, before any magistrate within the county in which such offense shall have been committed or by indictment in the court of general sessions or suit in the court of common pleas. All fines so accruing under the provisions of this section, when collected, shall be paid over by the magistrate to the county treasurer for the district in which such offense was committed. Every twenty-four hours such person, after being notified, shall suffer such obstructions to the hindrance or inconvenience of travelers or any person going along or upon such road or highway to continue shall be deemed an additional offense against the provisions of this section.
S.C. Code Ann. § 58-17-4080 (2011)

South Dakota
§ 49-16A-94. Blocking of highway crossings--Employees not liable where blocking necessary under state or federal rules.
No railroad employee shall be held liable for any railroad engine or cars occupying or blocking any street, road or highway grade crossing where such occupying or blocking is necessitated or required in order to comply with a rule, regulation or order issued by any state or federal regulatory body.
S.D. Codified Laws § 49-16A-94 (2012)
§ 49-16A-119. Trains prohibited from blocking streets, roads or highways during emergency--Violation as misdemeanor.
A standing railroad engine or car may not occupy or block any street, road, or highway grade crossing for more than twenty consecutive minutes, if the path of any emergency vehicle making an emergency trip is blocked by the railroad engine or car, unless it is disabled, by accident or otherwise and cannot be moved without striking any object or person on track. A violation of this section by a railroad corporation is a Class 2 misdemeanor.
S.D. Codified Laws § 49-16A-119 (2012)

Tennessee
No applicable statute related to this topic

Texas
§ 471.007. Obstructing Railroad Crossings; Offense

(a) A railway company commits an offense if a train of the railway company obstructs for more than 10 minutes a street, railroad crossing, or public highway.
(b) An offense under this section is a misdemeanor punishable by a fine of not less than $ 100 or more than $ 300.
(c) An officer charging a railway company for an offense under this section shall prepare in duplicate a citation to appear in court and attach one copy of the citation to the train or deliver the copy to an employee or other agent of the railway company. The citation must show:
(1) the name of the railway company;
(2) the offense charged; and
(3) the time and place that a representative of the railway company is to appear in court.
(d) It is a defense to prosecution under this section that the train obstructs the street, railroad crossing, or public highway because of an act of God or breakdown of the train.
(e) The hearing must be before a magistrate who has jurisdiction of the offense in the municipality or county in which the offense is alleged to have been committed.
(f) An appearance by counsel complies with the written promise to appear in court.
Tex. Transp. Code Ann. § 471.007 (2012)

§ 471.008. Franchise to Obstruct Street Crossing

(a) The governing body of a municipality by ordinance may grant a franchise to a railway company to obstruct a street crossing, other than a crossing of a designated state highway, by a passenger train for the purpose of receiving or discharging passengers, mail, express, or freight for a longer period than specified by Section 472.007.
(b) Section 471.007 does not apply to a street crossing named in an ordinance granting a franchise under this section.
c) This section does not apply to a municipality having a special charter unless it amends its charter to adopt this section.
Tex. Transp. Code Ann.§ 471.008 (2012)

Utah

§ 41-6a-1204. Trains -- Interference with vehicles limited

A person or government agency may not operate a train in a manner to prevent vehicular use of a roadway for a period of time in excess of five consecutive minutes except:
(1) when necessary to comply with signals affecting the safety of the movement of trains;
(2) when necessary to avoid striking any object or person on the track;
(3) when the train is disabled;
(4) when the train is in motion or while engaged in switching operations;
(5) when there is no vehicular traffic waiting to use the crossing;
(6) when necessary to comply with a governmental safety regulation; or
(7) as determined by a highway authority.
Utah Code Ann. § 41-6a-1204 (2012)

Vermont

§ 3586. Obstructing crossings; penalty

A person, corporation, or the agents or employees thereof, owning or operating a railroad, who wilfully or negligently obstruct a public highway or farm crossing with engines, tenders, or cars, shall be fined not more than $ 20.00 nor less than $ 5.00.
Vt. Stat. Ann. tit. 5, § 3586 (2013)
§ 3587. Obstructing crossing more than five minutes; penalty; exemption
(a) When a railroad crosses a highway or road required for farm use at rail level, the company operating such railroad shall not, nor shall its officer, agent, or employees permit an engine or railroad car, or any portion thereof, to stand on any part of such highway or road for a longer period than five minutes at any one time, or in shunting, to obstruct public traffic for a longer period than five minutes at any one time. A person or corporation violating the provisions of this section shall be fined not more than $ 50.00 nor less than $ 5.00.
(b) The provisions of this section shall not apply to:
(1) any grade crossings now existing or hereinafter established over the line of railroad extending through the city of Rutland between the River Street underpass and the Pine Street overpass; and
(2) the grade crossing in the town of Norton between the St. Lawrence & Atlantic Railroad and the class 4 town highway known as Gagnon Road (town highway #12).
Vt. Stat. Ann. tit. 5, § 3587 (2013)

Virginia
§ 56-412.1. Railroad cars obstructing street or road; standing vehicle on railroad track
It shall be unlawful for any railroad company, or any receiver or trustee operating a railroad, to obstruct for a longer period than five minutes the free passage on any street or road by standing cars or trains across the same, except a passenger train while receiving or discharging passengers, but a passway shall be kept open to allow normal flow of traffic; nor shall it be lawful to stand any wagon or other vehicle on the track of any railroad which will hinder or endanger a moving train; provided that when a train has been uncoupled, so as to make a passway, the time necessarily required, not exceeding three minutes, to pump up the air after the train has been recoupled shall not be included in considering the time such cars or trains were standing across such street or road. Any such railroad company, receiver or trustee, violating any of the provisions of this section shall be fined not less than $ 100 nor more than $ 500; provided that the fine may be $ 100 for each minute beyond the permitted time but the total fine shall not exceed $ 500.
Va. Code Ann. § 56-412.1 (2012)

Washington
No applicable statute related to this topic.

West Virginia
§ 31-2A-2. Blocking of crossing prohibited; time limit.
(a) It is unlawful for any railroad company, except in an emergency, to order, allow or permit the operation of or to operate or to so operate its system so that a train blocks the passage of vehicular traffic over the railroad crossing of any public street, road or highway of this state for a period longer than ten minutes. This section does not apply to an obstruction of any such

street, road or highway caused by a continuously moving train or caused by circumstances wholly beyond the control of the railroad, but does apply to all other obstructions as aforesaid, including, but not limited to, those caused by a stopped train or a train engaged in switching, loading or unloading operations: Provided, That if any such train is within the jurisdictional limits of any municipality which now has or hereafter shall have in force and effect an ordinance limiting the time a railroad crossing may be blocked by a train, such ordinance shall govern, and the provisions of this article shall not be applicable.

(b) Upon receiving notification from a law-enforcement officer, member of a fire department, operator of an emergency medical vehicle, or a member of an emergency services provider that emergency circumstances require the immediate clearing of a public highway railroad grade crossing, the members of the train crew of the train, railroad car or equipment, or engine blocking such crossing shall immediately notify the appropriate railroad dispatcher of the pending emergency situation. Upon receipt of notice of such emergency circumstances by the train crew or dispatcher, the railroad shall immediately clear the crossing, consistent with the safe operation of the train.

W. Va. Code Ann. § 31-2A-2 (2012)

***§ 31-2A-3. Responsibility of railroad company.**

The railroad company shall be solely responsible for the acts of its agents and employees in violating any provision of this article or any provision of any ordinance of any municipality or any provision of any order of a county or other public authority regulating the period of time any such street, road or highway may be so blocked by a train.

W. Va. Code Ann.§ 31-2A-3 (2012)

***§ 31-2A-6. Fines and penalties.**

(a) Any railroad company, carrier or railroad violating the provisions of subsection (a), section two [§ 31-2A-2] of this article is guilty of misdemeanor and, upon conviction thereof, shall be fined not less than one hundred fifty dollars; upon a second conviction occurring at the same crossing within one year thereafter, shall be fined not less than two hundred fifty dollars; and upon a third or subsequent conviction occurring at the same crossing within one year after the first conviction, shall be fined not less than three hundred fifty dollars.

(b) Any railroad company, carrier or railroad violating the provisions of subsection (b), section two [§ 31-2A-2] of this article is guilty of a misdemeanor and, upon conviction thereof, shall be fined not less than one thousand dollars; upon a second conviction occurring at the same crossing within one year thereafter, shall be fined not less than two thousand five hundred dollars; and upon a third or subsequent conviction occurring at the same crossing within one year after the first conviction, shall be fined not less than five thousand dollars.

W. Va. Code Ann. § 31-2A-6 (2012)

Wisconsin

192.292. Trains obstructing highways.

It shall be unlawful to stop any railroad train, locomotive or car upon or across any highway or street crossing, outside of cities, or leave the same standing upon such crossing longer than 10 minutes, except in cases of accident; and any railroad company that shall violate this section shall be liable to a fine of not more than 500 or any officer of such company responsible for the violation shall be liable to imprisonment of not more than 15 days.

Wis. Stat. § 192.292 (2012)

Wyoming
No applicable statute related to this topic

Appendix B System Programming Codes

```
from vms_oop import vms
import thread
import time
import RPi.GPIO as GPIO
import sys
from pad4pi import rpi_gpio

#exit flag to stop countdown
global exit_flag
global running_flag
running_flag=False
exit_flag=False
#IP of VMS
IP='192.168.11.121'
global countdownstep
countdownstep=10

#define messages to be displayed
# Standby=
"[fo1][jp1][jl3][pt40o5]DRIVE[nl]SAFELY[nl][np]NO[nl]ONCOMING[nl]TRAIN[np]"
# Arriving1 =
"[fo1][jp1][jl3][pt40o5]TRAIN[nl]CROSSING[nl]AHEAD[np]EXPECTED[nl]DELAY[nl]"
# Arriving2 = " MINUTES[np]TAKE[nl]WARLICK[nl]BLVD"
# Arriving3 = " MINUTE[np]TAKE[nl]WARLICK[nl]BLVD"
# Precaution1 = "[fo1][jp1][jl3][pt20o0]TRAIN[nl]ARRIVING IN[nl]"
# Precaution2 = " MINUTES[np]"
Standby= "[fo1][jp1][jl3][pt50o5]DRIVE[nl]SAFELY[nl][np][pt50o5]"
# Arriving1 =
"[fo1][jp1][jl3][pt50o5]TRAIN[nl]CROSSING[nl]AHEAD[np][pt150o5]EXPECTED
DELAY[nl]"
# Arriving2 = " MINUTES[np]"
# Arriving3 = " MINUTE[np]"
Precaution1 = "[fo1][jp1][jl3][pt20o0]TRAIN[nl]ARRIVING IN[nl]"
Precaution2 = " MINUTES[np]"

Arriving1 =
"[fo1][jp1][jl3][pt50o5]TRAIN[nl]CROSSING[nl]AHEAD[np][pt150o5]EXPECTED
DELAY[nl]{0} MINUTES[nl]& {1} SECONDS"
Arriving2 =
"[fo1][jp1][jl3][pt50o5]TRAIN[nl]CROSSING[nl]AHEAD[np][pt150o5]EXPECTED
DELAY[nl]{0} MINUTE[nl]& {1} SECONDS"
#Arriving3 = " MINUTE[np]"
```

```
#define buttons
# GPIO.setmode(GPIO.BOARD)
# min5=11
# min4=13
# min3=15
# min2=31
# min1=33
# stby=35
# minconv={min5:5,min4:4,min3:3,min2:2,min1:1,stby:0}
def callback(channel):
    global exit_flag
    global running_flag
    print "hello"
    print channel
    if(running_flag):
        print "waiting"
        exit_flag=True
        while exit_flag:
            pass
    # timedmessage(minconv[channel])
    thread.start_new_thread(timedmessage,(channel,))

#displays predefined Train crossing message with a countdown based on "minutes"
def timedmessage(minutes):
    global exit_flag
    global running_flag
    global countdownstep
    running_flag=True
    x=minutes
    z=0
    while(x>=0):
        if(z>0):
            print str(x)+" minutes remaining\n"
            if(x==1):
                # msg=Arriving1+str(x)+Arriving3
                msg=Arriving2.format(x,z)
            else:
                # msg=Arriving1+str(x)+Arriving2
                msg=Arriving1.format(x,z)
            if(x!=0):
                print run.setmsg(msg,'.3.253')
                run.activatemessage('.3.253',253,3)
        else:
```

```
            x=x-1
            z=60
        time.sleep(countdownstep)
        z=z-countdownstep
        if(exit_flag):
            exit_flag=False
            running_flag=False
            return 0
    run.activatemessage('.3.255',255,3)
    exit_flag=False
    running_flag=False
#sets the exit flag on user input
def setexit():
    global exit_flag
    while True:
        var=raw_input("enter y to exit\n")
        # var=raw[0]
        # print var
        if(var=="y"):
            # print "hi"
            exit_flag=True

            return 0
def setup():
    # GPIO.setup(min5,GPIO.IN,pull_up_down=GPIO.PUD_UP)
    # GPIO.setup(min4,GPIO.IN,pull_up_down=GPIO.PUD_UP)
    # GPIO.setup(min3,GPIO.IN,pull_up_down=GPIO.PUD_UP)
    # GPIO.setup(min2,GPIO.IN,pull_up_down=GPIO.PUD_UP)
    # GPIO.setup(min1,GPIO.IN,pull_up_down=GPIO.PUD_UP)
    # GPIO.setup(stby,GPIO.IN,pull_up_down=GPIO.PUD_UP)
    # # time.sleep(5)
    # GPIO.add_event_detect(min5,GPIO.RISING,callback=callback,bouncetime=200)
    # GPIO.add_event_detect(min4,GPIO.RISING,callback=callback,bouncetime=200)
    # GPIO.add_event_detect(min3,GPIO.RISING,callback=callback,bouncetime=200)
    # GPIO.add_event_detect(min2,GPIO.RISING,callback=callback,bouncetime=200)
    # GPIO.add_event_detect(min1,GPIO.RISING,callback=callback,bouncetime=200)
    # GPIO.add_event_detect(stby,GPIO.RISING,callback=callback,bouncetime=200)
    KEYPAD = [
            [1,4,7,10],
            [2,5,8,0],
            [3,6,9,11],
            [12,13,14,15]
    ]
```

```
    ROW_PINS = [4,14,15,17] # BCM numbering
    COL_PINS = [18,27,22,23] # BCM numbering

    factory = rpi_gpio.KeypadFactory()

    # Try factory.create_4_by_3_keypad
    # and factory.create_4_by_4_keypad for reasonable defaults
    keypad = factory.create_keypad(keypad=KEYPAD, row_pins=ROW_PINS,
col_pins=COL_PINS)
    keypad.registerKeyPressHandler(callback)


if __name__ == '__main__':
    while True:
        try:
            print "Attempting to connect...."
            run=vms(IP)
            break
        except Exception,e :
            print "hello"
            exc_type, exc_obj, exc_tb = sys.exc_info()
            print str(e)
            print(exc_type, exc_tb.tb_lineno)


    setup()
    print run.setmsg(Standby,'.3.255')
    # run.activatemessage('.3.253',253,3)
    # thread.start_new_thread(timedmessage,(5,))
    # thread.start_new_thread(setexit,())

    try:
        while True:
            pass
    except Exception,e :
        exc_type, exc_obj, exc_tb = sys.exc_info()
        print str(e)
        print(exc_type, exc_tb.tb_lineno)
        # GPIO.cleanup()
        keypad.cleanup()
        # raise
```

```
from mibs import MIB_code
```

```
from mibs import MIB_type
from easysnmp import Session
import time
import os
import sys
notUsed = 1
modifying = 2
validating = 3
valid = 4
error = 5
modifyReq = 6
validateReq = 7
notUsedReq = 8
priority=01
owner=''
class vms:
    session=None
    def __init__(self,IP):
        self.session = Session(hostname=IP, community='administrator', version=1)
    def setobj(self,param,value,snmptype):
        self.session.set(param,value,snmp_type=snmptype)
    def padder(self,val,num):
        while(len(val)<num):
            val='0'+val
        return val
    def getobj(self,param):
        return self.session.get(param)
    def setmsg(self,message,xy):
        #set message status to modify Request(6)
        while True:
            try:

self.setobj(MIB_code['dmsMessageStatus']+xy,modifyReq,MIB_type['dmsMessageStatus']+x
y)
                break
            except Exception,e :
                print "hello"
                exc_type, exc_obj, exc_tb = sys.exc_info()
                print str(e)
                print(exc_type, exc_tb.tb_lineno)
        x=str(self.getobj(MIB_code['dmsMessageStatus']+xy))
        x=x[21:22]
        # print "set"
        while(int(x)==modifyReq):
```

```
          time.sleep(1)
          x=str(self.getobj(MIB_code['dmsMessageStatus']+xy))
          x=x[21:22]
       #check if message status is changed to Modifying(2)
       if(int(x)!=modifying):
          return x
       #Set message string
       # /print "Start"

self.setobj(MIB_code['dmsMessageMultiString']+xy,message,MIB_type['dmsMessageMultiSt
ring']+xy)
       #set owner

self.setobj(MIB_code['dmsMessageOwner']+xy,owner,MIB_type['dmsMessageOwner']+xy)
       #set priority

self.setobj(MIB_code['dmsMessageRunTimePriority']+xy,priority,MIB_type['dmsMessageRu
nTimePriority']+xy)

       # set beacon
       self.setobj(MIB_code['dmsMessageBeacon']+xy,0,MIB_type['dmsMessageBeacon']+xy)
       # set pixel service

self.setobj(MIB_code['dmsMessagePixelService']+xy,0,MIB_type['dmsMessagePixelService']
+xy)

       # set message status to validate Request(7)

self.setobj(MIB_code['dmsMessageStatus']+xy,validateReq,MIB_type['dmsMessageStatus']+x
y)
       x=str(self.getobj(MIB_code['dmsMessageStatus']+xy))
       x=x[21:22]
       while(int(x)==validateReq):
          time.sleep(1)
          x=str(self.getobj(MIB_code['dmsMessageStatus']+xy))
          x=x[21:22]
       if(int(x)==valid):
          return "success"
       else:
          return x
       # check if message status is set to valid (4)
    def activatemessage(self,xy,number,type):
       val=str(self.getobj(MIB_code['dmsMessageCRC']+xy))
       start_index=val.find("value=")
```

```
        end_index=val.find(" ",start_index)

        # print end_index
        crc=int(val[start_index+7:end_index-1])
        # print crc

msg_string="0xFFFFFF0"+str(type)+self.padder(str(hex(number))[2:],4).upper()+self.padder(
str(hex(crc))[2:],4).upper()+'00000000'
        # print msg_string
        # setobj(MIB_code['ActivateMessage'],msg_string,MIB_type['ActivateMessage'])
        os.system("snmpset -v 1 -c administrator vms 1.3.6.1.4.1.1206.4.2.3.6.3.0 x " +
msg_string)
```

```
MIB_code={'brightness':'1.3.6.1.4.1.1206.4.2.3.7.6.0',
'ActivateMessage':'1.3.6.1.4.1.1206.4.2.3.6.3.0',
'dmsSupportedMultiTags':'1.3.6.1.4.1.1206.4.2.3.4.14.0',

'dmsMessageNumber':'1.3.6.1.4.1.1206.4.2.3.5.8.1.2',
'dmsMessageMultiString':'1.3.6.1.4.1.1206.4.2.3.5.8.1.3',
'dmsMessageOwner':'1.3.6.1.4.1.1206.4.2.3.5.8.1.4',
'dmsMessageCRC':'1.3.6.1.4.1.1206.4.2.3.5.8.1.5',
'dmsMessageBeacon':'1.3.6.1.4.1.1206.4.2.3.5.8.1.6',
'dmsMessagePixelService':'1.3.6.1.4.1.1206.4.2.3.5.8.1.7',
'dmsMessageRunTimePriority':'1.3.6.1.4.1.1206.4.2.3.5.8.1.8',
'dmsMessageStatus':'1.3.6.1.4.1.1206.4.2.3.5.8.1.9',
'dmsValidateMessageError':'1.3.6.1.4.1.1206.4.2.3.5.9',

'dmsMaxNumberPages':'1.3.6.1.4.1.1206.4.2.3.4.15.0'}

MIB_type={'brightness':'INTEGER',
'ActivateMessage':'OCTET STRING',
'dmsSupportedMultiTags':'OCTET STRING',
'dmsMessageNumber':'INTEGER',
'dmsMessageMultiString':'OCTET STRING',
'dmsMessageOwner':'OCTET STRING',
'dmsMessageCRC':'INTEGER',
'dmsMessageBeacon':'INTEGER',
'dmsMessagePixelService':'INTEGER',
'dmsMessageRunTimePriority':'INTEGER',
'dmsMessageStatus':'INTEGER',
'dmsValidateMessageError':'INTEGER',
'dmsMaxNumberPages':'INTEGER'}
```

Appendix C Train Activity Data Collection

ID	Date	Day	Train Direction	Gate closure	Gate open	Occupancy Time	# of vehicles in the first platoon	
							Westbound	Eastbound
1	1/31/2017	Tuesday	Southbound	6:03:08	6:06:22	0:03:14	2	1
2	1/31/2017	Tuesday	Southbound	6:47:31	6:50:49	0:03:18	9	8
3	1/31/2017	Tuesday	Southbound	12:38:39	12:45:13	0:06:34	28	30
4	1/31/2017	Tuesday	Southbound	13:07:22	13:12:40	0:05:18	28	22
5	1/31/2017	Tuesday	Southbound	14:10:14	14:13:09	0:02:55	20	30
6	1/31/2017	Tuesday	Southbound	15:27:35	15:30:30	0:02:55	26	23
7	1/31/2017	Tuesday	Southbound	16:08:00	16:12:43	0:04:43	25	51
8	1/31/2017	Tuesday	Southbound	17:52:50	17:56:42	0:03:52	34	49
9	1/31/2017	Tuesday	Southbound	18:15:00	18:19:42	0:04:42	34	27
10	1/31/2017	Tuesday	Southbound	18:40:19	18:44:23	0:04:04	29	43
11	2/1/2017	Wednesday	Northbound	7:02:15	7:04:16	0:02:01	4	2
12	2/1/2017	Wednesday	Southbound	11:33:08	11:38:00	0:04:52	11	29
13	2/1/2017	Wednesday	Southbound	11:58:00	12:02:48	0:04:48	12	20
14	2/1/2017	Wednesday	Northbound	13:35:28	13:38:10	0:02:42	13	16
15	2/1/2017	Wednesday	Southbound	15:01:27	15:05:00	0:03:33	19	12
16	2/1/2017	Wednesday	Southbound	15:43:50	15:47:11	0:03:21	14	29
17	2/1/2017	Wednesday	Southbound	16:11:02	16:15:44	0:04:42	37	36
18	2/1/2017	Wednesday	Northbound	16:57:57	17:03:23	0:05:26	60	74
19	2/1/2017	Wednesday	Southbound	17:30:37	17:33:28	0:02:51	54	33
20	2/1/2017	Wednesday	Southbound	17:51:03	17:54:55	0:03:52	33	27
21	2/2/2017	Thursday	Southbound	7:11:02	7:15:18	0:04:16	13	7
22	2/2/2017	Thursday	Southbound	9:26:32	9:31:15	0:04:43	17	25
23	2/2/2017	Thursday	Northbound	10:20:41	10:22:51	0:02:10	4	7
24	2/2/2017	Thursday	Southbound	11:00:14	11:04:27	0:04:13	5	21
25	2/2/2017	Thursday	Southbound	11:56:42	11:59:59	0:03:17	13	5
26	2/2/2017	Thursday	Southbound	14:28:04	14:32:01	0:03:57	29	13
27	2/2/2017	Thursday	Southbound	14:36:56	14:41:10	0:04:14	15	25
28	2/2/2017	Thursday	Southbound	14:44:20	14:47:01	0:02:41	10	10
29	2/2/2017	Thursday	Southbound	14:59:32	15:03:30	0:03:58	19	14
30	2/2/2017	Thursday	Southbound	15:32:37	15:35:32	0:02:55	21	24
31	2/2/2017	Thursday	Southbound	16:02:21	16:05:36	0:03:15	19	26
32	2/2/2017	Thursday	Southbound	16:07:01	16:11:26	0:04:25	34	24
33	2/2/2017	Thursday	Southbound	18:14:42	18:19:10	0:04:28	31	69
34	2/2/2017	Thursday	Southbound	19:20:19	19:23:06	0:02:47	12	35
35	2/2/2017	Thursday	Southbound	19:43:57	19:48:20	0:04:23	23	25

36	2/3/2017	Friday	Southbound	7:46:00	7:49:41	0:03:41	23	17
37	2/3/2017	Friday	Southbound	8:17:49	8:21:10	0:03:21	25	19
38	2/3/2017	Friday	Southbound	8:44:30	8:48:18	0:03:48	31	55
39	2/3/2017	Friday	Southbound	9:25:18	9:28:45	0:03:27	10	31
40	2/3/2017	Friday	Southbound	10:53:19	10:57:31	0:04:12	13	21
41	2/3/2017	Friday	Southbound	11:35:43	11:39:12	0:03:29	8	12
42	2/3/2017	Friday	Southbound	11:53:16	11:57:15	0:03:59	17	25
43	2/3/2017	Friday	Southbound	13:11:00	13:14:47	0:03:47	21	24
44	2/3/2017	Friday	Southbound	13:34:42	13:38:41	0:03:59	28	23
45	2/3/2017	Friday	Southbound	14:19:54	14:22:35	0:02:41	19	9
46	2/3/2017	Friday	Southbound	16:40:34	16:42:03	0:01:29	12	15
47	2/3/2017	Friday	Southbound	16:55:32	16:59:50	0:04:18	51	54
48	2/3/2017	Friday	Southbound	17:23:21	17:27:43	0:04:22	70	82
49	2/3/2017	Friday	Southbound	19:46:15	19:50:21	0:04:06	20	17
50	2/4/2017	Saturday	Southbound	6:12:21	6:16:26	0:04:05	3	0
51	2/4/2017	Saturday	Southbound	6:37:16	6:40:30	0:03:14	4	1
52	2/4/2017	Saturday	Southbound	7:43:01	7:45:24	0:02:23	5	0
53	2/4/2017	Saturday	Northbound	7:55:21	7:56:52	0:01:31	2	4
54	2/4/2017	Saturday	Southbound	8:41:42	8:45:14	0:03:32	10	7
55	2/4/2017	Saturday	Southbound	10:01:07	10:04:23	0:03:16	15	14
56	2/4/2017	Saturday	Southbound	11:31:38	11:36:03	0:04:25	26	41
57	2/4/2017	Saturday	Southbound	12:56:21	12:59:18	0:02:57	27	34
58	2/4/2017	Saturday	Southbound	14:16:29	14:21:09	0:04:40	42	21
59	2/4/2017	Saturday	Southbound	14:48:25	14:51:52	0:03:27	15	39
60	2/4/2017	Saturday	Southbound	16:22:32	16:25:56	0:03:24	20	24
61	2/4/2017	Saturday	Southbound	16:52:55	16:55:56	0:03:01	17	26
62	2/4/2017	Saturday	Southbound	17:06:02	17:09:30	0:03:28	38	29
63	2/4/2017	Saturday	Southbound	17:55:32	17:59:22	0:03:50	17	29
64	2/4/2017	Saturday	Southbound	18:20:08	18:23:56	0:03:48	21	38
65	2/19/2017	Sunday	Southbound	8:06:31	8:09:35	0:03:04	0	4
66	2/19/2017	Sunday	Southbound	9:20:00	9:21:15	0:01:15	2	6
67	2/19/2017	Sunday	Southbound	9:28:54	9:32:16	0:03:22	10	20
68	2/19/2017	Sunday	Southbound	10:14:27	10:18:16	0:03:49	11	11
69	2/19/2017	Sunday	Southbound	10:50:13	10:53:41	0:03:28	15	19
70	2/19/2017	Sunday	Southbound	13:39:55	13:43:56	0:04:01	43	20
71	2/19/2017	Sunday	Southbound	14:14:59	14:19:13	0:04:14	39	18
72	2/19/2017	Sunday	Southbound	15:10:35	15:13:24	0:02:49	42	36
73	2/19/2017	Sunday	Southbound	17:14:07	17:18:59	0:04:52	19	44
74	2/19/2017	Sunday	Southbound	17:39:24	17:44:56	0:05:32	33	31
75	2/19/2017	Sunday	Northbound	18:10:45	18:13:43	0:02:58	11	7

76	2/19/2017	Sunday	Southbound	18:17:16	18:22:16	0:05:00	16	27
77	2/19/2017	Sunday	Southbound	18:33:20	18:37:32	0:04:12	27	16
78	2/19/2017	Sunday	Southbound	19:07:10	19:10:56	0:03:46	14	23
79	2/20/2017	Monday	Southbound	6:45:04	6:51:56	0:06:52	22	20
80	2/20/2017	Monday	Northbound	7:13:51	7:19:30	0:05:39	16	14
81	2/20/2017	Monday	Northbound	7:26:22	7:29:20	0:02:58	19	26
82	2/20/2017	Monday	Southbound	8:01:58	8:05:05	0:03:07	16	35
83	2/20/2017	Monday	Southbound	9:19:59	9:22:46	0:02:47	13	18
84	2/20/2017	Monday	Southbound	10:13:08	10:17:26	0:04:18	15	27
85	2/20/2017	Monday	Southbound	12:30:58	12:34:14	0:03:16	18	18
86	2/20/2017	Monday	Southbound	13:27:37	13:30:41	0:03:04	14	29
87	2/20/2017	Monday	Southbound	13:35:47	13:39:31	0:03:44	11	18
88	2/20/2017	Monday	Southbound	14:11:41	14:16:04	0:04:23	24	24
89	2/20/2017	Monday	Southbound	15:13:03	15:17:22	0:04:19	31	41
90	2/20/2017	Monday	Southbound	16:07:38	16:10:26	0:02:48	35	25
91	2/20/2017	Monday	Northbound	17:30:01	17:31:12	0:01:11	20	11
92	2/20/2017	Monday	Both	17:43:54	17:49:39	0:05:45	37	43
93	2/20/2017	Monday	Southbound	18:25:55	18:28:49	0:02:54	13	25