STUDY OF BUS DRIVER BEHAVIOR AT THE ONSET OF YELLOW TRAFFIC SIGNAL INDICATION FOR THE DESIGN OF YELLOW TIMES

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

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June 27th, 2014
Blacksburg, VA

Keywords: Yellow Interval, Signal Timing, Dilemma Zone, PRT, Vehicle Deceleration, Bus

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ABSTRACT

Driver violations at traffic signals are a major cause of intersection vehicle crashes. The yellow interval is used to inform approaching drivers of an upcoming change in the traffic signal indication from green to red. Current yellow-interval durations are currently calculated to accommodate for dilemma zone protection for passenger cars only. Buses with different vehicle, driver, and occupancy characteristics behave differently at the onset of a yellow indication. The research presented in this thesis characterizes the difference between bus and passenger car driver behavior at the onset of yellow-indication. A revised set of yellow timing procedures are presented to address the requirements for bus dilemma zone protection.

A dataset of 864 stop-go records were collected as part of the research effort using a school bus approaching a traffic signal on the Virginia Smart Road facility. The experiment was conducted at an instructed speed limit of 57 km/h (35 mph) approach speed where participant drivers were presented with yellow indications. A total of 36 participating bus drivers were randomly selected from three age groups (under 40 years old, 40 to 64 years old and 65 and above) with equal number of male and female for each age group.

Using the data collected as part of this research effort, statistical models were created to model bus driver perception-reaction times (PRTs) and deceleration levels considering driver attributes (age and gender), roadway grade, vehicle approach speed, and time to intersection (TTI) at the onset of the yellow indication. A Monte-Carlo simulation was conducted to develop appropriate yellow indication timings to provide adequate dilemma zone protection for buses. Lookup tables were then developed for different reliability levels to provide practical guidelines for the design of yellow signal timings to accommodate different bus percentages within the traffic stream. The recommended change durations can be integrated within the Vehicle Infrastructure Integration (VII) initiative to provide customizable driver warnings prior to a transition to a red indication.

ACKNOWLEDGEMENTS

I would like to acknowledge my late father for his morale and financial support throughout my academic career and for encouraging me to continue pursuing a graduate degree. I would also like to thank my mother for her continued support in every aspect after my father passed away. I must thank my sisters for their continued morale support and encouragements.

I would like to thank my advisor, Dr. Hesham Rakha, for believing that I could finish my M.S. degree with a thesis in one year. He has also provided continuous support necessary for completing my research. His advices and critiques are invaluable to the quality and completion of my work.

I would also like to thank Dr. Ihab El-Shawarby for his patience and advice throughout the research and experiment process. His firsthand experiences with previous experiments conducted by former students were significant aids for the completion of my data collection.

I would like to thank Dr. Bryan Katz for lending us one of his school buses for the experiment.

I must extend my thanks to Mohamed Abdelmegeed, Hao Chen, and Raj Kishore Kamalanathsharma for helping me when conducting the experiments. I have to thank Craig Bryant for his help and advice with starting up the experiment and the pilot run during my first semester as a graduate student. I would also like to thank Dr. Hao Yang for helping me with the statistic portion of the research and KT Torrey from the Virginia Tech writing center for helping me to proofread my thesis.

Also I would like to thank members of the Smart Road Maintenance, Duane Cameron and Jeff Potter, for helping with getting fuel for the test vehicle and making sure the Smart Road was in optimal condition for the experiment. I would also like to thank members of the Smart Road Scheduling Team, Leonore Nadler and Lauren Butterfield, for working on scheduling plenty of Smart Road time for the experiment.

Finally I would also like to thank my girlfriend, Diep M. Nguyen, for moving to University of Georgia to do her PhD so that I could focus on finishing my graduate studies in one year.

ATTRIBUTIONS

Dr. Hesham Rakha, committee chair, and Dr. Ihab El-Shawarby, committee co-chair, oversaw and assisted in all aspects of data collection for this research effort. Dr. Rakha provided oversight and guidance in the modeling of driver behavior and the development of the models and yellow timing procedures. Dr. Rakha and Dr. El-Shawarby along with Dr. Bryan Katz, committee member, also assisted in the research, analysis, and conclusions that are presented in this thesis.

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CHAPTER 1: INTRODUCTION

Traffic signals were introduced to the highway system infrastructure in order to regulate the movement of vehicles traveling in conflicting directions at roadway intersections. In order to provide a smooth transition between various movements during a change in signal indication, a yellow interval is provided at the termination of each green indication. According to the Manual on Uniform Traffic Control Devices (MUTCD) [1], "*the yellow signal indication warns the vehicle that their green movement is being terminated and a red signal indication will be exhibited immediately*". The research presented in this thesis quantifies and models bus driver perception-reaction times (PRTs) and deceleration levels for the design of signal timing change intervals. Throughout this thesis, buses will used to reference any passenger vehicle that can transport more than 15 people as defined in the ITE Traffic Engineering Handbook, 6th edition as "three types of buses with different functions are generally considered in traffic engineering analyses: local transit buses, school buses, and intercity buses" [2]. This chapter presents an introduction to the study's background, objectives, and approach.

1.1 BACKGROUND

Yellow indication is used to alert drivers that a signal phase is ready to end and change to a red indication. At the onset of yellow, drivers approaching the intersection must decide either to proceed through the intersection or come to a complete stop and wait till the next green phase is presented. Drivers who chose to stop are at an increased risk of a rear-end collision if the decision is made to decelerate rapidly when the following vehicle expects the driver to proceed through the intersection. Drivers who elect to proceed through the intersection are at risk of either running a red light or being exposed to a right-angle collision if they are unable to clear the intersection before the all-red phase ends and conflicting traffic is presented with a green indication. Bus high vehicle occupancy increases the potential injury or fatalities if presented with a collision. Information and data from the NHTSA Fatality Analysis Reporting System (FARS) relating to buses involved in fatal crashes from 2000-2011 indicates a total of 3294 fatal crashes with 1302 being front point of impact and 449 as rear point of impact [3].

1.2 THESIS OBJECTIVES

The objectives of this research effort are three-fold. First, construct a comprehensive dataset of bus driver behavior at the onset of a yellow indication. Second, characterize and model the probability of running/stopping decision, PRT, and deceleration behavior at the onset of yellow indication considering the impact of driver age, approach speed, time-to-intersection, gender, and roadway grade on driver behavior. Third, design yellow timings to account for buses in the traffic stream and under wet roadway surface and rainy conditions considering different levels of reliability.

1.3 RESEARCH APPROACH

The initial task for this research effort was to design and conduct a field experiment to gather data on bus and bus driver behavior at the onset of a yellow indication for clear weather and dry roadway conditions. As mentioned previously, several previous studies were conducted for passenger cars approaching under different weather (clear or rainy) and pavement (dry or wet) conditions [4, 5]. Another study was conducted to assess truck driver behavior for clear weather and dry roadway conditions using a truck simulator [6]. In order to maintain consistency between the passenger car experiments, the experimental design was made identical with the exception of using a bus as the test vehicle for the experiment under clear weather and dry roadway conditions.

The experiment was conducted on the Virginia Smart Road test facility at the Virginia Tech Transportation Institute (VTTI), a unique, state-of-the-art, full-scale, closed test-bed research facility [7]. After obtaining the Virginia Tech Institutional Review Board (IRB) approval, human test subjects were recruited to participate in the experiment and drive on the Smart Road. Equipment and computer systems used for data collection and communication with the traffic signal were installed on the test vehicle. Data were recorded continuously throughout each experiment session under a researcher's surveillance.

Bus driver PRTs, deceleration levels, and probability of stopping/running decisions were studied and modeled based on collected data. New regression models were established for PRTs, deceleration levels, and stopping/running decisions considering the driver characteristics, roadway grade, and vehicle instantaneous states. The Institute of Transportation Engineers (ITE) yellow interval design formula was used to develop design guidelines in the form of look-up tables for traffic signal change interval timing plans under different weather conditions and different percentage of bus factor in the traffic stream at different reliability levels. Conclusions for the current study and recommendations for future works are presented at the end of the thesis.

1.4 THESIS ORGANIZATION

This chapter briefly presents an overview of the research in designing yellow interval durations for traffic streams with different bus percentage under different environment conditions like clear or rainy weather and dry or wet pavement. Chapter two presents a detailed literature review of various past researches on driver red-light running, deceleration levels, PRTs and weather effects on traffic signals. Brief discussions on heavy vehicle dilemma zones are also presented in chapter two. Chapter three discusses the experimental design in data collection and modeling the stop/run decision model, PRT and Deceleration model later used for Monte Carlo simulation. Chapter four discusses the application of the PRT and Deceleration model developed in chapter three in the Monte Carlo simulation to generating tables of proposed yellow indication durations with carrying approach speed limits, roadway grades, precipitation conditions, confidence intervals, and varying bus percentage within traffic stream. Finally, chapter five summarizes the conclusions made based on the research and recommends future research improvements.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The goal of the research presented in this thesis is to model the stop/run behavior of bus drivers at the onset of yellow indication. Before this effort is undertaken, an in-depth literature review on current and previous studies on dilemma zone modeling, vehicle deceleration behavior modeling, driver PRT modeling, and weather effect on traffic is performed.

2.2 DILEMMA AND OPTION ZONE AND YELLOW INTERVAL TIME DURATION

2.2.1 Dilemma and Option Zone

Red-light running is one of the most common causes of intersection crashes. According to the Manual on Uniform Traffic Control Devices [1]"*the yellow signal indication warns the vehicle that their green movement is being terminated and a red signal indication will be exhibited immediately*". Some jurisdictions supplement the yellow interval with an all-red interval to provide additional clearance time to clear the intersection of all vehicles that entered the intersection legally during the yellow interval. The concept of dilemma zone was first defined by Gazis et al. [8] in 1960, "*when confronted with an improperly timed amber light phase a motorist may find himself, at the moment the amber phase commences, in the predicament of being too close to the intersection to stop safely or comfortably and yet too far from it to pass completely through the intersection before the red signal commences*." Gazis et al. noted that the additional length of special vehicles such as trucks, buses and vehicles towing trailers extended the amount of time required for these vehicles to completely clear an intersection and concluded that it was prudent to take these vehicles into consideration when designing yellow intervals. Figure 2-1 presents a graphic description of the dilemma zone.

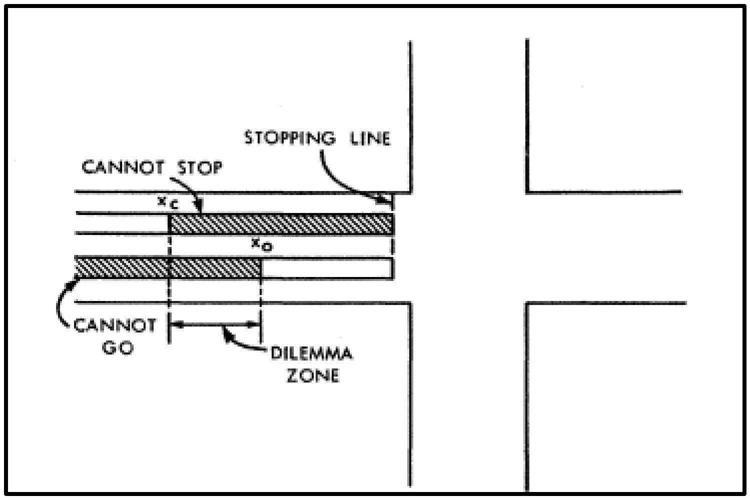

Figure 2-1: The Dilemma Zone [8]

In 1977, Zegeer et al. defines the term dilemma zone as the area in which greater than 10% of drivers and less than 90% of drivers stop [9]. Figure 2-2 demonstrates probability distribution curves for several approach speeds.

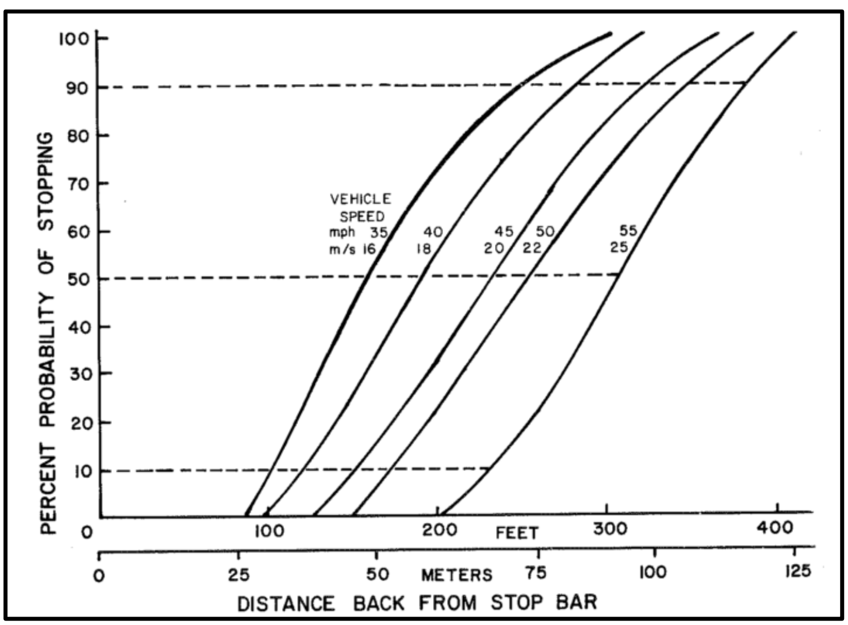

Figure 2-2: Probability Distribution of Stopping Behavior for Multiple Approach Speeds [9]

The phrase 'Dilemma Zone' has been used in recent years to describe this short coming of traffic signal design. El-Shawarby et al. [10] defined the concept of option zone where drivers can either decelerate the vehicle comfortably to a complete stop or clear the intersection during the same yellow interval. As illustrated in Figure 2-3, if a vehicle is farther than D_{stop} to the stop bar at the onset of yellow indication, it can come to a safe stop; if a vehicle is closer than D_{go} to the stop bar, it can legally clear the intersection.

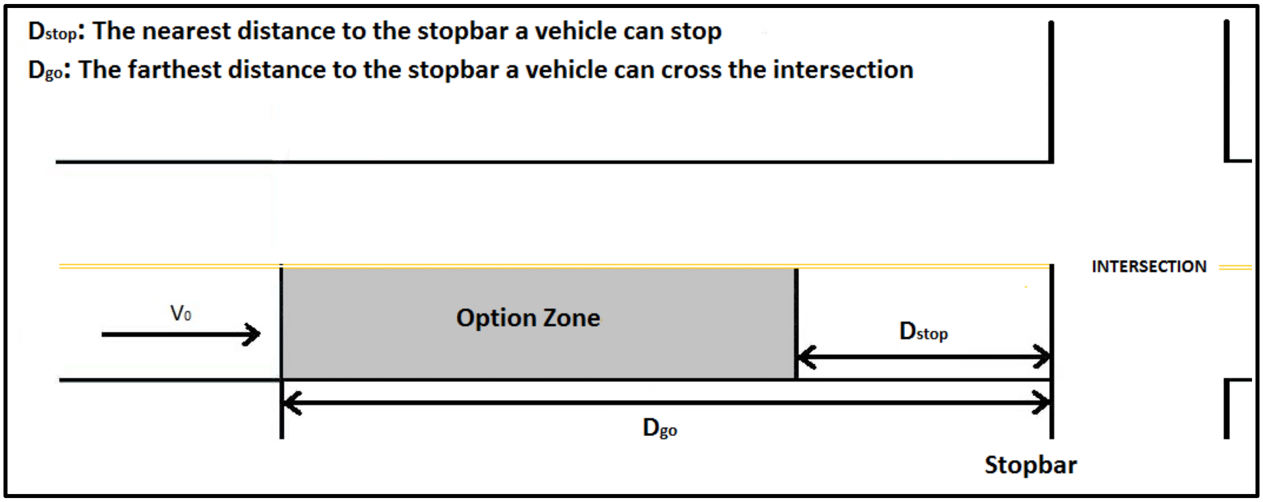

Figure 2-3: Option Zone [10]

Research found that the dilemma zone differs by a variety of parameters. For example, the dilemma zone is wider for the older drivers (65 years of age or older). Female drivers are more likely to stop than male drivers and the dilemma zone for the female drivers tend to be closer to the stop bar than male drivers [11].

2.2.2 Yellow Interval Duration

Matson et al. first defined the yellow interval time as a function of intersection width and assumed constant approach speed [12]. In this definition, driver response factors and vehicle deceleration levels were assumed to have no effect on yellow interval times. Further research proved that these assumptions were invalid. Later, Matson included driver PRTs and vehicle deceleration levels, as well as intersection clearance times to his model [13]. Subsequently, Gazis et al. developed the Gazis-Hemran-Maradudin (GHM) model which associated yellow interval duration with driver PRTs, vehicle deceleration characteristics, and intersection layout [8].

The current state-of-practice for yellow interval times is the ITE equation, presented as Equation 2.1, based on the kinematic model of vehicles' deceleration times at intersections. A field study of 10 intersections found that the yellow signal timings set to the current ITE equation reduced red light running violations [14]. Current state-of-practice only accommodates passenger cars and passenger car drivers.

$$y = t + \frac{v_0}{2(a + 9.81G)} + \frac{W + L}{v_0} \tag{2.1}$$

Where
- y is the yellow signal time duration (s)
- t is driver PRT (s)
- a is the constant deceleration rate (m/s^2)
- v_0 is the constant approach speed (m/s)
- G is the roadway grade (decimal)
- W is the effective intersection width (m)
- L is the length of vehicle (m)

The term $\frac{W+L}{v_0}$ is only used when there is no all-red interval

A study has found evidence that an increase of 1.0 s in yellow duration, such that it does not exceed 5.5 s) will decrease the frequency of red-light running by at least 50 percent, while driver adaptation to the change does not undo the benefit [15]. Some proposed yellow interval timing concluded in previous research studies are shown Table 2-1.

Table 2-1: Suggested Yellow Interval Duration [16]

Author \ Speed (mph)	30	35	40	45	50	55
Olson & Rothery [17]	4.1	--	4.3	--	5.1	--
Parsonson [18]	4.0	4.0	4.3	4.5	4.8	5.0
Herman [19]	4.0	4.2	4.4	4.8	5.0	--
Minnesota [20]	3.2	3.5	3.7	3.9	4.1	4.6
Zegger (Kentucky) [9]	--	5.0	4.8	4.9	4.8	4.8
Sheffi & Mahmassani [21]	--	4.7	4.8	4.9	5.0	5.1

2.3 HEAVY VEHICLE STOPPING BEHAVIOR

More than 85% of the commercial vehicles operating in the United States use S-cam drum foundation brakes in their air brake system [22]. Most tractor-trailer vehicles with a gross vehicle rating over 19,000 pounds, most single trucks with a gross vehicle weight rating over 31,000 pounds, most transit and inter-city buses, and about half of all school buses are equipped with airbrake systems [22]. Most heavy vehicle drivers have longer PRTs compared to passenger car drivers due to the airbrakes equipped in most vehicles as opposed to the hydraulic braking systems of passenger cars.

Heavy vehicles also have lower deceleration rates due to their significantly larger masses compared to passenger vehicles. Current state-of-practice for traffic signal yellow indications only account for design standards for passenger cars [23]. These design assumptions present a potential conflict where heavy vehicle drivers may be in situations where they have no choice but to run a red light.

In 2007, Gates et al. conducted a field study using video cameras at six intersections in the Madison, Wisconsin Area. Data were collected for the first-to-stop and last-to-go vehicles during each yellow signal interval. This study found that heavy vehicles such trucks, buses, and recreational vehicles (RVs) were more likely to proceed through a yellow signal than standard passenger vehicles [24].

In 2010, again conducting a field study using video cameras at intersections in the Madison, Wisconsin Area, Gates and Noyce found that tractor trailers were 3.6 times more likely 8 to run a red traffic signal than standard passenger cars [25]. Gates and Noyce concluded that the difference in stopping behavior for trucks was likely due to the fact that trucks do not stop as rapidly as passenger cars, truck drivers likely avoided aggressive braking events to prevent the shifting of their cargo, and that truck drivers are pressured to avoid stopping in order to avoid delay-related costs. Additionally, Gates and Noyce concluded that trucks do in fact have lower deceleration levels compared to standard passenger vehicles, stating that "*vehicle type was found to have a statistically significant effect on both deceleration rate and red light running occurrence but did not have an effect on brake response time. Deceleration rates were highest for cars and light trucks; single-unit trucks showed significantly lower deceleration rates. Deceleration rates for tractor trailers were similar to those of single-unit trucks*."

In 2007 Zimmerman conducted a study using a CORSIM simulation to examine the effect of various yellow time extensions on truck red light running. The simulation examined different percentages of trucks in the stream of traffic as well as different extensions of the dilemma zone to determine which conditions left the fewest trucks in the dilemma zone. The results of the simulation demonstrated that an increase in yellow times of 1.5 or 2.0 seconds reduced the number of trucks in the dilemma zone; an extension of 1.5 seconds, however, was found to be the most effective, reducing the number of trucks in the dilemma zone by 47 percent without significantly affecting the efficiency of the intersection [26].

In a 2009 paper, Wei et al. published an analysis of a field study conducted using video cameras at an intersection in Fairfield, OH. The speed limit of the approach of the intersection was 50 MPH and the yellow interval was set at 4.5 seconds. Analyzing the behavior of all first-to-stop and last-to-pass vehicles, the authors determined that the dilemma zone for heavy trucks began approximately 1.0 second further back from the intersection than did the dilemma zone for standard passenger cars [27].

In 2012, as part of a report prepared for the National Cooperative Highway Research Program, McGee et al. identified the need to factor trucks into the design of yellow times. However, this study only considered trucks when designing all-red times. This was done by considering the difference in vehicle length between a tractor-trailer and a standard passenger car [28].

2.4 SUMMARY AND PROPOSED RESEARCH

Based on the information presented and discussed in this chapter, it is concluded that there has been prior research performed investigating dilemma zone for passenger cars, few for trucks, and even fewer for buses. Gates and Noyce [25], Zimmerman [26], and Wei et al. [27] have recommended for extensions for yellow intervals to account for the dilemma zone associated with trucks but there was no mention for any recommendation for buses. These studies are limited in scope as they only acknowledge the difference in dilemma zone for different vehicles but fail to adequately identify and quantify the factors that contribute to this extended dilemma zone.

The following sections of this thesis will focus on an experiment conducted at the Virginia Tech Transportation (VTTI) on the Virginia Smart Road using a bus as the test vehicle to develop an agent-based stochastic approach to design yellow timings that account for the risk of bus drivers caught in a dilemma zone. This experiment builds on previous work done at VTTI involving passenger cars and trucks [4, 5, 6].

CHAPTER 3: ANALYSIS OF BUS DRIVER PRT AND DECELERATION BEHAVIOR AT SIGNALIZED INTERSECTIONS

Boon Teck Ong, Hesham Rakha, and Ihab El-Shawarby

3.1 ABSTRACT

The research presented in this paper quantifies and models bus driver perception-reaction times (PRTs) and deceleration levels at traffic signalized intersections. A total of 864 stop-run records were collected as part of the research effort for a 56 km/h (35 mi/h) approach speed where participant bus drivers encountered a yellow indication initiation at different distances from the intersection. The participant bus drivers were randomly selected in different age groups (under 40 years old, 40 to 64 years old, and 65 years of age or older) and genders (female and male). Using the gathered data, statistical models for driver PRT and deceleration levels were developed, considering roadway surface and environmental parameters, driver attributes (age and gender), roadway grade, approaching speed, and time and distance to the intersection at the onset of yellow. Effects of precipitation are included in the bus driver PRT and deceleration models using values derived from previous passenger car studies with the assumption that bus drivers are affected the same way as passenger car drivers. A logit model was developed using field data and driver characteristics to classify and predict the probability of bus drivers either running or stopping at the onset of yellow indication. The resulting bus driver PRT and deceleration models have an adjusted R^2 value of 0.16 and 0.87, respectively. The stop/run decision logit model has an 87.04% of correct classification for bus driver stop or run decision predictions. The resulting PRT and deceleration models can be used in designing yellow indication intervals to accommodate for buses in the traffic stream.

3.2 INTRODUCTION

Red-light running is one of the most common causes of intersection crashes. According to the Manual on Uniform Traffic Control Devices [1]"*the yellow signal indication warns the vehicle that their green movement is being terminated and a red signal indication will be exhibited immediately*." Some jurisdictions supplement the yellow interval with an all-red interval to provide additional clearance time to clear the intersection of all vehicles that entered the intersection legally during the yellow interval.

Studies of passenger car driver perception-reaction times and passenger car deceleration levels used in determining appropriate yellow and all-red change intervals have been conducted for decades and have continued to present day. The majority of these studies were focused on passenger cars with a small number dedicated to heavy vehicles like trucks, and even fewer for high occupancy vehicles like buses. Buses have significantly different physical characteristics compared to passenger cars and do not have the same behavior or response as passenger cars.

In summary, the objective of the study is to produce a PRT and deceleration model specific to bus driver behavior at the onset of a yellow indication. The resulting models can be used to generate yellow indication durations to account for different percentage of buses within the traffic stream. Finally, the study conclusions and recommendations for further research are presented.

3.3 BACKGROUND

Most tractor-trailer vehicles with a gross vehicle rating over 19,000 lb, most single trucks with a gross vehicle weight rating over 31,000 lb, most transit and inter-city buses, and about half of all school buses are equipped with air brake systems [22]. More than 85% of the commercial vehicles operating in the United States use S-cam drum foundation brakes in their air brake system [22]. Typically heavy vehicles equipped with air brake systems have longer PRTs before the brakes are effectively activated.

Buses have been defined as: any passenger vehicle that can transport more than 15 people [2]. Selected characteristics for some North American buses typically weigh between 14,000 to 36,000 pounds with an addition of 180 to 350 lb. per passenger compared to typical passenger cars with gross weights between 2,000 to 3,500 pounds [2]. Additional weight to the vehicle physical characteristics also contributes to a lower deceleration level. Typical dimensions of passenger cars are assumed to be 20 ft. in length which is significantly shorter than the accepted value of 40 ft. for transit buses and 60 ft. for articulated transit buses [2]. Due to the high occupancy capacity of buses making them significantly longer in length, they require more time to completely clear an intersection compared to passenger cars.

Information and data from the NHTSA Fatality Analysis Reporting System (FARS) relating to buses involved in fatal crashes from 2001-2011 indicates a total of 2969 fatal crashes with 1164 being front point of impact, 397 as rear point of impact, 138 from the left, and 107 from the right as point of impact [3].

When drivers are presented with a yellow indication, they must determine whether to stop safely or to proceed through the intersection before the end of the yellow interval. Incorrect decisions may result in either a rear-end collision if the following vehicles do not anticipate a rapid deceleration, or a right-angled collision if the driver does not have enough time to safely cross the intersection before conflicting flows are released.

The dilemma zone problem has been examined in the literature since its initial formulation [8], where the existence of dilemma zone at approaches to signalized intersections was identified and modeled as a binary decision problem to either stop or proceed when a yellow indication is triggered. However, an analysis of the literature demonstrates a lack of consensus in defining the dilemma zone. For example, the dilemma zone was defined "as that zone within which the driver can neither come to a safe stop nor proceed through the intersection before the end of the yellow phase" [21]. This definition represents the design definition of a dilemma zone. Alternatively, others define the dilemma zone (also called the decision zone) from a driver's perspective as the zone in which between 10 to 90 percent of the drivers stop [29]. The approach of modeling this problem was summarized as "developing dilemma zone curves of 'percent drivers stopping' versus 'distance from stop bar' at the instant when the signal indication changes from green to yellow" and that the driver behavior at high-speed signalized intersections when faced with a yellow indication can be viewed as a binary choice process, in which the relevant decisions are either to stop or proceed through the intersection [21].

Several research efforts have attempted to develop methods to decrease the possibility of being caught in the dilemma zone following this issue raised. Theoretically, when a vehicle is under the speed limit while approaching the signalized intersection, the dilemma zone can be totally eliminated by acceleration beyond a certain critical value or following a linear functional form. However, it is obviously inappropriate to urge drivers to accelerate blindly when they find themselves trapped in the dilemma zone. In terms of traffic signal design, a proper clearance interval can minimize or eliminate the number of drivers caught in dilemma zones [30]. Currently the commonly used method to compute the intervals is the ITE formula [2]. Equation (3.1) is the ITE formula based on the kinematic model of vehicles' deceleration times at intersections.

$$y = t + \frac{v_0}{2a + 2 \times 9.81G} \tag{3.1}$$

Where
- y is the yellow signal indication duration (s)
- t is driver PRT (s)
- v_0 is the constant approach speed (m/s)
- a is the constant deceleration rate (m/s^2)
- G Is the roadway grade (decimal)

A study by Wei et al. was found that heavy truck dilemma zones was significantly different in length from a light-duty vehicle dilemma zones, and indicated that it is offset upstream by approximately 1 second relative to light-duty vehicle dilemma zones [27]. The study demonstrated that heavy vehicles at intersections will likely run the light instead of attempting to stop. Another recent study conducted by McGee et al. for the National Cooperative Highway Research Program (NCHRP) highlighted the need to consider trucks in the design of intersection yellow and clearance times [28]. The study, however, only considered the effect of trucks in the design of all-red times by accounting for the differences in vehicle lengths.

From past studies, there were some but limited examinations of the dilemma zone associated with heavy-duty trucks, and even fewer for buses. Consequently, this paper attempts to address this void and design traffic signal yellow and clearance times considering bus impacts. This effort builds upon past research on passenger cars conducted at the Virginia Tech Transportation Institute (VTTI) that developed an agent-based stochastic approach for the design yellow timings that accounts for the risk of drivers being caught in the dilemma zone [4] and another study that quantified the impact of rainy and wet roadway surface conditions on the design of yellow timings [5]. Both studies will be described later in the following section. The studies demonstrated that the behavior in the controlled experiment was consistent with empirical observations from other studies in terms of PRTs, deceleration levels and driver stop-go behavior [4, 5, 31]. In both of these studies, light-duty sedan vehicles were used as the test vehicle to expose participants to 48 traffic signal timings in each trial, half of which were green and the other half entailed yellow indications introduced when the vehicle was at different distances from the intersection, and collected information including the approach speed, time to intersection, brake position, and other kinematic data. However, both of these studies, like many others, were limited to passenger cars.

3.4 EXPERIMENTAL DESIGN

In two previous studies [4, 5] performed by the same research group at Virginia Tech Transportation Institute, a controlled field data collection effort was conducted in an attempt to model passenger car driver PRT and deceleration behavior at the onset of yellow indications as a function of various driver, vehicle, and traffic stream characteristics under different weather and roadway conditions.

The field experiment described in this paper was conducted at the same location, the Virginia Department of Transportation's (VDOT) Smart Road facility. The focus of this study is on buses instead of passenger cars under clear weather and dry pavement conditions. Instructed speed limit for the experiment was 56 km/h (35 mph).

3.4.1 Test Facility

The Smart Road is a unique, state-of-the-art, full-scale, closed test-bed research facility, located at the Virginia Tech Transportation Institute (VTTI), owned and maintained by VDOT. The Smart Road is a 3.5 km (2.2 mi) two-lane road with one four-way signalized intersection, as illustrated in Figure 3-1. The section used for the data collection includes only the section between two turnarounds with the four-way signalized intersection. The first turnaround is a high-speed banked turnaround at one end and the second is a medium-speed speed flat turnaround at the other end. The intersection consists of two high-speed approaches and two low-speed approaches and is outfitted with customized controllers and vehicle presence sensors, as well as wireless communications. The horizontal layout of the experiment section is fairly straight with some minor horizontal curvatures which do not impact vehicles' speed and provides good front view visibility. The vertical layout of the experiment section has a substantial grade of 3 percent [31]. The participant drivers drove from the first turnaround and turned around on the second turnaround, so half the trials were on a 3 percent upgrade and the other half were on a 3 percent downgrade.

3.4.2 Experimental Equipment

A 1990 Blue Bird East school bus with a GMC diesel engine, driven by participant bus drivers (accompanied by a research assistant), was used in the experiment, as illustrated in Figure 3-1. The vehicle was equipped with a Differential Global Positioning System (DGPS), a real-time data acquisition system (DAS), and a laptop installed with VTTI proprietary programs to control the trials and road scenarios. The DAS is capable of data collection up to 0.1-second precision and was located behind the driver's seat. All data recorded were stored in a hard drive located beneath the driver's seat. Two video cameras were used: one was a digital color camera recording the front view of the test vehicle and the other was used to continuously record the participant's foot movements.

Figure 3-1: Instrumented Vehicle and Field Test Site

3.4.3 Participants

To protect the rights and safety of human subjects participating in the research, approval was obtained in October, 2013 from the Institutional Review Board (IRB #13-835) at Virginia Tech before recruiting the participant bus drivers. Participants were recruited from the VTTI internal participant database and through placement of flyers at nearby public schools and bus transit systems.

Participant bus drivers were screened through an oral questionnaire to determine eligibility for participation in the study. Participant bus drivers were required to have a valid Class-B commercial driver's license (CDL) and to be employed as a bus driver. Volunteers were paid $40 per hour for a 2 to 2.5 hour session. A total of 36 participants were recruited and were evenly distributed into three age groups as follows: below 40-years-old, between 40 to 64 years old, and age 65-years-old and above. There were equal numbers of male and female participants in each age group. Participating bus drivers were asked to participate individually in separate sessions with a reseacher present in the test vehicle at all times throughout the study to provide instructions, operate the computer system, supervise the experiment, and answer any questions.

3.4.4 Procedure

Testing was conducted under clear weather and dry pavement surface conditions. Upon arrival at VTTI, each participant was asked to review and sign an informed-consent form.

Before the first trial, the participant bus drivers were instructed to familiarize themselves with the Smart Road test facility by driving several laps and passing the intersection several times. Excluding the practice trials, the participant drove 24 laps around the instructed test area, passing the intersection 48 times and was instructed to cruise at a speed of 56 km/h (35 mi/h) while approaching the signalized intersection and to obey all traffic laws. One trial consisted of one approach to the intersection.

Among the 48 trials, there were 24 trials in which the yellow indications were triggered at 6 different distances to the intersection, 4 times each. The yellow indications were triggered when the front of the test vehicle was 36.6, 45.7, 54.9, 61, 67.1, and 76.2 m (120, 150, 180, 200, 220, and 250 ft.) from the intersection. On the remaining 24 trials the signal indications remained green. This scheme resulted in yellow/red signals being presented on 50 percent of the 48 trials; conversely, 50 percent of the 48 trials consisted solely of green signal indications. The yellow-light duration was 4 seconds. In the trials in which the yellow indications were initiated, outputs from the radar triggered the phase change at different distances to the intersection following a preset random order.

3.5 FIELD DATA ANALYSIS

More than 40 volunteers participated in the experiment. Due to unpredictability and sudden changes in the weather conditions, some tests were canceled halfway and those recorded data were excluded from the analysis. A total of 864 records for 36 participant bus drivers were available for analysis, including 551 stopping records and 313 running records. For each trial, the real-time data were tracked and recorded every deci-second.

3.5.1 Approach Speed at the Onset of Yellow

Participants were informed that the speed limit was 56 km/h (35 mi/h) along the signalized intersection approaches. However the participants' approach speeds to the signalized intersection ranged from a minimum of 40.1 km/h (24.9 mi/h) to a maximum of 64.1 km/h (39.8 mi/h), with a median of 56.3 km/h (35.0 mi/h), and a mean of 55.9 km/h (34.7 mi/h). The histogram of the approach speeds at the onset of yellow indications is presented in Figure 3-2.

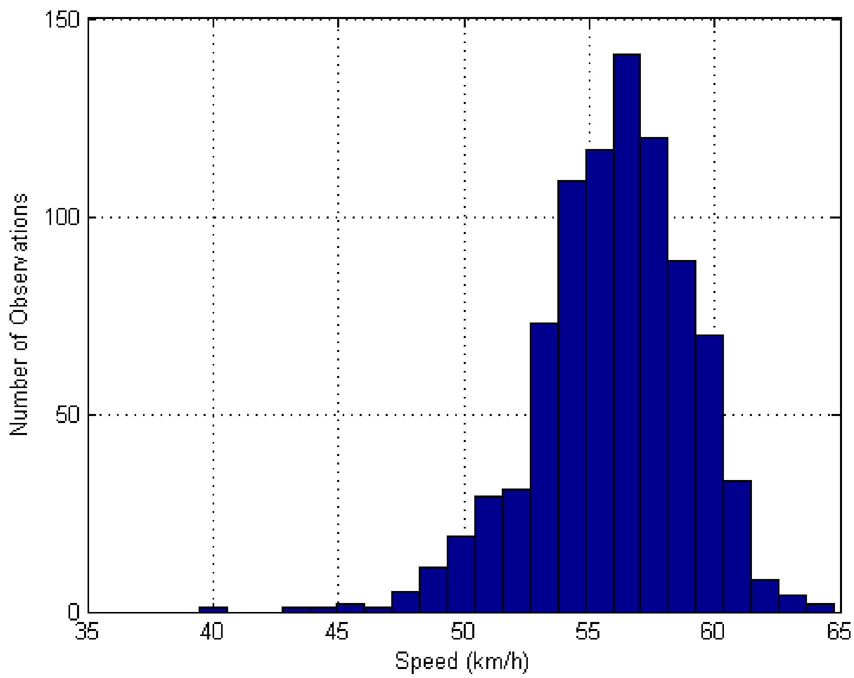

Figure 3-2: Histogram of Approach Speed at the Onset of Yellow

3.5.2 Probability Distribution of Stopping/Running Decision

The probabilities of stopping/running derived from the field experiment are illustrated in Figure 3-3. The average probabilities are sorted into equal sized bins based on driver's TTI at the onset of yellow signal indication.

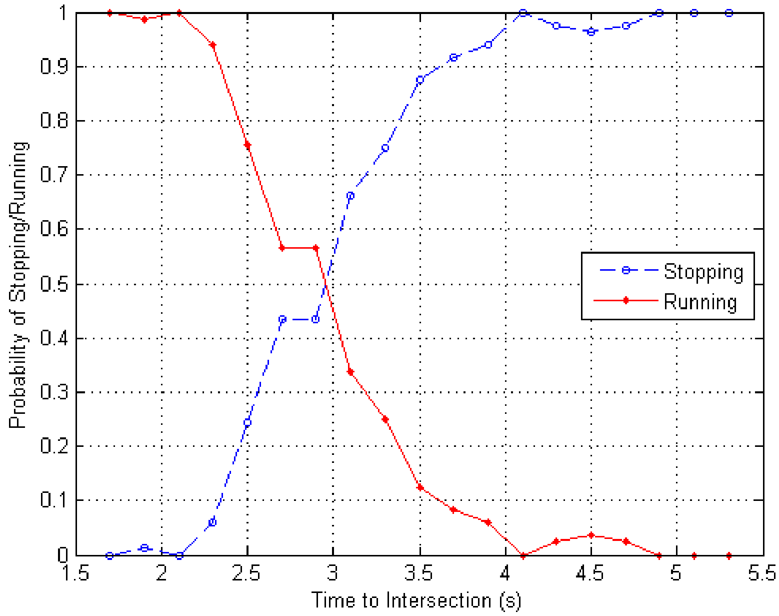

Figure 3-3: Probability Distribution of Stopping/Running Decision

A total of 864 stop-run decisions were available from the experiment, including driver age, TTI, vehicle approach speed at the onset of yellow, roadway grade (uphill or downhill), and a binary (0 or 1) driver stop-run decision variable to indicate whether a driver stopped or proceeded through the intersection. A Generalized Linear Model (GLM) of the logistic type was fit to the data considering a binomial distribution of the form in Equation (3.2).

$$ln\left(\frac{P_s}{P_r}\right) = ln\left(\frac{P_s}{1-P_s}\right) = logit(P_s) = \beta_0 + \beta_1 A + \beta_2 r + \beta_3 \frac{TTI}{y} + \beta_4 \frac{v}{v_f} + \beta_5 r \frac{v}{v_f} + \beta_6 A \frac{v}{v_f} \quad (3.2)$$

Where

P_s	is the probability of stopping,
P_r	is the probability of running,
β_i	are model constants,
r	is the gender (0 = male, 1 = female)
A	is the age (years)
TTI	is the time-to-intersection (s)
y	is the yellow time (s)
v and v_f	are the approaching speed and the speed limit (m/s)

Different multivariable model forms were evaluated and compared, but the above form was selected as the best model. The model calibrated coefficients and their corresponding P-values are summarized in Table 3-1 and show a good statistical fit. After validating the calibrated model, it was found that the model produced an 83.10% success rate (a total of 718 correctly classified decisions out of 864 total decisions).

Table 3-1: Statistical Model Calibration Results for GLM Logit Model

Coefficients	Coefficient Values	P-value
β_0	-7.332661	0.0132*
β_1	0.0818816	0.0288*
β_2	3.4715889	0.0119*
β_3	21.195963	<.0001*
β_4	-8.706717	<.0001*
β_5	-4.501843	0.0125*
β_6	-0.101528	0.0375*

It is noted that general linear model (GLM) ignores different observations by the same driver. A linear mixed model (LMM) can introduce the idea that an individual's pattern of responses is likely to depend on many characteristics of the subject, including some that are unobserved. The unobserved variables are then included in the model as random variables. The LMM model is found to have the same variables as the GLM with different coefficient values listed in Table 3-2.

Table 3-2: Statistical Model Calibration Results for LLM Logit Model

Coefficients	Coefficient Values	P-value
β_0	-5.282625	<.0001*
β_1	0.015393	0.000277
β_2	0.791930	<.0001*
β_3	18.894941	<.0001*
β_4	-8.914516	<.0001*
β_5	-0.758269	<.0001*
β_6	-0.009704	0.022105

The calibrated LMM model has produces a better stop/run classification compared to the GLM logit model with an 87.04% success rate (a total of 752 correctly classified decisions out of 864 total decisions). A sensitivity analysis was performed on the LMM stop/run logit model and the results are shown in Figure 3-4. The results show that both age and gender do not show significant changes to a driver's decision to stop or run a yellow light. However vehicle approach speed and yellow time duration do show more significant effect to a bus driver's decision to stop or run a yellow light. Results show buses approaching at lower speeds are less likely to run a yellow light with contrast to buses approaching at higher speeds. Increase in yellow indication duration will likely cause bus drivers to run a yellow light at higher TTI compared to shorter yellow light durations.

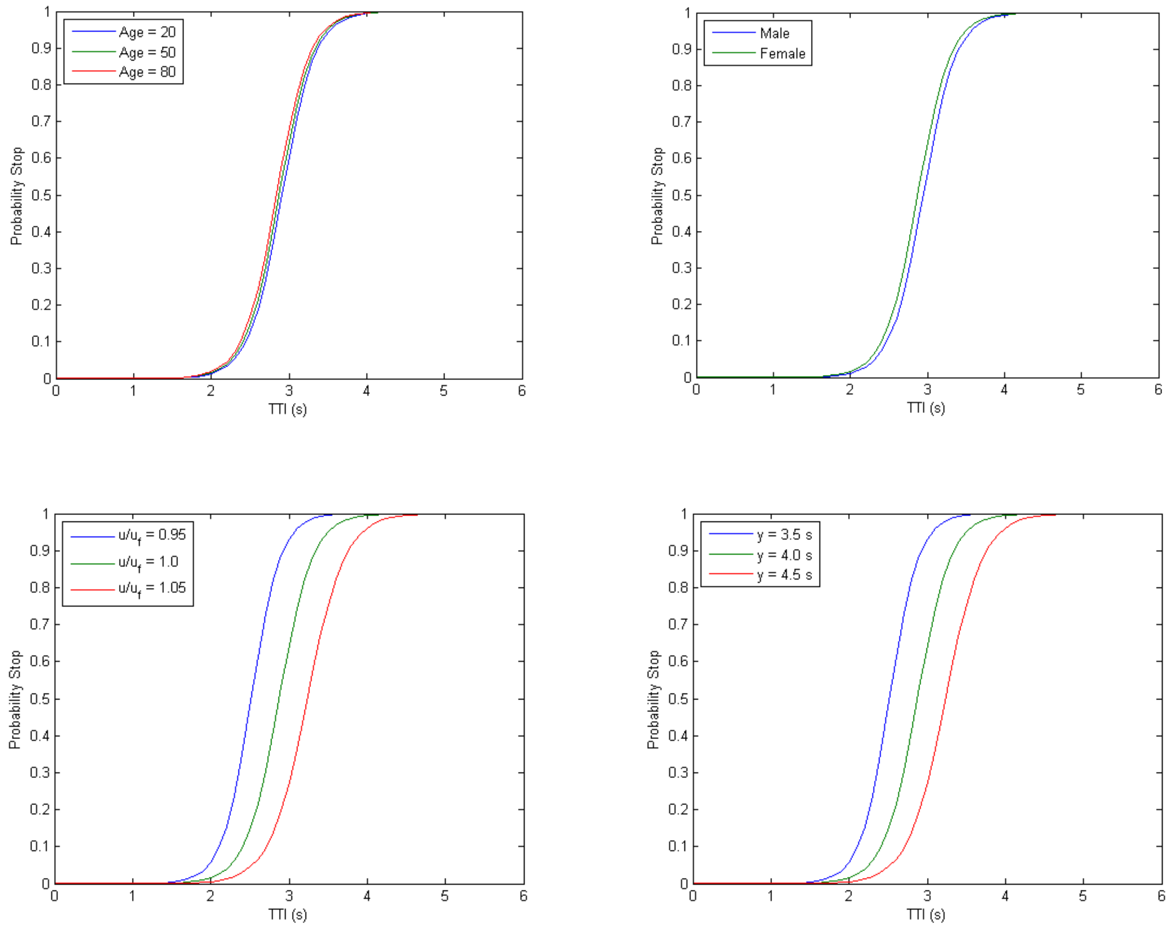

Figure 3-4: Sensitivity Analysis of the LMM Statistical Model Independent Variables

3.5.3 Analysis of Yellow/Red Light Running Behavior

To examine driver behavior after the running decision at the yellow indication, the scatter diagram in Figure 3-5 is plotted between the vehicle TTIs at the onset of yellow indications and their entry times. The entry time is defined as the elapsed time between the onset of yellow indication and the instant the vehicle traverses the stop line. TTI is computed as the vehicle's instantaneous DTI divided by the instantaneous speed at the onset of yellow. If the driver accelerates to ensure crossing the intersection without encountering a red, the entry time would be shorter than the TTI. On the contrary, if the driver slows down, the entry time would be longer than the TTI. In Figure 3-5, the scattered points follow a trend line with a slope of 1.0 and the intercept of 0.0. The trend line demonstrates that most drivers neither accelerated nor decelerated while running at the onset of a yellow indication. It can also be inferred that even for the red light signal violations, most drivers did not intentionally violate the red light but instead failed to make the correct decision. This phenomenon is consistent with previous passenger car studies in clear or rainy weather with dry or wet pavement conditions [4, 5].

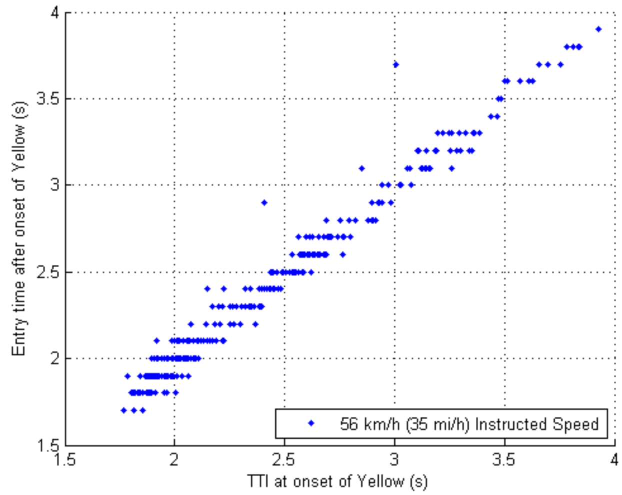

Figure 3-5: Relation between Entry Time and TTI at Yellow Indication Onset

3.5.4 Analysis of Yellow/Red Light Stopping Behavior

PRT is defined as the time taken as the duration from the onset of yellow indication till the instant the driver starts pressing the brake pedal. This duration includes the mental process time (perception time) and the movement time (reaction time). There are a total of 551 stopping records with 81 records of the bus drivers already releasing the accelerator before the onset of yellow indication. Only the remaining 470 records are considered valid PRT records. Figure 3-6 shows bus driver PRTs ranging from a minimum of 0.30s to a maximum of 1.40s, with a median and mean of 0.6s and 0.63s, respectively. The results also show an 85th percentile PRT value of 0.8 seconds.

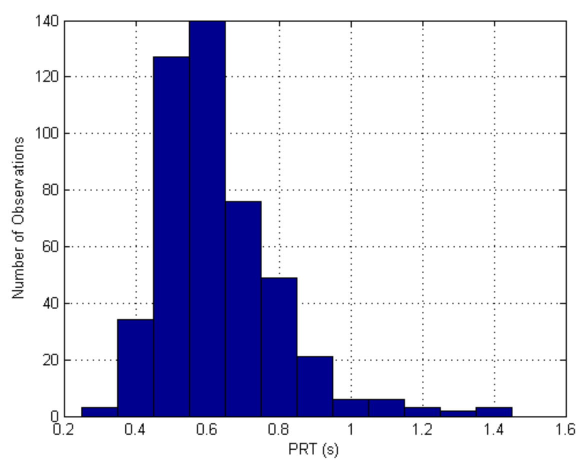

Figure 3-6: Histogram of Driver Perception-Reaction Times

The instantaneous speeds were recorded every deci-second as well as driver's foot movements and brake pedal positions. The average deceleration level is computed as:

$$d_{avg} = \frac{v_0 - v_1}{t_0 - t_1} \tag{3.3}$$

Where v_0 is the vehicle speed when the driver initially presses the brake pedal
v_1 is the final vehicle speed for the deceleration event (below 1 m/s)
t_0 is the time when brake pedal is initiated
t_1 is the time when vehicle reaches final speed

A total of 551 valid observations were available to compute the bus deceleration levels. The deceleration levels ranged from a minimum of 1.357 m/s^2 to a maximum of 4.502 m/s^2 with a median and mean of 2.477 m/s^2 and 2.555 m/s^2, respectively, as shown in Figure 3-7.

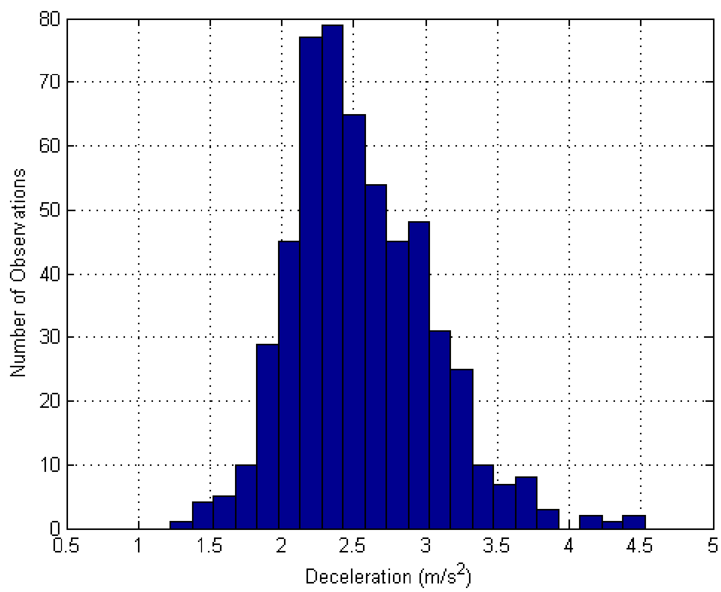

Figure 3-7: Histogram of Bus Drivers' Deceleration Levels

3.6 STATISTICAL MODELING FOR BUS DRIVER BEHAVIOR

3.6.1 Modeling of Bus Driver PRT

Contributing factors to PRT includes driver physical characteristics (gender and age), pavement features (grade), and vehicle physical states (TTI and speed). The statistical method of stepwise regression modeling was performed using JMP Pro 11 software to fit a model into the data. The final significant variables and their cross terms are shown in Equation (3.3)

$$t = \beta_0 + \beta_1 r + \beta_2 \frac{TTI}{y} + \beta_3 G \frac{TTI}{y} + \beta_4 r\, A \quad (3.3)$$

Where
- t is perception-reaction time (s)
- β_i are the coefficients
- r is the gender (0 = male, 1 = female)
- TTI is time-to-intersection at the onset of yellow indication (s)
- y y is the yellow interval duration (s)
- G is the roadway grade (percent/100)
- A Is the bus driver age (years)

The calibrated coefficients and corresponding P-values are summarized in Table 3-3. Results of low P-values suggest the statistical significance of each variable. The statistical modeling result indicates that the PRT has explanatory relationships with gender, TTI and the cross-product of grade with TTI and gender with age. The adjusted R^2 is 0.16 with very low explanatory power.

Table 3-3: Coefficients and P-values for Statistical Modeling of PRT

Coefficients	Coefficient Values	P-Value
β_0	0.33739	<.0001*
β_1	0.09543	0.0128*
β_2	0.29010	<.0001*
β_3	1.42499	<.0001*
β_4	-0.00139	0.0220*

An assumption is made where bus drivers' PRTs are affected the same way as passenger car drivers under different precipitation conditions. Thus the coefficient value representing precipitation from a previous study [32] was added into the PRT model to account for the difference in precipitation. The final form of the PRT model is shown in Equation (3.4).

$$t = 0.33739 + 0.09543 r + 0.2901 \frac{TTI}{y} + 1.42499 G \frac{TTI}{y} - 0.00139 r\, A + 0.4779 p \frac{v}{v_f} + err_t$$

Where
- t is perception-reaction time (s)
- β_i are the coefficients
- r is the gender (0 = male, 1 = female)
- TTI is time-to-intersection at the onset of yellow indication (s)
- y y is the yellow interval duration (s)
- G is the roadway grade (percent/100)
- A is the bus driver age (years)
- p is precipitation (0 = clear, 1 = very light rain, 2 = rainy)
- v approach speed (m/s)
- v_f Instructed speed limit (m/s)

3.6.2 Modeling of Bus Driver Deceleration Behavior

A previous study [33] suggested that for signal change interval design, joint consideration instead of independent consideration should be given to PRTs and deceleration levels when selecting their values. In addition, the study suggested that different PRTs and deceleration levels should be considered for different approach speeds rather than a single value (as used in the current practice). Consequently, PRT is added as an explanatory variable in addition to the driver gender and age, the roadway grade, TTI, and speed. The statistical method of stepwise regression modeling was performed using JMP Pro 11 software to fit a model into the data. The final significant variables and their cross terms are shown in Equation (3.5).

$$d = \beta_0 + \beta_1 A + \beta_2 r + \beta_3 t + \beta_4 \frac{TTI}{y} + \beta_5 \frac{v}{v_f} + \beta_6 r \frac{v}{v_f} + \beta_7 A \frac{TTI}{y} + \beta_8 \left(\frac{TTI}{y}\right)^2 \quad (3.5)$$

Where
d is deceleration rate (m/s^2)
β_i are the coefficients
A is the bus driver age (Years)
r is the gender (0 = male, 1 = female)
t is perception-reaction time (s)
TTI is time-to-intersection at the onset of yellow indication (s)
v approach speed (m/s)
v_f is instructed speed limit (m/s)

The calibrated coefficients and corresponding P-values are summarized in Table 3-4. Results of low P-values suggest the statistical significance of each variable. The statistical modeling result indicates that the PRT has explanatory relationships with age, gender, PRT, TTI, speed, TTI^2 and the cross-product of gender with speed, and age with TTI. The adjusted R^2 is 0.87.

Table 3-4: Coefficients and P-values for Statistical Modeling of Deceleration

Coefficient	Coefficient Values	P-Value
β_0	3.01933	<.0001*
β_1	0.01136	0.0117*
β_2	0.57089	<.0001*
β_3	0.75561	<.0001*
β_4	-5.85412	<.0001*
β_5	2.91615	<.0001*
β_6	-0.57337	0.0119*
β_7	-0.01199	<.0001*
β_8	1.90269	<.0001*

The same assumption here is also made in assuming that bus drivers' deceleration levels are affected the same way as passenger car drivers under cases of different precipitation. A coefficient representing precipitation from a previous study was added to the deceleration model to account for the difference in precipitation. The final form of the deceleration level model is shown in Equation (3.6).

$$d = 3.01933 + 0.01136A + 0.57089r + 0.75561t - 5.85412\frac{TTI}{y} + 2.9162\frac{v}{v_f} - 0.57337r\frac{v}{v_f} - 0.01199A\frac{TTI}{y} + 1.90269\left(\frac{TTI}{y}\right)^2 - 0.2934\,p\frac{TTI}{y} + err_d \quad (3.6)$$

3.7 DISCUSSION OF PRTs AND DECELERATION LEVELS

Results gathered from the experiment conducted for this study was compared with results from previous studies from the same research group. Table 3-4 shows a summary comparison for PRTs and deceleration levels for passenger cars under clear weather conditions, passenger cars under inclement weather conditions, truck with no load, truck with load, and buses.

Table 3-4: PRTs and Deceleration Levels Comparison

	Passenger Cars (Clear Weather) [34]	**Passenger Cars (Inclement Weather)** [5]	**Trucks (Empty)** [6]	**Trucks (Loaded)** [6]	**Buses**
		PRT (s)			
Minimum	0.22	0.40	-	-	0.30
Maximum	1.52	1.80	-	-	1.40
Median	0.72	0.80	1.10	1.10	0.60
Mean	0.73	0.85	1.16	1.16	0.63
		Deceleration (m/s^2)			
Minimum	2.31	1.43	0.50	0.62	1.36
Maximum	7.31	6.41	3.71	3.71	4.50
Median	3.55	3.30	1.84	1.77	2.48
Mean	3.70	3.44	1.98	1.94	2.56

It is observed from the data collected in Table 3-4 that bus drivers have shorter average PRTs compared to other vehicle modes. However it is observed that buses have an average of 44.5% lower deceleration levels compared to passenger cars under clear weather conditions and 34.4% lower than passenger cars under inclement weather. Buses, however, do have a 22.7% to 24.2% higher deceleration level compared to trucks.

3.8 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Results from the experiment have shown a significant difference between the PRTs and deceleration levels of different modes of transportation. Buses will require more than one third of the safe stopping distance compared to passenger cars to be able to decelerate comfortably to a complete stop. However, buses are able to come to a complete stop at a distance about one fifth less than what is required by trucks. Buses do behave similar to passenger cars when proceeding through a yellow indication where they are very likely to maintain the same approach speed.

It is recommended that the experiment be conducted under inclement weather conditions to observe buses and bus drivers' behavior under rain and wet pavement at signalized intersections at onset of yellow indication. Current limitation to the bus PRT and deceleration model is the assumption made where bus PRT and deceleration levels are affected similar to passenger cars under different precipitation.

This study is focused on one bus with no passengers and cross-traffic. Further work should look into the impacts that following or leading traffic, traffic density, as well as the presence of cross-traffic will have on bus driver behavior. Future studies should also look into the effect of bus occupancy on the bus drivers' behavior.

CHAPTER 4: DESIGNING TRAFFIC SIGNAL YELLOW TIMES AND CHANGE INTERVALS CONSIDERING SCHOOL BUS IMPACTS

Boon Teck Ong, Hesham Rakha, and Ihab El-Shawarby

4.1 ABSTRACT

The research in this paper looks to develop bus driver perception-reaction time (PRT) and deceleration level models to quantify the impact of different percentage of buses within traffic stream on yellow indication duration. A total of 864 stop/run records were collected as part of the research effort for a 56 km/h (35 mph) approach speed where participant bus drivers encountered a yellow indication initiation at different distances from the intersection. The participant drivers were randomly selected from different age groups (under 40 years old, 40 to 64 years old, and 65 years or older) and genders (male and female). Data collected were used to generate two different Linear Mixed Models (LMM): one for bus driver PRTs and one for deceleration levels. Both models consider roadway surface and environmental parameters, driver attributes (age and gender), roadway grade, approaching speed, and time and distance to the intersection at the onset of yellow. The proposed models were used to perform a Monte Carlo simulation in attempt to generate proposed yellow timing durations. Lookup tables of proposed yellow timing duration for different approach speeds, roadway grades, confidence intervals, precipitation, and percent of buses in traffic stream were generated to provide practical guidelines for the design of yellow signal timings.

4.2 INTRODUCTION

The dilemma zone problem has been studied for decades in various transportation research publications. However, the focus of the majority of these studies has been on light-duty vehicles and not on heavy-duty trucks and buses. Buses make up a considerable percentage of the traffic stream, especially around urban areas where there are considerable numbers of signalized intersections. According to the United States Department of Labor, since year 2012, there are as many as 654,300 bus drivers jobs in the United States and is projected to grow by 9% by year 2022 [35]. An analysis by Jovanis indicated that 40% of automobile and bus driver injuries that occur while the bus is in motion and 80% while the bus is stationary are due to rear-end collisions [36]. Data from the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System relating to buses involved in fatal crashes from 2000-2011 indicates that there were a total of 3294 fatal crashes with 1302 being front point of impact and 449 as rear point of impact [3]. Heavy vehicles on the road have become a greater concern recently as many passenger cars have become smaller and lighter, while heavy vehicles have continued to grow larger and their weight carrying capacities have increased [2]. Transit buses and articulated transit buses could measure between 20 to 60 ft. in length and weigh between 28,180 to 41,000 pounds when empty [2]. The number of bus registration according to Highway Statistic 2005 there were a total sum of 764,509 number of registered buses [37]. Buses make up approximately 0.3% of total rural traffic, 0.2% of total urban traffic, and a grand total of 0.2% total travel traffic in the U.S. [2].

4.3 BACKGROUND

Traffic signal design procedures only use light-duty vehicles including the design of yellow and clearance intervals [23]. Larger vehicles like buses may behave like trucks and are forced to run red signal that was set following state-of-the-art practice design standards to avoid injuring onboard passengers, leading to other safety concerns and traffic violations. Gates et al. in 2007 conducted a study which found that heavy vehicles are more likely to violate red signals than passenger cars. Gates and Noyce in 2010 [25] found that tractor trailers were 3.6 times more likely to violate red signals than passenger cars.

In a paper by Bonneson and Zimmerman, it was observed that an increase in the yellow time duration by 1 second, but not exceed a total time of 5.5 seconds, would decrease red light running by approximately 50 percent [15]. Gates and Noyce found through empirical observations that tractor trailer drivers do have a lower deceleration levels when compared to light-duty vehicles, which is in line with other research, although it is noted that their sample size was only eight observations [25].

A study by Wei et al. was found that heavy truck dilemma zone was too much different in length from a light-duty vehicle dilemma zone, and indicated it was offset upstream by approximately 1 second relative from light-duty dilemma zone [27]. The study demonstrated that heavy vehicles at intersections will likely run the light instead of attempting to stop. Another recent study conducted by McGee et al. for the National Cooperative Highway Research Program (NCHRP) highlighted the need to consider trucks in the design of intersection yellow and clearance times [28]. The study, however, only considered the effect of trucks in the design of all-red times by accounting for the differences in vehicle lengths.

From past studies, there were some but limited examinations of the dilemma zone associated with heavy-duty trucks, and even fewer for buses. Consequently, this paper attempts to address this void and design traffic signal yellow and clearance times considering bus impacts. This effort builds upon past research on passenger cars conducted at the Virginia Tech Transportation Institute (VTTI) that developed an agent-based stochastic approach for the design yellow timings that accounts for the risk of drivers being caught in the dilemma zone [4] and another study that quantified the impact of rainy and wet roadway surface conditions on the design of yellow timings [5]. Both studies will be described later in the following section. The studies demonstrated that the behavior in the controlled experiment was consistent with empirical observations from other studies in terms of PRTs, deceleration levels and driver stop-go behavior [4, 5, 31]. In both of these studies, light-duty sedan vehicles were used as the test vehicle to expose participants to 48 traffic signal timings in each trial, half of which were green and the other half entailed yellow indications introduced when the vehicle was at different distances from the intersection, and collected information including the approach speed, time to intersection, brake position, and other kinematic data. However, both of these studies, like many others, were limited to passenger cars.

4.4 EXPERIMENTAL DESIGN

In two previous studies [4, 5] performed by the same research group at Virginia Tech Transportation Institute, a controlled field data collection effort was conducted in an attempt to model passenger car driver PRT and deceleration behavior at the onset of yellow indications as a function of various driver, vehicle, and traffic stream characteristics under different weather and roadway conditions.

The field experiment described in this paper was conducted at the same location, the Virginia Department of Transportation's (VDOT) Smart Road facility. The focus of this study is on buses instead of passenger cars under clear weather and dry pavement conditions. Instructed speed limit for the experiment was 56 km/h (35 mph). The research presented in this paper uses the PRT and deceleration model developed as part of this field experiment, together with the models developed in the Li et al. and Amer et al. publications to develop yellow and intersection clearance times [4, 5]. Subsequently, yellow-time lookup tables were developed to assist practitioners in the design of traffic signal yellow timings.

4.4.1 Test Facility

The Smart Road is a unique, state-of-the-art, full-scale, closed test-bed research facility, located at the Virginia Tech Transportation Institute (VTTI), owned and maintained by VDOT. The Smart Road is a 3.5 km (2.2 mi) two-lane road with one four-way signalized intersection, as illustrated in Figure 3-1. The section used for the data collection includes only the section between T1 and T2. The first turnaround (T1) is a high-speed banked turnaround at one end of the test section and the second (T2) is a medium-speed speed flat turnaround at the other end. The intersection consists of two high-speed approaches and two low-speed approaches and is outfitted with customized controllers and vehicle presence sensors, as well as wireless communications. The horizontal layout of the experiment section is fairly straight with some minor horizontal curvatures which do not impact vehicles' speed and provide good front view visibility. The vertical layout of the experiment section has a substantial grade of 3 percent [31]. The participant bus drivers drove from T1 and turned around T2, so half the trials were on a 3 percent upgrade and the other half were on a 3 percent downgrade.

4.4.2 Experimental Equipment

A 1990 Blue Bird East school bus with a GMC diesel engine, driven by participant bus drivers (accompanied by a research assistant), was used in the experiment as illustrated in Figure 4-1. The vehicle was equipped with a Differential Global Positioning System (DGPS), a real-time data acquisition system (DAS), and a laptop installed with VTTI proprietary program to control the trials and road scenarios. The DAS is capable of data collection up to 0.1-second precision and was located behind the driver's seat. All data recorded were stored in a hard drive located beneath the driver's seat. Two video cameras were used: one was a digital color camera recording the front view of the test vehicle and the other was used to continuously record the participant's foot movements.

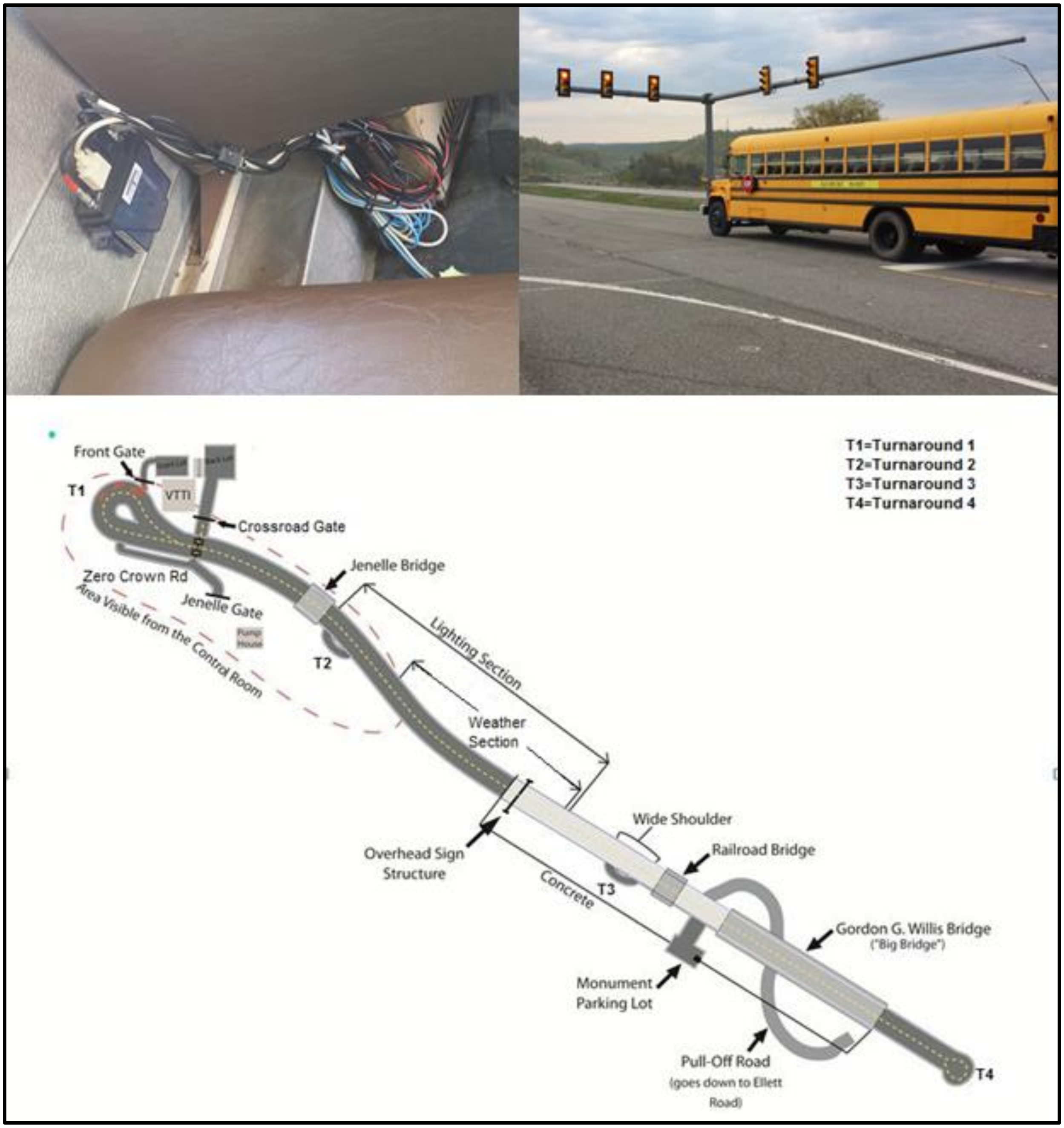

Figure 4-1: Instrumented Vehicle and Field Test Site

4.4.3 Participants

To protect the rights and safety of human subjects participating in the research, approval was obtained in October, 2013 from the Institutional Review Board (IRB #13-835) at Virginia Tech before recruiting the participating bus drivers. Participants were recruited from the VTTI internal participant database and through placement of flyers at nearby public schools and bus transit systems.

Participant bus drivers were screened through an oral questionnaire to determine eligibility for participation in the study. Participating bus drivers were required to have a valid Class-B commercial driver's license (CDL) and be employed as a bus driver. Volunteers were paid $40 per hour for a 2 to 2.5 hour session. A total of 36 participants were recruited and were evenly distributed into three age groups as follows: below 40-years-old, between 40 to 64 years old, and age 65-years-old and above. There were equal numbers of male and female participants in each age group. Participating bus drivers were asked to participate individually in separate sessions with a reseacher present in the test vehicle at all times throughout the study to provide instructions, operate the computer system, supervise the experiment, and answer any questions.

4.4.4 Procedure

Testing was conducted under clear weather and dry pavement surface conditions. Upon arrival at VTTI, each participant was asked to review and sign an informed-consent form. Before the first trial, the participant bus drivers were instructed to familiarize themselves with the Smart Road test facility by driving several laps and passing the intersection several times. Excluding the practice trials, the participant drove 24 laps around the instructed test area, passing the intersection 48 times and was instructed to cruise at a speed of 56 km/h (35 mi/h) while approaching the signalized intersection and to obey all traffic laws. One trial consisted of one approach to the intersection.

Among the 48 trials, there were 24 trials in which the yellow indications were triggered at 6 different distances to the intersection, 4 times each. The yellow indications were triggered when the front of the test vehicle was 36.6, 45.7, 54.9, 61, 67.1, and 76.2 m (120, 150, 180, 200, 220, and 250 ft.) from the intersection. On the remaining 24 trials the signal indications remained green. This scheme resulted in yellow/red signals being presented on 50 percent of the 48 trials; conversely, 50 percent of the 48 trials consisted solely of green signal indications. The yellow-light duration was 4 seconds. In the trials in which the yellow indications were initiated, outputs from the radar triggered the phase change at different distances to the intersection following a preset random order.

4.2 METHODOLOGY

The basis for the yellow interval duration design is the Institute of Transportation Engineers (ITE) formula [2] that is presented in Equation 4.1.

$$y = t + \frac{v_0}{2(a + 9.81G)} \tag{4.1}$$

Where y is the yellow signal indication duration (s)
t is driver PRT (s)
v_0 is the constant approach speed (m/s)
a is the constant deceleration rate (m/s^2)
G Is the roadway grade (decimal)

The state-of-practice is to use a constant *PRT* of 1s and a deceleration level of 10 ft/s^2 or 3 m/s^2.

4.2.2 Modeling Passenger Car Driver Behavior

The ITE formula recommends using a constant PRT of 1 second and a deceleration level of 3 m/s^2. However, the use of constant deterministic values for the PRT and the deceleration level is simplistic and does not allow the practitioner to make trade-off decisions between safety and operational considerations. Furthermore, the current approach fails to account for variations between different drivers approaching the same intersection at the onset of yellow. These variations include: driver's approach speed, PRT, and deceleration level. Such variations are confirmed based on the analyses made on both PRT and deceleration levels. That is Amer et al. [4] developed an agent-based approach to compute each driver's unique yellow time by considering differences in driver approach speed, PRT and deceleration levels. The distribution of yellow times for all drivers traversing the intersection can then be used to select a design yellow time for a specific reliability level. In the section that follows, the yellow clearance interval calculation formula, presented earlier in Equation (1), is used to conduct a Monte Carlo simulation exercise to model the required yellow time based on the actual mean values and the statistical models calibrated for the PRT and the deceleration level.

In order to model the required yellow time, a Monte Carlo simulation considering a sample of 1,000,000 drivers was simulated by randomly generating the independent variables affecting the PRT and the deceleration level with the corresponding yellow time. These variables include the driver's gender and age, roadway grade, TTI, and approach speed. In order to generate a TTI distribution, a uniform random number generator was used to produce TTI values from a range that is slightly larger than the option zone boundaries corresponding to the posted speed limit [4]. Using these models a Monte Carlo simulation of 1,000,000 vehicle arrivals were used to compute driver-specific yellow times for passenger cars. In addition the Li et al. study [5] extended the analysis by considering wet roadway surface and rainy conditions, as summarized in Equations (4.2) and (4.3).

$$t_{car} = 1.4995 - 0.840r + 0.0008A - 11.5464G + 0.2728\frac{TTI}{y} - 1.0422\frac{v}{v_f} - 0.4367p + 0.8450g\frac{v}{v_f} + 12.5101G\frac{v}{v_f} + 0.4779\frac{v}{v_f}p + \varepsilon_{PRT} \tag{4.2}$$

$$a_{car} = 10.6577 - 0.2782r - 0.0079A - 2.0816G - 20.0664\frac{TTI}{y} + 3.6821\frac{v}{v_f} + 0.2136p + 1.4376t + 8.0828\left(\frac{TTI}{y}\right)^2 + 0.0046rA - 0.2934\frac{TTI}{y}p + \varepsilon_d \tag{4.3}$$

Where

t_{car}	is passenger car driver PRT (s)
a_{car}	is passenger car deceleration (m/s^2)
r	is driver gender (0 = male, 1 = female)
A	is driver age (Years)
G	is roadway grade (percent/100)
TTI	is the time to intersection at onset of yellow indication (s)
y	is the yellow interval duration (s)
v	is the approach speed (m/s)
v_f	is the instructed speed (m/s)
p	is the precipitation level (0: clear, 1: wet surface/ very light rain, 2: rainy)

The epsilon terms are white noise error terms, which were calculated using the data collected in the first study [4]. It should be noted that the driver deceleration level (computed in Equation 4.3) is a function of the driver PRT, and thus both parameters are positively correlated. The introduction of a white noise term ensures that the approach is agent-based and captures each unique driver's behavior.

The approach speed distribution was also modeled as a random variable, using the empirically observed arrival speed distribution. The mean of the distribution was shifted to reflect the speed limit under consideration. This assumes that the variance is independent of the average speed.

In summary, rather than using fixed approach speed, PRT, and deceleration level (*v*, *PRT*, and *a* terms) the model introduces differences in driver behavior and captures the correlation between the driver PRT and deceleration level. These generate driver-specific yellow times that are then used to construct a distribution of design yellow times. The designer can then select a specific percentile design to ensure that an acceptable percentage of drivers are not caught in the dilemma zone.

4.2.3 Modeling of Buses and Derivation of Yellow Times

Using the same Monte Carlo modeling approach passenger car arrivals were generated using various random number generators. Specifically, the age of the driver was generated using a uniformly distributed random number that ranged between 20 and 80 years of age. The gender of the driver was generated using a binary random number (0 or 1). The minimum and maximum time to intersection (TTI) was increased by 0.15 and 0.30 for wet and rainy conditions, respectively. The location of the vehicle at the onset of the yellow interval was introduced using a uniformly distributed random number that ranged between the minimum and maximum value. The approach speed was generated using the empirical approach speed distribution while adjusting for the speed limit under consideration. A total of 1,000,000 driver/vehicle arrivals were generated for each grade, speed limit, and precipitation level. These trials were conducted for all grades between -4 and +4 percent at increments of 1 percent, for all three speed limits, and all three precipitation levels (dry, wet, and rainy).

In modeling the bus driver PRT and deceleration levels, the following equations (Equation 4.4 and 4.5) developed from an ongoing study for buses were used.

$$t_{bus} = 0.318095 + 0.09687r + 0.07657\frac{TTI}{y} + 1.44014G\frac{TTI}{y} - 0.0014r\,A + 0.4779p\frac{v}{v_f} + err_t \quad (4.4)$$

$$a_{bus} = 2.8117 + 0.01099A + 1.09933r + 0.7623t - 5.7327\frac{TTI}{y} + 3.0585\frac{v}{v_f} - 1.0987r\frac{v}{v_f} - 0.0116A\frac{TTI}{y} + 1.8412\left(\frac{TTI}{y}\right)^2 - 0.2934\,p\frac{TTI}{y} + err_d \quad (4.5)$$

t_{bus} is bus driver PRT (s)

Where a_{bus} is bus deceleration (m/s^2)
r is driver gender (0 = male, 1 = female)
A is driver age (Years)
G is roadway grade (percent/100)
TTI is the time to intersection at onset of yellow indication (s)
y is the yellow interval duration (s)
v is the approach speed (m/s)
v_f is the instructed speed (m/s)
p is the precipitation level (0: clear, 1: wet surface/ very light rain, 2: rainy)

The yellow times were calculated for each bus driver and bus using a Monte Carlo simulation by generating 1,000,000 buses and passenger cars realizations. Again these were done for each grade, approach speed limit, and weather condition combination. A mixed driver population (cars and buses) was then created by generating 1,000,000 random integer numbers for each simulation. These integer random numbers served as pointers in identifying the observations for consideration in the simulation. The breakdown of cars and buses was made to replicate the desired proportion of buses. For example, for a 10 percent buses population 100,000 buses were mixed with 900,000 cars. Using the randomly generated mixture of cars and buses 1,000,000 yellow interval durations were generated that were then used to compute the yellow time lookup tables, which will be discussed in the next section.

4.3 DATA ANALYSIS AND RESULTS

The first analysis was conducted to look at the yellow time distributions that were being calculated. The yellow times were plotted for 0%, 15%, and 30% buses at each of the speed limits and precipitation conditions on flat approach (0 percent grade), as illustrated in Figure 4-2.

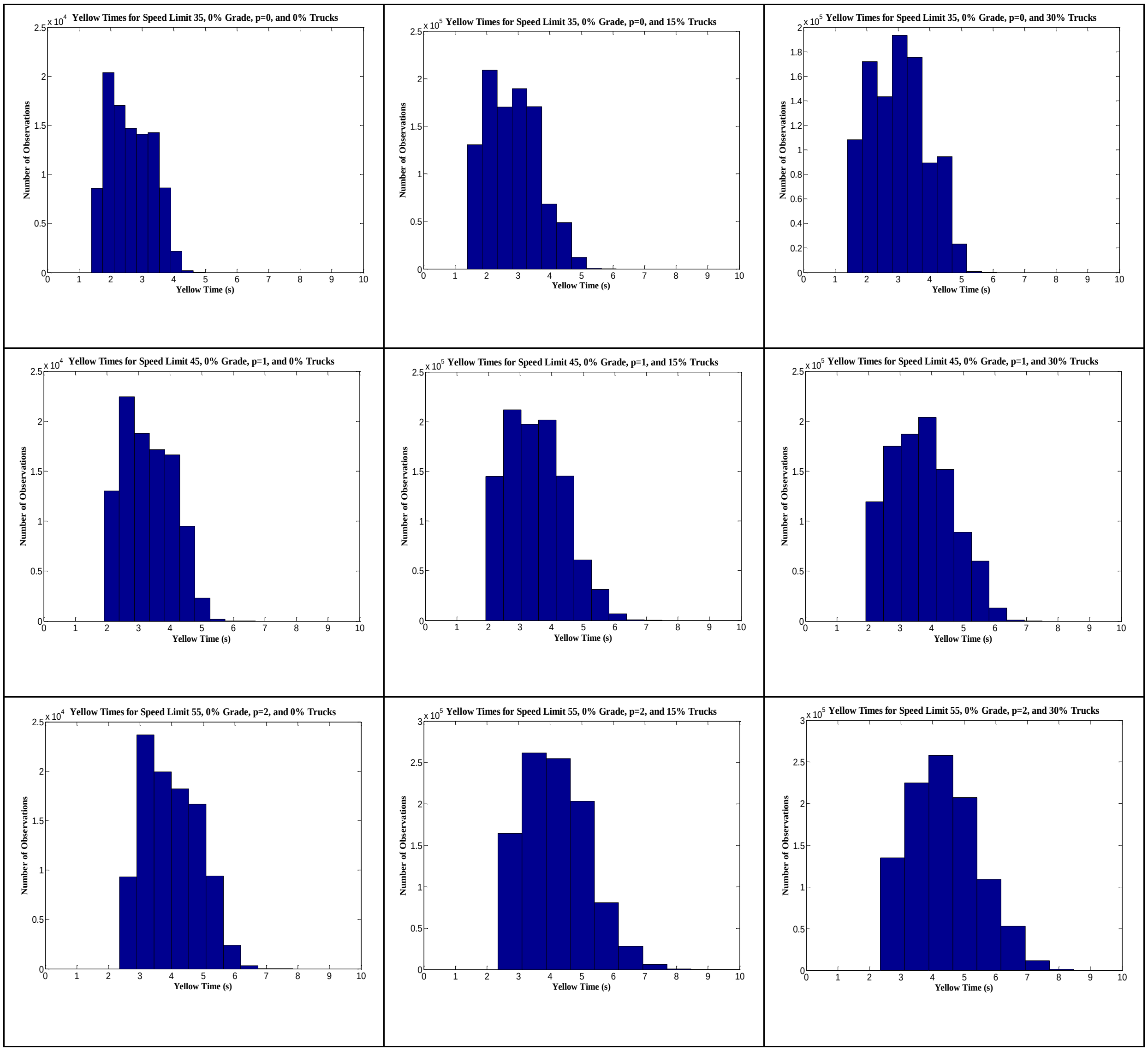

Figure 4-2: Agent-Based Yellow Time Distribution

The figures appear to demonstrate a tendency towards bi-modal distribution at lower speed limits (35 mi/h). The second mode is less pronounced at the 35 mi/h speed with heavy rain. In all cases, as would be expected buses shift the yellow intervals towards the higher value, but in many of the lower speed cases, it introduces a second mode to the right of the distribution. The results shown in figure 0.2 shows an important distinction that helps to illustrate why the lower speeds were more impacted by the buses than the higher speeds. This observed shift in yellow timings towards higher values implies that the yellow timings should be increased.

Lookup tables were developed for each speed and grade combination. To do this, the tables developed with 1,000,000 yellow times for each speed, grade, precipitation, and percentage bus combination were analyzed using MATLAB, where different percentiles were pulled out in order to make a comprehensive lookup table for eight different reliability levels ranging from 85 to 99.9 percent. These tables are meant for a practitioner or engineer to be able to identify the required yellow timings and provide a trade-off between yellow timings and percentage of vehicles caught in the dilemma zone. These tables are shown in Table 4-1, Table 4-2, and Table 4-3 for eight reliability levels. The reliability indicates the percentage of drivers/vehicles protected against the dilemma zone for the specific design yellow time. In these tables, the precipitation factor is 0 for clear conditions, 1 for misty and wet roadway conditions, and 2 for rainy conditions.

The values clearly demonstrate that the design yellow timings increase as the reliability measure increases. If engineers want more drivers protected from the dilemma zone, they would need to increase the yellow time. Consequently, these tables provide the practitioner with a means to quantify the trade-off of increasing or decreasing the yellow timings and the subsequent impact on drivers being caught in a dilemma zone. The tables also demonstrate that the yellow times increase with an increase in the travel speed and the introduction of precipitation. It should be noted that the proposed procedure is flexible and can be adapted to local intersection conditions if data on driver PRT and deceleration levels are available at the specific locality.

The first analysis that was done with these tables was to validate the zero percent bus scenarios with the results from previous research efforts [5]. The yellow times were found to be within 0.2 s of the yellow times found in previous publications, and thus the approach was deemed to be valid. The next step was to check the bus values against a calculation of the yellow time expected if the average PRTs and deceleration levels were used. This was accomplished by using Equation 4.6.

$$y = (\lambda)\left(PRT_b + \frac{v_b}{2(a_b + 9.81G)}\right) + (1 - \lambda)\left(PRT_c + \frac{v_c}{2(a_c + 9.81G)}\right) \tag{4.6}$$

Where y is the yellow time (s)
λ is the percentage of buses (percent/100)
PRT_b is the average PRT plus airbrake lag time (s)
v_b is the approach speed of buses (m/s)
a_b is the deceleration of buses (m/s^2)
G is roadway grade (percent/100)
PRT_c is the average PRT of passenger car drivers (s)
v_c is the approach speed of cars (m/s)

These values were calculated for each of the cases and were found to be consistent with the 97th to 99th percentile yellow time using the conservative ITE PRT and deceleration level. These findings are consistent with the findings of Amer et al. [4].

Table 4-1: Lookup Table for Grade of 0%

Speed (mi/h)	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Grade (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	3.8	3.9	4.0	4.0	4.1	4.1
90	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9	4.0	4.0	3.9	4.0	4.1	4.1	4.2	4.3	4.4
95	3.7	3.7	3.8	3.8	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.2	4.3	4.4	4.1	4.2	4.3	4.4	4.6	4.7	4.7
96	3.7	3.8	3.8	3.9	4.0	4.0	4.1	3.9	4.0	4.1	4.2	4.3	4.4	4.4	4.2	4.3	4.4	4.6	4.7	4.8	4.8
98	3.8	3.8	3.9	4.0	4.1	4.1	4.2	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.2	4.4	4.5	4.7	4.8	4.9	4.9
98	3.8	3.9	4.0	4.1	4.2	4.2	4.2	4.1	4.2	4.3	4.5	4.5	4.6	4.6	4.3	4.5	4.7	4.9	4.9	5.0	5.0
99	4.0	4.1	4.2	4.2	4.3	4.3	4.3	4.2	4.4	4.6	4.6	4.7	4.7	4.7	4.5	4.8	5.0	5.0	5.1	5.1	5.1
99.9	4.3	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.8	4.8	4.9	4.9	4.9	4.9	4.9	5.2	5.3	5.3	5.3	5.3	5.3
Speed (mi/h)	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Grade (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.4	4.4	4.5	4.6	4.6	4.7	4.8
90	4.1	4.1	4.2	4.2	4.3	4.4	4.4	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.8	4.9	5.0	5.0
95	4.3	4.4	4.4	4.5	4.6	4.7	4.7	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.2	5.3	5.4
96	4.3	4.4	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.9	5.0	5.1	5.1	4.8	4.9	5.1	5.2	5.3	5.4	5.5
98	4.4	4.5	4.6	4.7	4.8	4.8	4.9	4.6	4.7	4.9	5.0	5.1	5.2	5.2	4.9	5.0	5.2	5.4	5.5	5.5	5.6
98	4.5	4.6	4.7	4.8	4.9	4.9	5.0	4.7	4.9	5.0	5.2	5.2	5.3	5.3	5.0	5.2	5.4	5.5	5.6	5.7	5.7
99	4.6	4.8	4.9	5.0	5.0	5.0	5.1	4.8	5.1	5.3	5.3	5.4	5.4	5.4	5.1	5.4	5.6	5.7	5.7	5.8	5.8
99.9	4.9	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.5	5.5	5.5	5.6	5.6	5.6	5.6	5.9	5.9	5.9	5.9	5.9	5.9
Speed (mi/h)	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Grade (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.5	4.5	4.6	4.7	4.7	4.8	4.8	4.7	4.8	4.8	4.9	5.0	5.0	5.1	4.9	5.0	5.1	5.1	5.2	5.3	5.4
90	4.6	4.7	4.8	4.8	4.9	5.0	5.1	4.9	4.9	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.7
95	4.8	4.9	5.0	5.2	5.3	5.4	5.4	5.1	5.2	5.3	5.4	5.6	5.7	5.7	5.3	5.5	5.6	5.7	5.9	6.0	6.1
96	4.9	5.0	5.1	5.3	5.4	5.5	5.5	5.1	5.3	5.4	5.5	5.7	5.8	5.8	5.4	5.5	5.7	5.9	6.0	6.1	6.1
98	5.0	5.1	5.2	5.4	5.5	5.6	5.6	5.2	5.4	5.5	5.7	5.8	5.9	5.9	5.5	5.7	5.8	6.0	6.1	6.2	6.2
98	5.1	5.2	5.4	5.5	5.6	5.7	5.7	5.3	5.5	5.7	5.8	5.9	6.0	6.0	5.6	5.8	6.0	6.2	6.2	6.3	6.3
99	5.2	5.4	5.6	5.7	5.7	5.8	5.8	5.4	5.7	5.9	6.0	6.1	6.1	6.1	5.8	6.1	6.3	6.3	6.4	6.4	6.4
99.9	5.6	5.8	5.9	5.9	5.9	5.9	5.9	5.9	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.5	6.5	6.6	6.6	6.6	6.6

Table 4-2: Lookup Table for Grades of -4% and -2%

Speed (mi/h)	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Grade (%)	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.5	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.1	4.0	4.0	4.1	4.2	4.2	4.3	4.4
90	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.3	4.1	4.2	4.3	4.4	4.4	4.5	4.6
95	3.9	3.9	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.4	4.5	4.6	4.7	4.8	4.9	5.0
96	3.9	4.0	4.1	4.2	4.3	4.3	4.4	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.4	4.5	4.7	4.8	5.0	5.0	5.1
98	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.2	4.3	4.5	4.6	4.7	4.8	4.9	4.5	4.6	4.8	5.0	5.1	5.2	5.2
98	4.1	4.2	4.3	4.4	4.5	4.5	4.6	4.3	4.5	4.6	4.8	4.9	4.9	5.0	4.6	4.8	5.0	5.1	5.2	5.3	5.4
99	4.2	4.4	4.5	4.6	4.6	4.7	4.7	4.5	4.7	4.9	5.0	5.0	5.1	5.1	4.8	5.1	5.3	5.4	5.4	5.5	5.5
99.9	4.5	4.8	4.8	4.9	4.9	4.9	4.9	4.9	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.6	5.6	5.7	5.7	5.7	5.7
Speed (mi/h)	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Grade (%)	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.1	4.2	4.2	4.3	4.3	4.4	4.5	4.4	4.4	4.5	4.5	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.9	5.0	5.0
90	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.8	4.8	4.9	5.0	4.8	4.9	5.0	5.0	5.1	5.2	5.3
95	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.0	5.2	5.3	5.4	5.5	5.6	5.7
96	4.6	4.7	4.8	4.9	5.0	5.1	5.2	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.1	5.2	5.4	5.5	5.7	5.8	5.8
98	4.6	4.8	4.9	5.0	5.1	5.2	5.3	4.9	5.0	5.2	5.3	5.5	5.5	5.6	5.2	5.4	5.5	5.7	5.8	5.9	5.9
98	4.7	4.9	5.1	5.2	5.3	5.3	5.4	5.0	5.2	5.4	5.5	5.6	5.7	5.7	5.3	5.5	5.7	5.9	5.9	6.0	6.0
99	4.9	5.1	5.3	5.4	5.4	5.5	5.5	5.2	5.4	5.6	5.7	5.8	5.8	5.8	5.5	5.8	6.0	6.1	6.1	6.1	6.2
99.9	5.2	5.6	5.6	5.6	5.7	5.7	5.7	5.6	5.9	5.9	6.0	6.0	6.0	6.0	6.0	6.3	6.3	6.3	6.3	6.3	6.4
Speed (mi/h)	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Grade (%)	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.7	4.7	4.8	4.9	5.0	5.0	5.1	4.9	5.0	5.1	5.1	5.2	5.3	5.4	5.2	5.2	5.3	5.4	5.5	5.6	5.7
90	4.9	4.9	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.4	5.5	5.6	5.7	5.8	5.9	6.0
95	5.1	5.2	5.3	5.5	5.6	5.7	5.8	5.3	5.5	5.6	5.8	5.9	6.0	6.1	5.6	5.8	5.9	6.1	6.2	6.3	6.4
96	5.2	5.3	5.4	5.6	5.8	5.9	5.9	5.4	5.6	5.7	5.9	6.0	6.1	6.2	5.7	5.9	6.0	6.2	6.3	6.4	6.5
98	5.2	5.4	5.6	5.8	5.9	6.0	6.1	5.5	5.7	5.9	6.0	6.2	6.3	6.3	5.8	6.0	6.2	6.4	6.5	6.6	6.6
98	5.3	5.6	5.8	6.0	6.1	6.1	6.2	5.6	5.8	6.1	6.2	6.3	6.4	6.4	5.9	6.2	6.4	6.5	6.6	6.7	6.7
99	5.5	5.8	6.1	6.2	6.2	6.3	6.3	5.8	6.1	6.3	6.4	6.5	6.5	6.6	6.1	6.5	6.7	6.8	6.8	6.8	6.9
99.9	5.9	6.3	6.4	6.4	6.4	6.4	6.4	6.3	6.6	6.7	6.7	6.7	6.7	6.7	6.7	6.9	7.0	7.0	7.0	7.0	7.0
Speed (mi/h)	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Grade (%)	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.7	3.8	3.8	3.9	3.9	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.5	4.5	4.6
90	3.9	3.9	4.0	4.1	4.1	4.2	4.3	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.4	4.5	4.5	4.6	4.7	4.8	4.9
95	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.7	4.8	4.9	5.0	4.7	4.8	4.9	5.0	5.2	5.3	5.4
96	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.4	4.5	4.7	4.8	4.9	5.0	5.1	4.7	4.9	5.0	5.2	5.3	5.4	5.5
98	4.2	4.4	4.5	4.6	4.7	4.8	4.9	4.5	4.6	4.8	4.9	5.1	5.2	5.2	4.8	5.0	5.2	5.3	5.4	5.5	5.6
98	4.3	4.5	4.7	4.8	4.9	5.0	5.0	4.6	4.8	5.0	5.1	5.3	5.3	5.4	5.0	5.2	5.4	5.5	5.6	5.7	5.8
99	4.5	4.7	4.9	5.0	5.1	5.2	5.2	4.8	5.1	5.3	5.4	5.5	5.5	5.5	5.2	5.5	5.7	5.8	5.8	5.9	5.9
99.9	4.9	5.3	5.4	5.4	5.4	5.5	5.5	5.3	5.7	5.7	5.8	5.8	5.8	5.8	5.9	6.1	6.2	6.2	6.2	6.2	6.3
Speed (mi/h)	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Grade (%)	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.3	4.4	4.5	4.5	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.9	5.0	5.0	4.9	4.9	5.0	5.1	5.2	5.3	5.3
90	4.5	4.6	4.7	4.8	4.8	4.9	5.0	4.8	4.9	5.0	5.0	5.1	5.2	5.3	5.1	5.2	5.3	5.4	5.5	5.6	5.6
95	4.8	4.9	5.0	5.1	5.3	5.4	5.5	5.1	5.2	5.3	5.4	5.6	5.7	5.8	5.4	5.5	5.6	5.8	5.9	6.0	6.1
96	4.8	5.0	5.1	5.3	5.4	5.5	5.6	5.1	5.3	5.4	5.6	5.7	5.8	5.9	5.5	5.6	5.8	5.9	6.0	6.1	6.2
98	4.9	5.1	5.3	5.4	5.6	5.7	5.8	5.2	5.4	5.6	5.7	5.9	6.0	6.1	5.6	5.7	5.9	6.1	6.2	6.3	6.4
98	5.0	5.2	5.5	5.6	5.8	5.8	5.9	5.3	5.6	5.8	5.9	6.1	6.1	6.2	5.7	5.9	6.1	6.3	6.4	6.4	6.5
99	5.2	5.5	5.8	5.9	6.0	6.0	6.0	5.5	5.8	6.1	6.2	6.3	6.3	6.3	5.9	6.2	6.4	6.5	6.6	6.6	6.6
99.9	5.6	6.1	6.2	6.2	6.2	6.3	6.3	6.1	6.4	6.5	6.5	6.5	6.6	6.6	6.6	6.8	6.8	6.9	6.9	6.9	6.9
Speed (mi/h)	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Grade (%)	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.3	5.4	5.5	5.6	5.7	5.4	5.5	5.6	5.7	5.8	5.9	6.0
90	5.1	5.2	5.3	5.4	5.6	5.7	5.8	5.4	5.5	5.6	5.7	5.8	5.9	6.1	5.7	5.8	5.9	6.0	6.1	6.2	6.4
95	5.4	5.5	5.7	5.9	6.1	6.2	6.3	5.7	5.8	6.0	6.2	6.3	6.5	6.6	6.0	6.1	6.3	6.5	6.6	6.7	6.8
96	5.5	5.6	5.8	6.0	6.2	6.4	6.5	5.7	5.9	6.1	6.3	6.5	6.6	6.7	6.1	6.3	6.4	6.6	6.8	6.9	7.0
98	5.6	5.8	6.0	6.2	6.4	6.5	6.6	5.8	6.1	6.3	6.5	6.6	6.8	6.8	6.2	6.4	6.6	6.8	6.9	7.0	7.1
98	5.7	5.9	6.3	6.5	6.6	6.7	6.7	6.0	6.2	6.5	6.7	6.8	6.9	7.0	6.3	6.6	6.8	7.0	7.1	7.2	7.2
99	5.9	6.3	6.6	6.7	6.8	6.8	6.9	6.2	6.6	6.9	7.0	7.0	7.1	7.1	6.6	6.9	7.1	7.2	7.3	7.3	7.4
99.9	6.4	6.9	7.0	7.0	7.1	7.1	7.1	6.7	7.2	7.2	7.3	7.3	7.3	7.3	7.3	7.5	7.5	7.6	7.6	7.6	7.6

Table 4-3: Lookup Table for Grades of 2% and 4%

Speed (mi/h)	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Grade (%)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.3	3.3	3.3	3.3	3.4	3.4	3.5	3.4	3.5	3.5	3.5	3.6	3.6	3.7	3.6	3.7	3.7	3.8	3.8	3.9	4.0
90	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	3.9	4.0	4.1	4.2
95	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.8	3.8	3.9	4.0	4.1	4.1	3.9	4.0	4.1	4.2	4.4	4.5	4.5
96	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	4.0	4.1	4.1	4.2	3.9	4.1	4.2	4.3	4.5	4.5	4.6
98	3.6	3.6	3.7	3.8	3.8	3.8	3.9	3.8	3.9	4.0	4.1	4.2	4.2	4.3	4.0	4.1	4.3	4.5	4.6	4.6	4.7
98	3.7	3.7	3.8	3.8	3.9	3.9	3.9	3.8	4.0	4.1	4.2	4.3	4.3	4.4	4.1	4.3	4.5	4.6	4.7	4.7	4.8
99	3.7	3.8	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.3	4.4	4.4	4.4	4.4	4.2	4.5	4.7	4.8	4.8	4.8	4.9
99.9	4.0	4.1	4.1	4.1	4.1	4.1	4.1	4.3	4.5	4.5	4.5	4.5	4.6	4.6	4.6	4.9	5.0	5.0	5.0	5.0	5.0
Speed (mi/h)	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Grade (%)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.8	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.4	4.4	4.5	4.6
90	3.9	4.0	4.0	4.0	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.4	4.4	4.5	4.3	4.4	4.5	4.6	4.6	4.7	4.8
95	4.1	4.1	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.5	4.5	4.6	4.7	4.8	4.5	4.6	4.7	4.9	5.0	5.1	5.1
96	4.1	4.2	4.3	4.3	4.4	4.5	4.5	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.6	4.7	4.8	5.0	5.1	5.2	5.2
98	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.4	4.5	4.6	4.7	4.8	4.9	4.9	4.6	4.8	4.9	5.1	5.2	5.3	5.3
98	4.3	4.3	4.4	4.5	4.6	4.6	4.6	4.5	4.6	4.8	4.9	4.9	5.0	5.0	4.7	4.9	5.1	5.2	5.3	5.4	5.4
99	4.4	4.5	4.6	4.6	4.7	4.7	4.7	4.6	4.8	4.9	5.0	5.1	5.1	5.1	4.8	5.1	5.3	5.4	5.4	5.5	5.5
99.9	4.6	4.8	4.8	4.8	4.8	4.8	4.8	4.9	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.5	5.6	5.6	5.6	5.6	5.6
Speed (mi/h)	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Grade (%)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.3	4.3	4.4	4.4	4.5	4.6	4.6	4.5	4.5	4.6	4.7	4.7	4.8	4.9	4.7	4.8	4.8	4.9	5.0	5.1	5.2
90	4.4	4.5	4.6	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.9	4.9	5.0	5.1	4.9	4.9	5.0	5.1	5.2	5.3	5.4
95	4.6	4.7	4.8	4.9	5.0	5.0	5.1	4.8	4.9	5.0	5.1	5.3	5.3	5.4	5.1	5.2	5.3	5.5	5.6	5.7	5.8
96	4.7	4.8	4.9	5.0	5.0	5.1	5.2	4.9	5.0	5.1	5.2	5.4	5.4	5.5	5.1	5.3	5.4	5.6	5.7	5.8	5.8
98	4.7	4.8	4.9	5.1	5.1	5.2	5.2	4.9	5.1	5.2	5.4	5.5	5.5	5.6	5.2	5.4	5.5	5.7	5.8	5.9	5.9
98	4.8	4.9	5.1	5.2	5.2	5.3	5.3	5.0	5.2	5.4	5.5	5.6	5.6	5.7	5.3	5.5	5.7	5.8	5.9	6.0	6.0
99	4.9	5.1	5.3	5.3	5.4	5.4	5.4	5.2	5.4	5.6	5.7	5.7	5.7	5.7	5.4	5.7	5.9	6.0	6.1	6.1	6.1
99.9	5.2	5.4	5.5	5.5	5.5	5.5	5.5	5.5	5.8	5.8	5.8	5.8	5.8	5.8	5.8	6.1	6.2	6.2	6.2	6.2	6.2
Speed (mi/h)	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Grade (%)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.1	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.8	3.8
90	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.6	3.6	3.7	3.8	3.9	3.9	4.0
95	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.5	3.6	3.7	3.7	3.8	3.9	3.9	3.7	3.8	3.9	4.1	4.2	4.3	4.3
96	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.8	3.9	3.9	4.0	3.8	3.9	4.0	4.2	4.3	4.4	4.4
98	3.4	3.5	3.5	3.6	3.6	3.6	3.7	3.6	3.7	3.8	3.9	4.0	4.0	4.1	3.8	3.9	4.1	4.3	4.4	4.4	4.5
98	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.9	4.0	4.1	4.1	4.1	3.9	4.1	4.3	4.4	4.5	4.5	4.6
99	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	3.9	4.1	4.1	4.2	4.2	4.2	4.0	4.3	4.5	4.6	4.6	4.6	4.6
99.9	3.8	3.8	3.9	3.9	3.9	3.9	3.9	4.0	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.7	4.7	4.7	4.7	4.7	4.7
Speed (mi/h)	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Grade (%)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.2	4.3	4.3	4.4
90	3.8	3.8	3.8	3.9	3.9	3.9	4.0	3.9	4.0	4.1	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.4	4.4	4.5	4.6
95	3.9	4.0	4.0	4.1	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.4	4.5	4.5	4.3	4.4	4.5	4.7	4.8	4.9	4.9
96	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.4	4.5	4.6	4.8	4.9	4.9	5.0
98	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.2	4.3	4.4	4.5	4.6	4.6	4.7	4.4	4.5	4.7	4.9	5.0	5.0	5.1
98	4.1	4.1	4.2	4.3	4.3	4.3	4.4	4.3	4.4	4.5	4.6	4.7	4.7	4.7	4.5	4.7	4.9	5.0	5.1	5.1	5.1
99	4.1	4.2	4.3	4.4	4.4	4.4	4.4	4.4	4.6	4.7	4.7	4.8	4.8	4.8	4.6	4.9	5.1	5.1	5.2	5.2	5.2
99.9	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.6	4.9	4.9	4.9	4.9	4.9	4.9	4.9	5.3	5.3	5.3	5.3	5.3	5.3
Speed (mi/h)	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Grade (%)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Precipitation	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
Percentage Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
85	4.1	4.2	4.2	4.3	4.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.9	5.0
90	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.7	4.8	4.9	4.6	4.7	4.8	4.9	5.0	5.1	5.2
95	4.4	4.5	4.6	4.6	4.7	4.8	4.8	4.6	4.7	4.8	4.9	5.0	5.1	5.1	4.8	4.9	5.1	5.2	5.3	5.4	5.5
96	4.5	4.5	4.6	4.7	4.8	4.8	4.9	4.7	4.8	4.9	5.0	5.1	5.2	5.2	4.9	5.0	5.2	5.3	5.4	5.5	5.6
98	4.5	4.6	4.7	4.8	4.8	4.9	4.9	4.7	4.8	5.0	5.1	5.2	5.2	5.3	4.9	5.1	5.3	5.4	5.5	5.6	5.6
98	4.6	4.7	4.8	4.9	4.9	5.0	5.0	4.8	5.0	5.1	5.2	5.3	5.3	5.4	5.0	5.2	5.5	5.6	5.7	5.7	5.7
99	4.7	4.8	5.0	5.0	5.0	5.1	5.1	4.9	5.1	5.3	5.4	5.4	5.4	5.4	5.2	5.5	5.7	5.7	5.8	5.8	5.8
99.9	5.0	5.1	5.1	5.1	5.1	5.2	5.2	5.2	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.8	5.9	5.9	5.9	5.9	5.9

In comparing the results, it is observed that there is a need to increase the duration of yellow time by approximately between 0.2 to 0.6 seconds with the increase in percent of buses in the traffic stream. An increase in precipitation has a significant effect on required minimum duration for yellow time with the increase in bus traffic volume. However, approach speed has very little effect on the required increase in yellow time duration with the increase in bus traffic volume from base case of 100% passenger car volume.

Results from the study are consistent with findings from previous studies [4, 5], and provide easy and clear guidelines for practitioners and engineers to use in designing yellow times for signalized intersections. Ranges of confidence intervals are listed due to the stochastic nature of drivers and roadway conditions.

The last aspect examined was the all-red interval. The all-red interval is a signal phase used to ensure the intersection is cleared of vehicles that legally entered before the termination of the yellow phase. The equation, from ITE [2], is shown in Equation 4.7.

$$AR = \frac{W + L}{v} \tag{4.7}$$

Where W is the width of the intersection (m)
L is the length of the vehicle (m)
v is the approach speed (m/s)

The width of the intersection was assumed to be a two lane road with 10 foot shoulders, meaning the width of the intersection was 44 feet or 13.4 meters wide. L is the length of the vehicle, which was taken as 20 feet (6.1 meters) for a passenger car and 40 feet (12.2 meters) for a transit bus while 60 feet (18.3 meters) for an articulated transit bus [2]. Finally, v is the approach speed in m/s. These calculations were done for the different percentages of buses by using a weighted average, as shown in Equation 4.8. The results of this are shown in Table 4-4.

$$AR = \lambda\left(\frac{W + L_b}{v_b}\right) + (1 - \lambda)\left(\frac{W + L_c}{v_c}\right) \tag{4.8}$$

Where W is the width of the intersection (m)
L_b is the length of the bus (m)
v_b is the approach speed of the bus(m/s)
L_c is the length of the car (m)
v_c is the approach speed of the car (m/s)

Table 4-4: Required All-Red Times

		Speed Limit (mi/h)					
		Transit Buses (40 ft.)			Articulated Transit Buses (60 ft.)		
		35	45	55	35	45	55
Percentage Buses (%)	0	1.2	1.0	0.8	1.2	1.0	0.8
	5	1.3	1.0	0.8	1.3	1.0	0.8
	10	1.3	1.0	0.8	1.3	1.0	0.8
	15	1.3	1.0	0.8	1.4	1.1	0.8
	20	1.3	1.0	0.8	1.4	1.1	0.9
	25	1.3	1.0	0.9	1.4	1.1	0.9
	30	1.4	1.1	0.9	1.5	1.2	0.9

It is observed that longer clearance intervals are required for approaches with lower speed limits. With an addition of buses into the traffic stream, an additional clearance time ranging between 1.6 to 9.4 percent for transit buses and 3.1 to 18.8 percent for articulated transit buses for all speed limits. It is evident that longer clearance time is also required for traffic streams with higher composition of longer vehicles. This can be a significant increase when compared to current practice where only passenger cars are being accounted for in clearance time design.

4.4 CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

The results from this experiment are presented as tables of proposed developments of yellow and all-red interval durations that provide dilemma zone protection for passenger cars and heavy vehicles. It was observed that an addition of buses to traffic stream volume will require an increase in yellow indication and all-red duration by approximately 4 to 13 percent depending on the approach speed, grade, and weather conditions. In absolute terms, yellow duration requires an increase between 0.1 to 0.5 seconds to provide adequate protection. In addition, all-red intervals may require up to an additional 0.3 seconds, depending on the width of the intersection, speed limit, and type of bus length that the interval is designed for to ensure buses are cleared before conflicting traffic is released.

Such a finding may prompt a change in thinking, as all equations and practices used do not consider buses in the design of traffic signal timings. One possibility to provide this protection is to add a bus factor to the ITE yellow time formula so that buses can be adequately protected at signalized intersections. Another method to solve this problem may entail the use of vehicle-to-infrastructure communication to alert bus drivers of an impending signal change to ensure that they have adequate time to respond.

This study focused on one bus approaching an intersection with little cross-traffic. Therefore future work should look at the impacts that following or leading traffic, traffic density, as well as the presence of cross-traffic will have on bus driver behavior. Also, this study was conducted assuming bus drivers were affected by precipitation the same way as passenger car drivers. An empirical study of bus driver behavior is needed to develop PRTs and deceleration levels with the inclusion of precipitation.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 CONCLUSIONS

The research presented in this thesis entailed an in-depth discussion of the experiment that was conducted, including a detailed description of the experimental design, testing equipment and procedures, and presentation of the results. The experiment was designed and conducted to identify and quantify the dilemma zone for bus drivers and to investigate the factors that cause this dilemma zone to be different from the dilemma zones for cars and trucks. Analysis of the data presented demonstrates a significant difference between the dilemma zone for buses, trucks and passenger cars.

- The PRTs for bus drivers from the experiment had an average of 0.6 seconds with an 85^{th} percentile value of 0.8 seconds which is less than the ITE recommended value of 1.0 seconds for calculation of yellow time.
- Deceleration levels for buses are lower than passenger cars but higher than trucks. Bus deceleration level is lower than passenger cars due to its larger mass and use of S-cam air braking system. However, buses have higher deceleration levels compared to trucks because their masses are significantly lower than trucks.
- When considering buses for the development of yellow times, it is possible to provide dilemma zone protection with 99.9% confidence without adversely affecting the operations of the intersection.
- It is necessary to consider buses when designing all-red times in order to provide adequate times for buses to clear the intersection before designing the right of way to conflicting traffic.

Generally, it is believed that bus drivers will behave differently if the bus has a high occupancy. The field test conducted included only the bus driver and research assistant on the test vehicle. The effects of precipitation on bus stopping behavior in this study were assumed to be the same as the effects of precipitation for passenger cars. It is recommended that additional field tests be conducted to investigate the impacts of both high vehicle occupancy and precipitation conditions on bus stopping behavior.

As vehicle to infrastructure communications become more prevalent, the conclusions reached in this study can be applied to make signalized intersections more efficient and safer. If yellow times were increased to provide adequate protection for buses at all times, the cumulative delay introduces into the system would cause obvious decrease Level of Service at intersections. With vehicle to infrastructure communications, a signalized intersection can be notified of an approaching bus. The intersection control can adjust its yellow times accordingly to minimize the risk of the vehicle being caught in a dilemma zone thus avoiding unnecessary delay when no buses are present.

5.2 RECOMMENDATIONS

In order to continue the work presented in this thesis and further develop the state of practice, it is recommended that the following research precautions be undertaken:

- Examine the impact of high occupancy (include more passengers on the test vehicle) on the bus driver behavior at the onset of yellow.
- Investigate the impact of platooning conditions (such as bus following car, car following bus) on bus driver behavior at the onset of yellow.
- Investigate the impact of precipitation factors and roadway conditions on bus driver behavior at the onset of yellow.
- Conduct the same experiment but at higher approach speeds to observe bus driver behavior at high speed approaches (45 mph or 55 mph posted speed limit).

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APPENDIX A – VIRGINIA TECH INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

VirginiaTech

Office of Research Compliance
Institutational Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: October 3, 2013

TO: Hesham A Rakha, Ihab E Elshawarby, Boon Teck Ong, John Sangster, Craig William Bryant, Jinghui Wang, Mohamed Ahmed Elbadawy Taha Abdelmegeed, Mohammed Mamdouh Elhenawy, Raj Kishore Kamalanathsharma, Hao Chen

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)

PROTOCOL TITLE: Bus Dilemma Zone

IRB NUMBER: **13-835**

Effective October 3, 2013, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 6,7**
Protocol Approval Date:	**October 3, 2013**
Protocol Expiration Date:	**October 2, 2014**
Continuing Review Due Date*:	**September 18, 2014**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?
10/03/2013	06207204	Virginia Center for Transportation Innovation & Research	Compared on 10/03/2013

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.

APPENDIX B – PARTICIPANT RECRUITMENT MATERIAL

The Virginia Tech Transportation Institute is looking for

PARTICIPANTS FOR A BUS STUDY

$40 per hour (For 1.5 - 2.5 hours),

Are you 18 years old or older, can drive a bus, and have a valid Class B commercial driver's license?

If yes, please e-mail: ongbt98@vt.edu
or call 540-231-2528

You can also sign up to become a future participant at:
http://www.vtti.vt.edu/participate/participate-in-a-study.html

APPENDIX C – TELEPHONE SCRIPT AND SCREENING QUESTIONNAIRE

Telephone Script and Driver Screening Questionnaire

Note to Researcher:
Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding eligibility for this study.

Introductory Statement:
After prospective participant calls or you call them, use the following script to guide you through the screening interview.

Hello. My name is _____ and I am a researcher at the Virginia Tech Transportation Institute in Blacksburg, VA and I am recruiting bus drivers to participate in a driving study that will take place on the Smart Road.

This study involves participating in one driving session. If you choose to participate, you will drive a bus on the Smart Road for about two hours during daylight when the road is dry. Participants are paid $40 per hour prorated at $10 per 15 minutes or fraction thereof. Does this sound like something you would be interested in doing?

<u>If they indicated that they are not interested:</u>

Thank you for your time.

<u>If they indicated that they are interested:</u>

That's great. I would like to ask you some questions to see if you are eligible to participate. Do I have your consent to ask these questions?
(If Yes, Proceed)

Questions

1. *Do you have a valid Class B commercial driver's license?*
   (Criterion for participation: Must have a valid Class B commercial driver's license)

   □ Yes □ No

2. *Are you eligible for employment in the United States?*
   (Criterion for participation: Must be able to work in the US.)

   □ Yes □ No

3. *Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide*

their social security number to receive payment for participation in our studies. You do NOT need to provide it now, but are you willing to provide us with your social security number?
(Criterion for participation: Must answer yes)

□ Yes □ No

4. *What is your age?* ________
   (Criterion for participation: Must be over 18 at time of experiment)

5. *Are you able to drive a standard automatic transmission in a bus without assistive devices?*
   (Criterion for participation: Must be able to drive standard automatic transmission in a bus without assistance)

   □ Yes □ No

6. *How often do you drive a bus*?
   (Criterion for participation: Must drive a bus at least 2 times per week)

   □ Less than 2 times per week
   □ 2 to 4 times per week
   □ More than 4 times per week

7. *Do you have normal hearing and vision?*
   (Criterion for participation: Must have normal hearing and vision)

   □ Yes □ No

8. ***(Females only)*** *Are you currently pregnant?*

   □ Yes □ No

If "YES" inform them that they are still eligible for participation, but they are advised to discuss with their physician. They will be provided with the consent form and other details on the experiment proceedings which may help their physician in his judgment.

9. *Have you had any moving violations in the past 3 years? If so, please explain each case.*
   (Criterion for participation: Must not have more than two moving violations in the past 3 years)

   □ No □ Yes (*Please describe*) ____
   ____

10. *Have you been involved in any accidents within the past 3 years? If so, please explain.*
    (Criterion for participation: Must not have caused an accident in the past 3 years.)

□ No □ Yes (*Please describe*) ____
____
____

11. Do you have a history of any of the following? If so, please explain.
(Interviewer: Read the conditions in slowly. Try to determine whether the condition has been resolved, or continues to present a risk to driving ability.)

Heart Condition
(Criterion for participation: Must not have lingering effects of heart condition.)
□ No
□ Yes (*Please describe*) ________________________________

Stroke
(Criterion for participation: Must not have lingering effects of stroke.)
□ No
□ Yes (*Please describe*) ________________________________

Brain tumor
(Criterion for participation: Must not have lingering effects of brain tumor.)
□ No
□ Yes (*Please describe*) ________________________________

Head injury
(Criterion for participation: Must not have had a recent concussion or lingering effects of any head injury.)
□ No
□ Yes (*Please describe*) ________________________________

Epileptic seizures in past 12 months
(Criterion for participation: Must not have epileptic seizures or lapses of consciousness.)
□ No
□ Yes (*Please describe*) ________________________________

Current uncontrolled respiratory disorders?
(Criterion for participation: Must not have current uncontrolled respiratory disorders or any disorder that requires oxygen.)
□ No
□ Yes (*Please describe*)________________________________

Motion sickness

(Criterion for participation: Must not have motion sickness.)
□ No
□ Yes (*Please describe*) ________________________________

Inner ear problems
(Criterion for participation: Must not have inner ear problems.)
□ No
□ Yes (*Please describe)*________________________________

Dizziness, vertigo, or other balance problems
(Criterion for participation: Must not have dizziness, vertigo, or other balance problems.)
□ No
□ Yes (*Please describe*)________________________________

Uncontrolled Diabetes for which insulin is required
(Criterion for participation: Must not have uncontrolled diabetes for which insulin is required.)
□ No
□ Yes (*Please describe*)________________________________

Chronic migraine or tension headaches
(Criterion for participation: Must not have chronic migraine or tension headaches.)
□ No
□ Yes (*Please describe*)________________________________

12. Are you taking any medications that could interfere with your driving ability?
(Criterion for participation: Must not be taking any substances that may interfere with driving ability)
□ Yes □ No

Criteria for Participation:

1. **Must hold a valid Class B commercial driver's license.**
2. **Must be eligible for employment in the U.S.**
3. **Must have normal (or corrected with contacts to normal) hearing and vision.**
4. **Participants must be at least 18 years old**
5. **Must be able to drive an automatic bus transmission vehicle without assistive devices.**
6. **Must drive a bus at least 2 times per week.**
7. **Must not have more than two moving violations in the past three years.**
8. **Must not have caused an injurious accident in the past three years.**
9. **Cannot have lingering effects of heart condition, brain damage from stroke, tumor, or head injury, recent concussion. Cannot have had epileptic seizures in last 12 months, current uncontrolled respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, uncontrolled diabetes for which insulin is required, chronic migraine or tension headaches.**
10. **Cannot currently be taking any substances/medications that may interfere with driving ability.**

Note to Researcher:

If a response to any of the questions does not meet its criterion, politely read the following:

Unfortunately you are not eligible for this particular study. Thank you for your time and in interest in participating. Would you like to be called for future studies?

If the Participant is Eligible:

You're eligible to participate in this study. I would like to set up a time when you can come to the Virginia Tech Transportation Institute and participate in this study. Would it be possible for you to come in on ___________ (day of week) *at* ____*:*____ *hrs* (time)*?*

If the response is yes, go ahead and schedule the participant.

If the response is no, ask the following to the participant:

What day and time would be convenient for you?

If requested day and time is available then schedule the participant. If requested day and time is not available then suggest closer day and time slots and see if that will work for the participant.

Once the researcher has scheduled the participant, repeat the schedule day and time back to the participant.

Great! I have you scheduled for ___________ *(day) at* ___:____ hrs.

I will be calling you a day before to remind you of your schedule. If you need to cancel or reschedule, please call me at 540-231-2528.

We will have to cancel if it is raining or if the road is wet. What is the best number for me to reach you the day of the study if I need to cancel?

Phone #: ______________________

Here are the directions to the Institute. I can also email them to you if you wish.

From I-81:

1. Take exit 118B onto US-460 W towards Christiansburg.

2. Continue on US-460 W for approximately 10 miles.

3. Take exit 5AB toward US-460-BR W/US-460-BR E. The sign for this exit will read "Smart Road Center/Control Center.

4. Stay to your right on the exit ramp until you come to a stop sign at Industrial Park Drive.

5. Turn right onto Industrial Park Dr.

6. Take an immediate right onto Transportation Research Dr.

7. Turn left onto Transportation Research Plaza.

8. Drive up to the building

When you come to VTTI, you may park in any open space available and walk to reception area of the main building, which is two levels tall. An experimenter will be there to greet you a few minutes before your scheduled time. If you do not see someone, please wait and an experimenter will be with your shortly.

We ask that all subjects refrain from drinking alcohol and taking any substances that will impair their ability to drive prior to participating in our study.

Please bring reading glasses if you typically use them for filling out forms.

Do you have any questions that I can answer for you? (Answer the questions if any).

Great then I'll see you on _____________ (day) *at* ____:____ hrs *for the study. Thanks.*

Have a good day.

Information for Screened and Eligible Participant:

Screener: Please record this information if the participant is eligible. File this sheet separately from the screening questionnaire.

Name ____

Age __________

Gender __________

Phone Number ____________________

Best Time/Day to Call ___________________________________

Date and Time Scheduled ___________________________________

APPENDIX D – IRB APPROVED INFORMED CONSENT FORM

Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: Bus Signalized Intersection Study

Investigator(s): Hesham Rakha, Ihab El-Shawarby, and Boon Teck Ong

Section I. Purpose of this Research/Project:

The purpose of this study is to look at traffic signal timing involving buses. We are asking for your voluntary participation to help study this topic. The results of this research will be useful to researchers and others who want to improve the safety and efficiency of the nation's highways. About fifty bus driver adults will be recruited to participate for this study.

Section II. Procedures:

1. Read and sign this informed consent form.
2. Take a copy of the informed consent form for your records.
3. Complete the W-9 form.
4. Show a current commercial driver's license (CDL).
5. After that, you will be taken to a test vehicle where you will familiarize yourself with the test vehicle (fasten the seat belt securely, properly adjust seat and mirrors, and learn how to operate all vehicle controls).
6. During the study, you will drive the test vehicle on a two-lane highway that is closed to traffic. There is only one traffic signal on that road. While driving the test vehicle, your responses (like brake, accelerator, and speed) will be recorded, a camera will record your foot movements, and the other camera will record the forward view of the test vehicle (your face will not be recorded). You will first drive two orientation loops before beginning the 24 test loops (Passing the intersection 48 times). This will take approximately 1.5 hours to complete.
7. You will be asked to maintain a speed of 35 mph except as necessary on curves, and to obey traffic signals. You should follow all normal traffic rules and obey all traffic laws. A research assistant will ride with you and will be present at all times during the study to provide instructions, supervise the operation of the computer system, and answer questions as necessary.
8. At the end of the experiment, you will drive back to the Virginia Tech Transportation Institute where you will be paid and sign a receipt for payment.

Section III. Risks:

This study does not present more than minimal risk to current bus drivers. Caution should be exercised when operating a vehicle with which you are not familiar. Please be aware that events such as equipment failure, changes in the road, stray or wild animals entering the road, and weather changes may require you to respond accordingly. If at any point in the session the

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experimenter believes that continuing the session would endanger you or the equipment, he/she will stop the testing.

As a participant, you may be exposed to the following risks or discomforts by volunteering for this research:

1. Any risk present when driving a new and unfamiliar vehicle.
2. The risk of an accident normally present while driving at a speed of 35 mph.

You are not to do anything that you would not do when driving in other situations. That is, do not brake or steer beyond your capabilities.

The following precautions will be taken to ensure minimal risk to you:

1. You may decide not to participate at any time.
2. A break will be offered whenever you feel it is necessary.
3. The test vehicle has an up-to-date Virginia safety inspection tag.
4. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
5. You will be required to familiarize yourself with the test vehicle and to wear the seat belt while operating the test vehicle. You will proceed to the pre-test driving only when you are familiar, to the satisfaction of yourself and the experimenter's assistant, with the controls, displays, and test procedures.
6. Before the first trial, you will drive 2 pre-test practice loops to familiarize yourself with the vehicle and the Smart Road.
7. The portion of the Smart Road used for this test was built to all current Interstate safety standards for roadway, shoulder, clear zones, and crash mitigation
8. Testing will only be conducted when the road is dry and free of excess debris. There will be no other vehicle on the test section of the road when the test is conducted.
9. In the event of a medical emergency, or at your request, Virginia Tech Transportation Institute (VTTI) staff will arrange medical transportation to a nearby hospital emergency room. Note that in addition to the in-vehicle experimenter being present, the road and its communications channels are monitored by dispatchers at all times, who can quickly notify the necessary emergency services if required.

In the event of an accident or injury in an automobile owned or leased by Virginia Tech, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of the automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by your insurance.

Your safety and comfort are of paramount concern and will not be compromised for any reason. If you feel that you are being asked to do anything unsafe, please terminate your participation in the study and notify the experimenter immediately.

Section IV. Benefits:

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. This research is intended to support development of improvements in traffic signal timing and highway safety. Thus, there may be indirect benefits to the entire public from your participation in this experiment.

Section V. Extent of Anonymity and Confidentiality:

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You may withdraw your data from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed. The data may be used in future VTTI research projects, and identifying data will remain under the control of the project investigators. Some of the data gathered may be compared with other statistical data collected by other agencies involved in highway safety and highway operations. It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

Section VI. Compensation:

The driving portion of the study requires 1 participation session, taking approximately 1.5 to 2.5 hours to complete. Upon completion of the session, you will be paid $40 per hour in cash, prorated in 15 minute intervals, for time spent in the test vehicle and completing paperwork. You may stop at any time. If you decide to stop, you will be paid for the amount of time you participated. The maximum total compensation if you participate in the two sessions would be in the range of $60 to $100. If these payments are in excess of $600 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600, it is up to you as the participant to report any additional income as Virginia Tech will not file Form 1099 with the IRS. You must complete a W-9 form before receiving payment.

Section VII. Freedom to Withdraw:

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated.

Section VIII. Subject Responsibilities:

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties.
3. To wear the seat belt.
4. To abide by the instructed speed limits and traffic laws.
5. To abstain from any substances that will impair your ability to drive.
6. To drive the test vehicle in a safe and responsible manner.

Section IX. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent.

____ Date__________

Subject signature

Section X. For Further Information:

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury, I may contact:

Investigators	Telephone/email
Hesham Rakha	540-231-1505 / hrakha@vt.edu
Ihab El-Shawarby	540-231-1577/ shawarby@vt.edu
Boon Teck Ong	ongbt98@vt.edu
David M. Moore Chair, Virginia Tech Institutional Review Board for the Protection of Human Subjects Office of Research Compliance	540-231-4991 / moored@vt.edu

[NOTE: Subjects must be given a complete copy (or duplicate original) of the signed Informed Consent.]

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APPENDIX E – W-9 FORM

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

VENDOR REGISTRATION
Substitute Form W-9
Mail, e-mail or Fax completed form to:
201 Southgate Center, Blacksburg, VA 24061
W9@vt.edu Phone: (540) 231-2544/Fax: (540) 231-7221

Legal Name: ____________________
(as it appears on your tax return)

Trade Name: ____________________
(DBA)

Mail PURCHASE ORDERS and BIDS to:		Mail PAYMENTS to:	
PO Telephone # *(preferably toll free)*	PO Fax # *(preferably toll free)*	Email address:	
		AP email address:	

Taxpayer Identification Number:		
Employer Identification Number(EIN):	AND/OR	**Social Security Number (SSN):**

Entity Type (one MUST be checked)

___ Corporation
___ Government Entity
___ Non-Profit Organization
___ LLC
If "LLC" is checked, type **MUST** be marked below:
___ C Corporation (C)
___ S Corporation (S)
___ Partnership (P)
___ Partnership
___ Sole Proprietor
___ Individual (see below)

For Individuals ONLY:
____ I am a U.S. Citizen, **or**
____ I have been granted permanent residency (green card holder), **or**
____ I am a Resident Alien for tax purposes and have contacted the international tax specialist at 540-231-3754 or jakunz@vt.edu to discuss additional documentation that is required by federal law.

Business Classification Type (check ALL that apply): *for descriptions see: http://www.purch.vt.edu/Vendor/class.html*

_____ Large Business _____ Small Business _____ Minority owned Business _____ Women Owned Business _____ Other

Certification: Under penalties of perjury, I certify that:
(1) The number(s) shown on this form is my correct taxpayer identification number(s) (or I am waiting for a number to be issued to me), ***and*** (2) The organization entity and all other information provided is accurate, ***and*** (3) I am not subject to backup withholding either because I have not been notified that I am subject to backup withholding as a result of a failure to report all interest or dividends, or the Internal Revenue Service has notified me that I am no longer subject to backup withholding.

You must cross out item (3) above if you have been notified by IRS that you are currently subject to backup withholding because of underreporting interest or dividends on your tax return.

____________________ ____________________
Authorized Signature *Title*

____________________ ____________________ ____________________
Printed or Typed Name *Phone Number* *Date*

APPENDIX F – YELLOW TIME LOOKUP TABLES

Speed Limit	35																				
Grade (%)	0																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.5	2.6	2.6	2.6	2.7	2.7	2.7	2.7	2.8	2.8	2.9	2.9	3.0	3.0	2.9	3.0	3.0	3.1	3.2	3.2	3.3
60	2.8	2.8	2.8	2.9	2.9	2.9	3.0	3.0	3.0	3.1	3.1	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.4	3.5	3.5
70	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3	3.4	3.4	3.4	3.5	3.4	3.5	3.5	3.6	3.6	3.7	3.7
80	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9	4.0
85	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	3.8	3.9	4.0	4.0	4.1	4.1
90	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9	4.0	4.0	3.9	4.0	4.1	4.1	4.2	4.3	4.4
95	3.7	3.7	3.8	3.8	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.2	4.3	4.4	4.1	4.2	4.3	4.4	4.6	4.7	4.7
96	3.7	3.8	3.8	3.9	4.0	4.0	4.1	3.9	4.0	4.1	4.2	4.3	4.4	4.4	4.2	4.3	4.4	4.6	4.7	4.8	4.8
97	3.8	3.8	3.9	4.0	4.1	4.1	4.2	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.2	4.4	4.5	4.7	4.8	4.9	4.9
98	3.8	3.9	4.0	4.1	4.2	4.2	4.2	4.1	4.2	4.3	4.5	4.5	4.6	4.6	4.3	4.5	4.7	4.9	4.9	5.0	5.0
99	4.0	4.1	4.2	4.2	4.3	4.3	4.3	4.2	4.4	4.6	4.6	4.7	4.7	4.7	4.5	4.8	5.0	5.0	5.1	5.1	5.1
99.9	4.3	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.8	4.8	4.9	4.9	4.9	4.9	4.9	5.2	5.3	5.3	5.3	5.3	5.3

Speed Limit	35																				
Grade (%)	1																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.5	2.5	2.6	2.6	2.6	2.7	2.7	2.7	2.7	2.8	2.8	2.9	2.9	3.0	2.9	2.9	3.0	3.1	3.1	3.2	3.2
60	2.7	2.8	2.8	2.8	2.9	2.9	2.9	2.9	3.0	3.0	3.1	3.1	3.1	3.2	3.1	3.2	3.2	3.3	3.3	3.4	3.4
70	3.0	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.7
80	3.2	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.9
85	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.8	3.8	3.9	3.9	4.0	4.1
90	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.9	3.9	3.8	3.9	4.0	4.0	4.1	4.2	4.3
95	3.6	3.6	3.7	3.7	3.8	3.8	3.9	3.8	3.9	3.9	4.0	4.1	4.2	4.2	4.0	4.1	4.2	4.3	4.5	4.6	4.6
96	3.6	3.7	3.7	3.8	3.8	3.9	3.9	3.8	3.9	4.0	4.1	4.2	4.3	4.3	4.1	4.2	4.3	4.4	4.6	4.6	4.7
97	3.7	3.7	3.8	3.9	3.9	4.0	4.0	3.9	4.0	4.1	4.2	4.3	4.4	4.4	4.1	4.3	4.4	4.6	4.7	4.8	4.8
98	3.7	3.8	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.2	4.4	4.6	4.7	4.8	4.9	4.9
99	3.8	3.9	4.0	4.1	4.1	4.2	4.2	4.1	4.3	4.4	4.5	4.5	4.6	4.6	4.3	4.6	4.8	4.9	4.9	5.0	5.0
99.9	4.1	4.2	4.3	4.3	4.3	4.3	4.3	4.4	4.6	4.7	4.7	4.7	4.7	4.7	4.8	5.1	5.1	5.1	5.1	5.1	5.1

Speed Limit	35																				
Grade (%)	2																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.5	2.5	2.5	2.6	2.6	2.6	2.7	2.6	2.7	2.7	2.8	2.8	2.9	2.9	2.8	2.9	2.9	3.0	3.1	3.1	3.2
60	2.7	2.7	2.8	2.8	2.8	2.8	2.9	2.9	2.9	3.0	3.0	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.3	3.3	3.4
70	2.9	3.0	3.0	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.6
80	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.8
85	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.7	3.6	3.7	3.7	3.8	3.8	3.9	4.0
90	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	3.9	4.0	4.1	4.2
95	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.8	3.8	3.9	4.0	4.1	4.1	3.9	4.0	4.1	4.2	4.4	4.5	4.5
96	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	4.0	4.1	4.1	4.2	3.9	4.1	4.2	4.3	4.5	4.5	4.6
97	3.6	3.6	3.7	3.8	3.8	3.8	3.9	3.8	3.9	4.0	4.1	4.2	4.2	4.3	4.0	4.1	4.3	4.5	4.6	4.6	4.7
98	3.7	3.7	3.8	3.8	3.9	3.9	3.9	3.8	4.0	4.1	4.2	4.3	4.3	4.4	4.1	4.3	4.5	4.6	4.7	4.7	4.8
99	3.7	3.8	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.3	4.4	4.4	4.4	4.4	4.2	4.5	4.7	4.8	4.8	4.8	4.9
99.9	4.0	4.1	4.1	4.1	4.1	4.1	4.1	4.3	4.5	4.5	4.5	4.5	4.6	4.6	4.6	4.9	5.0	5.0	5.0	5.0	5.0

Speed Limit	35																				
Grade (%)	3																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.6	2.7	2.7	2.8	2.8	2.8	2.9	2.8	2.8	2.9	3.0	3.0	3.1	3.2
60	2.7	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.9	2.9	3.0	3.0	3.0	3.1	3.0	3.1	3.1	3.2	3.2	3.3	3.3
70	2.9	2.9	2.9	3.0	3.0	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.3	3.2	3.3	3.3	3.4	3.4	3.5	3.5
80	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.4	3.5	3.5	3.6	3.6	3.7	3.7
85	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.8	3.8	3.9
90	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.7	3.8	3.9	3.9	4.0	4.1
95	3.4	3.5	3.5	3.5	3.6	3.6	3.7	3.6	3.7	3.7	3.8	3.9	4.0	4.0	3.8	3.9	4.0	4.1	4.3	4.4	4.4
96	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.9	4.0	4.0	4.1	3.9	4.0	4.1	4.2	4.4	4.4	4.5
97	3.5	3.6	3.6	3.7	3.7	3.7	3.8	3.7	3.8	3.9	4.0	4.1	4.1	4.2	3.9	4.0	4.2	4.4	4.5	4.5	4.6
98	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	3.9	4.0	4.1	4.2	4.2	4.2	4.0	4.2	4.4	4.5	4.6	4.6	4.7
99	3.7	3.7	3.8	3.8	3.9	3.9	3.9	3.8	4.0	4.2	4.2	4.3	4.3	4.3	4.1	4.4	4.6	4.7	4.7	4.7	4.7
99.9	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.1	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.8	4.8	4.8	4.8	4.9	4.9

Speed Limit	35																				
Grade (%)	4																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.4	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.9	2.9	3.0	3.1	3.1
60	2.6	2.7	2.7	2.7	2.7	2.8	2.8	2.8	2.8	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.2	3.2	3.3
70	2.8	2.9	2.9	2.9	2.9	3.0	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.4	3.4	3.5
80	3.0	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.7
85	3.1	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.8	3.8
90	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.6	3.6	3.7	3.8	3.9	3.9	4.0
95	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.5	3.6	3.7	3.7	3.8	3.9	3.9	3.7	3.8	3.9	4.1	4.2	4.3	4.3
96	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.8	3.9	3.9	4.0	3.8	3.9	4.0	4.2	4.3	4.4	4.4
97	3.4	3.5	3.5	3.6	3.6	3.6	3.7	3.6	3.7	3.8	3.9	4.0	4.0	4.1	3.8	3.9	4.1	4.3	4.4	4.4	4.5
98	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.9	4.0	4.1	4.1	4.1	3.9	4.1	4.3	4.4	4.5	4.5	4.6
99	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	3.9	4.1	4.1	4.2	4.2	4.2	4.0	4.3	4.5	4.6	4.6	4.6	4.6
99.9	3.8	3.8	3.9	3.9	3.9	3.9	3.9	4.0	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.7	4.7	4.7	4.7	4.7	4.8

Speed Limit	35																				
Grade (%)	-1																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.6	2.6	2.6	2.7	2.7	2.8	2.8	2.7	2.8	2.9	2.9	3.0	3.0	3.1	2.9	3.0	3.1	3.2	3.2	3.3	3.3
60	2.8	2.9	2.9	2.9	3.0	3.0	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.3	3.2	3.3	3.3	3.4	3.5	3.5	3.6
70	3.1	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.8
80	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1
85	3.5	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.9	3.9	3.9	4.0	4.1	4.1	4.2	4.2
90	3.6	3.6	3.7	3.7	3.8	3.8	3.9	3.8	3.9	3.9	4.0	4.0	4.1	4.2	4.0	4.1	4.2	4.2	4.3	4.4	4.5
95	3.8	3.8	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.2	4.3	4.4	4.6	4.7	4.8	4.9
96	3.8	3.9	4.0	4.0	4.1	4.2	4.2	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.3	4.4	4.5	4.7	4.8	4.9	5.0
97	3.9	4.0	4.0	4.1	4.2	4.3	4.3	4.1	4.2	4.3	4.5	4.6	4.6	4.7	4.4	4.5	4.7	4.8	4.9	5.0	5.1
98	4.0	4.0	4.2	4.2	4.3	4.4	4.4	4.2	4.3	4.5	4.6	4.7	4.7	4.8	4.4	4.6	4.9	5.0	5.1	5.1	5.2
99	4.1	4.2	4.3	4.4	4.5	4.5	4.5	4.3	4.5	4.7	4.8	4.8	4.9	4.9	4.6	4.9	5.1	5.2	5.2	5.3	5.3
99.9	4.4	4.6	4.6	4.7	4.7	4.7	4.7	4.7	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.4	5.4	5.5	5.5	5.5	5.5

Speed Limit	35																				
Grade (%)	-2																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.6	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.9	3.0	3.0	3.1	3.1	3.0	3.0	3.1	3.2	3.3	3.3	3.4
60	2.9	2.9	2.9	3.0	3.0	3.1	3.1	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.3	3.3	3.4	3.5	3.5	3.6	3.6
70	3.1	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.9
80	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.8	3.9	4.0	4.0	4.1	4.1	4.2
85	3.5	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.1	4.0	4.0	4.1	4.2	4.2	4.3	4.4
90	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.3	4.1	4.2	4.3	4.4	4.4	4.5	4.6
95	3.9	3.9	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.4	4.5	4.6	4.7	4.8	4.9	5.0
96	3.9	4.0	4.1	4.2	4.3	4.3	4.4	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.4	4.5	4.7	4.8	5.0	5.0	5.1
97	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.2	4.3	4.5	4.6	4.7	4.8	4.9	4.5	4.6	4.8	5.0	5.1	5.2	5.2
98	4.1	4.2	4.3	4.4	4.5	4.5	4.6	4.3	4.5	4.6	4.8	4.9	4.9	5.0	4.6	4.8	5.0	5.1	5.2	5.3	5.4
99	4.2	4.4	4.5	4.6	4.6	4.7	4.7	4.5	4.7	4.9	5.0	5.0	5.1	5.1	4.8	5.1	5.3	5.4	5.4	5.5	5.5
99.9	4.5	4.8	4.8	4.9	4.9	4.9	4.9	4.9	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.6	5.6	5.7	5.7	5.7	5.7

Speed Limit	35																				
Grade (%)	-3																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.6	2.7	2.7	2.8	2.8	2.9	2.9	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.0	3.1	3.2	3.3	3.3	3.4	3.4
60	2.9	3.0	3.0	3.0	3.1	3.1	3.2	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.3	3.4	3.5	3.5	3.6	3.7	3.7
70	3.2	3.2	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9	4.0
80	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.9	3.9	3.9	4.0	3.9	4.0	4.1	4.1	4.2	4.2	4.3
85	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.9	3.9	4.0	4.0	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.3	4.4	4.5
90	3.8	3.8	3.9	3.9	4.0	4.1	4.1	4.0	4.1	4.1	4.2	4.3	4.3	4.4	4.3	4.3	4.4	4.5	4.6	4.7	4.8
95	4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.5	4.6	4.7	4.9	5.0	5.1	5.2
96	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.6	4.7	4.8	5.0	5.1	5.2	5.3
97	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.8	4.9	5.0	5.0	4.7	4.8	5.0	5.1	5.3	5.3	5.4
98	4.2	4.3	4.5	4.6	4.7	4.8	4.8	4.5	4.6	4.8	4.9	5.0	5.1	5.2	4.8	5.0	5.2	5.3	5.4	5.5	5.5
99	4.3	4.5	4.7	4.8	4.9	4.9	4.9	4.6	4.9	5.1	5.2	5.2	5.3	5.3	5.0	5.3	5.4	5.6	5.6	5.7	5.7
99.9	4.7	5.0	5.1	5.1	5.1	5.2	5.2	5.1	5.4	5.5	5.5	5.5	5.5	5.6	5.6	5.8	5.9	5.9	5.9	6.0	6.0

Speed Limit	35																				
Grade (%)	-4																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.7	2.7	2.8	2.8	2.9	2.9	3.0	2.9	2.9	3.0	3.1	3.1	3.2	3.2	3.1	3.2	3.2	3.3	3.4	3.4	3.5
60	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3	3.4	3.5	3.5	3.4	3.5	3.5	3.6	3.7	3.7	3.8
70	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	3.9	4.0	4.0	4.1
80	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.1	4.1	4.2	4.2	4.3	4.3	4.4
85	3.7	3.8	3.8	3.9	3.9	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.5	4.5	4.6
90	3.9	3.9	4.0	4.1	4.1	4.2	4.3	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.4	4.5	4.5	4.6	4.7	4.8	4.9
95	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.7	4.8	4.9	5.0	4.7	4.8	4.9	5.0	5.2	5.3	5.4
96	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.4	4.5	4.7	4.8	4.9	5.0	5.1	4.7	4.9	5.0	5.2	5.3	5.4	5.5
97	4.2	4.4	4.5	4.6	4.7	4.8	4.9	4.5	4.6	4.8	4.9	5.1	5.2	5.2	4.8	5.0	5.2	5.3	5.4	5.5	5.6
98	4.3	4.5	4.7	4.8	4.9	5.0	5.0	4.6	4.8	5.0	5.1	5.3	5.3	5.4	5.0	5.2	5.4	5.5	5.6	5.7	5.8
99	4.5	4.7	4.9	5.0	5.1	5.2	5.2	4.8	5.1	5.3	5.4	5.5	5.5	5.5	5.2	5.5	5.7	5.8	5.8	5.9	5.9
99.9	4.9	5.3	5.4	5.4	5.4	5.5	5.5	5.3	5.7	5.7	5.8	5.8	5.8	5.8	5.9	6.1	6.2	6.2	6.2	6.2	6.3

Speed Limit	45																				
Grade (%)	0																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.0	3.1	3.1	3.2	3.2	3.3	3.3	3.2	3.3	3.3	3.4	3.4	3.5	3.6	3.4	3.5	3.5	3.6	3.7	3.8	3.8
60	3.3	3.3	3.4	3.4	3.5	3.5	3.6	3.5	3.5	3.6	3.6	3.7	3.8	3.8	3.7	3.7	3.8	3.9	4.0	4.0	4.1
70	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	3.9	4.0	4.0	4.1	3.9	4.0	4.1	4.1	4.2	4.3	4.3
80	3.8	3.9	3.9	3.9	4.0	4.0	4.1	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.2	4.3	4.4	4.4	4.5	4.5	4.6
85	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.4	4.4	4.5	4.6	4.6	4.7	4.8
90	4.1	4.1	4.2	4.2	4.3	4.4	4.4	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.8	4.9	5.0	5.0
95	4.3	4.4	4.4	4.5	4.6	4.7	4.7	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.2	5.3	5.4
96	4.3	4.4	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.9	5.0	5.1	5.1	4.8	4.9	5.1	5.2	5.3	5.4	5.5
97	4.4	4.5	4.6	4.7	4.8	4.8	4.9	4.6	4.7	4.9	5.0	5.1	5.2	5.2	4.9	5.0	5.2	5.4	5.5	5.5	5.6
98	4.5	4.6	4.7	4.8	4.9	4.9	5.0	4.7	4.9	5.0	5.2	5.2	5.3	5.3	5.0	5.2	5.4	5.5	5.6	5.7	5.7
99	4.6	4.8	4.9	5.0	5.0	5.0	5.1	4.8	5.1	5.3	5.3	5.4	5.4	5.4	5.1	5.4	5.6	5.7	5.7	5.8	5.8
99.9	4.9	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.5	5.5	5.5	5.6	5.6	5.6	5.6	5.9	5.9	5.9	5.9	5.9	5.9

Speed Limit	45																				
Grade (%)	1																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.2	3.2	3.3	3.3	3.4	3.5	3.5	3.3	3.4	3.5	3.6	3.6	3.7	3.8
60	3.2	3.3	3.3	3.4	3.4	3.4	3.5	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.6	3.7	3.8	3.8	3.9	3.9	4.0
70	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.9	3.9	4.0	4.1	4.1	4.2	4.2
80	3.7	3.8	3.8	3.9	3.9	3.9	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.3	4.3	4.4	4.4	4.5
85	3.9	3.9	3.9	4.0	4.0	4.1	4.1	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.3	4.3	4.4	4.5	4.5	4.6	4.7
90	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.4	4.5	4.6	4.7	4.7	4.8	4.9
95	4.2	4.2	4.3	4.4	4.4	4.5	4.6	4.4	4.5	4.6	4.7	4.8	4.8	4.9	4.6	4.7	4.9	5.0	5.1	5.2	5.3
96	4.2	4.3	4.4	4.5	4.5	4.6	4.6	4.4	4.5	4.6	4.8	4.9	4.9	5.0	4.7	4.8	4.9	5.1	5.2	5.3	5.4
97	4.3	4.4	4.5	4.5	4.6	4.7	4.7	4.5	4.6	4.7	4.9	5.0	5.0	5.1	4.8	4.9	5.1	5.2	5.3	5.4	5.4
98	4.4	4.5	4.6	4.7	4.7	4.8	4.8	4.6	4.7	4.9	5.0	5.1	5.1	5.2	4.8	5.0	5.2	5.4	5.4	5.5	5.5
99	4.5	4.6	4.7	4.8	4.8	4.9	4.9	4.7	4.9	5.1	5.2	5.2	5.2	5.3	5.0	5.3	5.5	5.5	5.6	5.6	5.6
99.9	4.8	4.9	5.0	5.0	5.0	5.0	5.0	5.1	5.3	5.3	5.4	5.4	5.4	5.4	5.4	5.7	5.7	5.7	5.7	5.8	5.8

Speed Limit	45																				
Grade (%)	2																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.0	3.0	3.0	3.1	3.1	3.2	3.2	3.1	3.2	3.2	3.3	3.3	3.4	3.5	3.3	3.4	3.4	3.5	3.6	3.7	3.7
60	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.5	3.6	3.7	3.8	3.8	3.9	3.9
70	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.9	3.9	3.8	3.9	3.9	4.0	4.0	4.1	4.2
80	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.2	4.2	4.3	4.4	4.4
85	3.8	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.4	4.4	4.5	4.6
90	3.9	4.0	4.0	4.0	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.4	4.4	4.5	4.3	4.4	4.5	4.6	4.6	4.7	4.8
95	4.1	4.1	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.5	4.5	4.6	4.7	4.8	4.5	4.6	4.7	4.9	5.0	5.1	5.1
96	4.1	4.2	4.3	4.3	4.4	4.5	4.5	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.6	4.7	4.8	5.0	5.1	5.2	5.2
97	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.4	4.5	4.6	4.7	4.8	4.9	4.9	4.6	4.8	4.9	5.1	5.2	5.3	5.3
98	4.3	4.3	4.4	4.5	4.6	4.6	4.6	4.5	4.6	4.8	4.9	4.9	5.0	5.0	4.7	4.9	5.1	5.2	5.3	5.4	5.4
99	4.4	4.5	4.6	4.6	4.7	4.7	4.7	4.6	4.8	4.9	5.0	5.1	5.1	5.1	4.8	5.1	5.3	5.4	5.4	5.5	5.5
99.9	4.6	4.8	4.8	4.8	4.8	4.8	4.8	4.9	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.5	5.6	5.6	5.6	5.6	5.6

Speed Limit	45																				
Grade (%)	3																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.9	3.0	3.0	3.0	3.1	3.1	3.2	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.2	3.3	3.4	3.5	3.5	3.6	3.7
60	3.1	3.2	3.2	3.3	3.3	3.3	3.4	3.3	3.4	3.4	3.5	3.5	3.6	3.6	3.5	3.6	3.6	3.7	3.8	3.8	3.9
70	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.9	3.9	4.0	4.0	4.1
80	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.0	4.1	4.1	4.2	4.3	4.3
85	3.7	3.7	3.8	3.8	3.9	3.9	3.9	3.9	3.9	4.0	4.0	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.3	4.4	4.5
90	3.8	3.9	3.9	4.0	4.0	4.0	4.1	4.0	4.1	4.1	4.2	4.3	4.3	4.4	4.2	4.3	4.4	4.5	4.5	4.6	4.7
95	4.0	4.0	4.1	4.2	4.2	4.3	4.3	4.2	4.3	4.3	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.8	4.9	5.0	5.0
96	4.0	4.1	4.2	4.2	4.3	4.3	4.4	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.5	4.6	4.7	4.9	5.0	5.0	5.1
97	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.5	4.7	4.8	5.0	5.1	5.1	5.2
98	4.2	4.2	4.3	4.4	4.4	4.5	4.5	4.4	4.5	4.6	4.7	4.8	4.8	4.9	4.6	4.8	5.0	5.1	5.2	5.2	5.3
99	4.2	4.4	4.4	4.5	4.5	4.6	4.6	4.5	4.7	4.8	4.9	4.9	4.9	5.0	4.7	5.0	5.2	5.3	5.3	5.3	5.3
99.9	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.8	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.4	5.4	5.4	5.4	5.4	5.5

Speed Limit	45																				
Grade (%)	4																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	2.9	2.9	3.0	3.0	3.0	3.1	3.1	3.0	3.1	3.1	3.2	3.3	3.3	3.3	3.2	3.3	3.3	3.4	3.5	3.6	3.6
60	3.1	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.4	3.5	3.6	3.6	3.7	3.8	3.8
70	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.7	3.8	3.9	3.9	4.0	4.0
80	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.9	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.2
85	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.2	4.3	4.3	4.4
90	3.8	3.8	3.8	3.9	3.9	3.9	4.0	3.9	4.0	4.1	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.4	4.4	4.5	4.6
95	3.9	4.0	4.0	4.1	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.4	4.5	4.5	4.3	4.4	4.5	4.7	4.8	4.9	4.9
96	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.4	4.5	4.6	4.8	4.9	4.9	5.0
97	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.2	4.3	4.4	4.5	4.6	4.6	4.7	4.4	4.5	4.7	4.9	5.0	5.0	5.1
98	4.1	4.1	4.2	4.3	4.3	4.3	4.4	4.3	4.4	4.5	4.6	4.7	4.7	4.7	4.5	4.7	4.9	5.0	5.1	5.1	5.1
99	4.1	4.2	4.3	4.4	4.4	4.4	4.4	4.4	4.6	4.7	4.7	4.8	4.8	4.8	4.6	4.9	5.1	5.1	5.2	5.2	5.2
99.9	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.6	4.9	4.9	4.9	4.9	4.9	4.9	4.9	5.3	5.3	5.3	5.3	5.3	5.3

Speed Limit	45																				
Grade (%)	-1																				
Precipitation	Clear							Very Light Rain							Rain						
% Trucks	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.2	3.3	3.4	3.4	3.5	3.6	3.6	3.4	3.5	3.6	3.7	3.8	3.8	3.9
60	3.3	3.4	3.4	3.5	3.5	3.6	3.6	3.5	3.6	3.7	3.7	3.8	3.8	3.9	3.7	3.8	3.9	4.0	4.0	4.1	4.2
70	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.2	4.2	4.3	4.4	4.4
80	3.9	3.9	4.0	4.0	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.5	4.5	4.6	4.7	4.7
85	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.3	4.3	4.4	4.4	4.5	4.6	4.6	4.5	4.6	4.6	4.7	4.8	4.8	4.9
90	4.2	4.2	4.3	4.4	4.4	4.5	4.6	4.4	4.5	4.6	4.6	4.7	4.8	4.9	4.7	4.7	4.8	4.9	5.0	5.1	5.2
95	4.4	4.5	4.6	4.6	4.7	4.8	4.9	4.6	4.7	4.8	4.9	5.0	5.1	5.2	4.9	5.0	5.1	5.3	5.4	5.5	5.6
96	4.4	4.5	4.6	4.7	4.8	4.9	5.0	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.0	5.1	5.2	5.4	5.5	5.6	5.7
97	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.8	4.9	5.0	5.2	5.3	5.4	5.4	5.0	5.2	5.4	5.5	5.6	5.7	5.8
98	4.6	4.7	4.9	5.0	5.1	5.1	5.2	4.8	5.0	5.2	5.3	5.4	5.5	5.5	5.1	5.3	5.5	5.7	5.8	5.8	5.9
99	4.7	4.9	5.1	5.2	5.2	5.2	5.3	5.0	5.3	5.4	5.5	5.6	5.6	5.6	5.3	5.6	5.8	5.9	5.9	5.9	6.0
99.9	5.1	5.3	5.4	5.4	5.4	5.4	5.4	5.4	5.7	5.7	5.7	5.8	5.8	5.8	5.8	6.0	6.1	6.1	6.1	6.1	6.1

Speed Limit	45																				
Grade (%)	-2																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.3	3.4	3.4	3.5	3.6	3.6	3.7	3.5	3.6	3.7	3.7	3.8	3.9	4.0
60	3.4	3.4	3.5	3.6	3.6	3.7	3.7	3.6	3.7	3.7	3.8	3.8	3.9	4.0	3.8	3.9	4.0	4.0	4.1	4.2	4.2
70	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.3	4.3	4.4	4.5	4.5
80	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.4	4.5	4.5	4.4	4.5	4.6	4.6	4.7	4.8	4.8
85	4.1	4.2	4.2	4.3	4.3	4.4	4.5	4.4	4.4	4.5	4.5	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.9	5.0	5.0
90	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.8	4.8	4.9	5.0	4.8	4.9	5.0	5.0	5.1	5.2	5.3
95	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.0	5.2	5.3	5.4	5.5	5.6	5.7
96	4.6	4.7	4.8	4.9	5.0	5.1	5.2	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.1	5.2	5.4	5.5	5.7	5.8	5.8
97	4.6	4.8	4.9	5.0	5.1	5.2	5.3	4.9	5.0	5.2	5.3	5.5	5.5	5.6	5.2	5.4	5.5	5.7	5.8	5.9	5.9
98	4.7	4.9	5.1	5.2	5.3	5.3	5.4	5.0	5.2	5.4	5.5	5.6	5.7	5.7	5.3	5.5	5.7	5.9	5.9	6.0	6.0
99	4.9	5.1	5.3	5.4	5.4	5.5	5.5	5.2	5.4	5.6	5.7	5.8	5.8	5.8	5.5	5.8	6.0	6.1	6.1	6.1	6.2
99.9	5.2	5.6	5.6	5.6	5.7	5.7	5.7	5.6	5.9	5.9	6.0	6.0	6.0	6.0	6.0	6.3	6.3	6.3	6.3	6.3	6.4

Speed Limit	45																				
Grade (%)	-3																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.2	3.2	3.3	3.3	3.4	3.5	3.5	3.3	3.4	3.5	3.6	3.6	3.7	3.8	3.6	3.6	3.7	3.8	3.9	4.0	4.0
60	3.4	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.7	3.8	3.9	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.2	4.3	4.3
70	3.7	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.0	4.1	4.2	4.2	4.3	4.3	4.2	4.3	4.4	4.4	4.5	4.6	4.6
80	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.7	4.6	4.6	4.7	4.8	4.8	4.9	5.0
85	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.7	4.7	4.8	4.9	4.7	4.8	4.9	5.0	5.0	5.1	5.2
90	4.4	4.5	4.5	4.6	4.7	4.8	4.9	4.7	4.7	4.8	4.9	5.0	5.1	5.2	4.9	5.0	5.1	5.2	5.3	5.4	5.5
95	4.6	4.7	4.8	5.0	5.1	5.2	5.3	4.9	5.0	5.1	5.3	5.4	5.5	5.6	5.2	5.3	5.5	5.6	5.7	5.8	5.9
96	4.7	4.8	4.9	5.1	5.2	5.3	5.4	5.0	5.1	5.2	5.4	5.5	5.6	5.7	5.3	5.4	5.6	5.7	5.8	5.9	6.0
97	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.1	5.2	5.4	5.5	5.7	5.7	5.8	5.4	5.5	5.7	5.9	6.0	6.1	6.1
98	4.9	5.0	5.2	5.4	5.5	5.6	5.6	5.2	5.4	5.6	5.7	5.8	5.9	5.9	5.5	5.7	5.9	6.1	6.1	6.2	6.3
99	5.0	5.3	5.5	5.6	5.7	5.7	5.8	5.3	5.6	5.8	5.9	6.0	6.0	6.1	5.7	6.0	6.2	6.3	6.3	6.4	6.4
99.9	5.4	5.8	5.9	5.9	5.9	5.9	6.0	5.8	6.2	6.2	6.2	6.3	6.3	6.3	6.3	6.5	6.6	6.6	6.6	6.6	6.6

Speed Limit	45																				
Grade (%)	-4																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.2	3.3	3.3	3.4	3.5	3.5	3.6	3.4	3.5	3.6	3.6	3.7	3.8	3.8	3.6	3.7	3.8	3.9	4.0	4.0	4.1
60	3.5	3.6	3.6	3.7	3.8	3.8	3.9	3.7	3.8	3.9	3.9	4.0	4.1	4.1	4.0	4.0	4.1	4.2	4.3	4.3	4.4
70	3.8	3.9	4.0	4.0	4.1	4.1	4.2	4.1	4.1	4.2	4.3	4.3	4.4	4.5	4.3	4.4	4.5	4.5	4.6	4.7	4.7
80	4.2	4.2	4.3	4.3	4.4	4.5	4.5	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.7	4.7	4.8	4.9	5.0	5.0	5.1
85	4.3	4.4	4.5	4.5	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.9	5.0	5.0	4.9	4.9	5.0	5.1	5.2	5.3	5.3
90	4.5	4.6	4.7	4.8	4.8	4.9	5.0	4.8	4.9	5.0	5.0	5.1	5.2	5.3	5.1	5.2	5.3	5.4	5.5	5.6	5.6
95	4.8	4.9	5.0	5.1	5.3	5.4	5.5	5.1	5.2	5.3	5.4	5.6	5.7	5.8	5.4	5.5	5.6	5.8	5.9	6.0	6.1
96	4.8	5.0	5.1	5.3	5.4	5.5	5.6	5.1	5.3	5.4	5.6	5.7	5.8	5.9	5.5	5.6	5.8	5.9	6.0	6.1	6.2
97	4.9	5.1	5.3	5.4	5.6	5.7	5.8	5.2	5.4	5.6	5.7	5.9	6.0	6.1	5.6	5.7	5.9	6.1	6.2	6.3	6.4
98	5.0	5.2	5.5	5.6	5.8	5.8	5.9	5.3	5.6	5.8	5.9	6.1	6.1	6.2	5.7	5.9	6.1	6.3	6.4	6.4	6.5
99	5.2	5.5	5.8	5.9	6.0	6.0	6.0	5.5	5.8	6.1	6.2	6.3	6.3	6.3	5.9	6.2	6.4	6.5	6.6	6.6	6.6
99.9	5.6	6.1	6.2	6.2	6.2	6.3	6.3	6.1	6.4	6.5	6.5	6.5	6.6	6.6	6.6	6.8	6.8	6.9	6.9	6.9	6.9

Speed Limit	55																				
Grade (%)	0																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.5	3.6	3.6	3.7	3.8	3.8	3.9	3.7	3.8	3.8	3.9	4.0	4.1	4.1	3.9	3.9	4.0	4.1	4.2	4.3	4.4
60	3.8	3.8	3.9	4.0	4.0	4.1	4.1	4.0	4.0	4.1	4.2	4.2	4.3	4.4	4.1	4.2	4.3	4.4	4.5	4.6	4.6
70	4.0	4.1	4.2	4.2	4.3	4.3	4.4	4.2	4.3	4.4	4.4	4.5	4.6	4.6	4.4	4.5	4.6	4.7	4.8	4.8	4.9
80	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.7	4.8	4.9	4.9	4.7	4.8	4.9	5.0	5.0	5.1	5.2
85	4.5	4.5	4.6	4.7	4.7	4.8	4.8	4.7	4.8	4.8	4.9	5.0	5.0	5.1	4.9	5.0	5.1	5.1	5.2	5.3	5.4
90	4.6	4.7	4.8	4.8	4.9	5.0	5.1	4.9	4.9	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.7
95	4.8	4.9	5.0	5.2	5.3	5.4	5.4	5.1	5.2	5.3	5.4	5.6	5.7	5.7	5.3	5.5	5.6	5.7	5.9	6.0	6.1
96	4.9	5.0	5.1	5.3	5.4	5.5	5.5	5.1	5.3	5.4	5.5	5.7	5.8	5.8	5.4	5.5	5.7	5.9	6.0	6.1	6.1
97	5.0	5.1	5.2	5.4	5.5	5.6	5.6	5.2	5.4	5.5	5.7	5.8	5.9	5.9	5.5	5.7	5.8	6.0	6.1	6.2	6.2
98	5.1	5.2	5.4	5.5	5.6	5.7	5.7	5.3	5.5	5.7	5.8	5.9	6.0	6.0	5.6	5.8	6.0	6.2	6.2	6.3	6.3
99	5.2	5.4	5.6	5.7	5.7	5.8	5.8	5.4	5.7	5.9	6.0	6.1	6.1	6.1	5.8	6.1	6.3	6.3	6.4	6.4	6.4
99.9	5.6	5.8	5.9	5.9	5.9	5.9	5.9	5.9	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.5	6.5	6.6	6.6	6.6	6.6

Speed Limit	55																				
Grade (%)	1																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.5	3.5	3.6	3.6	3.7	3.8	3.8	3.6	3.7	3.8	3.9	3.9	4.0	4.0	3.8	3.9	4.0	4.0	4.1	4.2	4.3
60	3.7	3.8	3.8	3.9	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.3	4.4	4.5	4.5
70	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.4	4.4	4.5	4.5	4.4	4.4	4.5	4.6	4.7	4.7	4.8
80	4.2	4.3	4.3	4.4	4.4	4.5	4.6	4.4	4.5	4.6	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.9	4.9	5.0	5.1
85	4.4	4.4	4.5	4.5	4.6	4.7	4.7	4.6	4.6	4.7	4.8	4.8	4.9	5.0	4.8	4.9	4.9	5.0	5.1	5.2	5.3
90	4.5	4.6	4.7	4.7	4.8	4.9	4.9	4.7	4.8	4.9	5.0	5.1	5.1	5.2	5.0	5.1	5.1	5.2	5.3	5.4	5.5
95	4.7	4.8	4.9	5.0	5.1	5.2	5.3	4.9	5.0	5.2	5.3	5.4	5.5	5.6	5.2	5.3	5.5	5.6	5.7	5.8	5.9
96	4.8	4.9	5.0	5.1	5.2	5.3	5.3	5.0	5.1	5.3	5.4	5.5	5.6	5.7	5.3	5.4	5.6	5.7	5.8	5.9	6.0
97	4.8	5.0	5.1	5.2	5.3	5.4	5.4	5.1	5.2	5.4	5.5	5.6	5.7	5.7	5.3	5.5	5.7	5.8	5.9	6.0	6.1
98	4.9	5.1	5.2	5.3	5.4	5.5	5.5	5.2	5.3	5.5	5.7	5.7	5.8	5.8	5.4	5.6	5.9	6.0	6.1	6.1	6.2
99	5.1	5.3	5.4	5.5	5.5	5.6	5.6	5.3	5.6	5.8	5.8	5.9	5.9	5.9	5.6	5.9	6.1	6.2	6.2	6.2	6.3
99.9	5.4	5.6	5.7	5.7	5.7	5.7	5.7	5.7	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.3	6.3	6.4	6.4	6.4	6.4

Speed Limit	55																				
Grade (%)	2																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.6	3.6	3.7	3.8	3.9	3.9	4.0	3.7	3.8	3.9	4.0	4.1	4.2	4.2
60	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.8	3.9	4.0	4.0	4.1	4.2	4.2	4.0	4.1	4.2	4.3	4.3	4.4	4.5
70	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.4	4.5	4.6	4.6	4.7
80	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.4	4.4	4.5	4.5	4.6	4.6	4.7	4.6	4.6	4.7	4.8	4.8	4.9	5.0
85	4.3	4.3	4.4	4.4	4.5	4.6	4.6	4.5	4.5	4.6	4.7	4.7	4.8	4.9	4.7	4.8	4.8	4.9	5.0	5.1	5.2
90	4.4	4.5	4.6	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.9	4.9	5.0	5.1	4.9	4.9	5.0	5.1	5.2	5.3	5.4
95	4.6	4.7	4.8	4.9	5.0	5.0	5.1	4.8	4.9	5.0	5.1	5.3	5.3	5.4	5.1	5.2	5.3	5.5	5.6	5.7	5.8
96	4.7	4.8	4.9	5.0	5.0	5.1	5.2	4.9	5.0	5.1	5.2	5.4	5.4	5.5	5.1	5.3	5.4	5.6	5.7	5.8	5.8
97	4.7	4.8	4.9	5.1	5.1	5.2	5.2	4.9	5.1	5.2	5.4	5.5	5.5	5.6	5.2	5.4	5.5	5.7	5.8	5.9	5.9
98	4.8	4.9	5.1	5.2	5.2	5.3	5.3	5.0	5.2	5.4	5.5	5.6	5.6	5.7	5.3	5.5	5.7	5.8	5.9	6.0	6.0
99	4.9	5.1	5.3	5.3	5.4	5.4	5.4	5.2	5.4	5.6	5.7	5.7	5.7	5.7	5.4	5.7	5.9	6.0	6.1	6.1	6.1
99.9	5.2	5.4	5.5	5.5	5.5	5.5	5.5	5.5	5.8	5.8	5.8	5.8	5.8	5.8	5.8	6.1	6.2	6.2	6.2	6.2	6.2

Speed Limit	55																				
Grade (%)	3																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.5	3.6	3.7	3.7	3.8	3.9	3.9	3.7	3.8	3.8	3.9	4.0	4.1	4.2
60	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.8	3.8	3.9	4.0	4.0	4.1	4.1	3.9	4.0	4.1	4.2	4.3	4.3	4.4
70	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.2	4.2	4.3	4.4	4.2	4.3	4.4	4.4	4.5	4.5	4.6
80	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.7	4.7	4.8	4.9
85	4.2	4.3	4.3	4.3	4.4	4.4	4.5	4.4	4.5	4.5	4.6	4.6	4.7	4.8	4.6	4.7	4.7	4.8	4.9	5.0	5.1
90	4.3	4.4	4.5	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.7	4.8	4.9	5.0	4.7	4.8	4.9	5.0	5.1	5.2	5.3
95	4.5	4.6	4.7	4.7	4.8	4.9	4.9	4.7	4.8	4.9	5.0	5.1	5.2	5.3	4.9	5.1	5.2	5.3	5.5	5.6	5.6
96	4.6	4.6	4.7	4.8	4.9	5.0	5.0	4.8	4.9	5.0	5.1	5.2	5.3	5.3	5.0	5.1	5.3	5.4	5.6	5.6	5.7
97	4.6	4.7	4.8	4.9	5.0	5.0	5.1	4.8	5.0	5.1	5.2	5.3	5.4	5.4	5.1	5.2	5.4	5.6	5.7	5.7	5.8
98	4.7	4.8	4.9	5.0	5.1	5.1	5.2	4.9	5.1	5.2	5.4	5.4	5.5	5.5	5.2	5.4	5.6	5.7	5.8	5.8	5.9
99	4.8	5.0	5.1	5.2	5.2	5.2	5.2	5.0	5.3	5.4	5.5	5.5	5.6	5.6	5.3	5.6	5.8	5.9	5.9	5.9	5.9
99.9	5.1	5.3	5.3	5.3	5.3	5.3	5.3	5.4	5.6	5.6	5.7	5.7	5.7	5.7	5.7	6.0	6.0	6.0	6.0	6.0	6.0

Speed Limit	55																				
Grade (%)	4																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.3	3.4	3.4	3.5	3.5	3.6	3.6	3.5	3.5	3.6	3.7	3.7	3.8	3.9	3.6	3.7	3.8	3.9	3.9	4.0	4.1
60	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.7	3.8	3.8	3.9	4.0	4.0	4.1	3.9	4.0	4.0	4.1	4.2	4.2	4.3
70	3.8	3.8	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.3	4.4	4.5	4.5
80	4.0	4.1	4.1	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.4	4.4	4.5	4.5	4.4	4.4	4.5	4.6	4.6	4.7	4.8
85	4.1	4.2	4.2	4.3	4.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.9	5.0
90	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.7	4.8	4.9	4.6	4.7	4.8	4.9	5.0	5.1	5.2
95	4.4	4.5	4.6	4.6	4.7	4.8	4.8	4.6	4.7	4.8	4.9	5.0	5.1	5.1	4.8	4.9	5.1	5.2	5.3	5.4	5.5
96	4.5	4.5	4.6	4.7	4.8	4.8	4.9	4.7	4.8	4.9	5.0	5.1	5.2	5.2	4.9	5.0	5.2	5.3	5.4	5.5	5.6
97	4.5	4.6	4.7	4.8	4.8	4.9	4.9	4.7	4.8	5.0	5.1	5.2	5.2	5.3	4.9	5.1	5.3	5.4	5.5	5.6	5.6
98	4.6	4.7	4.8	4.9	4.9	5.0	5.0	4.8	5.0	5.1	5.2	5.3	5.3	5.4	5.0	5.2	5.5	5.6	5.7	5.7	5.7
99	4.7	4.8	5.0	5.0	5.0	5.1	5.1	4.9	5.1	5.3	5.4	5.4	5.4	5.4	5.2	5.5	5.7	5.7	5.8	5.8	5.8
99.9	5.0	5.1	5.1	5.1	5.1	5.2	5.2	5.2	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.8	5.9	5.9	5.9	5.9	5.9

Speed Limit	55																				
Grade (%)	-1																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.6	3.6	3.7	3.8	3.8	3.9	4.0	3.7	3.8	3.9	4.0	4.1	4.1	4.2	3.9	4.0	4.1	4.2	4.3	4.4	4.5
60	3.8	3.9	4.0	4.0	4.1	4.2	4.2	4.0	4.1	4.2	4.3	4.3	4.4	4.5	4.2	4.3	4.4	4.5	4.6	4.6	4.7
70	4.1	4.2	4.2	4.3	4.4	4.4	4.5	4.3	4.4	4.5	4.5	4.6	4.7	4.7	4.5	4.6	4.7	4.8	4.9	4.9	5.0
80	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.8	4.9	5.0	5.0	4.9	4.9	5.0	5.1	5.2	5.2	5.3
85	4.6	4.6	4.7	4.8	4.8	4.9	5.0	4.8	4.9	4.9	5.0	5.1	5.2	5.2	5.0	5.1	5.2	5.3	5.4	5.5	5.5
90	4.7	4.8	4.9	5.0	5.1	5.2	5.2	5.0	5.1	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.4	5.5	5.6	5.7	5.8
95	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.2	5.3	5.5	5.6	5.7	5.8	5.9	5.5	5.6	5.8	5.9	6.0	6.1	6.2
96	5.0	5.1	5.3	5.4	5.5	5.6	5.7	5.3	5.4	5.6	5.7	5.8	5.9	6.0	5.5	5.7	5.9	6.0	6.2	6.3	6.3
97	5.1	5.2	5.4	5.6	5.7	5.8	5.8	5.3	5.5	5.7	5.9	6.0	6.1	6.1	5.6	5.8	6.0	6.2	6.3	6.4	6.4
98	5.2	5.4	5.6	5.7	5.8	5.9	5.9	5.4	5.7	5.9	6.0	6.1	6.2	6.2	5.8	6.0	6.2	6.3	6.4	6.5	6.5
99	5.3	5.6	5.8	5.9	6.0	6.0	6.0	5.6	5.9	6.1	6.2	6.3	6.3	6.3	5.9	6.3	6.5	6.5	6.6	6.6	6.6
99.9	5.7	6.1	6.1	6.1	6.1	6.2	6.2	6.0	6.4	6.4	6.4	6.5	6.5	6.5	6.4	6.7	6.7	6.8	6.8	6.8	6.8

Speed Limit	55																				
Grade (%)	-2																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	0	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.6	3.7	3.8	3.8	3.9	4.0	4.0	3.8	3.9	4.0	4.1	4.1	4.2	4.3	4.0	4.1	4.2	4.3	4.4	4.5	4.5
60	3.9	4.0	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.3	4.4	4.5	4.6	4.7	4.7	4.8
70	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.4	4.5	4.6	4.6	4.7	4.8	4.8	4.6	4.7	4.8	4.9	5.0	5.0	5.1
80	4.5	4.6	4.6	4.7	4.8	4.9	4.9	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.0	5.1	5.1	5.2	5.3	5.4	5.5
85	4.7	4.7	4.8	4.9	5.0	5.0	5.1	4.9	5.0	5.1	5.1	5.2	5.3	5.4	5.2	5.2	5.3	5.4	5.5	5.6	5.7
90	4.9	4.9	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.4	5.5	5.6	5.7	5.8	5.9	6.0
95	5.1	5.2	5.3	5.5	5.6	5.7	5.8	5.3	5.5	5.6	5.8	5.9	6.0	6.1	5.6	5.8	5.9	6.1	6.2	6.3	6.4
96	5.2	5.3	5.4	5.6	5.8	5.9	5.9	5.4	5.6	5.7	5.9	6.0	6.1	6.2	5.7	5.9	6.0	6.2	6.3	6.4	6.5
97	5.2	5.4	5.6	5.8	5.9	6.0	6.1	5.5	5.7	5.9	6.0	6.2	6.3	6.3	5.8	6.0	6.2	6.4	6.5	6.6	6.6
98	5.3	5.6	5.8	6.0	6.1	6.1	6.2	5.6	5.8	6.1	6.2	6.3	6.4	6.4	5.9	6.2	6.4	6.5	6.6	6.7	6.7
99	5.5	5.8	6.1	6.2	6.2	6.3	6.3	5.8	6.1	6.3	6.4	6.5	6.5	6.6	6.1	6.5	6.7	6.8	6.8	6.8	6.9
99.9	5.9	6.3	6.4	6.4	6.4	6.4	6.4	6.3	6.6	6.7	6.7	6.7	6.7	6.7	6.7	6.9	7.0	7.0	7.0	7.0	7.0

Speed Limit	55																				
Grade (%)	-3																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.7	3.7	3.8	3.9	4.0	4.0	4.1	3.9	3.9	4.0	4.1	4.2	4.3	4.4	4.1	4.1	4.2	4.3	4.4	4.5	4.6
60	4.0	4.0	4.1	4.2	4.3	4.3	4.4	4.2	4.3	4.4	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.7	4.8	4.8	4.9
70	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.7	4.7	4.8	4.9	5.0	4.7	4.8	4.9	5.0	5.1	5.2	5.2
80	4.6	4.7	4.8	4.8	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.2	5.2	5.3	5.1	5.2	5.3	5.4	5.4	5.5	5.6
85	4.8	4.9	4.9	5.0	5.1	5.2	5.3	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.3	5.4	5.5	5.6	5.7	5.7	5.8
90	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.2	5.3	5.4	5.5	5.6	5.8	5.9	5.5	5.6	5.7	5.8	5.9	6.1	6.2
95	5.2	5.4	5.5	5.7	5.8	6.0	6.1	5.5	5.6	5.8	5.9	6.1	6.2	6.3	5.8	5.9	6.1	6.3	6.4	6.5	6.6
96	5.3	5.5	5.6	5.8	6.0	6.1	6.2	5.6	5.7	5.9	6.1	6.2	6.4	6.4	5.9	6.1	6.2	6.4	6.5	6.6	6.7
97	5.4	5.6	5.8	6.0	6.1	6.2	6.3	5.7	5.9	6.1	6.3	6.4	6.5	6.6	6.0	6.2	6.4	6.6	6.7	6.8	6.9
98	5.5	5.7	6.0	6.2	6.3	6.4	6.4	5.8	6.0	6.3	6.5	6.6	6.6	6.7	6.1	6.4	6.6	6.8	6.9	6.9	7.0
99	5.7	6.1	6.3	6.4	6.5	6.5	6.6	6.0	6.3	6.6	6.7	6.8	6.8	6.8	6.3	6.7	6.9	7.0	7.0	7.1	7.1
99.9	6.1	6.6	6.7	6.7	6.7	6.7	6.7	6.5	6.9	6.9	7.0	7.0	7.0	7.0	7.0	7.2	7.2	7.3	7.3	7.3	7.3

Speed Limit	55																				
Grade (%)	-4																				
Precipitation	Clear							Very Light Rain							Rain						
% Buses	0	5	10	15	20	25	30	0	5	10	15	20	25	30	0	5	10	15	20	25	30
50	3.7	3.8	3.9	4.0	4.1	4.1	4.2	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.1	4.2	4.3	4.4	4.5	4.6	4.7
60	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.3	4.4	4.4	4.5	4.6	4.7	4.8	4.5	4.6	4.7	4.8	4.9	4.9	5.0
70	4.4	4.5	4.5	4.6	4.7	4.8	4.8	4.6	4.7	4.8	4.9	4.9	5.0	5.1	4.9	4.9	5.0	5.1	5.2	5.3	5.4
80	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.0	5.1	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.4	5.5	5.6	5.7	5.8
85	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.3	5.4	5.5	5.6	5.7	5.4	5.5	5.6	5.7	5.8	5.9	6.0
90	5.1	5.2	5.3	5.4	5.6	5.7	5.8	5.4	5.5	5.6	5.7	5.8	5.9	6.1	5.7	5.8	5.9	6.0	6.1	6.2	6.4
95	5.4	5.5	5.7	5.9	6.1	6.2	6.3	5.7	5.8	6.0	6.2	6.3	6.5	6.6	6.0	6.1	6.3	6.5	6.6	6.7	6.8
96	5.5	5.6	5.8	6.0	6.2	6.4	6.5	5.7	5.9	6.1	6.3	6.5	6.6	6.7	6.1	6.3	6.4	6.6	6.8	6.9	7.0
97	5.6	5.8	6.0	6.2	6.4	6.5	6.6	5.8	6.1	6.3	6.5	6.6	6.8	6.8	6.2	6.4	6.6	6.8	6.9	7.0	7.1
98	5.7	5.9	6.3	6.5	6.6	6.7	6.7	6.0	6.2	6.5	6.7	6.8	6.9	7.0	6.3	6.6	6.8	7.0	7.1	7.2	7.2
99	5.9	6.3	6.6	6.7	6.8	6.8	6.9	6.2	6.6	6.9	7.0	7.0	7.1	7.1	6.6	6.9	7.1	7.2	7.3	7.3	7.4
99.9	6.4	6.9	7.0	7.0	7.1	7.1	7.1	6.7	7.2	7.2	7.3	7.3	7.3	7.3	7.3	7.5	7.5	7.6	7.6	7.6	7.6