UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Safety Modeling of Highway Railway Grade Crossings using Intelligent Transportation System (ITS) Data

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Abstract

This research investigates driver behaviors when confronting an on-coming train at HRGCs in a large range area. Unlike the traditional decision-making model, which assumes drivers make a simple one-time decision, this study divided the decision-making process into three distinct zones: the awareness zone, the assessment zone, and the action zone. Each zone is detailed in the report. Corresponding recommendations for improving the safety based on the study of traffic violations are provided at the end of the report. While the study is location specific, this study provides a method that can be easily expanded to a wide range of traffic locations and situations.

Chapter 1 Introduction

1.1 Background

In 2004, the Federal Railroad Administration (FRA) established an ultimate goal of "zero tolerance" for rail-related accidents, injuries, and fatalities (1). In pursuit of that goal, significant progress has been made over the past decades in reducing the number of HRGC incidents. As the US DOT reported, the fatal crashes at HRGCs have declined from 359 in 2005 to 231 in 2013 due, in part, to deployment of a wide range of active countermeasures (3). However, the crash rate at HRGC areas is still relatively high at 9.1 per 1 million train events (4). According to police-reported accident data from the Nebraska Department of Roads (5), there were a total of 1,118 traffic accidents reported at HRGCs in Nebraska from 2008 to 2013, and the HRGC accidents tend to be more severe (with greater rates of fatal and disabling injury accidents) compared to accidents reported at non-HRGC locations. In the near future, HRGCs are still among the top locations for fatal crashes and continue to be of major concern despite an ever-increasing focus on improved design and engineering practices (6 and 7).

Because of the dual mode nature of highway and railway, the HRGC has a number of unique traffic characteristics and operations. For example, HRGCs differ from other at-grade intersections in that the railroad traffic always has priority over roadway traffic, thus the roadway traffic has to wait 4 to 10 minutes or even longer as the train blocks the intersection.

Traffic control at HRGCs can be categorized as belonging to one of two types: passive and active. A passive HRGC provides static information that does not inform roadway users of the approach or presence of trains in real-time. Examples are crossbucks, stop signs and yield signs. **Figure 1.1** shows a passive HRGC where the yield sign is applied. An active HRGC is equipped with traffic warning and controlling systems such as flashing light signals or/and automatic gates that are automatically activated by an oncoming train. **Figure 1.2** shows a typical active HRGC, where the automatic gates and flashing beacons are equipped in front of the stop line.

Figure 1.1 A passive HRGC equipped with a yield sign and a crossbuck

Figure 1.2 An active HRGC equipped with red flashing beacons and automatic gate arms

Compared to the passive HRGCs with yield signs or stop signs, which require a driver's discrimination of an event of an on-coming train, flashing warning lights combined with automatic gates, which are the focus of this study, are considered among the most effective and safest HRGC countermeasures (8). **Figure 1.3** shows the layout of an active HRGC. Nevertheless, it is still the automobile driver's responsibility to take appropriate actions to avoid possible hazards at HRGCs when trains are present. Crashes at HRGCs are particularly dangerous to roadway drivers because a train's mass is much greater than that of a motor vehicle. Also, because of its weight, length, and operating characteristics, a train requires a significant amount of distance if it has to stop to avoid potential crash. In the vast majority of situations, it is impossible for train drivers to stop their trains in time once they identify a potential collision at the HRGC. For example, a 150-car freight train traveling 30 miles per hour takes 3500 feet to stop, and an 8-car passenger train traveling 60 miles per hour takes 3500 feet to stop (9). Thus, it is set by traffic regulations that vehicles must yield to a coming train in any circumstance.

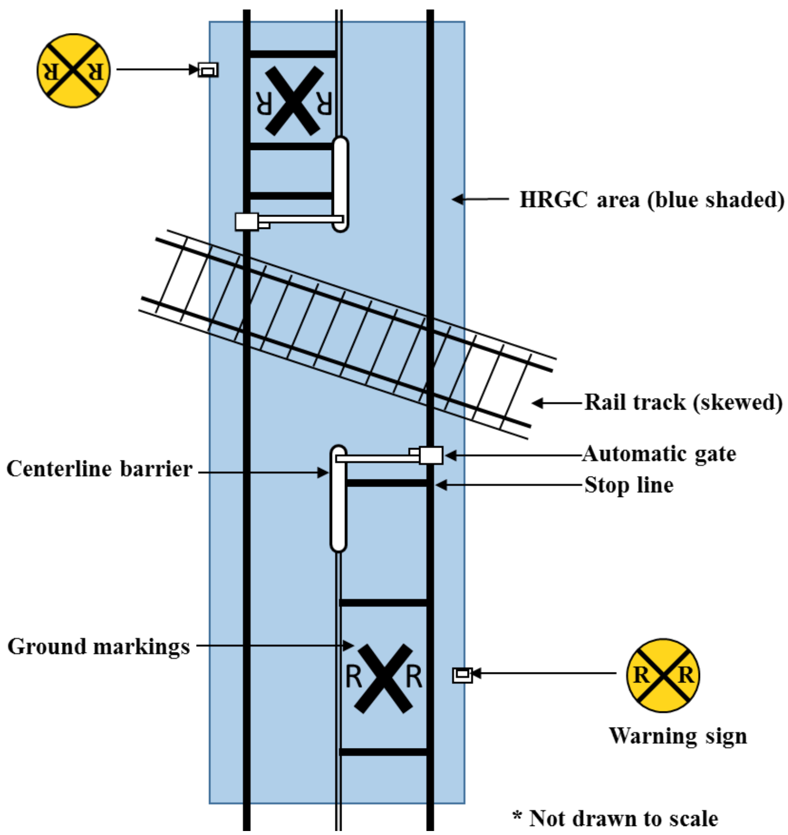


Figure 1.3 Components of an active HRGC (Source: Figure 8B-6 in MUTCD, 2003 (10))

Violating the right-of-way of an oncoming train can cause severe or fatal accidents. A study (11) indicates that the probability of a motorist being killed in a vehicle-train collision is 40 times higher than in other type of accidents. Thus, the HRGC handbook and the Uniform Vehicle Code and Model Traffic Ordinance (12 and 13) have defined “appropriate actions” to avoid driving hazardous in the event of a train. For example, the driver shall stop no less than 15 ft from the nearest rail when the warning system indicates a train is coming. It is also stated that the driver shall not drive through the crossing when “a clearly visible electric or mechanical signal device gives warning of the immediate approach of a railroad train.” In Nebraska, the law states: “never drive any vehicle through, around or under any crossing gate or barrier” at a railroad crossing while such gate or barrier is closed or is being closed (14 and 15). Typical violation behaviors at HRGCs include:

1. driving through the flashing warning signals without stopping;
2. driving under the gates as they are descending;
3. driving around the gates after they are fully descended; and
4. stopping past the stop-line before, during, or after the gate descent.

Though some of these violation types may be considered less hazardous than others, they are all considered illegal and thus inappropriate. As the main concern of this study is drivers’ reactions toward the flashing warning signals and the automatic gate, the focus is on violations such as driving under the gates as they are descending (i.e., gate violation) and violations that involve stopping over the stop-line or too close to the tracks (i.e., stop violation).

As HRGC crashes are highly infrequent events, many researchers have identified surrogate measures for quantifying safety. HRGC violation was found to be a significant surrogate safety measure (16) of HRGC crashes due to it being correlative, quantifiable, and frequent.

Some may argue that "gate-running" is excusable if no train is present or approaching. This argument ignores the fact that under many circumstances, automatic gates are installed because some characteristic of the highway-railroad grade crossing, such as sight distance obstruction or higher train speeds, may limit the motorist's ability to detect the train and judge its speed. Under those circumstances, it is not safe to rely upon the motorist's judgment (17).

There are several reasons that account for the occurrences of traffic violations. For example, drivers' inattentive or distractive driving (e.g., using a cellphone or talking to passengers while driving), drivers' incorrect estimation of the train distance and speed, or drivers' deliberate passing around the lowered gates, etc. Despite numerous studies focusing on improving the safety at HRGCs, the performance of the rail level-crossing violations and crashes due to drivers' behaviors – such as decision making, driver error, and situation awareness – remain ambiguous. This is largely because many of the factors contributing to a driver's behavior are hard to identify. Studies have identified that unintentional behaviors, such as drivers' failure to detect the level crossing signals (18) or poorly comprehending their meanings (19), or lacking an awareness of the situation (20), which result in incorrect decision-making, are key causal factors to crashes during a driver's approach to an HRGC.

Existing safety evaluation methods (e.g., accident prediction models) do not adequately and meticulously describe or unveil drives' behavioral characteristics that are most detrimental to highway-rail crossing safety, thus preventing the prioritization or targeting of safety improvements (21). While this report focuses on the driver's decision-making behaviors when they approach an HRGC with active control devices when the warning lights are activated and the gates are descending. The goal is to investigate the entire process of the how a driver makes a correct or incorrect decision when facing an activated HRGC, thus leading to countermeasures that aim to improve the driving safety at the HRGC area.

1.2 Problem Statement

In lieu of crossing elimination or grade separation, installation of train-activated flashing warning signals and automatic gates constitutes, in theory, the maximum level of safety improvement currently feasible at HRGCs. However, it is still unclear whether the current design and operation methodologies at HRGCs actually result in the maximum safety of the travelling public. Consequently, there is a need to assess drivers' behaviors as they approach HRGCs, and to automatically identify safety violating factors. It is hypothesized in this report that HRGCs may be made safer (e.g., by reducing violations) if the operational models take into account the stochastic nature of the driver's decision-making process. To test this hypothesis, four specific needs have to be addressed.

- Setup an automatic data collection platform for capturing behavioral data

Currently, the most common methods for obtaining violation behavior data (e.g., rush through the gate while it is lowering or lowered) at HRGCs are by video recording and manual observation (8, 22, and 23). The video recording approach is both labor intensive and time consuming and consequently the number of observations is often small which leads to questions of statistical validity. In addition, it is susceptible to observer bias. In most cases, it is impossible to obtain trajectory information from vehicles, which is why most of the previous studies only focus driver behavior on a certain space/time point (e.g., stop line location or start of flashing light). Thus, by establishing a comprehensive data collection system and automatic data processing platform, a more robust dataset will be developed. Critical parameters that will be obtained will include vehicular speed versus time profiles, distance (to stop-line) versus time profiles, gate movements over time, train movements, and other traffic environments such as pedestrians and bicycles, intersection geometry, etc. Gathering the comprehensive information is a necessary condition for developing the behavioral-based models of drivers' decision making as they approach active HRGCs.

- Develop a driver decision-making model over time and space

Many studies indicated that it is critical to analyze the driver decision making process in a discrete manner so that more detailed behavioral factors that shape a driver's final decision (especially risk decision) could be captured (12 and 24). However, these fixed zones are not easy, nor impossible, to show the variability of the driver behaviors such as a driver's response at the start of the warning flashing light or a driver's decision making point. When the decision making process is assumed as dynamic either in distance or in time, a discrete model in terms of how many sections and how large a portion of each section are proposed as functions of behavioral parameters (e.g., speed, acceleration, deceleration).

1.3 Research Objectives

The primary goal of this research is to investigate drivers' behaviors and the stochastic and dynamic nature of the driver decision making process as a function of parameters as they approach an activated HRGC. The ultimate goal is to improve the safety level of the HRGC. The goal can be achieved by the following specific aims:

1. establish an automatic data collection platform based on the NTC ITS testbed;
2. investigate drivers' approaching processes toward the activated HRGC over time and space;
3. compare the traditional stop/go model with the new developed decision-making model; and
4. explore the relationship between drivers' decision making and the violation behaviors at HRGCs.

1.4 Research Approach and Methods

The primary goal of this research is to assess driver behavior as a function of distance and time as they approach an HRGC. Of particular interest will be the relationship between the final decision (violation/compliance) and critical variables, including vehicle location, vehicle speed, and train speed.

1.5 Organization of the Report

This report is organized into five chapters. Chapter 1 provides the background knowledge of HRGCs, states the safety problems, and outlines the structure of the report. Chapter 2 is a comprehensive literature review. This review covers the basic information concerning the surrogate safety analysis measure:

driver behavior when approaching the HRGCs. The chapter ends with identification of gaps in existing research. Chapter 3 describes the process of data collection and reduction, which includes the data collection system, multiple data sources, and program coding logic of the data reduction. Chapter 4 presents analyses of drivers' behaviors approaching HRGCs. Three distinct zones are identified on the approach to an HRGC. Lastly, chapter 5 summarizes the project work, presents conclusions from the analysis, and provides recommendations for safety improvement at HRGCs.

Chapter 2 Literature Review

2.1 Safety Study at Highway-Rail Grade Crossing

Crashes and injuries at highway-rail grade crossings are much higher than other types of traffic accidents due to the significant mass difference between vehicles and trains (25).

To study the safety at a HRGCs, two models are usually developed: crash frequency and injury severity. Crash occurrence frequency counts the number of crashes at a given crossing for given period of time, using statistical models such as the Poisson model (26), the negative binomial model (21), or the nonparametric statistical method of hierarchical tree-based regression model (25) are developed to analyze factors influencing collision frequency.

For the injury severity study, Hu et al. (27) used a generalized logit model to investigate the key factors. Miranda-Moreno et al. (28) used a multinomial logit model to study injury severity of vehicle occupants involved in highway-railway crossing collisions. To consider the ordinal nature of the injury-severity levels, an ordered probit model (29) and ordered logit model (30) were also used.

However, endogenous factors are not found in models. Human factors include unintentional errors, encompassing situations where the drivers may fail to detect the warnings or to apprehend their meaning, even if the site is known and the warnings are clearly visible. These drivers do not detect potential threats and therefore are at great risk. The second explanation may be that drivers see the lights and are fully aware of their meaning, but intentionally cross based on their own judgment (31). For example, male drivers (4, 32) and 16-25 year-old drivers (33) are more likely to not comply with crossing signals. Besides this classification, Caird et al. (32) and Sussman et al. (34) classified the primary reasons for accidents at grade crossings as intentional, distraction-caused, or other (visibility issues or driver confusion) for both passive and active grade crossings.

Other human factors including drivers' judgments of speed and distance. It was found that road users' perceptual underestimation of a train's time-to-arrival at grade crossings become larger with the closer trains at crossings due to systematic illusions within the human vision (35).

2.2 Surrogate Safety Measure - Violations

Accident rates (i.e., accident numbers divided by traffic volume) for one thing are rare data which may lead to inconclusive results. After-event data also lack details for understanding the failure mechanism of the driver's crash behavior. Similarly, HRGC accidents are even highly infrequent events when considering a single crossing or small group of crossings. There are many studies trying to find alternative methods to measure the HRGC safety. It is well acknowledged that crash and fatality rates could be measured by using surrogate approaches such as time to accident (near-crash) or potential conflicts (36 and 37). For example, the more vehicles that potentially conflict with an upcoming train would probably result in a high possibility of crashes. There is a relationship between the number of accidents and the number of violations that occur at HRGCs (38). By studying the violation rates at a given crossing, one can estimate the degree of hazard present at a particular site (39).

Research conducted by Abraham et al. (40) identified surrogate measures to be used in determining the hazard presented by a specific crossing or small set of crossings. Driver behavior was observed at seven HRGCs equipped with flashing warning lights and automatic gates. There were 89 violations recorded from videos and manually by field observers. Results of the study showed a possible correlation between accident rates and violation rates at HRGCs, and a Pearson correlation coefficient of 0.49 was found to exist between the violation and accident. It was concluded that a reasonable association between accidents and violations do exist.

The two types of behavioral vehicles, i.e., stopping and proceeding, may result in two types of violations: gate violation and stop violation. Gate violation means a passing vehicle passed the stop-line after the gate started descending. Stop violation indicates that a stopping vehicle failed to stop in front of the stop-line while stopping on or over the stop-line.

Khattak et al. (41) identified violations with different levels of hazardous outcomes such as violating the flashing light, hitting the lowering gate, and going around the lowered gate. In the current study, an effort of collecting varied violations from the video clips was made, which included but were not limited to the following movements:

- vehicles entering the crossing after the warning flashers were activated;
- vehicles entering the crossing while the gates were descending;
- vehicles going around the gate after the gate was fully deployed;
- vehicles could not stop in front of the stop-line;
- vehicles stopping on or near the tracks because of traffic queues ahead; and
- vehicle/train collisions.

2.3 Traditional Driver Decision-making Model

As drivers approach a gated HRGC where the flashing light is activated, a process would be initiated to notify the driver of an HRGC ahead to enable making decision and taking actions to go or stop, etc. In reality, this process is more complicated and decisions and actions are not a one-time deal. Many researchers are focused on a specific space/time points such as the stop line in space and the start of a flashing light in time.

While the literature of on-road observational studies provide important findings, particularly with regard to drivers' reactions and final violations with the HRGC devices (25), they shed little light on the entire behavioral process of vehicles approaching activated HRGCs.

In dividing the approaching lane distance, Moon et al. (42) have divided the approach lane into 3 sections by fixed distance (100 ft or 50 ft marking reference). This is a good way to collect and manipulate data. Later, the railroad-highway grade crossing handbook (12) divided the approaching lane by placing three cones at three determined distances, as shown in Figure 2.1. Cone A is placed at the point where the driver first obtains information (which comes from the advance warning sign, the pavement markings, or the crossing itself) that there is a crossing ahead. This distance is based on the decision sight distance, which is the distance required for a driver to detect a crossing and to formulate actions needed to avoid colliding with trains. Cone B is placed at the point where the approaching driver must be able to see an approaching train so that a safe stop can be made if necessary. This distance is the distance from the stopping sight to the stop line, which is based on the design vehicle speed. Cone C is placed at the stop line, which is assumed to be 4.6 meters (15 feet) from the near rail of the crossing, or 8 feet from the gate if one is present.

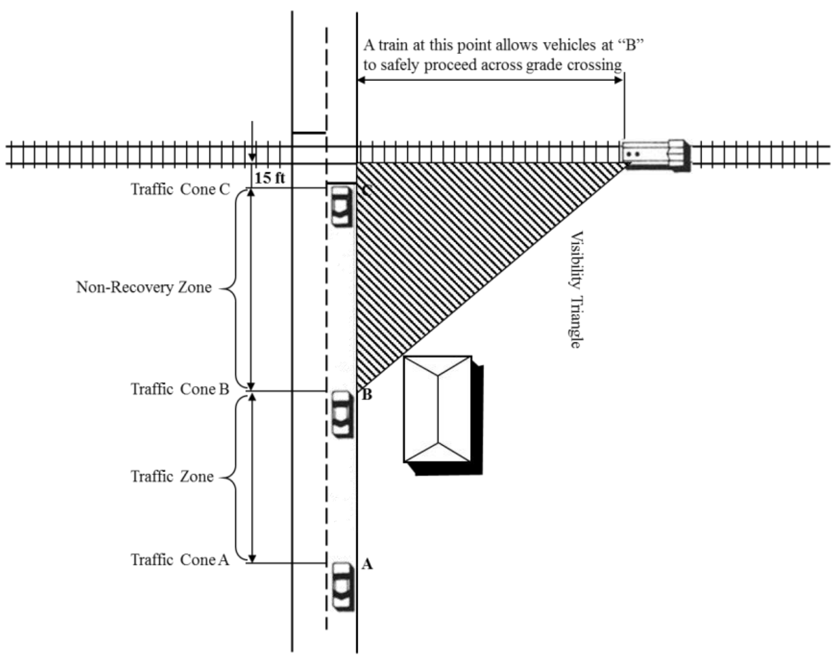


Figure 2.1 Approaching lane divisions in HRGC handbook (12)

HRGC accidents have not focused on the role of drivers' decision making. Rahimi (43) conducted research to explore the hypothesis that drivers' decision-making styles influence highway-rail crossing accidents. From his study, one-third of rail accidents and over 80 percent of train collisions are caused by human error. In this research, a “descriptive-differential” approach was used to match the driver’s decision style, driving task demands, and then the fit to the environmental factors of highway-rail crossings was determined. An analysis of variance experiment was designed with three independent variables including “driver decision style,” “driver time pressure,” and “intersection complexity.” The decision style modes included in this research were: 1) the manner in which the driver reacts to a given crossing situation; and 2) the manner of interaction with other environment factors including time pressures and mental load. The research concludes that decision styles are important factors to understanding HRGC driving activities. This research could provide insight into experimental design approach and help us understand human factor as a significant factor to influencing highway-rail crossing safety. However, this research is lacking a real data source to validate the previous conclusions, and FRA data will be used to prove human factor as a key factor in our research.

The traditional stop or go model is simple. When the warning signal starts, drivers will experience a short period of perception-reaction time (PRT), which AASHTO recommended as 1.5 seconds (44). After that, the driver will implement his or her “one-time” decision. That is, if the driver decided to go, AASHTO assumes that the driver will keep constant speed (i.e., acceleration rate equals to zero), however, if the driver decided to stop, the speed profile will show a continuous speed reduction. The deceleration rate for comfortable slowing down is 3.4 m/s2 (44). The model is illustrated in **Figure 2.2**.

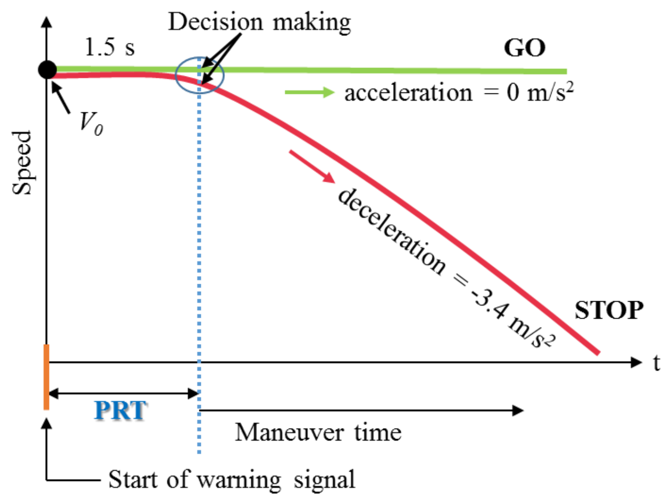


Figure 2.2 Traditional simplistic stop/go model and the recommended values by AASHTO

Factors that impact the driver's decision-making include: 1) human factors like gender, age (include novice drivers), and distracted driving (use of cellphone), which all significantly impact the aggressive driving behavior on high-speed signalized intersection approaches in response to yellow indication (45 and 46); 2) situational factors like the initial position of a vehicle when a yellow-light phase is displayed will significantly affects drivers' stopping/passing behavior (46 and 47); 3) and environmental factors such as inclement weather (48).

2.4 Summary of the Research Gaps

In summary, this review of the literature revealed multiple sources of information on the safety of motorists at HRGCs and the safety of non-motorists in traffic, while relatively fewer documents were uncovered on violation models at HRGCs. In addition, the various causes of level crossing crashes remain poorly understood. It can be seen that HRGC accident studies have not focused on the role of drivers' decision-making. It is also believed that the decision styles of the drivers have a significant impact on the way in which the HRGC actions are motivated.

Chapter 3 Data Collection and Reduction

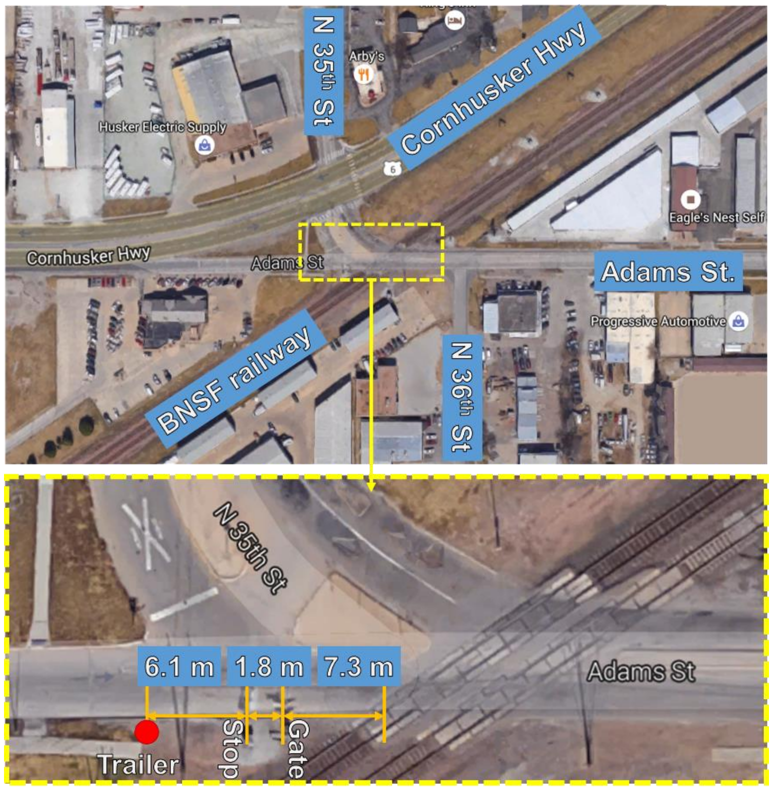
3.1 Define the Study Area and Set Up the Permanent Test Bed

A test bed near the intersection of 35th Street and Adams Street was chosen as the study site, a diagram of which is provided in Figure 3.1(a). It may be seen that the HRGC is located at the intersection of Adams Street and the Burlington Northern – Santa Fe (BNSF) mainline. It may be seen that Adams Street is a two-lane road and that the eastbound lane is “fed” from both eastbound Cornhusker Highway and southbound traffic from 35th Street. The speed limits are 45 mph on Cornhusker Highway and 35 mph on Adams Street and 33rd Street.

The HRGC is equipped with two-quadrant automatic gates, along with red flashing lights. The stop line is 20 feet away from the gate, and the gate is 24 feet away from the nearest track. The flashing warning interval is set to be 4 seconds. Once this time has elapsed, the gate begins its descent. It takes approximately 6 seconds to go from completely vertical to completely horizontal. Given that the railway provides a minimum of 20 seconds of warning time, this would imply the train arrives at a minimum of 10 seconds after the gate is fully horizontal.

The railway experiences relatively high train volumes of 50-70 trains per day. As such, there are numerous train events per day, and the HRGC has been identified as one of the most dangerous in Nebraska.

(a) The layout of the selected HRGC site



(b) The geometry of the selected HRGC site

Figure 3.1 The study area—Adam St. HRGC test bed

A pre-sample of the data from the data collection system was collected by the mobile trailer and analyzed prior to implementing automatic large data, where the trailer was located 0.6 meters from the pavement edge of the eastbound Adams St. and 6.1 meters from the HRGC stop line, as shown in Figure 3.1(b). This allows any data collection-related problems to be identified prior to collecting the majority of the data. The goal is to make the data collection process as automatic as possible so that the greatest range of driver behavior and driving conditions can be analyzed.

3.2 Data Collection System

To acquire data, the equipment was mounted on the Nebraska Transportation Center's (NTC) mobile device trailer, as seen Figure 3.2. The system consisted of one Wavetronix smartsensor advances

(AD), one Wavetronix smartsensor high definition (HD), one internet protocol (IP) camera, and one analog camera with Autoscope kit. These were all installed on the trailer mast. The AD sensor utilizes digital wave radar technology to track the vehicles upstream of the trailer and record vehicles' time, speed, lane, and distance. It can track vehicles over a distance of 600 feet in the upstream direction. The IP camera covers the range of the AD sensor and is used to confirm traffic behavior and eliminate false calls. The HD sensor counts vehicles and records vehicle length and vehicle speed as the vehicles pass through the detection zone adjacent to the trailer. The camera with the Autoscope kit is used to obtain the gate movements when they are activated in a train event.

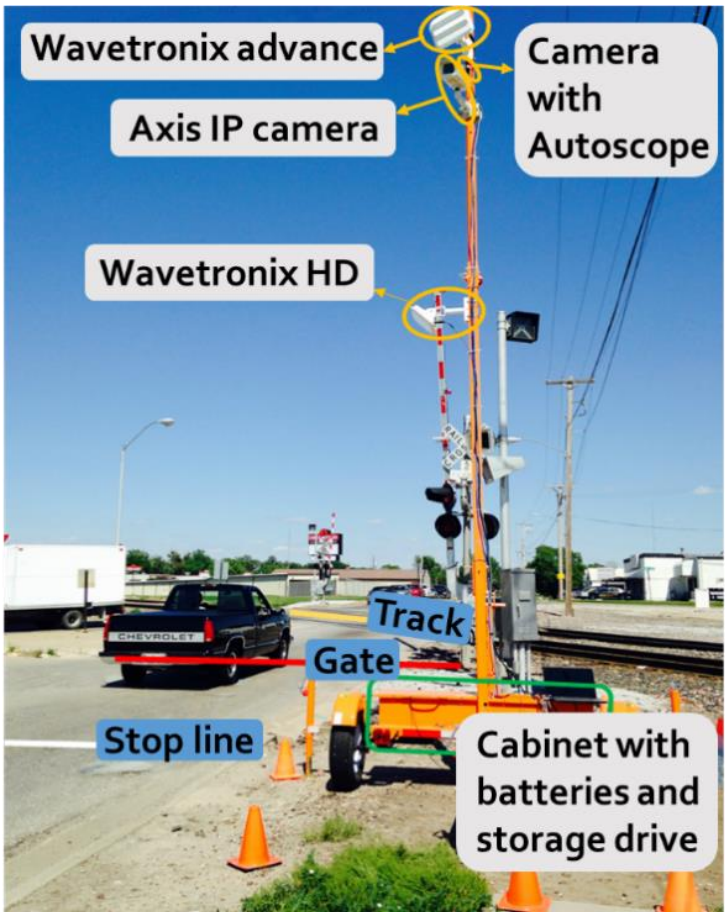


Figure 3.2 Mobile trailer data collection (MTDC) system

All the sensors are powered by batteries stored in the trailer cabinet, located near the trailer wheels. These are automatically charged by a solar panel. Located in the trailer cabinet is the local server that consists of a laptop and a digital hard drive. The data from different devices are sent to the server and are saved into the hard drive automatically. Note that the time stamp for all the sensors are synchronized to the server in the trailer cabinet. Thus, the different data sources have the same time baseline.

3.3 Sensor Performance Evaluation

Figure 3.3 shows a screen shot of the user interfaces of the Wavetronix smartsensors while they are collecting data. The left side interface (e.g., labeled "AD") shows the output from the AD sensor that targets the traffic upstream of the trailer. Each data record (e.g., line) consists of the range, speed, and ETA (i.e., Estimated Time to Arrival) of an identified vehicle that is moving toward the sensor location. The right side interface (e.g., labeled "HD") is from the HD sensor, where each data record represents a vehicle passing by the sensor location. The time of detection, instantaneous speed, length of vehicle, and distance to the sensor location are all collected and stored.

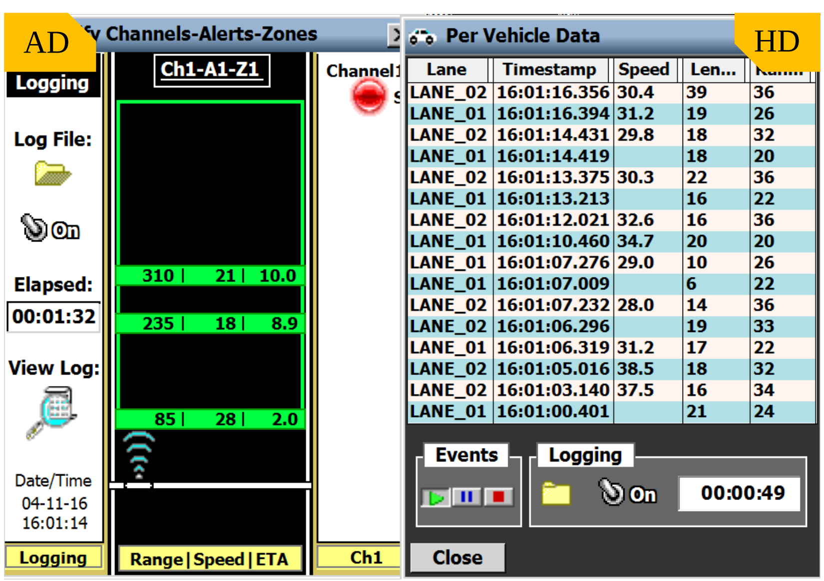


Figure 3.3 Real-time data collection interfaces of Wavetronix AD (left) and HD (right)

In addition to the real-time data collection, the performance specifications of the Wavetronix AD and HD sensors, as reported by manufacturer, are shown in Figure 3.4. Note that the specification for the percentages of small vehicles and large vehicles identified by the AD sensor within 400 ft of the trailer location are 90% and 95%, respectively. This means the two upstream and downstream sensors have an effective 800 ft vehicle tracking range with at least 90% accuracy. Speed accuracy is within 5 mph for 90% of the measurements for both the AD sensor and the HD sensor.

Wavetronix AD Performance	
Maximum mounting distance from center of lanes	50 ft (15.2 m)
Maximum mounting height	40 ft (12.2 m)
Detection area	50 to 600 ft (15.2 to 182.9 m)
Percentage of vehicles detected before 400 ft (121.9 m)	all motor vehicles 90%; large vehicles 95%
Detection accuracy	large vehicles 98%; all motor vehicles 95%
Range accuracy	±10 ft (3 m) for 90% of measurements
Speed accuracy	±5 mph (8 kph) for 90% of measurements
ETA accuracy	±1 sec. for 85% of measurements

Wavetronix HD Performance	
Typical per-direction volume accuracy	98%–99%
Minimum per-direction volume accuracy	95%
Typical per-lane volume accuracy	98%–99%
Minimum per-lane volume accuracy	90%
Minimum separation between two vehicles	5.5 ft. (1.67 m)
Per-lane average speed accuracy	±3 mph (5kph)
Per-vehicle speed measurement accuracy	±5mph (8 kph) for 90% of measurements
Method of speed measurement	dual radar speed trap
Typical classification accuracy	90%
Minimum classification accuracy	80%

Figure 3.4 Performance of Wavetronix smartsensors provided by product manufacturer

In a previous study (49), 55 test runs were performed with a portable GPS to validate the accuracy of Wavetronix AD. The speed difference of the two sensors were used to measure accuracy. It was found that the error is distributed with the mean close to 0.01 mph and the standard deviation at 1.39 mph. This indicates that the Wavetronix AD sensor provides acceptable values for speed and distance.

The Wavetronix HD has been widely used in traffic vehicle counts and speed detection. An evaluation study of the non-intrusive Wavetronix HD for traffic detection (5050) has found that the volume accuracy is within 2 percent in free flow conditions. The error determined in the 30 min average speed between the HD sensor and the manual measurement was 0.6 mph. The length-based vehicle classification had an error of 2.3 percent for passenger cars and an error of 15.3 percent for trucks, compared with the Piezo-Loop-Piezo baseline. The overall error for all vehicles is approximately 3.0 percent.

Autoscope kit (including software and hardware) is used to record the time stamps of: 1) the start of the flashing light, 2) the start of the gate lowering, and 3) the end of the gate lowering. Essentially, virtual detectors are overlapped on the gate area of the video so that whenever there is a movement of the gate, it records the time stamp. This is manually verified by checking the recorded video. After a period of 7 hours, i.e., 18 train events, by manually checking the video and the Autoscope data processing, it was found that the Autoscope had 100% of the gate lowering movement. The difference on the start of the gate lowering time, on average, is 0.3 seconds between the Autoscope processed time and manual observed time for a total of 18 train events.

Below Figure 3.5 shows an example of a vehicle that was approaching the HRGC when the warning signal started (left) and continually violated the lowing gate (right). It was recorded by the IP camera and the Analog camera with Autoscope kit. Note that the green bars are the virtual detectors that were activated by the moving object (e.g., lowering gate).

Figure 3.5 Sample of violation video records and the virtual Autoscope detectors

The Autoscope kit (including software and hardware) is used to record the time stamps of: 1) the start of the flashing light, 2) the start of the gate lowering and, 3) the end of the gate lowering. Essentially it sets virtual detectors overlapped on the gate area of the video so that whenever there is a movement of the gate, it records the time stamp. This is manually verified by checking the recorded video. After a period of 7 hours (i.e., 18 train events) by manually checking the video and the Autoscope data processing, it was found that the Autoscope had 100% of the gate lowering movement. The difference on the start of the gate lowering time, on average, is 0.3 second, between the Autoscope processed time and manual observed time for a total of 18 train events.

3.4 Data Synchronize Logic and Program Coding

To synchronize the different data sources, the following flowchart in **Figure 3.6** of logic will be applied to the automatic programming coding.

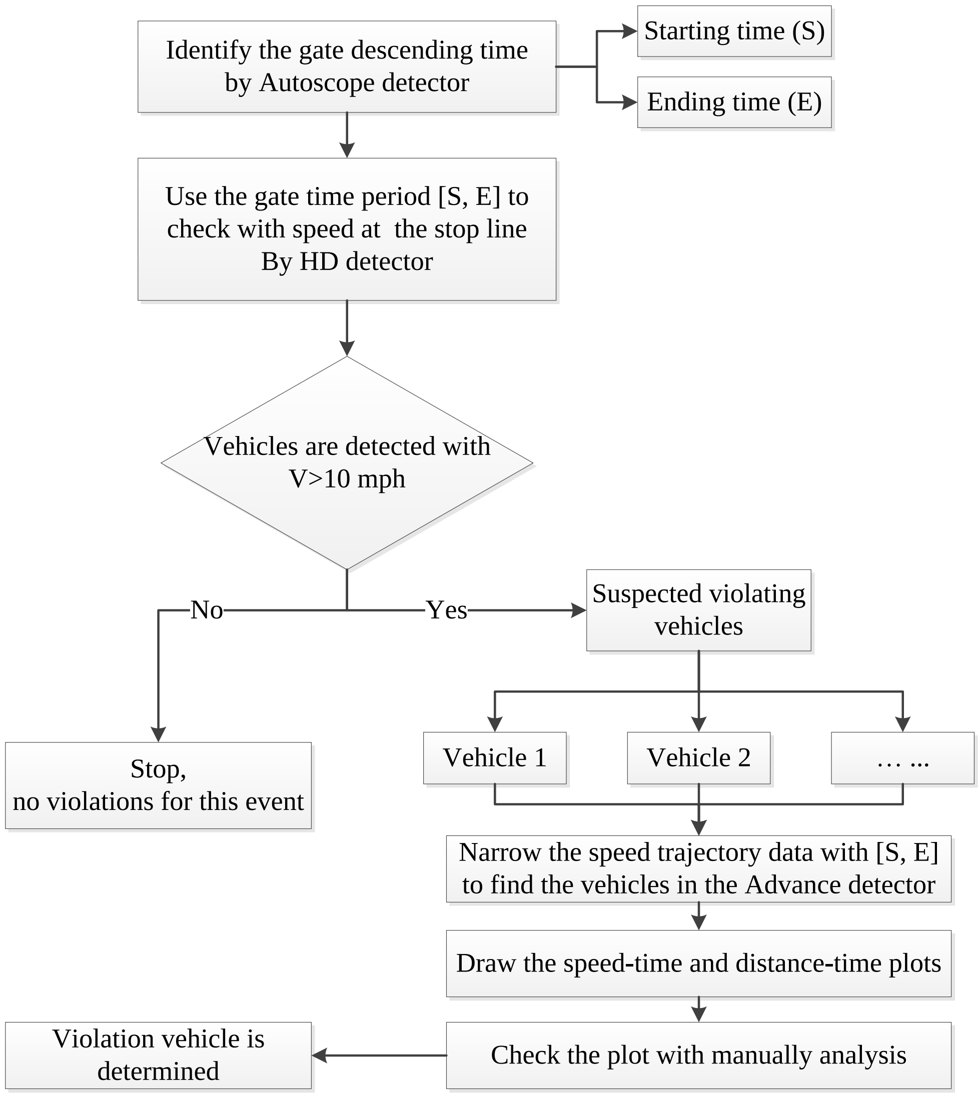


Figure 3.6 The logic of the data synchronization

Since the raw ITS data contains discrepancies and outliers, it will initially require "cleaning" and processing for quality control. Next, the program coding will be written to help obtain cleaned data. Then the data synchronization logic will be coded into the program to identify the violating vehicles, as shown in Figure 3.7.

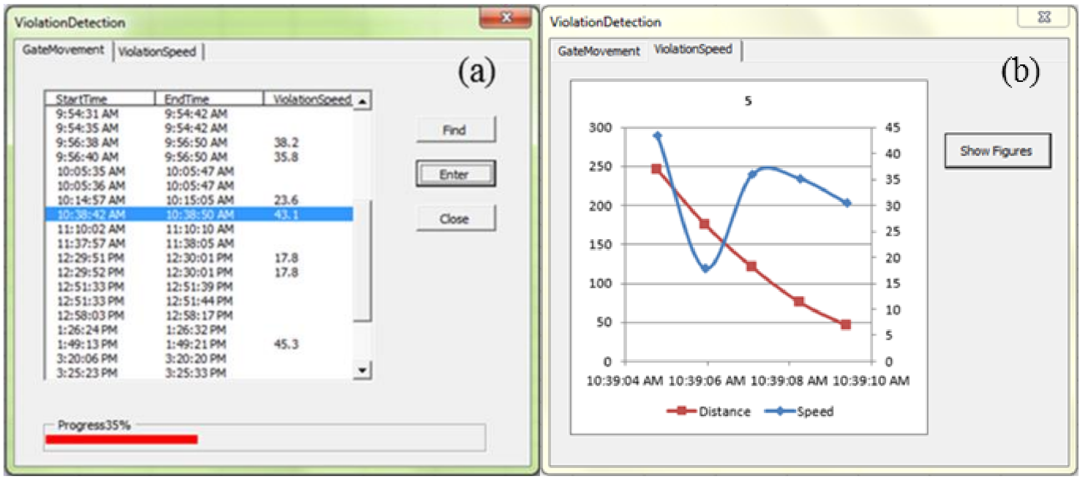


Figure 3.7 User interface of program coding for the data analysis

In the data processing back end, there are actually several potential violation vehicles that were recorded due to their speed profiles and the time around the gate. By referring the time point from gate movement, as well as the speed profile and distance to the stop line, the most likely violation vehicle will be identified and reported to the user interface (see **Figure 3.7**(b) and **Figure 3.8** with the red dashed square). The detailed codes can be found in the Appendix.

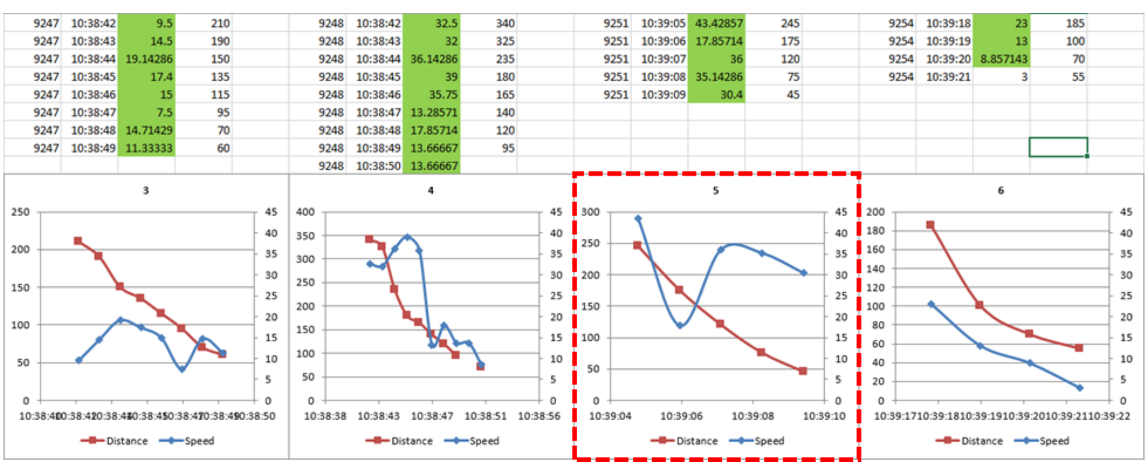


Figure 3.8 Data of all the potential violation vehicles

Based on the definition of the violations, a stop-line violation vehicle is determined based on the distance criteria that any vehicle stops beyond the stop-line; a gate violation vehicle is determined based on the time criteria that any vehicle proceeds through the gate after the gate begins to lower. It should be noted that after the HRGC warning system has been activated, the vehicles that last proceeded through the gate and/or first stopped at the stop-line will be collected. Henceforth, there are at most two vehicles that will be studied, thus the number of violation vehicles for each train event could be either stop-line violation or gate violation, or both.

All driving behavior associated variables will be examined to indicate the degree of contributions to the final outcomes of violations or compliances. Standard quality control methods will be implemented to clean the data. Basic statistics on key parameters such as travel time (e.g., mean and variance as a function of time of day) will be calculated.

3.5 Data Size

Data was collected from 9:00 am to 4:30 pm for 26 weekdays over a period lasting from May 2014 to October 2014. There were times when: 1) the data was not synchronized and/or, 2) not all equipment was functioning properly. In these situations the data was discarded. The data from the four sources included: 1) each vehicle's trajectory as defined by its speed, time, and distance to the stop line; 2) each vehicle's speed at the stop line; 3) gate movements (e.g., the start of the gate lowering and the end of the gate lowering) and; 4) archived videos showing the approaching vehicles on eastbound Adams St. and the crossing.

A series of automatic data reduction algorithms were used to identify vehicles whose drivers had to make a decision on whether to stop or traverse the HRGC. The focus was on identifying vehicles: 1) who were the last to traverse the HRGC prior to the train arriving and, 2) who were the first vehicle to stop for an approaching train. Data was only collected on days where there was no rain and visibility was good. During the data collection, 106 vehicle trajectories were obtained. Of these vehicles, 59 vehicles were the last to traverse the HRGC prior to the arrival of the train, and 47 vehicles were the first to stop prior to the arrival of the train.

Chapter 4 Modeling for Analyzing Driver's Approaching Behavior at HRGC

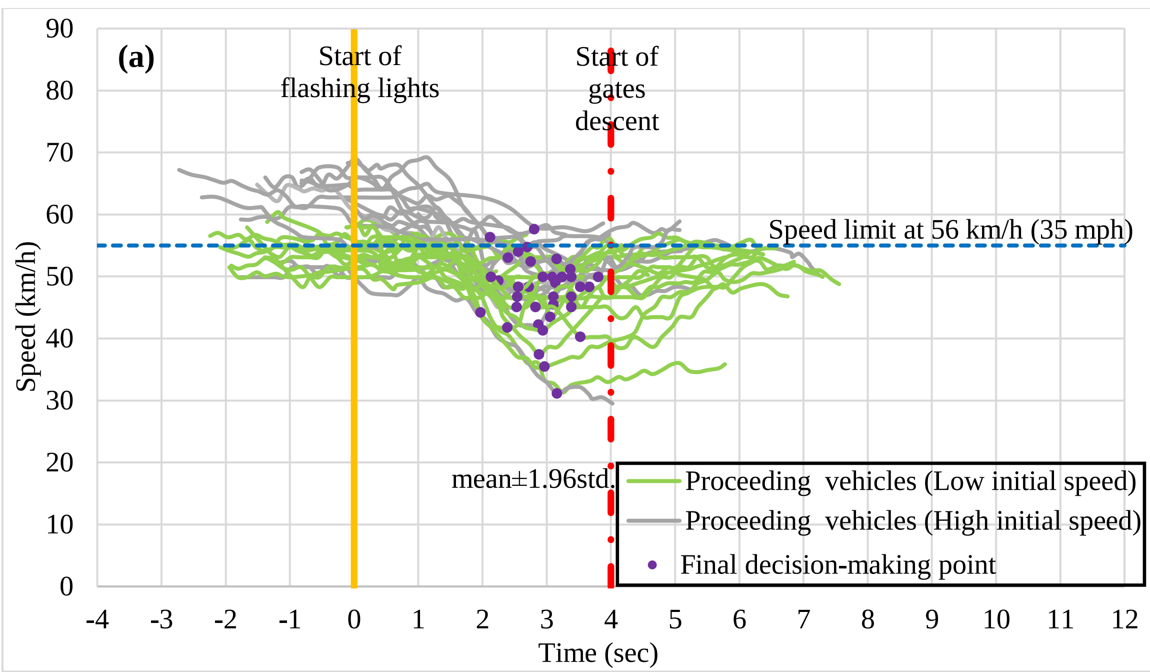
This chapter is to evaluate individual driver behavior during the approach to a HRGC. The focus is on the driver's decision to either stop or proceed when they approach an HRGC equipped with active control devices where the flashing lights are activated and the gates are either: 1) about to begin their descent; or 2) are descending. The focus was on identifying: 1) vehicles that were the last to proceed through the HRGC prior to the arrival of the train, and 2) vehicles who were the first to stop for an approaching train. The former will be referred to as last-to-proceed vehicles and the latter as first-to-stop vehicles. After the data reduction, a total of 106 speed profiles of drivers who have to make a decision to stop or proceed in response to a train event are selected in this chapter, which consisted of 59 last-to-proceed vehicles and 47 first-to-stop vehicles.

Standard engineering theory postulates that after a perception-reaction time drivers make a choice to proceed or stop. However, it was observed that the drivers do not appear to treat the stop/proceed decision as a static binary choice because their speed profiles exhibit a wide range of acceleration and deceleration behaviors. It was hypothesized that the decision to stop or proceed through an HRGC was best modeled as a dynamic and stochastic process. It was decided to divide the approach into three zones: awareness zone, assessment zone, and action zone. A stochastic model of drivers' decision-making as they approach an HRGC was developed. The speed profiles of drivers who violate the traffic laws and those that do not were compared, and it was found that the former experienced a longer decision-making time. It was hypothesized that if information was provided earlier to drivers about a potential train event then the decision-making time would be reduced, and the violation rate would decline.

4.1 Vehicles' Approaching Speed Profiles

The empirical speed versus time profiles are shown in **Figure 4.1**, where the speed is on the y axis and the time is on the x axis. **Figure 4.1** (a) shows the profiles of the last-to-proceed vehicles, and **Figure**

4.1 (b) shows the profiles of the first-to-stop vehicles. Also shown on **Figure 4.1** (a) and **Figure 4.1** (b) are the time the flashing lights become active (i.e., t = 0 second) and the time when the gates begin descending (i.e., t = 4 seconds). The profiles are color coded. Grey indicates a vehicle initially traveling above the speed limit, green indicates a vehicle initially traveling at or below the speed limit and ultimately proceeding through the HRGC, and red indicates a vehicle traveling at or below the speed limit and ultimately stopping prior to the HRGC. Note that while the profiles appear to be continuous, they are based on readings at 0.2 second intervals. It should be noted that the start time of the flashing lights on each speed profile is normalized to zero seconds for analysis purposes. Distance is not shown in figure 3. Therefore, the vehicles are, in most cases, in different locations for a given time.



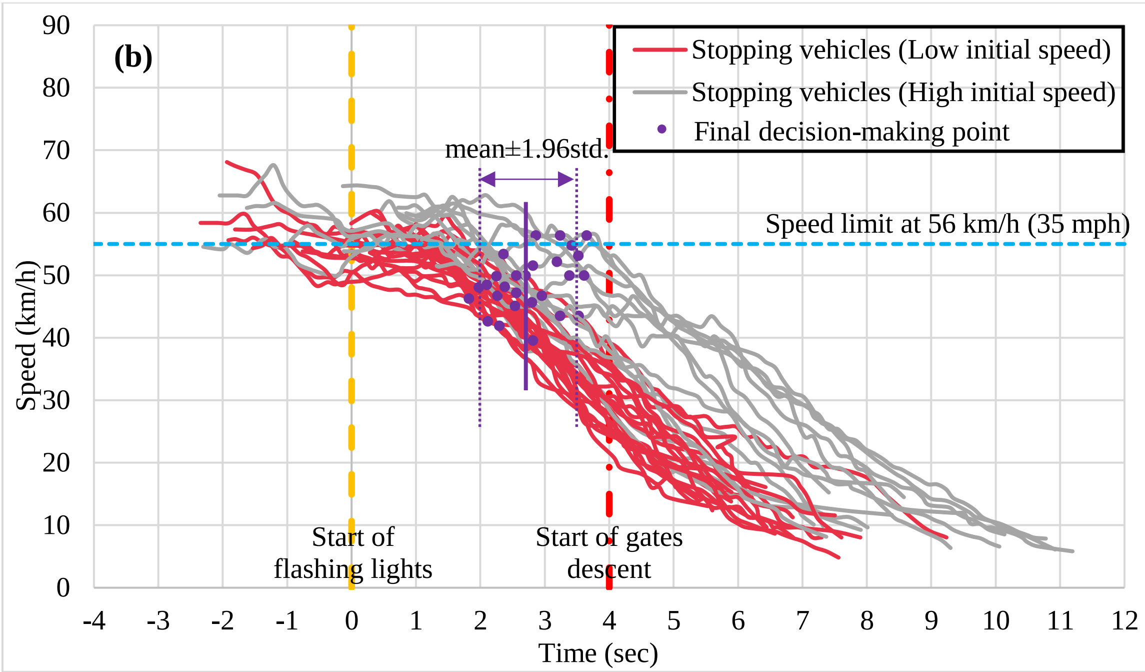


Figure 4.1 Speed profiles and final decision-making points for (a) proceeding vehicles, and (b) stopping vehicles

As shown in Figure 4.1, the purple dots represent the final decision-making points where it is assumed that the driver makes a final decision to stop or to proceed. In this study, the final decision-making point for proceeding vehicles is defined as the time when the vehicle begins to accelerate from its absolute minimum value of speed after the warning lights start flashing. Note that the driver might slow down later and that the average acceleration rate for these vehicles could be negative. For stopping vehicles, the final decision point is determined when the vehicle experiences a 15 percent drop in instantaneous speed compared to the instantaneous speed at the onset of the flashing lights.

4.2 Study on the Discreteness of the Approaching Process

4.2.1 Prior to the Start of Flashing Lights

The speed profiles prior to time 0 show driver behavior prior to the start of the flashing lights. As can be seen in **Figure 4.1** (a) for proceeding vehicles, the speeds prior to the start of the flashing lights are fairly stable and vary about the speed limit. However, for the stopping vehicles shown in **Figure 4.1** (b), drivers tend to reduce their speeds prior to the start of the flashing lights.

Table 4.1 shows the statistics of the differences between the instantaneous speed at the start of the flashing lights and the average instantaneous speed before that time (i.e., the time period from when the vehicle is first detected by the sensor to the start of the flashing lights). For the stopping vehicles, the reduced speed of 6.7 km/h is statistically significant at the 95 percent confidence level. Note that the change in speed limit from 45 mph to 35 mph, where vehicles exit from Cornhusker Highway to Adams Street, would account for some of the observed speed drop. Interestingly, the drivers that ultimately decided to stop are the ones that have, on average, the largest speed drop before the start of the flashing lights. It is hypothesized that these drivers are cautious and are therefore more likely to choose to stop when the warning lights begin flashing.

Table 4.1 Test of speed differences (unit: km/h)

	Obs.	Average instantaneous speed before the start of flashing light (*std.*[a])	Instantaneous speed at the start of flashing light (*std.*[a])	Speed diff.	F-stat	Sig.
Last-to-proceed vehicles	59	57.5 (*5.54*)	56.3 (*5.32*)	1.2	2.14	.74
First-to-stop vehicles	47	58.8 (*4.18*)	53.1 (*3.75*)	6.7	10.37	**.02**[b]

[a] Standard deviation of the speed, in *italics*
[b] Statistically significant result (alpha = .05)

4.2.2 After the Final Decision-Making Point

At the final decision-making point, the driver makes a final choice on whether to proceed through the HRGC or stop. After this point, the vehicle will accelerate or decelerate, depending on their choices, in an approximately continuous manner. Note that for the stopping vehicles the deceleration rate for an individual driver is relatively constant. In contrast, for the proceeding vehicles the acceleration rates for an individual driver varies over time. In addition, for those proceeding vehicles, the speed at the final decision-making point is noticeably reduced as compared with the speed at the start of the flashing lights, as shown in **Figure 4.1**. As discussed previously, it is assumed that the drivers slow down due to the "bumpiness" of the HRGC associated with proceeding through two sets of railway tracks.

As can be seen from **Figure 4.1**, once the final decision is made, the speed profiles show smooth trends. If the driver decides to proceed through the HRGC, the speed tends to increase to an upper limit speed before leveling out. If the driver decides to stop, the speed decreases at a fairly consistent rate. The average acceleration and deceleration changes in speed over time after the decision-making point (till the end of the proceeding/stopping) are estimated for proceeding vehicles and stopping vehicles, respectively, as shown in **Figure 4.2** (a) and (b).

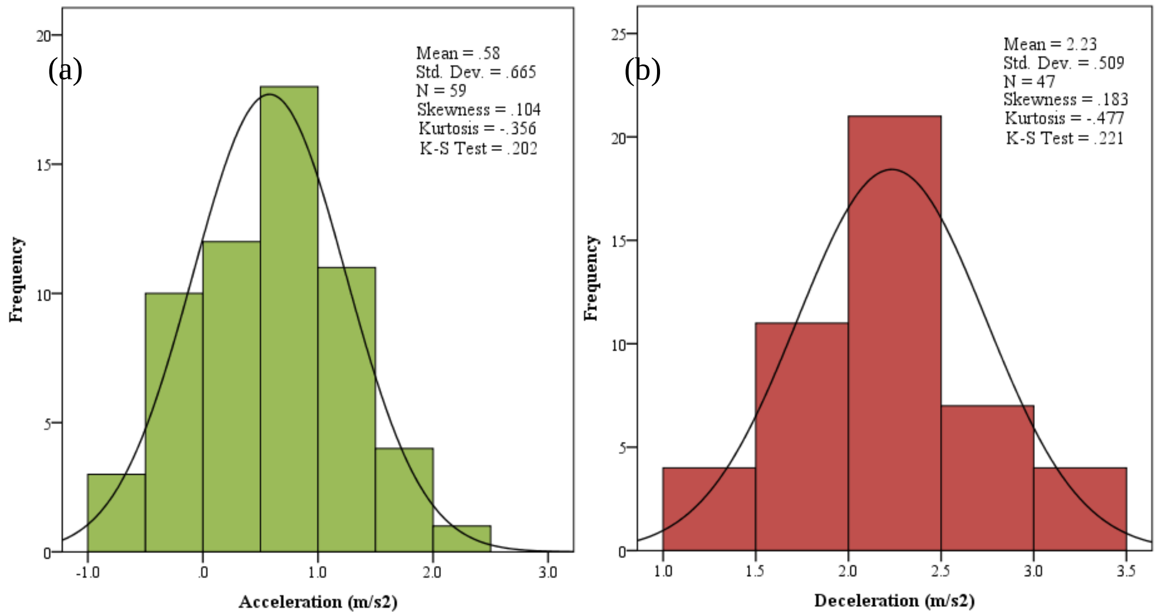


Figure 4.2 The estimated acceleration and deceleration rates in zone 3 for (a) proceeding vehicles, and (b) stopping vehicles

The proceeding vehicles experienced very small acceleration with a mean of 0.58 m/s^2. The stopping vehicles experienced relatively high deceleration rates with an average value of 2.23 m/s^2. As shown in **Figure 4.2**, the Kolmogorov-Smirnov test indicates that both acceleration and deceleration distributions are Gaussian shaped with p-values greater than the significance level of 0.05.

4.2.3 Between the Start of the Flasher and the Final Decision-Making Point

After the flashing lights are activated, drivers will have to make a decision to proceed or stop. Note that during this process the external information that the driver obtained is dynamic over time. This information includes flashing warning signals, automatic gates gradually descending, activation of train or wayside horn and, perhaps, visual confirmation of the train by the driver. This dynamic information may affect driving behavior and the driver's choice. For example, a possible scenario could be that the driver perceives the warning signal, decides to brake, subsequently changes his mind and begins to accelerate before changing his mind a second time and stops. These decisions, and their associated behaviors, will be reflected in the speed profiles after the flashing lights are activated, as shown in **Figure 4.1**.

For a given driver, the time from the start of the flashing lights to the final decision-making point, which is essentially the time length of zone 2, is referred to as the decision-making time (DMT). **Figure 4.3** (a) and (b) show the histogram of the DMTs. Also shown are a fitted normal distribution curves for the proceeding vehicles and stopping vehicles, respectively. For proceeding vehicles, the average DMT is 2.02 seconds with a standard deviation of 0.70 seconds; for stopping vehicles, the average DMT is 2.47 seconds with a standard deviation of 0.83 seconds. The difference in average of DMT for stopping vehicles of 0.45 seconds, as compared to proceeding vehicles, was statistically significant at the 95 percent confidence level (p-value=0.003).

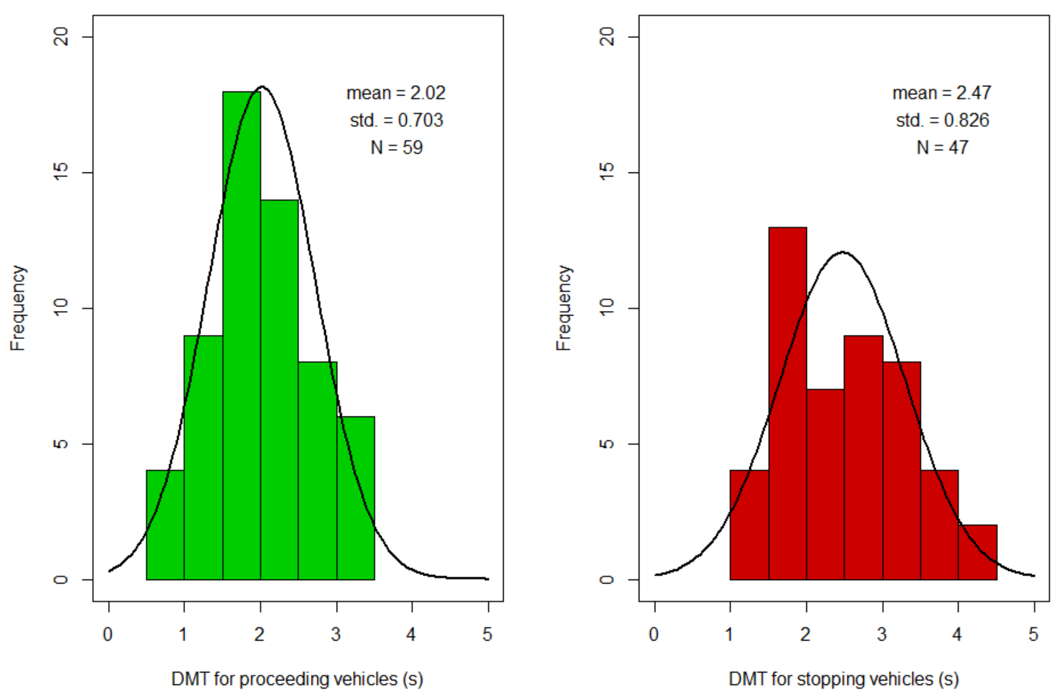


Figure 4.3 Histograms of length, in seconds, of DMT

As can be seen in Figure 4.3, the time at which a driver makes the final decision to stop or proceed varies considerably across drivers. It is expected, as the DMT is a function of the driver's current speed, how long the active warning devices had been flashing, the driver's distance to the HRGC, the presence of other vehicles, whether the train is visible to the driver, the driver's familiarity of the HRGC, an individual driving risk profile, etc. It is also possible that the driver makes a series of choices several times before making a final decision. Note that the DMT is greater than the perception-reaction time used in the HRGC design. For example, AASHTO assumes 1.5 seconds (44) and ITE assumes 1.0 second (51) of perception-reaction time for the driver's reaction and decision-making to the flashing lights. This implies that the drivers are using more time to decide fully on whether to stop for the train or proceed through the HRGC.

4.3 Driver Decision-Making Model – 3 A's Zone Model

Based on the previous speed profile analysis, a conceptualization of the driver's decision-making process as they approach an HRGC was developed, as shown in figure 4.4. The driver's approaching process is divided into three distinct zones as the driver approaches the HRGC: 1) the awareness zone, 2) the assessment zone, and 3) the action zone. Each zone is elaborated on in the following paragraphs.

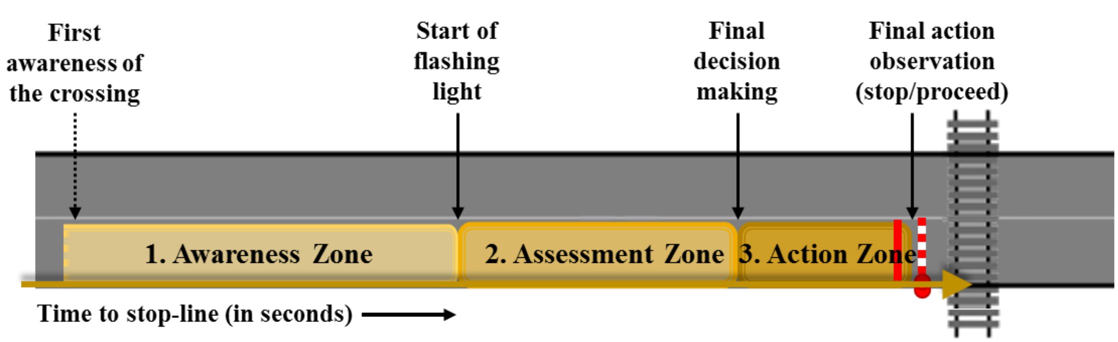


Figure 4.4 Conceptualization of driver's decision-making when approaching an actuated HRGC

Firstly, the awareness zone starts in the general vicinity of the advance railway warning signs and/or pavement markings, where it is assumed that the drivers first obtain information and are aware that there is an at-grade train crossing ahead, but they have been given no indication, other than possibly visual observation of a train in the crossing area. The first information usually takes on the following forms: advance railroad warning signs, pavement markings, or prior familiarity with the crossing. The awareness zone is characterized as the driver preparing a change in the possible driving environment from the highway road segment to a highway-railroad crossing area, usually with a decrease in travel speed as the driver approaches the HRGC.

The distance should be long enough to allow drivers to detect a crossing and to adjust their speed to prepare a stop-or-proceed decision once the HRGC flashing lights are activated. For a 35 mph approach lane, the railroad-highway grade crossing handbook (12) recommends that the advance warning sign be placed 180 meters (590 ft) upstream from the HRGC while the MUTCD (10) recommends 122 meters (400 ft). For the test site used in this study, the advance warning sign is placed 79 meters (260 ft) upstream from the nearest track. It is hypothesized that the short awareness zone is not beneficial because it does not provide sufficient time to aware the change of the road environment, which may aggravate the burden of the decision making to the next assessment zone. Note that if there are no trains in the area, the awareness zone will last from the time drivers identify the crossing to the time they safely proceed through the HRGC and neither of the other two zones, as described below, will exist.

The second zone is the assessment zone. It begins when the flashing lights are on display. In this zone, drivers become aware that the flashing lights are active and they know that they have to make a decision to stop or proceed. Under traditional static modeling of HRGCs, the length of this period of time is equal to the perception-reaction time. That is, drivers make a binary decision immediately after they perceive the flashing lights are active. As hypothesized in this paper, the decision-making process at HRGCs are more complex than currently assumed in that the driver may make a series of decisions, including to "wait and see" before ultimately deciding on a course of action. The length of this zone is equal to the DMT, as defined previously. The high variability in speed that was observed at the test site tends to support this hypothesis.

The assessment zone is essentially a decision-making zone, where drivers are informed of an on-coming train by the start of the flashing lights. In this zone, drivers may make a series of decisions before the final decision is made. The current models in literature assume that a driver makes a single decision at the end of the perception-reaction time associated with the start of the flashing lights and that the driver does not change this decision at a later time. In other words, the perception-reaction time is all that drivers use to make a stop or proceed decision. However, as argued in this paper, the actual decision-making process requires a longer time as drivers may change their decisions during the approaching process.

The last zone is the action zone that starts immediately after the final decision-making point. In this zone drivers implement their decisions. For proceeding vehicles, it ends at the time when vehicles successfully traverse the gate. For stopping vehicles, it ends when vehicles complete a stop at the stop-line. This section is characterized by either a near constant deceleration rate for stopping vehicles or a near constant acceleration rate for proceeding vehicles.

4.4 Time Length Identification of the Three Zones

It is important to know how much time is needed for each zone to minimize the violation behaviors, if possible. To answer this question, a data set of 106 vehicle samples, including 59 proceeding vehicles and 47 stopping vehicles, are used. Among them, 29 are gate violation vehicles and 2 are stop-line violation vehicles. The time length for each zone is calculated by data groups as shown in **Figure 4.**.

Note that the width of the violin plot indicates the data distribution. The white diamond in the black bar indicates the median, and the red line with the label indicates the mean of the zone length.

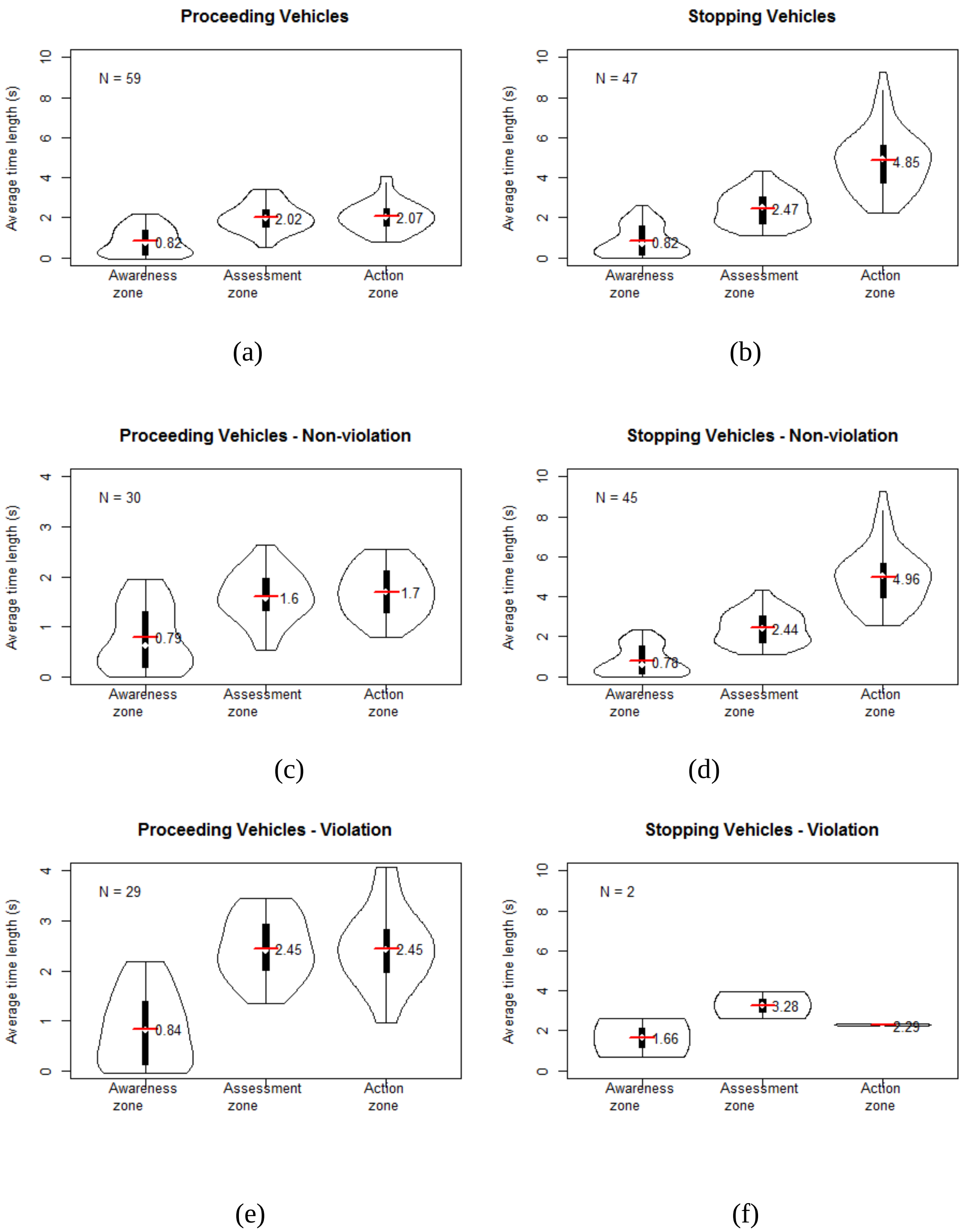


Figure 4.5 Time length of the three zones

It is found in figure 4.5 (a) and (b) that there is no difference in the average time length of the awareness zone for stopping and proceeding behaviors. This is expected because in this zone, while drivers are aware that there is an HRGC ahead, they have not been notified by the active warning system that a train is approaching. The only exception is if they were able to visually identify the train, which is extremely difficult at this test bed because of the geometry of the HRGC and the speed of the trains in the corridor. Specifically at this site, the advance warning sign is 260 ft upstream from the nearest track. This translates to a travel time of 5.1 seconds to the nearest track, assuming the driver is traveling at the average speed. As the warning flashing time is 4 seconds, there are only 1.1 seconds for drivers to be aware of the HRGC ahead before the flashing lights are actuated.

The average time lengths of the assessment zone for drivers (both proceeding and stopping) who commit a violation (i.e., Figure 4. (e) and (f)) are longer than those drivers who do not commit a violation (i.e., Figure 4. (c) and (d)). The DMTs are 35 percent longer for proceeding vehicles and 26 percent longer for stopping vehicles for drivers who end up committing a violation. There are two possible reasons for this issue. The first is that the awareness zone for drivers who commit a violation is shorter than for drivers who do not commit a violation. Thus, these drivers have to increase their DMTs to react to the flashing lights. The second possible reason is that these drivers make a decision and then subsequently change their minds as more information becomes available. In some instances, a series of decisions are made before the final decision, which is reflected in the variation of their travel speed profiles. This is different from the theoretical assumption in the past that drivers make stop-or-proceed decisions at a single point in time.

The average time lengths of the action zone for proceeding vehicles that have a violation (i.e., Figure 4. (e)) is longer, with a wider dispersion, compared to that of proceeding vehicles that do not have a violation (i.e., Figure 4. (c)). It is hypothesized that the reason is because these drivers originally decided to stop, and when they change their minds (to proceed through), they do not have enough time to proceed through the HRGC without committing a violation. Although only two stop violations are observed, it is hypothesized that the average time length of the action zone for stopping vehicles that have a violation (i.e., Figure 4. (f)) is shorter, with a wider dispersion, compared to that of stopping vehicles that do not have a violation (i.e., Figure 4. (d)). This is because drivers who violate the stop-line usually are too close to the stop-line and thus have to decelerate faster in a shorter amount of time.

Chapter 5 Conclusions and Recommendations

This research seeks to investigate driver behaviors when confronting an on-coming train at HRGCs in a large range area. Drivers' corresponding decision-making were modeled. Based on an analysis of the individual vehicle trajectories, a multistage model (i.e., the 3A zone based model) was developed to depict the driving behaviors at different locations along the process of approaching the HRGC.

Unlike the traditional decision-making model which assumes drivers make a simple one-time decision, this study divided the decision-making process into three distinct zones: the awareness zone, the assessment zone, and the action zone.

- The awareness zone was characterized by speed reduction. This finding is consistent with most of the conclusions in the literature. It indicated that drivers slowed down as they approached the HRGC before being informed of an oncoming train by the warning system.
- The assessment zone is essentially a decision-making zone. It was characterized by a longer decision-making time, compared with the perception-reaction time in the traditional model. Drivers may experience several attempts of stopping or proceeding before the final stop/proceed decision, which took a longer time.
- The action zone was characterized by the relatively constant acceleration rate or deceleration rate. Since starting from this zone, drivers implemented their final decision and would not change. It was also found that the acceleration rate or deceleration rate was quite mild, indicating a more comfortable driving style.

The 3 A's zone based model is often used to better understand the driver's decision-making in a specific segment of the approaching process. Rather than the simple traditional decision-making with regard to the decision-making process as a point, the proposed decision-making model helps to investigate factors that impact driver behaviors regarding traffic violations. In this way, targeted and implementable measures can be put forward in each section of the approach, with respect to reducing potential violations.

To reduce violations, the transportation agency can either have earlier warning information of the HRGC (i.e., longer awareness zone) or shorten the decision-making process (i.e., shorter assessment zone). Variable message signs, for example, can be installed at the appropriate location by calculating the safe stopping distance. By detecting the movement information of the vehicle, different drivers may receive different warnings or suggestions based on their own traffic situations. Similarly, in-vehicle warning systems have the potential to provide an earlier warning regarding the presence of a train and to potentially provide advice on the safest course of action. These countermeasures would serve a similar purpose as the amber signal at highway-highway intersections and provide more advance warning about the activation of the warning signals.

It is hypothesized that reducing the vehicle speed would reduce the number of violations. As the speed profile study shows in this report, a considerable number of drivers choose to drive faster than the speed limit and this is problematic when the flashing lights become active. This can be achieved through physical methods such as installing transverse rumble strips, driver education, or better enforcement of existing traffic laws.

While this study is location specific, it provides a method that can be easily expanded to a wide range of traffic locations and situations. This is important in order to do the violation-need study such as the determination of optimal clearance interval or the improvement of HRGC geometry.

References

1. US DOT. Railroad Safety Statistics 2005 Annual Report, Federal Railroad Administration, December 2016.

2. FRA Annual Report 2013

3. Campbell, B.N., J.D. Smith, and W.G.Najm. Analysis of Fatal Crashes Due to Signal and Stop Sign Violations. Report DOT-HS-809-779. U.S. Department of Transportation, Washington, D.C., 2004.

4. Raub R.A. Examination of highway-rail grade crossing collisions nationally from 1998 to 2007, Transportation Research Record 2122, pp 63-71, 2009

5. Nebraska Department of Roads - Office of Highway Safety. “2002-2013 Motor Vehicle Crash Data.”

6. Cooper D.L., and D.R. Ragland. Addressing Inappropriate Driver Behavior at Rail-Highway Crossings. Transportation Research Board 87th Annual Meeting, Washington, D.C., 2008.

7. Austin R.D., and J.L. Carson. An Alternative Accident Prediction Model for Highway-rail Interfaces. Accident Analysis & Prevention 34(1): 31-42, 2002.

8. Khattak, Aemal. "Comparison of driver behavior at highway-railroad crossings in two cities." Transportation Research Record: Journal of the Transportation Research Board 2122 (2009): 72-77.

9. Operation Lifesaver website. Accessed on March 3, 2015. http://www.minnesotasafetycouncil.org/OL/stop.cfm

10. Manual on Uniform Traffic Control Devices (MUTCD). FHWA 2009

11. Hall, Brett O. "Collision avoidance system." U.S. Patent No. 6,223,125. 24 Apr. 2001.

12. Ogden, B. D. *Railroad-Highway Grade Crossing Handbook: Revised*. Technical Report

FHWA-SA-07-010, US Department of Transportation, Federal Highway Administration, Washington, D.C., 2007.

13. Uniform Vehicle Code and Model Traffic Ordinance. National Committee on Uniform Traffic Laws and Ordinances, 1992.

14. Lincoln Municipal Code. Section 10.14 - Rules of the Road, Lincoln Nebraska. https://www.lincoln.ne.gov/city/attorn/lmc/contents.htm. Access Date: July 15th, 2016.

15. *Nebraska DMV 2015*.

16. Abraham J., T. Datta, and S. Datta. Driver Behavior at Rail-highway Crossings. Transportation Research Record: Journal of the Transportation Research Board 1648: 28-34, 1998.

17. Fitzpatrick, Kay, et al. Traffic violations at gated highway-railroad grade crossings. No. TX-98/2987-1. 1997.

18. Lenné, M. G., C. M. Rudin-Brown, J. Navarro, and et al. Driver Behavior at Rail Level Crossings: Responses to Flashing Lights, Traffic Signals and Stop Signs in Simulated Rural Driving. *Applied ergonomics*, Vol. 42, No. 4, 2011, pp. 548-554.

19. Pickett, M. W., and G. B. Grayson. Vehicle Driver Behavior at Level Crossings. Health and Safety Executive, Sheffield, 1996.

20. Salmon, P. M., M. G. Lenné, K. L. Young, and et al. An On-road Network Analysis-based Approach to Studying Driver Situation Awareness at Rail Level Crossings. Accident Analysis & Prevention, No. 58, 2013, pp. 195-205.

21. R.D. Austin, and J. L. Carson. "An alternative accident prediction model for highway-rail interfaces." Accident Analysis & Prevention 34.1 (2002): 31-42.

22. Carlson, P. J., K. Fitzpatrick, and J. Bean. A study of gate violations at highway-railroad

grade crossings. 68th Annual Meeting of the Institute of Transportation Engineers, 1998.

23. Tey, Li-Sian, Luis Ferreira, and Angela Wallace. Measuring driver responses at railway level crossings. Accident Analysis & Prevention 43(6): 2134-2141, 2011.

24. Moon, Young J., and Fred Coleman. Dynamic dilemma zone based on driver behavior and car-following model at highway–rail intersections. Transportation Research Part B: Methodological 37.4 (2003): 323-344.

25. Yan, Xuedong, Stephen Richards, and Xiaogang Su. "Using hierarchical tree-based regression model to predict train–vehicle crashes at passive highway-rail grade crossings." Accident Analysis & Prevention 42.1 (2010): 64-74.

26. Frank Saccomanno, Liping Fu, and Luis Miranda-Moreno. Risk-Based Model for Identifying Highway-Rail Grade Crossing Blackspots. Transportation research record 1862

27. Shou-Ren Hu, Chin-Shang Li and Chi-Kang Lee. Investigation of Key Factors for Accident Severity at Railroad Grade Crossings by Using a Logit Model. Safety Science, 48(2), 186-194, 2010.

28. Miranda-Moreno L.F., Fu L., Lord D. and Ukkusuri S. (2009), “How to incorporate accident severity and vehicle occupancy into the hotspot identification process?” Transportation Research Record. 2102, 53-60.

29. Wei Hao, Camille Kamge and Dan Wan. The effect of time of day on driver's injury severity at highway-rail grade crossings in the United States. Journal of Traffic and Transportation Engineering, 3(1): 37-50, 2016.

30. Eluru, Naveen, et al. A latent class modeling approach for identifying vehicle driver injury severity factors at highway-railway crossings. Accident Analysis & Prevention 47 (2012): 119-127.

31. K. Witte, W.A. Donohue. Preventing vehicle crashes with trains at grade crossings: the risk seeker challenge. Accident Analysis and Prevention, 32 (2000), pp. 127 – 139.

32. Caird, J.K., Transportation Development Centre (Canada), University of Calgary, Cognitive Ergonomics Research Laboratory, 2002. A Human Factors Analysis of Highway-Railway Grade Crossing Accidents in Canada. Transportation Development Centre, Montreal.

33. Taylor, K., 2008. Addressing road user behavioural changes at railway level crossings. In: Proceedings of Joint ACRS-Travelsafe National Conference, pp. 368–375.

34. Sussman, E.D., Raslear, T.G., 2007. Railroad human factors. Rev. Hum. Factors Ergon. 3 (1), 148–189.

35. Soren Underlien Jonsen (2007). Passive Railroad-Highway Grade Crossings: Relevant human factors and effects of safety measures.

http://www.trafitec.dk/sites/default/files/publications/Passive%20railroadhighway%20grade%20crossings_0.pdf , accessed in Jan 12, 2017

36. Hyden, C. The development of a Method for Traffic Safety Evaluation: The Swedish Traffic Conflicts Technique. Bulletin 70, Dept. of Traffic Planning and Engineering, Lund University, Lund, Sweden, 1987.

37. Tarko, Andrew, et al. Surrogate measures of safety. White paper, ANB20 (3), Subcommittee on Surrogate Measures of Safety, 2009.

38. Carlson, Paul, and Kay Fitzpatrick. "Violations at gated highway-railroad grade crossings." Transportation Research Record: Journal of the Transportation Research Board 1692 (1999): 66-73.

39. Motorist understanding of railroad-highway grade crossing traffic control devices and associated traffic laws. Transportation research record No 1160. Pp.52-59. Transportation

research board, national research council, Washington DC. 1988.

40. Abraham J., T. Datta, and S. Datta. Driver Behavior at Rail-highway Crossings. Transportation Research Record: Journal of the Transportation Research Board 1648: 28-34, 1998.

41. Khattak, Aemal J. Gate violations by truck drivers at highway-rail grade crossings in two cities. Journal of the Transportation Research Forum, 52(1), 2013.

42. Moon, Young J., and Fred Coleman III. Highway-Rail Quad Gate Operation Time by System Simulation of Dynamic Dilemma Zone. Journal of Transportation Engineering 129(3): 253-261, 2003.

43. Rahimi, M., Najmedin M. (2001). "Human Factors in Highway-Rail Crossing Accidents: the Influence of Driver Decision Style." Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. http://drivingassessment.uiowa.edu/DA2001/70_Rahimi_Mansour.pdf. Accessed in 2012.

44. American Association of State Highway and Transportation Officials (AASHTO). A Policy on Geometric Design of Highways and Streets, 5th Edition. Washington, D.C., 2004.

45. Shinar, D. and R. Compton, Aggressive driving: an observational study of driver, vehicle, and situational variables. Accident Analysis & Prevention, 2004. 36(3): p. 429-437.

46. Hicks, T., R. Tao, and E. Tabacek, Observations of Driver Behavior in Response to Yellow at Nine Intersections in Maryland, in Transportation Research Board 84th Annual Meeting. 2005, Transportation Research Board: Washington D.C.

47. Ahmed Amer, Hesham Rakha (2011). Stochastic Modeling of Driver Decision at the Onset of a Yellow Indication at Signalized Intersections

48. Hao, Wei, and Janice Daniel. "Driver injury severity related to inclement weather at

highway–rail grade crossings in the United States." Traffic injury prevention 17.1 (2016): 31-38.

49. Sharma, A., Rilett, L., Wu, Z., & Wang, S. (2012). Speed Limit Recommendation in Vicinity of Signalized, High-Speed Intersection.

50. Minge, Erik, Jerry Kotzenmacher, and Scott Peterson. Evaluation of non-intrusive technologies for traffic detection. No. MN/RC 2010-36. Minnesota Department of Transportation, Research Services Section, 2010.

51. Institute of Traffic Engineers. Traffic Engineering Handbook, Institute of Traffic Engineers, Washington, D.C., 1999.

Appendix: Data Reduction Program in VBA

```
Private Sub CommandButton1_Click()

Dim i As Integer

Dim j As Integer

Dim m As Integer

Dim n As Integer

Dim myrange As Range

Sheets.Add(after:=Sheets(Sheets.Count)).Name = "Sheet5"  'create sheet5

Sheet2.Cells(1, 2) = "TIME"

Sheets("Sheet5").Cells(1, 1) = "StartTime"

Sheets("Sheet5").Cells(1, 2) = "EndTime"

Sheets("Sheet5").Cells(1, 3) = "ViolationSpeed"

'------------------------------------------ Autoscope data -------------------------------------------'

Sheet1.Activate  'find presence sensor 107/106 and 108/110 movement

j = 1

For i = 2 To Sheet1.UsedRange.Rows.Count

If Cells(i, 9) = 1 And Cells(i + 1, 9) = 1 And (Cells(i, 3) = 107 And

Cells(i + 1, 3) = 106 Or Cells(i, 3) = 106 And Cells(i + 1, 3) = 107) Then

If Cells(i + 2, 9) = 0 Then

j = j + 1

Sheets("Sheet5").Cells(j, 1) = Format(Sheet1.Cells(i + 1, 6), "hh:mm:ss")  'write gate start time

to sheet5

Re1:                          Set myrange1 = Sheets("sheet1").Range(Cells(i, 3), Cells(i

+ 15, 3)).Find(what:="110")
```

```
If myrange1 Is Nothing Then GoTo nextstep
If (Cells(myrange1.Row, 6) * 86400 - Cells(i, 6) * 86400) < 8 Or
(Cells(myrange1.Row, 6) * 86400 - Cells(i, 6) * 86400) > 15 Then
Rows(myrange1.Row).Select
Selection.Delete Shift:=xlUp
i = i - 1
GoTo Re1
End If
Sheets("Sheet5").Cells(j, 2) =Format(Sheet1.Cells(myrange1.Row,
6), "hh:mm:ss") 'write gate end time to sheet5
End If
        End If
nextstep: Next i

Sheets("Sheet5").Activate 'delete false gate movement time
For i = 2 To Sheets("Sheet5").UsedRange.Rows.Count
If Cells(i, 1) = "" Then GoTo Re2
If Cells(i, 2) = "" Then
Sheets("Sheet5").Rows(i).Select
Selection.Delete Shift:=xlUp
i = i - 1
End If
Next i
```

```
Re2:


'------------------------------------------- Smartsensor HD ----------------------------------------'
Sheet2.Activate
For i = 2 To Sheet2.UsedRange.Rows.Count
If Cells(i, 1) = "" Then GoTo Re3
If Cells(i, 4) > 5 Then Cells(i, 2) = Format(Mid(Cells(i, 1), 11, 11), "Long Time")
If Cells(i, 4) < 5 Then   'delete smartsonsor speed lower than 5 mph
Sheet2.Rows(i).Select
Selection.Delete Shift:=xlUp
i = i - 1
End If
Next i
Re3:
For i = 2 To Sheet2.UsedRange.Rows.Count
Cells(i, 10) = Int(Cells(i, 2) * 86400)
If Mid(Cells(i, 10), 5, 1) = 9 Then Cells(i, 10) = Cells(i, 10) + 1
Next i


'----------------------------------------------- Data fusion -------------------------------------------'
Sheets("Sheet5").Activate
For i = 2 To Sheets("Sheet5").UsedRange.Rows.Count
If Cells(i, 1) = "" Then GoTo Re4
```

```
Sheet2.Cells(i, 12) = Round(Mid(Sheets("Sheet5").Cells(i, 1), 1, 8) * 86400, 0)
Sheet2.Cells(i, 13) = (Mid(Sheet2.Cells(i, 12), 1, 4) + 1) * 10
Sheet2.Activate
m = Sheet2.UsedRange.Rows.Count
Range(Sheet2.Cells(2, 10), Sheet2.Cells(m, 10)).Select
'find potention violation speed between gate movement
Set myrange2 = Sheets("sheet2").Range(Sheet2.Cells(2, 10), Sheet2.Cells(1008,
10)).Find(what:=Sheet2.Cells(i, 13))
If myrange2 Is Nothing Then GoTo Re5
If Sheet2.Cells(myrange2.Row, 4) > 10 Then Sheets("Sheet5").Cells(i, 3) =
Sheet2.Cells(myrange2.Row, 4)
Re5:
Next i

'-----------------------------------------------Final Data-------------------------------------------'
Re4:
Sheet2.Columns("J:R").Select
Selection.Delete Shift:=xlToLeft
Sheets("Sheet5").Activate
Cells(1, 1).Select
With Me.ListBox1
.ColumnCount = 3
.ColumnHeads = True
```

```
.RowSource = "A2:C40"

End With


End Sub


'---------------------------------------------- Interface ---------------------------------------------'

Private Sub CommandButton2_Click()

Unload UserForm1

End Sub


Sub CommandButton3_Click()

Dim intEventCount As Integer

intEventCount = intEventCount + 1

Sheets.Add(after:=Sheets(Sheets.Count)).Name = "Sheet4"  'create sheet4


If Sheet3.Cells(intEventCount, 8) = "" Then Sheet3.Cells(intEventCount, 8) =

Format(ListBox1.List(ListBox1.ListIndex, 0), "hh:mm:ss")

MsgBox "Done"

Dim Val As Integer


'------------------------------------- Find Gate Start Time ------------------------------------------'

Sheet3.Activate

For x = 0 To 5   'search gate start time
```

```
m = Format((Cells(1, 8) * 86400 - 10 - x) / 86400, "hh:mm:ss")
Set myrange1 = Sheet3.Range(Cells(2, 3), Cells(Sheet3.UsedRange.Rows.Count,
3)).Find(what:=m)
If Not myrange1 Is Nothing Then GoTo nextstep1
Next x
If myrange1 Is Nothing Then GoTo stop0
nextstep1:

Set myrange2 = Sheets("sheet3").Range(Cells(2, 2), Cells(Sheet3.UsedRange.Rows.Count,
2)).Find(what:=Cells(myrange1.Row, 2))
If myrange2 Is Nothing Then GoTo nextstep3
Cells(2, 8) = Cells(myrange1.Row, 2)
For i = 0 To 10
Cells(2, 8) = Cells(2, 8) + 1
Set myrange4 = Sheets("sheet3").Range(Cells(2, 2),
Cells(Sheet3.UsedRange.Rows.Count, 2)).Find(what:=Cells(2, 8))
Sheet3.Cells(myrange4.Row, 3).Select
Cells(2, 9) = Cells(myrange4.Row, myrange4.Column)
For j = 1 To 50
Set myrange3 = Sheets("sheet3").Range(Cells(2, 2),
Cells(Sheet3.UsedRange.Rows.Count, 2)).Find(what:=Cells(2, 9))
If myrange3 Is Nothing Then GoTo nextstep2
Sheets("Sheet4").Cells(30 * (intEventCount - 1) + j, 5 * i + 1) =
```

```
Sheet3.Cells(myrange3.Row, 2)
Sheets("Sheet4").Cells(30 * (intEventCount - 1) + j, 5 * i + 2) =
Format(Sheet3.Cells(myrange3.Row, 3), "hh:mm:ss")
Sheets("Sheet4").Cells(30 * (intEventCount - 1) + j, 5 * i + 3) =
Sheet3.Cells(myrange3.Row, 4)
Sheets("Sheet4").Cells(30 * (intEventCount - 1) + j, 5 * i + 4) =
Sheet3.Cells(myrange3.Row, 5)
Rows(myrange3.Row).Select
Selection.Delete Shift:=xlUp
Next j
nextstep2:
Next i
nextstep3:

'------------------------------ Repair broken data from lost vehicles ----------------------------'
Sheets("Sheet4").Activate
For i = 0 To Sheets("Sheet4").UsedRange.Columns.Count
If Cells(30 * (intEventCount - 1) + 1, 5 * i + 1) = "" Then GoTo nextstep4
If (Cells(Cells(65536, 5 * i + 4).End(xlUp).Row, 5 * i + 2) * 86400 - Cells(1, 5 *
(i + 1) + 2) * 86400 < 2) And (Cells(Cells(65536, 5 * i + 4).End(xlUp).Row, 5 * i
+ 2) < Cells(1, 5 * (i + 1) + 2)) And (Cells(Cells(65536, 5 * i +
4).End(xlUp).Row, 5 * i + 4) - Cells(1, 5 * (i + 1) + 4) > 0) Then
        If (Cells(Cells(65536, 5 * i + 4).End(xlUp).Row, 5 * i + 4) - Cells(1, 5 *
```

```
(i + 1) +4)) < 20 And Cells(65536, 5 * (i + 1) + 4).End(xlUp).Row <
15 Then
        Range(Cells(1, 5 * (i + 1) + 1), Cells(Cells(65536, 5 * (i + 1) +
4).End(xlUp).Row, 5 * (i + 1) + 4)).Select
        Selection.Cut
        Cells(Cells(65536, 5 * i + 4).End(xlUp).Row + 1, 5 * i + 1).Select
            ActiveSheet.Paste
            With Selection.Interior
                .Pattern = xlSolid
                .PatternColorIndex = xlAutomatic
                .Color = 65535
                .TintAndShade = 0
                .PatternTintAndShade = 0
        End With
        Range(Columns(5 * (i + 1) + 1), Columns(5 * (i + 1) + 5)).Select
        Selection.Delete Shift:=xlToLeft
End If
End If
Next i
nextstep4:

For j = 0 To Sheets("Sheet4").UsedRange.Columns.Count
If Cells(1, 5 * j + 1) = "" Then GoTo nextstep5
```

```
If (30 * (intEventCount - 1) + Cells(Cells(65536, 5 * j + 4).End(xlUp).Row, 5 * j
+ 2) * 86400 - Cells(30 * (intEventCount - 1) + 1, 5 * j + 2) * 86400 <= 3) Then
Range(Cells(30 * (intEventCount - 1) + 1, 5 * j + 1), Cells(30 *
(intEventCount - 1) + Cells(65536, 5 * j + 4).End(xlUp).Row, 5 * j
+ 5)).Select
                    Selection.Delete Shift:=xlToLeft
                    j = j - 1
          End If
Next j
nextstep5:

'---------------------------------------- Time step: 1 sec interval -------------------------------------'
For j = 0 To Sheets("Sheet4").UsedRange.Columns.Count
'----- Delete repeated time (second) -----'
If Cells(30 * (intEventCount - 1) + 1, 5 * j + 1) = "" Then GoTo stop0
For i = 1 To Sheets("Sheet4").UsedRange.Rows.Count
If Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1) = "" And Cells(30 *
(intEventCount - 1) + i + 1, 5 * j + 2) = "" Then GoTo nextstep8
          k = 1 '//INITIATE THE VARIABLE
          ACC = Cells(30 * (intEventCount - 1) + i, 5 * j + 3)
 If Cells(30 * (intEventCount - 1) + i, 5 * j + 2) = Cells(30 * (intEventCount - 1) +
i + 1, 5 * j + 2) Then   '//FIND THE SAME TIME
                    ACC = Cells(30 * (intEventCount - 1) + i, 5 * j + 3) + Cells(30 *
```

```
(intEventCount - 1) + i + 1, 5 * j + 3)
                    For k = 2 To 20
                              If Cells(30 * (intEventCount - 1) + i + k, 5 * j + 1) = "" Then GoTo
nextstep6
                              c = Cells(30 * (intEventCount - 1) + i + k, 5 * j + 2) * 86400
                              d = Cells(30 * (intEventCount - 1) + i, 5 * j + 2) * 86400
                              If c - d > 1 Then GoTo nextstep6
                              If c - d = 1 Then GoTo nextstep60
                    If c = d Then ACC = ACC + Cells(30 * (intEventCount - 1) + i +
k, 5 * j + 3)
Next k
nextstep6:
End If
nextstep60:
AVE = ACC / k  '//AVERAGE AMONG THE SAME TIME
Cells(30 * (intEventCount - 1) + i, 5 * j + 3) = AVE
Cells(30 * (intEventCount - 1) + i, 5 * j + 3).Select '//MARK WITH COLOR
With Selection.Interior
                    .Pattern = xlSolid
                    .PatternColorIndex = xlAutomatic
                    .Color = 5296274
                    .TintAndShade = 0
                    .PatternTintAndShade = 0
```

```
End With

For m = 1 To Cells(65536, 5 * j + 1).End(xlUp).Row
'//DELETE THE REPEATED TIME
If Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1) = "" Then GoTo
nextstep7
e = Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 2) * 86400
f = Cells(30 * (intEventCount - 1) + i, 5 * j + 2) * 86400
If e - f = 2 Then
Range(Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1), Cells(30 *
(intEventCount - 1) + i + 1, 5 * j + 4)).Select
                        Selection.Insert Shift:=xlDown, CopyOrigin:=
xlFormatFromLeftOrAbove
Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 2) = (Cells(30 *
(intEventCount - 1) + i, 5 * j + 2) * 86400 + 1) / 86400
Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 3) = Cells(30 *
(intEventCount - 1) + i, 5 * j + 3)
Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1) = Cells(30 *
(intEventCount - 1) + i, 5 * j + 1)
                End If
If e - f = 1 Then GoTo nextstep7
If e - f = 0 Then
If i <> 1 Then Cells(30 * (intEventCount - 1) + i, 5 * j + 4) =
```

```
Cells(30 *(intEventCount - 1) + i + 1, 5 * j + 4)
Range(Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1), Cells(30 *
(intEventCount - 1) + i + 1, 5 * j + 4)).Select
                        Selection.Delete Shift:=xlUp
                End If
Next m
nextstep7:
Next i
nextstep8:

'----- Insert missing time (second) -----'
For i = 1 To Sheets("Sheet4").UsedRange.Rows.Count
If Cells(30 * (intEventCount - 1) + i, 5 * j + 1) = "" And Cells(30 *
(intEventCount - 1) + i, 5 * j + 2) = "" Then GoTo nextstep9
'//FIND THE LAST ROW
TIM1 = Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 2) * 86400
        TIM2 = Cells(30 * (intEventCount - 1) + i, 5 * j + 2) * 86400
        TIM3 = (TIM1 - TIM2)
        Val = Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 3) - Cells(30 *
(intEventCount - 1) + i, 5 * j + 3)
        If TIM3 < 1.1 And TIM3 > 0.9 Then GoTo nextstep10
        If TIM3 > 1.1 Then
                Range(Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1), Cells(30 *
```

```
(intEventCount - 1) + i + 1, 5 * j + 4)).Select
                     Selection.Insert Shift:=xlDown, CopyOrigin:=
xlFormatFromLeftOrAbove
                    ' TIM4 = CLng(TIM2) * 86400
                    TIM = (TIM2 + 1) / 86400 - 1 + TIM2
                    Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 2) = TIM
                    If Val = 0 Then Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 3) =
Cells(30 * (intEventCount - 1) + i, 5 * j + 3)
'//THE INSERTED SPEED IS CHANGABLE
          If Val > 0 Or Val < 0 Then Cells(30 * (intEventCount - 1) + i + 1, 5 * j +
3) = Cells(30 * (intEventCount - 1) + i, 5 * j + 3) + Val / TIM3
                    Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 1) = Cells(30 *
                    (intEventCount - 1) + i, 5 * j + 1)
                    Cells(30 * (intEventCount - 1) + i + 1, 5 * j + 4) = (Cells(30 *
(intEventCount - 1) + i, 5 * j + 4) + Cells(30 * (intEventCount - 1) + i + 2,
5 * j + 4)) / 2
End If
nextstep10:
Next i
nextstep9:

'-------------------------------------------- Plot figures --------------------------------------------'
Set ab = Sheets("Sheet4").Range(Cells(30 * (intEventCount - 1) + 10, 5 * j + 1),
```

```
Cells(30 * (intEventCount - 1) + 25, 5 * j + 5)) 'figure area
Set bbb = ActiveSheet.ChartObjects.Add(0, 0, 0, 0)
bbb.Chart.ChartType = xlXYScatterSmooth 'chart type
bbb.Chart.SetSourceData Source:=Sheets("Sheet4").Range(Cells(30 * (intEventCount - 1) + 1, 5
* j + 2), Cells(30 * (intEventCount - 1) + Cells(65536, 5 * j + 4).End(xlUp).Row, 5 * j + 4))
'data source
With bbb
.Top = ab.Top
.Left = ab.Left
        .Width = ab.Width
        .Height = ab.Height
End With
 bbb.Chart.HasTitle = True
bbb.Chart.ChartTitle.Text = j + 1
bbb.Chart.ChartTitle.Font.Size = 10
bbb.Chart.FullSeriesCollection(1).AxisGroup = 2
bbb.Chart.FullSeriesCollection(1).Name = "=""Speed"""
bbb.Chart.FullSeriesCollection(2).Name = "=""Distance"""
bbb.Chart.Axes(xlValue, xlSecondary).MinimumScale = 0
bbb.Chart.Axes(xlValue, xlSecondary).MaximumScale = 45
bbb.Chart.Legend.Position = xlLegendPositionBottom
Next j
```

```
stop0:

Sheet3.Activate

Sheet3.Columns("H:I").Select

Selection.Delete Shift:=xlToLeft

' Application.DisplayAlerts = False

' Sheets("Sheet5").Delete

'Application.DisplayAlerts = True

Sheets("Sheet4").Activate

stopend:

End Sub

Private Sub UserForm_Click()

End Sub
```