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

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ABSTRACT

Traffic signal violations by drivers are a leading contributor to crashes at signalized intersections. The yellow indication is used to inform drivers of an upcoming change in the status of the traffic signal. Yellow-interval durations are currently calculated to provide dilemma zone protection for passenger cars. Due to differences in vehicle characteristics and driver characteristics, heavy trucks such as tractor-trailers behave differently at the onset of a yellow-indication. The research presented in this thesis characterizes the difference in driver behavior between truck and light-duty vehicle driver behavior at the onset of yellow-indication and then revises the yellow timing procedures to address the truck requirements.

A dataset of 910 stop-go records was collected using a truck driving simulator located at the Virginia Tech Transportation Institute (VTTI). Participant drivers were placed in a simulated urban environment with a speed limit of 45 MPH and instructed to drive as they would regularly drive in such a situation. Participant drivers were recruited using the VTTI participant database.

Using the data collected as part of this research effort, statistical models were created to model driver perception-reaction times (PRTs) and deceleration levels considering driver attributes (age) and the time to the intersection at the onset of yellow. The data collected, along with the statistical models developed were compared to data collected and statistical models created by the same research organization in 2008 in a similar study of passenger car driver

behavior. Lastly, a Monte-Carlo simulation was conducted to develop appropriate yellow indication timings to provide adequate dilemma zone protection for trucks.

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ATTRIBUTIONS

Dr. Hesham Rakha, committee chair, and Dr. Ihab E El-Shawarby, committee member, oversaw and assisted with 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

The work presented in this thesis characterizes and quantifies the behavior of truck drivers at the onset of a yellow indication at high-speed signalized intersections. Throughout this thesis truck is used to reference combination trucks, defined in the ITE Traffic Engineer Handbook, 6th ed. as "combination trucks consisting of a power unit or tractor and one or more trailers, hence the name tractor trailer" [1]. This chapter provides an introduction to the study, background on the research conducted, and information about the approach of the research effort.

1.1 BACKGROUND

The yellow indication is used to alert drivers that the signal is preparing to change to a red indication. At the onset of yellow, drivers must make a decision to either continue through the intersection or to stop prior to entering the intersection. Drivers who decide to stop are at risk of a rear-end collision if they slam on their brakes too hard and the driver behind them expects them to proceed through the intersection. Drivers who elect to go are at risk of running a red light and/or a right-angle collision if they are unable to clear the intersection prior to conflicting traffic receiving a green indication and entering the intersection. The mass of trucks exacerbates the effects of these collisions both in terms of property damage and potential for injury and loss of life.

1.2 RESEARCH OBJECTIVES

There are three objectives for this research effort. The first objective is to construct a dataset of truck driver behavior at the onset of a yellow indication at high-speed signalized intersections. The second objective is to develop statistical models for truck driver perception-reaction time (PRT) and deceleration levels. These models will be developed considering the impact of driver age, approach speed, time-to-intersection at the onset of a yellow indication. Finally, the third objective of this research effort is to develop yellow indication timings that provide adequate dilemma zone protection for trucks at signalized intersections.

1.3 RESEARCH APPROACH

The first task conducted as part of this research effort was to design and conduct a study to collect data on truck driver behavior at the onset of a yellow indication. A previous effort undertaken by the same research organization used a MATLAB-based Monte-Carlo simulation to capture light-duty vehicle driver behavior in the design of yellow timings [2]. The results of this Monte-Carlo simulation were used to develop the timing scenarios used in this study.

The field experiment was conducted using the Commercial Training and Prototyping (CTAP) simulator at the Virginia Tech Transportation Institute. The CTAP simulator is a high-fidelity simulator that is instrumented for data collection. Upon approval from the Virginia Tech Institutional Review Board (IRB) study participants were recruited using the VTTI participant database. All participant events were conducted under the supervision of a researcher and data was continuously recorded during all participant events.

Several software packages including Microsoft EXCEL, MATLAB, SPSS, and JMP were used during the data analysis and modeling phases of the research effort. Statistical models for truck driver PRT and deceleration levels were created based on the data collected.

1.4 THESIS ORGANIZATION

This chapter presented an introduction to the subject matter to be discussed in this thesis as well as a brief description of the research effort conducted. Chapter two presents a review of available literature on the dilemma zone, truck stopping behavior, truck deceleration, driver PRTs, and the use of driving simulators for testing purposes. Chapter three presents an in-depth description of the research effort undertaken for this project including the results of the field experiments and discussion of the statistical models developed. Chapter four summarizes the conclusions of the research effort, contributions of this research effort to the current state-of-the practice, and provides recommendations for future research efforts.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The goal of this thesis is to model the stop/run behavior of truck drivers at the onset of yellow indication at high-speed signalized intersections. Before this effort can be undertaken, however, an in-depth review of current literature and previous studies on the dilemma zone, vehicle deceleration behavior, driver PRTs, and stopping behavior of truck drivers must be conducted.

2.2 THE DILEMMA AND OPTION ZONES AND YELLOW INTERVAL TIMES

2.2.1 The Dilemma and Option Zones

The yellow signal indication is used to inform drivers of an impending change in right-of-way at a signalized intersection [3]. When presented with a yellow signal while approaching a signalized intersection, drivers are forced to make a decision to either continue through the intersection or to stop prior to reaching the intersection. The concept of the dilemma zone was first defined by Gazis et al. [4] 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*." Figure 2-1 presents a graphic depiction of the dilemma zone. 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**.

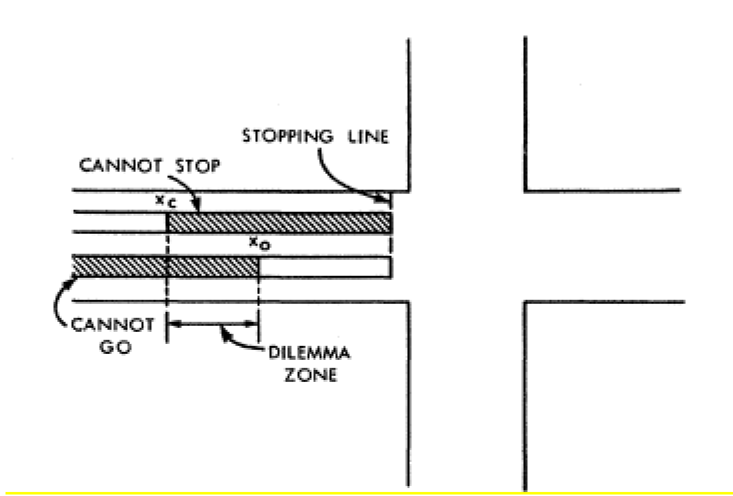

Figure 2-1: The Dilemma Zone [4]

In 1977, Zegeer further defined the term dilemma zone as the area in which greater than 10% of drivers and less than 90% of drivers stop [5]. Figure 2-2 demonstrates probability distribution curves for several approach speeds.

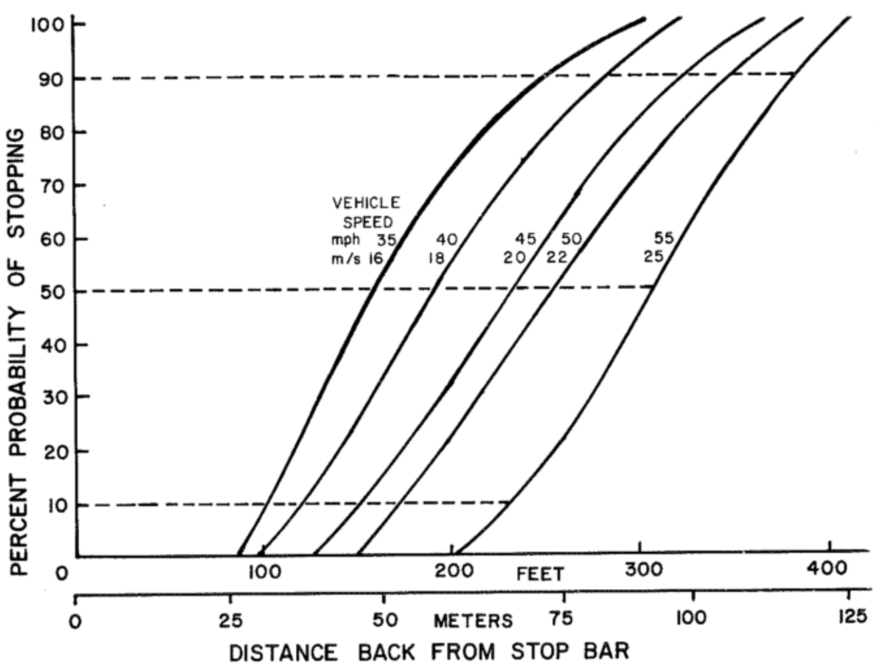

Figure 2-2: Probability Distribution of Stopping Behavior for Multiple Approach Speeds [5]

More recently, El-Shawarby et al. have defined the option zone [6]. The option zone differs from the dilemma zone. Whereas the dilemma zone defines an area where a driver cannot make a proper or correct decision, the option zone defines an area where the driver has to make a decision whether to go or stop. Figure 2-2 depicts the option zone. Coupling the dilemma zone and option zone define all possible scenarios a driver may face at the onset of yellow indication.

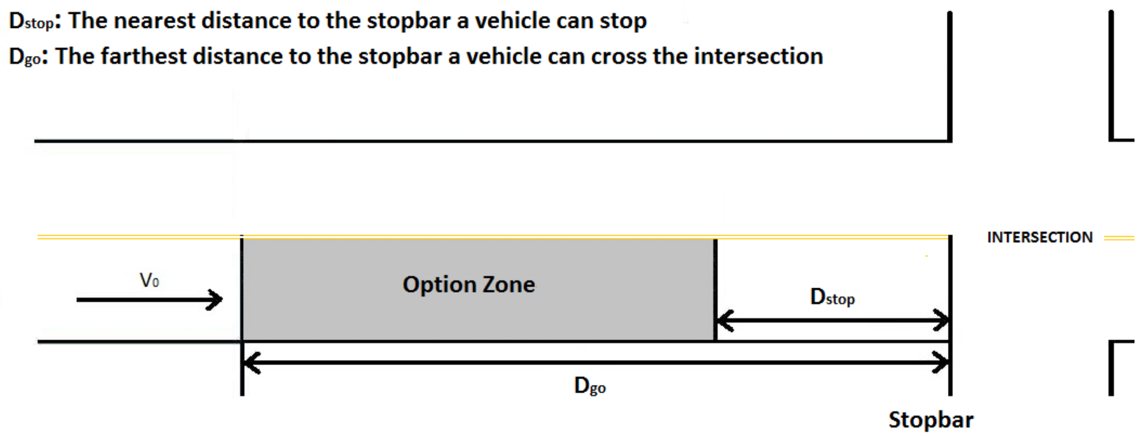

Figure 2-3: The Option Zone [6]

2.2.2 Yellow Interval Duration

Matson first defined the yellow interval time as a function of intersection width and an assumed constant approach speed [7]. In this definition driver response factors and vehicle deceleration levels were assumed to not have an effect on yellow interval times. Further research proved that these assumptions were not valid. Later, Matson added driver perception PRTs and vehicle deceleration levels as well as intersection clearance times to his model [8]. Subsequently, Gazis et al. developed the Gazis-Hemran-Maradudin (GHM) model which associated the yellow interval duration with driver PRTs, vehicle deceleration characteristics, and intersection layout [4].

The current state of practice for yellow interval times is the ITE equation, presented as Equation 2.1. A field study of 10 intersections found that yellow signal timings set to the current

ITE equation reduced red light running violations [9]. The current state of the practice is to calculate yellow light timings assuming all vehicles are passenger cars and passenger car drivers.

$$Y = PRT + \frac{v}{2(d+9.81*g)} \tag{2.1}$$

Where $PRT = driver\ perceptionr\ reaction\ time\ (seconds)$

$$v = vehicle\ approach\ speed\ (\frac{meters}{second})$$

$$d = deceleration\ rate\ (\frac{meters}{second^2})$$

$$g = roadway\ grade\ in\ decimal\ form$$

2.3 TRUCK STOPPING BEHAVIOR

Though it has been acknowledged that truck driver PRTs are typically longer than those for passenger vehicle drivers, that truck air braking systems are slower to engage when compared to the hydraulic braking systems of passenger vehicles, and that deceleration levels are lower for trucks; it is still the state-of-practice that traffic signals are designed using driver and vehicle characteristics of passenger cars [10]. These assumptions present a potential conflict in which the driver of a truck may be placed in a situation where they have no choice but to run a red traffic signal.

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 a trucks, buses, and recreational vehicles (RVs) were more likely to proceed through a yellow signal than standard passenger vehicles [11].

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 to run a red traffic signal than a standard passenger vehicle [12]. 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 2004 Bonneson and Zimmerman conducted a field study at multiple high speed signalized intersections to investigate the relationship between yellow signal timing and red light running. The authors concluded that increasing the ITE standard yellow time by 1.0s led to a 50 percent reduction in red light running. The authors recommended that total yellow times not exceed 5.5 seconds even after the increase. The authors noted that drivers may recognize and adapt to the increased yellow times and conducted an analysis of this behavior. This analysis found that drivers did adapt to the extended yellow times, however the adaptation did not counter the benefits gained by increasing the yellow times [13].

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 [14].

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 [15].

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 [16] [17].

2.4 USE OF DRIVING SIMULATORS FOR TESTING PURPOSES

Driving simulators can be used to replicate various conditions to place drivers in an environment that is intended to replicate reality as closely as possible. However, no simulator is able to completely replicate real world driving conditions and this limitation must be taken into consideration when using driving simulators to evaluate the effects of roadway conditions such as changes in signal timings. Several studies have been conducted to validate the use of driving simulators for testing.

In 2011 Underwood et al. conducted a study based on hazard detection using both a real passenger vehicle and a driving simulator. In the study three experiments were conducted to measure hazard recognition times for drivers. In one experiment hazard recognition times were measured while participants were driving an actual vehicle, in the second experiment hazard recognition times were measured while participants were operating a driving simulator, and in the final experiment hazard recognition times were measured while participants were watching a video taken from a vehicle. The study found consistent results in all three experiments and the authors concluded that this validated the use of driving simulators for testing purposes [17].

In 2005 Bella conducted an experiment to validate the use of simulators when designing work zones. In the study, field data were collected for vehicles traveling through a work zone. The work zone was then recreated using a driving simulator and participant drivers were asked to drive through the simulated work zone. An analysis of the speed data collected in the field and during the simulator experiment yielded consistent results, validating the use of the simulator for such applications [18].

In 2006, Inman et al. conducted an experiment evaluating driver response to hazard warning systems to reduce red light running at the onset of a yellow indication. Experiments were conducted using actual field data collected from drivers operating on a controlled test bed. One of the scenarios from the field data was replicated using a driving simulator. The results of the field experiment and the simulator experiment were consistent and the authors concluded that the use of the driving simulator was valid for testing purposes [19].

2.5 SUMMARY AND PROPOSED RESEARCH

Based on the information presented in this chapter, it can be concluded that there has been prior research done investigating the dilemma zone for trucks. In 1960, Gazis et. al stated that trucks and other special vehicles should in fact be considered when designing yellow times:

> "…the required τ_{min} is substantially longer for vehicles such as long trucks…even assuming that these vehicles can stop with the same maximum deceleration ${a_2}^*$ as shorters ones. One may retort that traffic signals should not be designed for these 'unusual' cases. However, these unusual vehicles are allowed on the highways and if the design of the amber phase does not take them into account then the questions raised in the introduction regarding the compatability of law and physical characteristics become even more acute." [4].

Gates and Noyce [12], Zimmerman [14], and Wei et al. [15] put forth recommendations for extensions of yellow intervals to account for the dilemma zone associated with trucks. However, these studies are limited in scope as they only acknowledge the difference in the dilemma zone for trucks but fail to adequately identify and quantify the factors that contribute to this extended dilemma zone. Additionally, it has been shown in several studies that the use of driving simulators is valid for testing and modeling driver behavior.

The remainder of this thesis will focus on an experiment conducted at the Virginia Tech Transportation Institute (VTTI) using a truck driving simulator to develop an agent-based stochastic approach to design yellow timings that account for the risk of truck drivers being caught in a dilemma zone. This experiment builds on previous work done at VTTI involving passenger cars.

CHAPTER 3 ANALYSIS OF TRUCK DRIVER BEHAVIOR AT ONSET OF YELLOW SIGNAL

3.1 INTRODUCTION

This chapter provides a detailed description of the research effort untaken to collect the data used in the writing of this thesis. First, a description of the experimental design is presented including a description of the truck simulator used in the proposed research effort. Following will be an analysis of the data collected. Following this will be a description of the statistical models created to model driver deceleration levels and perception-reaction times. The final portion of this chapter presents a Monte-Carlo simulation that was conducted to develop look-up tables for appropriate yellow indication intervals to provide dilemma zone protection for trucks at high-speed signalized intersections.

3.2 EXPERIMENTAL DESIGN

The experiment described in this thesis was conducted using the Commercial Testing and Prototyping Simulator (CTAPS) at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, VA. Previous studies have shown that the use of driving simulators for testing purposes, and specifically modeling driver stop/run decisions at the onset of a yellow indication is valid. Additionally, the CTAPS was validated for use in training drivers during an experiment conducted at the Virginia Tech Transportation Institute and the Delaware Technical Community College [20].

This experiment followed a previous effort by the same research organization to simulate truck stopping behavior using truck characteristics and truck driver behavior found in the literature to conduct a MATLAB-based Monte-Carlo simulation. The experiment differs in that the CTAPS was used to collect data to be used to characterize the stopping behavior of truck drivers and to develop models for deceleration levels and PRTs.

3.2.1 Simulated Driving Environment

The experiment was designed to collect data on the stopping behavior of truck drivers at the onset of a yellow indication at high-speed signalized intersections on the CTAPS at VTTI. Drivers were placed in a simulated town and drove a specified route. Figure 3-1 depicts an overhead representation of the study trial route; active signals are indicated with red circles containing numbers indicating the order in which the signals were encountered. Throughout the route drivers encountered six signalized-intersections where they were presented a yellow indication. A 10-hz data acquisition system (DAS) was used to capture various performance measures as well as a video recording of the route being driven and the CTAPS cab foot as well.

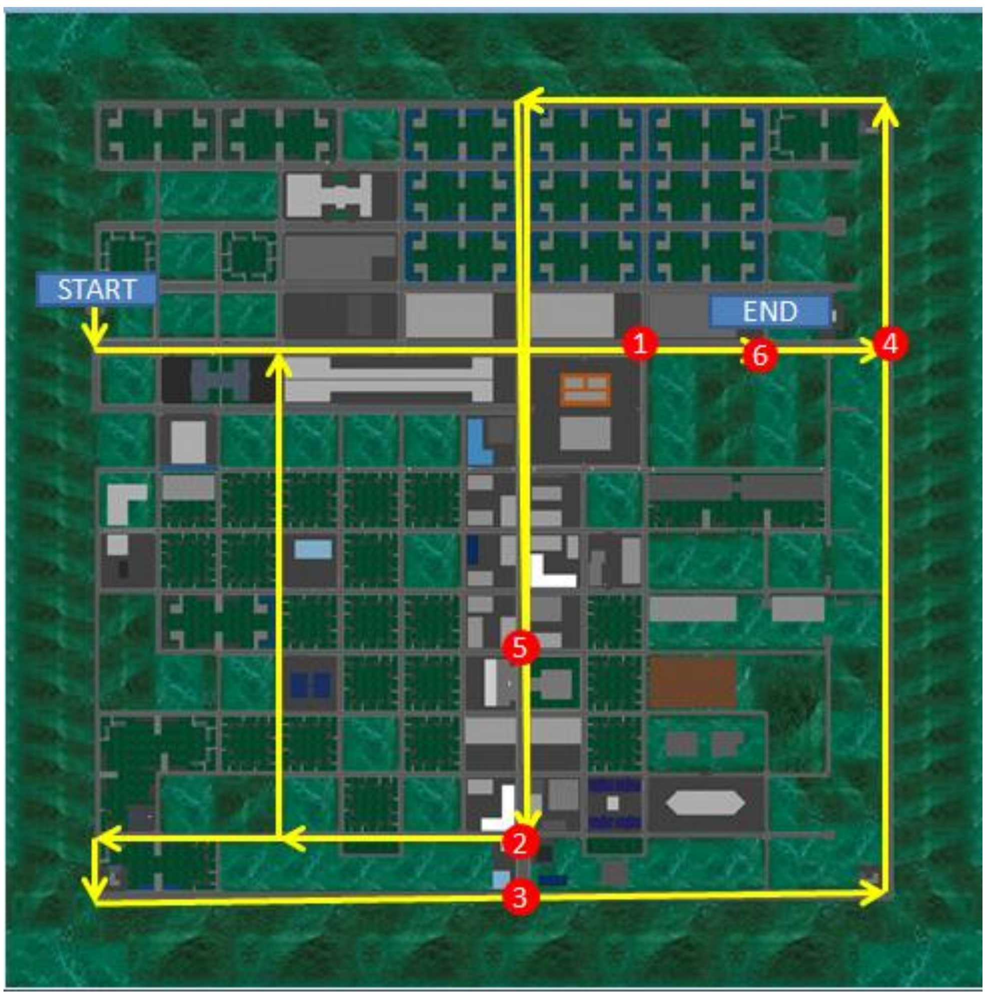

Figure 3-1: Study Trial Route

3.2.2. Experimental Equipment

The Commercial Testing and Prototyping Simulator (CTAPS) at VTTI was used to conduct all experiments for this research effort. The CTAPS places drivers in a real truck cab complete with a standard instrument cluster, steering wheel, force-feedback pedals, force-feedback seat, and a standard shift tower. The CTAPS is connected to a 10-hz data acquisition system (DAS) to record data during participant sessions. The CTAPS is controlled via the Instructor's Operating Station (IOS). During the experiment administrative data including the participant number, age, and gender are available on the monitor of the DAS. The DAS and IOS are located on a separate desk away from the CTAPS. Additionally a camera was used to record views of the driver's foot movements and a recording was made of the simulated environment as the driver progressed through the experiment.

For all participant sessions the CTAPS was operated using a simulated 490-hp Detroit Diesel motor. During the initial orientation drive a simulated Eaton-Fuller Autoshift transmission was used and the CTAPS was operated without a trailer, commonly referred to as a bobtail configuration. During subsequent drives the CTAPS was operated using a simulated 10-speed synchronized Meritor transmission with 40-foot and 48-foot van trailers. Research personnel were with participant drivers at all times during orientation drives and study trials.

Figure 3-2: Pictorial Collage of CTAPS

3.2.3 Participants

Prior to recruiting any participant drivers, approval was gained from the Institutional Review Board (IRB) at Virginia Tech in order to protect the rights of study participants and ensure their safety while participating in the study. Appendix A of this thesis consists of the IRB approval letter and the informed consent form that was used to explain all risks associated with the study to participant drivers.

Participant drivers were recruited from the VTTI internal participant database and through placement of flyers with local freight carriers. Participant drivers were initially screened using a telephone questionnaire to establish eligibility for the study. Participant drivers were required to be male, hold a valid, Class-A commercial driver's license (CDL), be between the ages of 21 to 55, be able to drive a standard 10-speed manual transmission with no assistive devices, hold a valid Department of Transportation (DOT) medical examination, and operate a truck a minimum of 2 to 4 times per week. Previous studies undertaken using the CTAPS showed that simulator sickness was more prevalent in drivers over 55 years of age, therefore eligibility for the study was restricted to drivers who were 55 years old or younger. Additionally, females represent only 6.9% of the commercial truck driving force in the United States [21], for this reason it was decided that using an all-male participant pool would indeed be a valid representative sample. Appendix B of this thesis contains the script and questionnaire used to screen potential participants.

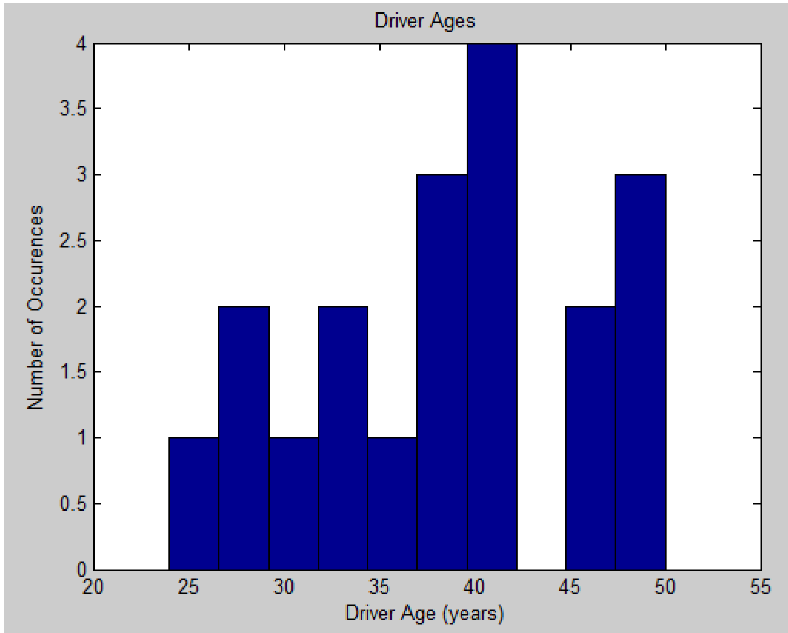

Figure 3-3: Histogram of Participant Driver Ages

3.2.4 Procedures

Upon arrival participant drivers were briefed on the nature of the study and advised of any risks involved with participation in the study, written informed consent was obtained from each participant driver. Participant drivers also completed several brief questionnaires regarding their medical history and truck driving experience. Appendix C contains all questionnaires completed by participant drivers. Following completion of all consent forms and surveys participant drivers were given an orientation to the CTAPS cab in order to familiarize them with the location of various features of the CTAPS.

For the first orientation drive participant drivers drove a simulated traditional truck tractor without a trailer, commonly referred to as a bobtail configuration, with a simulated Detroit Diesel 490 HP motor and a simulated five-speed automatic transmission. At the completion of this first orientation drive the participant drivers were administered a simulator sickness questionnaire. Based on the results of these questionnaire participant drivers who were determined to be at a high risk for simulator sickness were asked not to continue with the study. Appendix D of this thesis contains the simulator sickness questionnaire. Those drivers not identified as being at a high risk for simulator sickness next moved to a second orientation drive. During the second orientation drive participant drivers drove a simulated traditional truck tractor configured with a 40-foot van trailer, the same simulated Detroit Diesel 490 HP motor, and a simulated ten-speed manual synchronized Meritor transmission.

After the completion of both orientation drives, drivers then moved on to the first of the four-study trials. As previously stated, eight scenarios were developed for study trials. In each of these eight scenarios, the same six traffic signals were considered ‘active’, however the distance from the stop-bar at which these signals were triggered to change to yellow was varied from among six different distances to the intersection. Participant drivers conducted one participation session driving with a simulated empty 48-foot van trailer and one participation session driving with a simulated full 48-foot van trailer. The order for an empty or loaded trailer was determined using a Microsoft Excel generated random number, if the number was less than 0.5 the driver would conduct the first session with a simulated empty trailer and the second using a simulated fully-loaded truck. This order was reversed if the number was greater than 0.5.All study trials were conducted using the same simulated 490-hp Detroit Diesel motor and simulated 10-speed manual synchronized Meritor transmission. The speed limit of the approach to all 6 of the active signals was 45 MPH (72.42 KPH).

DTI (feet)	*TTI (s)*
224	3.4
264	4.0
284	4.3
304	4.6
330	5.0
363	5.5

Table 3-1: Yellow Indication Trigger Distances

Upon completion of the four-study trial drives, drivers completed a post-experiment questionnaire providing feedback on their observations during the experiment, the experimental design, and the simulated environment. Appendix E of this thesis contains the post-experiment questionnaire completed by the drivers. At the completion of their first participation session participant drivers were paid and a second participant session was scheduled. The second participation session followed the same outline as the first participation session, however the surveys regarding health and driving history and the initial orientation drive and accompanying simulator sickness questionnaire were not conducted during the second participation session.

3.3 SIMULATION RESULTS

A total of 25 drivers participated in the study. A total of 4 drivers developed simulator sickness at some point during the experiment and 2 drivers produced data that was corrupt/incomplete. Consequently these 6 driver data were not considered in the analysis. Additionally several interactions with the signals malfunctioned during participant sessions and these records also were not included in the analysis. A record was classified as a stop if the vehicle reached a speed of 2.2 mph (1 meter/second) or less, this threshold was chosen based on the average walking speed of a pedestrian being approximately 1 meter per second [22]. A total of 910 records were collected, 723 (79.46%) records were stopping records while 187 (20.54%)

records were non-stopping records. These records are classified as non-stopping records because whether the driver actually ran a red signal or not was not considered for analysis as the purpose the research was to identify and characterize the behavior of truck drivers at the onset of yellow indication.

3.3.1 Approach Speeds

As stated previously, the speed limit on the approaches to all active signals in the simulated environment was 45 MPH (72.42 KPH). Drivers were instructed to drive as they typically would for the speed limit and the characteristics being displayed in the simulated environment. Approach speeds for drivers varied from a minimum of 22.83 MPH (36.74KPH) to a maximum of 55.3 MPH (88.99 KPH), with a mean approach speed of 40.50 MPH (65.19 KPH), a median approach speed of 40.95 MPH (65.90 KPH), and a standard deviation of 5.04 MPH (8.12 KPH). The histogram shows that the approach speeds are approximately normally distributed.

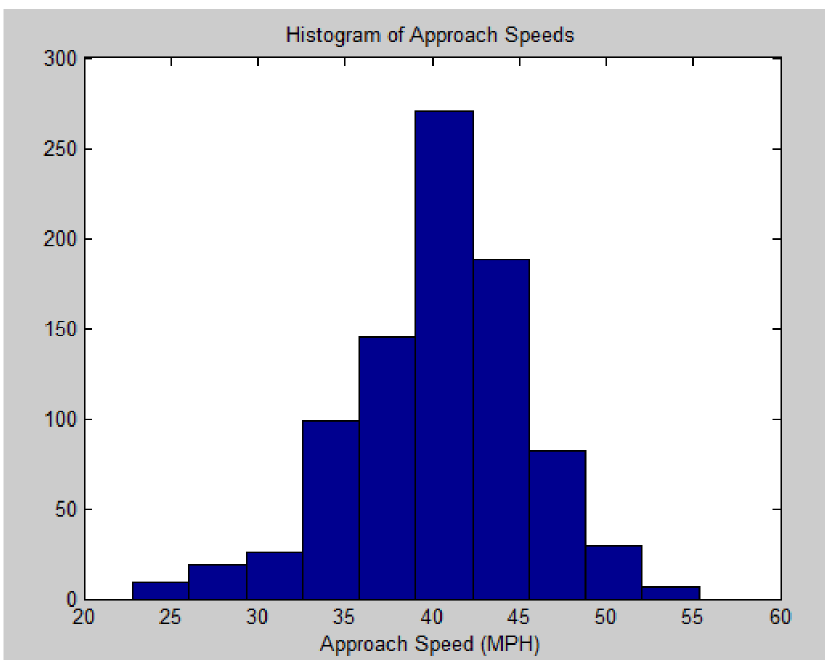

Figure 3-4: Histogram of Approach Speeds

Further analysis was conducted to determine if the approach speeds were different for records in which drivers were operating with a simulated loaded trailer or a simulated empty trailer. A total of 455 records were collected using a simulated empty trailer. Approach speeds for these records ranged from a minimum of 22.83 MPH (36.74 KPH) to a maximum of 55.3 MPH (88.99 KPH), with a mean of 40.17 MPH (64.65 KPH) and standard deviation of 5.57 MPH (8.97 KPH), and a median of 40.81 MPH (65.68 KPH). A total of 455 records were collected using a simulated loaded trailer. Approach speeds for these records ranged from a minimum of 26.74 MPH (43.03 KPH) to a maximum of 53.05 MPH (85.38 KPH), with a mean of 40.82 MPH (65.69 KPH) and a standard deviation of 4.43 MPH (7.13 KPH, and a median of 41.08 MPH (66.11 KPH).

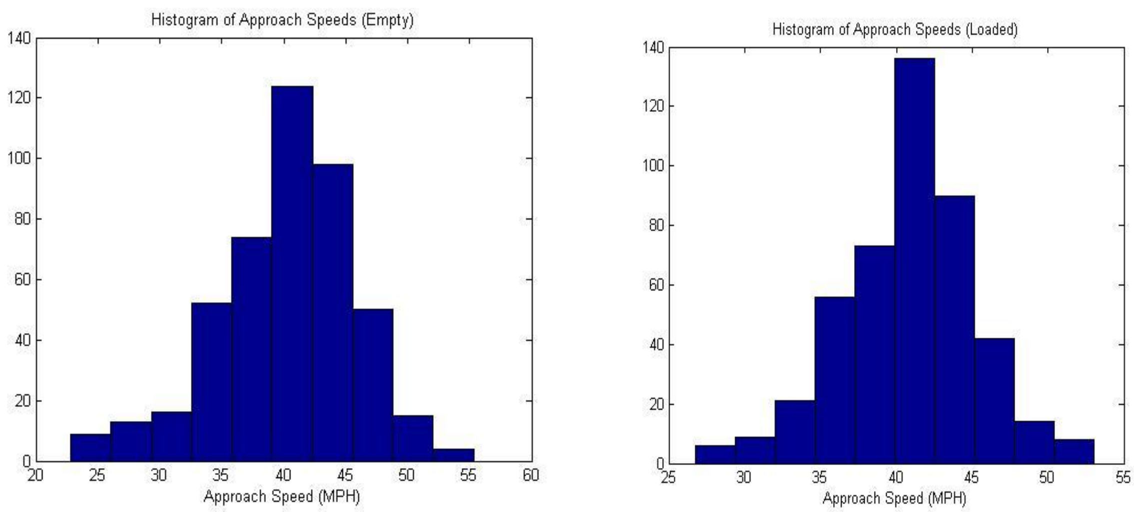

Figure 3-5: Distribution of Arrival Speeds for Empty and Loaded Trucks

3.3.2 Stopping/Running Modeling

The 2009 MUTCD recommends using a pedestrian walking speed of 3.5 feet per second (1.06 meters per second) [22]. From this it was determined that a record would be classified as a stopping record if the final speed of the vehicle reached a value equal to or lower than 2.2 MPH (1 meter per second). Records were then divided into bins that represented 0.2 second intervals, starting with 2.9 seconds TTI; one exception to this separation did occur as there was one record with a TTI of 2.6 seconds, this record was included in the 2.9-3.1 seconds TTI bin for analysis and presentation purposes. Figure 3-6 shows the probability distribution of stopping for each bin, while Figure 3-7 shows a continuous plot of the probability of stopping. The 0.9/0.1 split for stop/non-stop occurs between a TTI of 5.1 to 5.2 seconds. This value compares with a range of 3.6 to 3.8 seconds for passenger cars in clear weather conditions [23]. The 0.5/0.5 split for stop/non-stop occurs between 3.8 and 4.0 seconds TTI. This value compares with approximately 3.1 seconds for passenger cars in clear weather conditions [23].

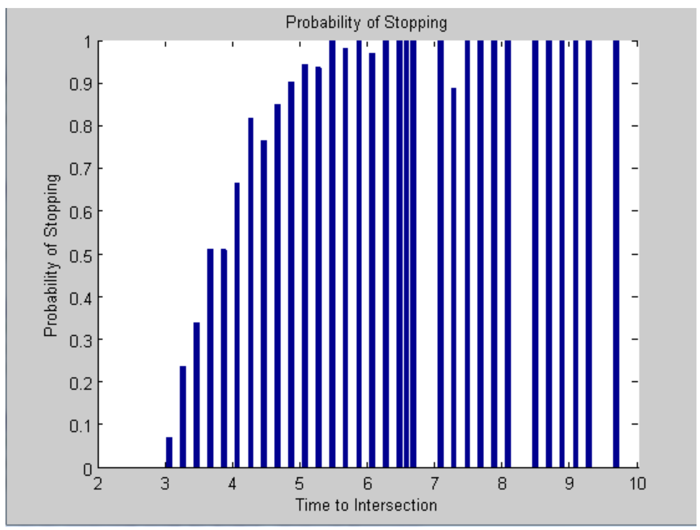

Figure 3-6: Probability Distribution of Stopping/Non-Stopping

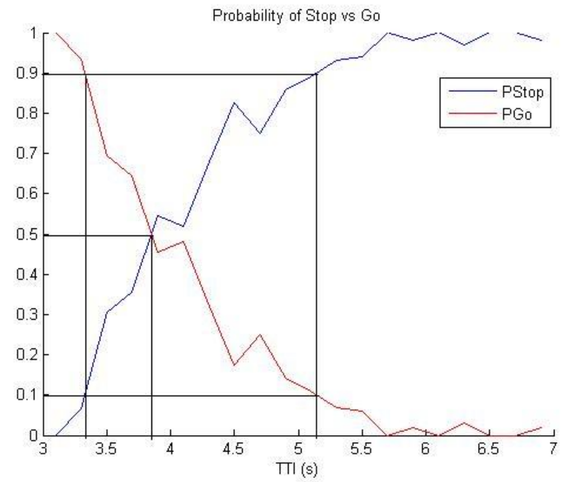

Figure 3-7: Continuous Plot of Stopping Probability

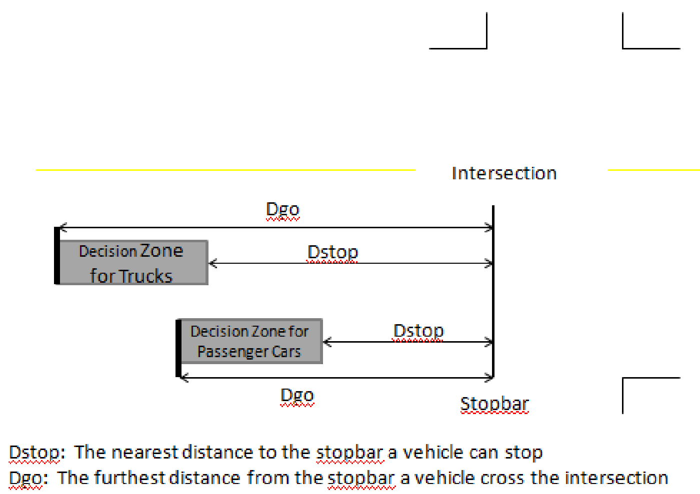

Figure 3-8: Comparison of Decision Zones for Trucks and Passenger Cars

An analysis was conducted to determine if the probability of stopping changes based on a loaded versus empty trailer. Figures 3-9 shows the probability distribution for stopping for loaded and empty trailers.

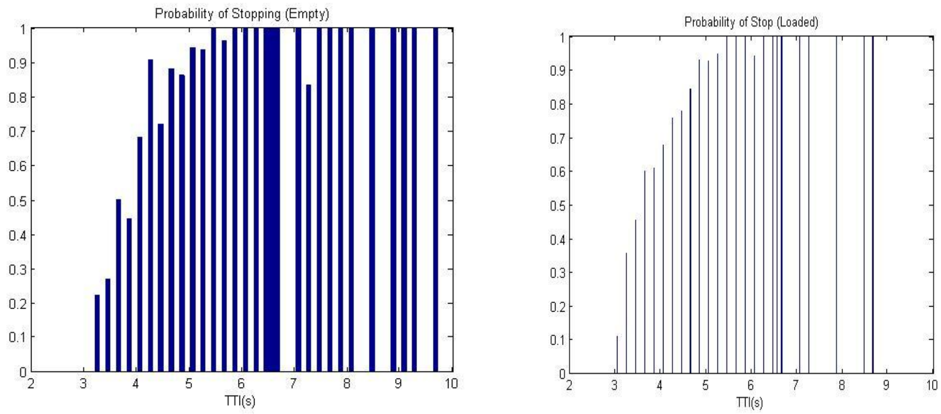

Figure 3-9: Probability Distribution of Stopping for Empty and Loaded Trailers

A binomial logistic regression model for stopping behavior was created using SPSS. Equation 3.1 shows this regression model. The model predicts a stop/non-stop using a cut value of 0.50 and has a prediction accuracy rate of 89.3 %. It is worth noting that the positive coefficient for loading factor suggests that truck drivers are more likely to stop when they are driving a truck with a load. The coefficient for throttle position indicates that the harder a driver is pressing the throttle at the onset of a yellow signal the less likely the driver is to stop. Based on the positive coefficient for TTI it can be concluded that the further a driver is from the intersection at the onset of a yellow signal the more likely the driver is to stop. The coefficient for perception reaction time (PRT) suggests that drivers with longer PRTs are more likely to stop, further examination of the data could not explain this counterintuitive observation. The negative coefficient for the $\frac{v}{v_f}$ term indicates that drivers approaching the intersection with higher speeds are less likely to stop.

$$P_{STOP} = 2.016 - 3.421TP + 1.395TTI + 1.955PRT + 0.527LF - 8.434\frac{v}{v_f} \qquad (3.1)$$

Where $TP = Throttle\ Position, a\ unitless\ value\ that\ is\ continuous\ between\ 0\ and\ 1$

$$TTI = time\ to\ intersection\ (seconds)$$

$$PRT = Driver\ perception\ reaction\ time\ (seconds)$$

$$LF = Loading\ factor\ (0\ if\ trailer\ is\ empty, 1\ if\ trailer\ is\ full)$$

$$V = vehicle\ approach\ speed\ at\ onset\ of\ yellow\ signal$$

$$V_f = free - flow\ speed\ or\ speed\ limit\ (must\ be\ in\ same\ units\ as\ V)$$

3.3.3 Truck Driver Perception-Reaction Times

The PRT is defined as the amount of time elapsed between the onset of yellow and the time the driver begins braking. For the purposes of analyzing PRT records in which the driver was already pressing the brake pedal at the time of onset of yellow were removed from the dataset. Additionally, records in which the driver was not pressing the throttle at the time of the onset of yellow were removed from the dataset as these records do not accurately reflect the entire time for the driver to perceive the change in signal and move from the accelerator to the brake pedal. A total of 452 records remained for PRT analysis. These records showed an average PRT of 1.16 seconds with a standard deviation of 0.46 seconds and a median value of 1.1 seconds. This value compares with an average PRT of 0.74 seconds and median PRT of 0.72 seconds for light duty vehicles in clear weather observed during a previous study by the same research group [24]. The 85th percentile PRT observed was 1.5 seconds, which is the same value that is published in the Missouri Department of Transportation's Commercial Driver's License manual [10]. No reliable model for estimation of PRT could be derived from the dataset, however, the distribution of PRT was found to fit a Beta distribution with an alpha value of 5.176 and a beta value of 19.380. Figure 3-10 shows the distribution of PRTs. Figure 3-11 shows the distribution of PRT with the fitted Beta curve.

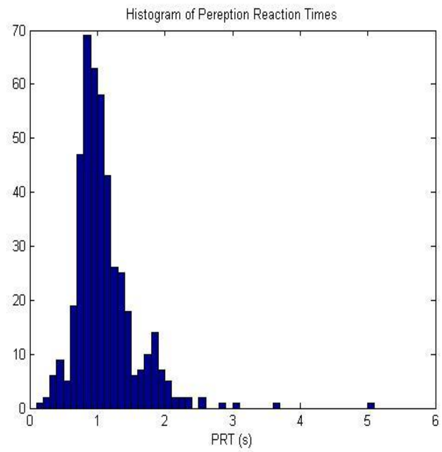

Figure 3-10: Histogram of Driver Perception Reaction Times

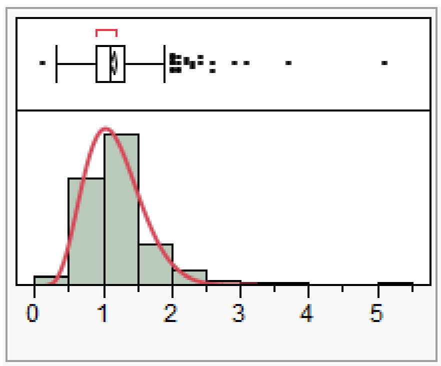

Figure 3-11: Distribution of Perception Reaction Times with Fitted Beta Distribution

3.3.4 Modeling Truck Deceleration Levels

As previously discussed, trucks do not decelerate as well as their passenger vehicle counterparts. This difference in deceleration level contributes to the change in dilemma zone for trucks. For the purposes of deceleration analysis only the 723 stopping records were considered. Deceleration levels were calculated for each record using the following formula (equation 3-2).

$$D = \frac{v_{initial} - v_{final}}{t} \tag{3-2}$$

Where

$V_{initial}$

$$= speed\ at\ the\ instant\ the\ driver\ presses\ the\ brake\ after\ onset\ of\ yellow\ (meters\ per\ second)$$

$$V_{final} = first\ speed\ equal\ to\ or\ less\ than\ 1\ \frac{m}{s}\ (meters\ per\ second)$$

$$t = time\ elapse\ between\ V_{initial} and\ V_{final}\ (seconds)$$

Considering the entire population, deceleration levels varied from a minimum of 0.5 m/s^2 to a maximum of 3.71 m/s^2 with an average deceleration level of 1.98 m/s^2 and a standard deviation of 0.72 m/s^2, and a median deceleration level of 1.84 m/s^2 , the 85th percentile deceleration level was 2.90 $m/s^{2.}$ An analysis was conducted to determine if there was a difference in deceleration levels between records for an empty trailer versus a loaded trailer. A total of 358 stopping records were used for an empty trailer. Deceleration levels for these records ranged from a minimum of 0.54 m/s^2 to a maximum of 3.21 m/s^2, with an average of 2.0 m/s^2 and standard deviation of 0.72 m/s^2 and a median of 1.92 m/s^2, the 85th percentile deceleration level was 2.89 m/s^2 . A total of 365 stopping records were considered for a loaded trailer. Deceleration levels for these records ranged from a minimum of 0.62 m/s^2 to a maximum of 3.71 m/s^2 with an average of 1.94 m/s^2 and standard deviation of 0.71 m/s^2, with a median deceleration of 1.77 m/s^2, the 85th percentile deceleration level was 2.97 m/s^2. Figures 3-12 shows deceleration levels as a function of TTI for loaded and empty records.

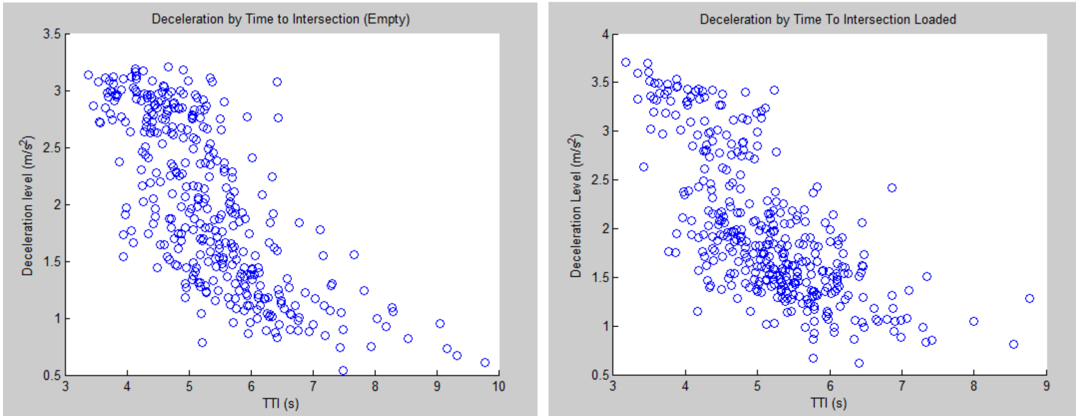

Figure 3-12: Deceleration Rates

A linear regression model for deceleration levels was constructed using JMP. This model is included as Equation 3-3. This model has an R^2 value of 0.72, indicating that it is an acceptable model for estimation of deceleration levels. The calibrated coefficients and their P-value are included as Table 3-2

$$D = 5.2387 - 0.074A - 6.2386\left(\frac{TTI}{y}\right) + 1.9931\left(\frac{v}{v_f}\right) - 0.4788PRT + 1.587\left(\frac{TTI}{y}\right)^2 - 0.0829LF \qquad (3\text{-}3)$$

Where $A = driver\ age\ (years)$

$$TTI = time\ to\ intersection\ (seconds)$$

$$PRT = Perception\ reaction\ time\ (seconds)$$

$$LF = loading\ factor\ (0\ if trailer\ is\ empty, 1\ if\ trailer\ is\ loaded)$$

$$v = approach\ speed$$

$$v_f = freeflow\ speed\ or\ speed\ limit\ (must\ be\ in\ same\ units\ as\ V)$$

$$y = yellow\ interval\ for\ v_f\ calculated\ using\ ITE\ equation$$

Term	*Coefficient*	*P-Value*
b0(Intercept)	5.2387	<.0001
b1(Age)	-0.0074	<.0001
b2(TTI)	-6.2386	<.0001
b3(v/vf)	1.9931	<.0001
b4(PRT)	0.4788	<.0001
b5((TTI/y)^2)	1.587	<.0001
b6(Loading Factor)	-0.0829	<.0001

Table 3-2: Calibrated Coefficients of Vehicle Deceleration Model

3.3.5 Designing Yellow Times

The ITE equation computes the yellow time as a function of the driver PRT, approach speed, vehicle deceleration characteristics, and approach roadway grade. Using a Monte Carlo simulation technique it is possible to generate a population of drivers and vehicles to use for the calculation of yellow interval times. These simulated yellow intervals are then used to calculate look-up tables for yellow interval times at certain reliability levels for use by practitioners in the field.

A MATLAB uniform random number generator is used to generate driver ages, approach speeds, and time to intersection for 100,000 agents. Separate age profiles were used for car drivers and truck drivers. The age profile for car drivers was uniformly distributed between the ages of 20 and 65 years old while the age profile for truck drivers was uniformly distributed between the ages of 21 and 55 years old. These age profiles were consistent with the distribution of the ages of the drivers used to calibrate the respective deceleration and PRT models. Due to the fact that a model could not be generated with any acceptable level of confidence for driver PRT, a Beta distribution was used for modeling purposes. For the purposes of this simulation the original PRT dataset was used, however any record with a time to intersection of greater than 6.6 seconds was removed. These records were removed because it is believed that at such a long

TTI interval drivers may wait to press the brake pedal because they are not stressed for time. These records were deleted so that this interval of inaction did not affect the results of the simulation. A new Beta distribution of the remaining 410 records was derived using JMP and this distribution with a minimum value of 0.1 seconds and maximum value of 3.7 seconds, mean of 1.11 seconds, alpha value of 5.068, and beta value of 12.88 was used. Deceleration rates were calculated using the properties of the randomly generated agents. For passenger cars, Equation 3-4, developed during a previous study by the same research group [25] was used to model light-duty vehicle deceleration behavior.

$$d = 10.6577 - 0.2782g - 0.0079a - 2.0816G - 20.0664\left(\frac{TTI}{y}\right) + 3.6821\left(\frac{v}{v_f}\right) + 0.2136p + 1.4376t + 8.0828\left(\frac{TTI}{y}\right)^2 + 0.0046ga - 0.2934\left(\frac{TTI}{y}\right)p + err_d \quad (3\text{-}4)$$

Where g = the driver gender (0=male, 1=female)

a = driver age (years)

G = roadway grade in decimal form

TTI = time to intersection at onset of yellow indication (seconds)

y = yellow interval for the approach speed limit calculated using the ITE equation

v = the approach speed

v_f = the freeflow speed or speed limit

p = precipitation level (0=clear, 1= very light rain, 2 = rainy)

err_d = term of random error

Due to the fact that the effect of precipitation was not observed during the field experiments it was decided to use the same precipitation terms and coefficients that are present in the deceleration model for passenger cars and add them to the deceleration model for trucks to account for the effect of precipitation on truck deceleration levels. The modified equation is provided below as Equation 3-5.

$$d = 5.2387 - 0.074A - 6.2386\left(\frac{TTI}{y}\right) + 1.9931\left(\frac{v}{v_f}\right) - 0.4788PRT + 1.587\left(\frac{TTI}{y}\right)^2 - 0.0829LF + 0.2136p - 0.2934\left(\frac{TTI}{y}\right)p \quad (3\text{-}5)$$

Where A = driver age (years)

TTI = time to intersection (seconds)

PRT = Perception reaction time (seconds)

LF = loading factor (0 iftrailer is empty, 1 if trailer is loaded)

v = approach speed

v_f = freeflow speed or speed limit (must be in same units as V)

y = yellow interval for v_f calculated using ITE equation

p = precipitation (0 = clear, 1 = very light rain, 2 = rainy)

It was found that precipitation conditions have an extremely small effect on the deceleration levels of vehicles and thus the modification of the truck deceleration model using terms and coefficients calculated for cars was considered reasonable for the purposes of the simulation. Figure 3-13 shows a plot of deceleration levels calculated for cars and trucks in different precipitation conditions. All inputs other than precipitation were held constant when developing these figures.

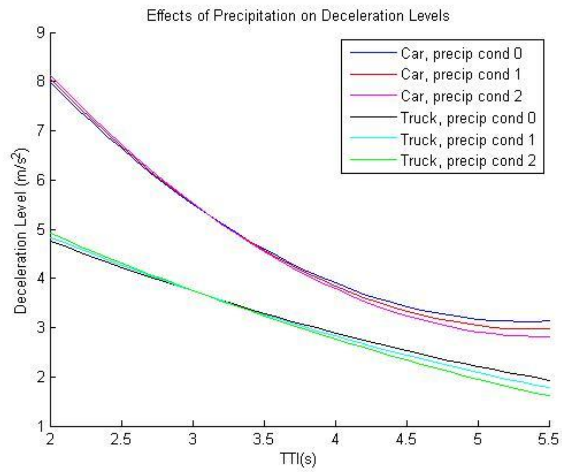

Figure 3-13: Effects of Precipitation on Deceleration Levels

A total 1,000,000 interactions with a yellow signal were then generated for each possible permutation of approach speed limit, approach grade, percentage trucks in the traffic stream, and precipitation condition. Approach speed limits simulated were 35 MPH, 45 MPH, and 55 MPH. Approach grades were simulated from -4% to 4% in 1% intervals. Three precipitation levels were simulated with 0 corresponding to dry conditions, 1 corresponding to wet conditions, and 2 corresponding to rainy conditions. For precipitation condition 1 the minimum and maximum TTIs generated by the random number generator were increased by 0.15 seconds, for precipitation condition 2 the increase was 0.30 seconds. Percentage trucks in the traffic stream were simulated at the 0%, 5%, 10%, 15%, 20%, 25%, and 30% level. These simulations produced look up for yellow interval durations, an example of these lookup tables can be seen in Figures 3-14 and 3-15, the full look up tables are available in Appendix F of this thesis. The reliability levels indicate the percentage of vehicles that are protected from the dilemma zone at the particular design yellow time.

Speed Limit	***35 MPH***																				
Grade (%)	***2***																				
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***
85	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8
90	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.7	3.8	3.8	3.9	3.9	4.0	4.0
95	3.5	3.6	3.6	3.7	3.7	3.8	3.9	3.7	3.8	3.8	3.9	3.9	4.0	4.1	3.9	4.0	4.0	4.1	4.2	4.3	4.3
96	3.5	3.6	3.7	3.7	3.8	3.9	4.0	3.7	3.8	3.9	3.9	4.0	4.1	4.2	4.0	4.0	4.1	4.2	4.3	4.4	4.4
97	3.6	3.7	3.7	3.8	3.9	4.0	4.1	3.8	3.9	3.9	4.0	4.1	4.2	4.3	4.0	4.1	4.2	4.3	4.4	4.5	4.6
98	3.7	3.7	3.9	4.0	4.1	4.1	4.2	3.9	3.9	4.1	4.2	4.3	4.4	4.4	4.1	4.2	4.3	4.5	4.6	4.7	4.8
99	3.7	3.9	4.1	4.2	4.3	4.4	4.4	4.0	4.1	4.3	4.5	4.6	4.6	4.7	4.2	4.4	4.6	4.8	4.9	5.0	5.1
99.9	4.0	4.6	4.8	4.9	5.0	5.0	5.1	4.3	4.9	5.2	5.4	5.5	5.6	5.6	4.6	5.4	5.7	5.9	6.1	6.2	6.3

Speed Limit	***45 MPH***																				
Grade (%)	***2***																				
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***
85	3.8	3.8	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.4	4.4
90	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.2	4.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.6
95	4.1	4.1	4.2	4.3	4.3	4.4	4.5	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.9	4.9
96	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.3	4.4	4.5	4.6	4.6	4.7	4.8	4.6	4.6	4.7	4.8	4.9	5.0	5.1
97	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	4.6	4.7	4.8	4.9	5.0	5.1	5.2
98	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.7	4.8	5.0	5.1	5.2	5.3	5.4
99	4.4	4.5	4.7	4.8	4.9	5.0	5.1	4.6	4.8	4.9	5.1	5.2	5.3	5.4	4.9	5.0	5.2	5.4	5.6	5.7	5.8
99.9	4.7	5.3	5.5	5.6	5.7	5.8	5.8	4.9	5.6	5.8	6.0	6.1	6.2	6.3	5.2	6.1	6.4	6.5	6.7	6.9	7.0

Speed Limit	***55 MPH***																				
Grade (%)	***2***																				
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***
85	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.7	4.7	4.8	4.7	4.7	4.8	4.8	4.9	4.9	5.0
90	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.7	4.8	4.8	4.9	5.0	4.9	4.9	5.0	5.0	5.1	5.1	5.2
95	4.6	4.7	4.8	4.9	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.1	5.2	5.3	5.1	5.1	5.2	5.3	5.4	5.5	5.5
96	4.7	4.8	4.8	4.9	5.0	5.1	5.2	4.9	5.0	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.6
97	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.0	5.0	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.4	5.5	5.6	5.7	5.8
98	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.0	5.1	5.3	5.4	5.5	5.6	5.7	5.3	5.4	5.5	5.7	5.8	5.9	6.0
99	4.9	5.1	5.3	5.5	5.6	5.7	5.7	5.2	5.3	5.5	5.7	5.8	5.9	6.0	5.4	5.6	5.8	6.0	6.2	6.3	6.4
99.9	5.3	5.9	6.1	6.3	6.4	6.5	6.6	5.5	6.2	6.5	6.7	6.8	6.9	7.0	5.8	6.6	7.0	7.2	7.4	7.5	7.6

Figure 3-14: Lookup Table for 2% Approach Grade

Speed Limit	***35 MPH***																				
Grade (%)	***4***																				
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***
85	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.7
90	3.2	3.3	3.3	3.3	3.4	3.4	3.5	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8
95	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.5	3.6	3.6	3.7	3.8	3.8	3.9	3.7	3.8	3.8	3.9	4.0	4.0	4.1
96	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.6	3.6	3.7	3.8	3.8	3.9	4.0	3.8	3.8	3.9	4.0	4.1	4.1	4.2
97	3.4	3.5	3.6	3.7	3.8	3.8	3.9	3.6	3.7	3.8	3.8	3.9	4.0	4.1	3.8	3.9	4.0	4.1	4.2	4.3	4.3
98	3.5	3.6	3.7	3.8	3.9	4.0	4.0	3.7	3.8	3.9	4.0	4.1	4.2	4.2	3.9	4.0	4.1	4.2	4.3	4.4	4.5
99	3.6	3.7	3.9	4.0	4.1	4.2	4.2	3.8	3.9	4.1	4.2	4.3	4.4	4.5	4.0	4.1	4.4	4.5	4.6	4.7	4.8
99.9	3.8	4.4	4.5	4.6	4.7	4.7	4.8	4.0	4.6	4.8	5.0	5.1	5.1	5.2	4.3	5.0	5.3	5.4	5.5	5.6	5.7
Speed Limit	***45 MPH***																				
Grade (%)	***4***																				
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***
85	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.2
90	3.8	3.8	3.9	3.9	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.3	4.3	4.3	4.4
95	3.9	4.0	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.2	4.3	4.3	4.4	4.5	4.3	4.4	4.4	4.5	4.6	4.6	4.7
96	4.0	4.0	4.1	4.2	4.2	4.3	4.4	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.4	4.4	4.5	4.6	4.6	4.7	4.8
97	4.0	4.1	4.2	4.2	4.3	4.4	4.5	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
98	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.5	4.6	4.7	4.8	4.9	5.0	5.1
99	4.2	4.3	4.5	4.6	4.7	4.8	4.8	4.4	4.5	4.7	4.8	4.9	5.0	5.1	4.6	4.8	4.9	5.1	5.2	5.3	5.4
99.9	4.4	5.0	5.2	5.3	5.3	5.4	5.5	4.7	5.2	5.5	5.6	5.7	5.8	5.8	4.9	5.6	5.9	6.0	6.2	6.3	6.4
Speed Limit	***55 MPH***																				
Grade (%)	***4***																				
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***
85	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.7	4.7	4.7
90	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.5	4.6	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.8	4.9	4.9
95	4.4	4.5	4.6	4.6	4.7	4.8	4.9	4.6	4.7	4.8	4.8	4.9	5.0	5.0	4.9	4.9	5.0	5.0	5.1	5.2	5.2
96	4.5	4.6	4.6	4.7	4.8	4.9	4.9	4.7	4.7	4.8	4.9	5.0	5.1	5.1	4.9	5.0	5.0	5.1	5.2	5.3	5.4
97	4.5	4.6	4.7	4.8	4.9	5.0	5.0	4.7	4.8	4.9	5.0	5.1	5.2	5.2	5.0	5.0	5.1	5.2	5.3	5.4	5.5
98	4.6	4.7	4.8	5.0	5.1	5.1	5.2	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.0	5.1	5.3	5.4	5.5	5.6	5.7
99	4.7	4.9	5.1	5.2	5.3	5.4	5.4	4.9	5.1	5.3	5.4	5.5	5.6	5.7	5.2	5.3	5.5	5.7	5.8	5.9	6.0
99.9	5.0	5.6	5.8	5.9	6.0	6.1	6.2	5.2	5.9	6.1	6.2	6.4	6.4	6.5	5.5	6.2	6.5	6.7	6.8	6.9	7.0

Figure 3-15: Lookup Table for 4% Approach Grade

The lookup tables depict a clear correlation between yellow timings and increased reliability. In practical terms, if a designer wishes to provide additional dilemma zone protection then he or she should increase the yellow time interval. Also evident in the tables are an increase in yellow times as speed increases and precipitation levels worsen, conversely as grade increases yellow times decrease. This method of simulation and developing yellow time intervals is portable and can be adapted to fit individual intersection conditions provided data on local driver population behavior and vehicle characteristics are available.

In order to validate the simulation method used the yellow times calculated for zero percent truck scenarios were compared with the yellow times calculated for passenger cars in a previous research effort [25]. At reliability levels up to and including 98% the values calculated were within 0.2 seconds of the previously published values. At the 99% and 99.9% reliability levels however there were increases of up to 0.6 seconds. It was assumed however that in practice reliability levels of less than 98% would be used. Additionally changes were made to the actual code used for the simulated that made it more computationally efficient and provided more consistent results. Taking these two facts into consideration the simulation was determined to be valid.

Observing the percentage change in yellow times reveals several trends. The addition of trucks to the traffic stream produces only minimal absolute changes (0.1-0.3 seconds) at reliability levels of 98% or less and truck traffic concentrations of 10% or less. As reliability beginning at the 99% reliability level for 10% trucks and going up the absolute increases grow to as much as 3.3 seconds. Absolute increases in yellow times were consistent for different precipitation levels assuming approach speed and grade were held constant. As expected, negative road grades produced larger increases to yellow times in terms of both absolute increase and percentage increase. Lower approach speeds and downhill approach grades produced the largest changes in terms of both absolute increase and percentage change. In general, percentage change decrease for all scenarios as approach speeds increased. The effect of large percentage of trucks in the traffic stream was also strongly evident. At the 5% truck mix level the absolute increase was 0.0-1.4 seconds, while at the 30% truck mix level the absolute increase was 0.2-4.0 seconds with the largest absolute change being observed at the 35 MPH approach speed level.

When compared with the results of a previous simulation conducted using assumptions about the deceleration rates of trucks and perception reaction times of trucks the results produce both similarities and differences. In the previous study it was determined that trucks have more of an impact on yellow times at positive approach grade, while in this study it was determined that trucks have their largest impact on negative approach grades. Both studies, however, showed that the effect of trucks is largest at lower approach speeds [2].

The observation that trucks have their largest effect at the 35 MPH speed is particularly important as this is the predominant speed limit in many urban areas, which are also the areas where traffic signals are most common. Using the lookup tables it can be seen that even at the 98% confidence level dilemma zone protection for a traffic stream consisting of 30% trucks can be provided by increasing yellow times by no more than 1.1 seconds. This would leave only 2% of the traffic stream at risk of being placed in a dilemma zone. Additionally, consistent with the findings of Bonneson et al. in 2007 [13] this increase is not expected to have a measurable decrease in the level of service of the intersection.

3.4 DESIGN OF ALL-RED TIMES

The last component of signal timing that must be addressed is the all-red clearance interval. According to the ITE Traffic Engineering Handbook, 6th ed. “The red clearance interval is used to provide additional time following the yellow change interval before conflicting traffic is released. [1]" This all-red interval provides additional dilemma zone protection for drivers as it allows them to fully clear the intersection without risk of a right angle collision. The ITE equation for the all-red interval is given in equation 3-6

$$R = \frac{w+l}{V} \tag{3-6}$$

Where R=all red interval (sec)

W= width of stop line to far side no-conflict point

V= design speed (ft/sec)

L = length of vehicle.

In practice a generic vehicle length of 20 feet is used to calculate the all-red interval. This value does not adequately represent the length of a truck and thus does not provide adequate clearance time for a truck to fully clear the intersection before conflicting traffic is released. The length of the average tractor trailer is roughly 70-80 feet, or 3.5-4 times longer than the typical passenger car [26]. In order to adequately determine the necessary all-red time to provide adequate accident protection for trucks a weighted average was used to calculate all-red times for 3 different intersection widths at 3 different approach speeds. Intersection widths were calculated assuming 3, 4, and 6 travel lanes respectively, plus 30 feet to provide for crosswalks and safety buffers on either side of the intersection. For trucks l was assumed to be 80 feet. Table 3-3 shows the resulting all-red times.

Intersection Width	66	78	120	66	78	120	66	78	120
Approach Speed (MPH)	35	35	35	45	45	45	55	55	55
Percentage Trucks									
0	1.7	1.9	2.7	1.3	1.5	2.1	1.1	1.2	1.7
5	1.7	2.0	2.8	1.3	1.5	2.2	1.1	1.3	1.8
10	1.8	2.0	2.8	1.4	1.6	2.2	1.1	1.3	1.8
15	1.9	2.1	2.9	1.4	1.6	2.3	1.2	1.3	1.8
20	1.9	2.1	3.0	1.5	1.7	2.3	1.2	1.4	1.9
25	2.0	2.2	3.0	1.5	1.7	2.3	1.3	1.4	1.9
30	2.0	2.3	3.1	1.6	1.8	2.4	1.3	1.4	2.0

Table 3-3: All-Red Times

The addition of trucks to the calculation of all red times resulted in changes of 0.0-0.4 seconds (2.1-20.9%), with the greatest change showing in the slowest approach speed at the shortest intersection width. This suggests that the effect of trucks in the traffic stream is magnified at lower speeds and shorter distances while at higher speeds and larger distances trucks behave more closely to passenger cars.

3.4 CONCLUSIONS

This chapter has presented an in-depth discussion of the field experiment that was conducted including a detailed description of the experimental design, testing equipment and procedures, and presentation of results. The experiment was designed and conducted to identify and quantify the dilemma zone for truck drivers and to investigate the factors that cause this dilemma zone to be different than the dilemma zone for passenger cars. Analysis of the data presented demonstrates a significant difference between the dilemma zone for trucks and passenger cars.

This chapter presented an analysis of driver stopping behavior for truck drivers at the onset of yellow indication, an analysis of perception reaction times for truck drivers, and an analysis of deceleration levels for trucks. Counter to hypotheses as the beginning of the experiment, whether or not the vehicle has a loaded or empty trailer does not seem to have a large effect on stopping behavior or deceleration rates.

A Monte Carlo simulation was conducted to develop lookup tables for use in designing yellow times for intersections given approach speed limit, roadway grade, precipitation conditions, and truck to passenger car concentration levels. As expected yellow times increased as the percentage of trucks in the traffic stream increased. At confidence levels up to 99% the increase in yellow intervals was generally less than 10% for truck concentrations up to 20%. At truck traffic concentrations greater than 20% and confidence levels of 99% and above however the increase in yellow intervals exceeded 10% and reached a maximum increase of roughly 30% at a truck concentration of 30% and confidence level of 99.9%. Additionally it was found that as precipitation levels increased from 0 to 1 to2 the percentage change for a given truck concentration and confidence level increased, meaning the effect of precipitation is not linear. This observation is due to the fact that at higher precipitation levels the TTI is assumed to increase and in the deceleration models for both cars and trucks one term including the TTI is raised to the second power. Figure 3-16 shows a histogram of yellow interval times where the free-flow speed and roadway grade of the approach are held constant while the precipitation conditions are varied.

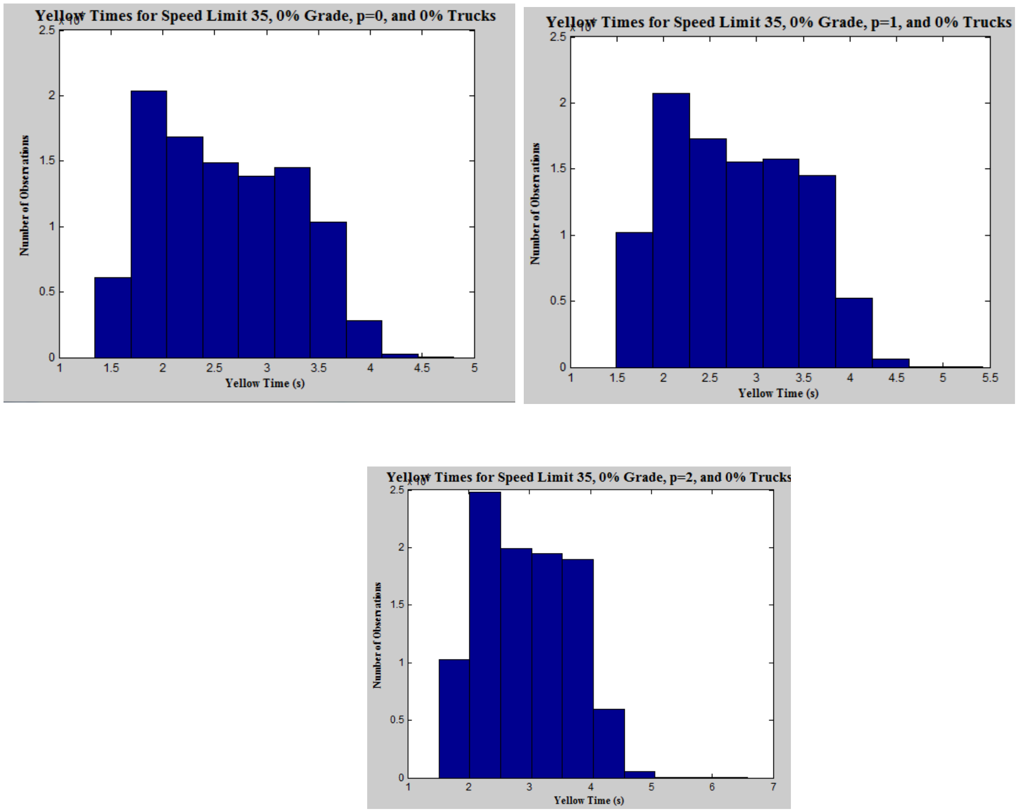

Figure 3-16: Comparison of Histograms of Yellow Intervals

Figures 3-17, 3-18, and 3-19 show a comparison of the percentage change in yellow intervals at several combinations of free-flow speed, truck concentration and reliability levels.

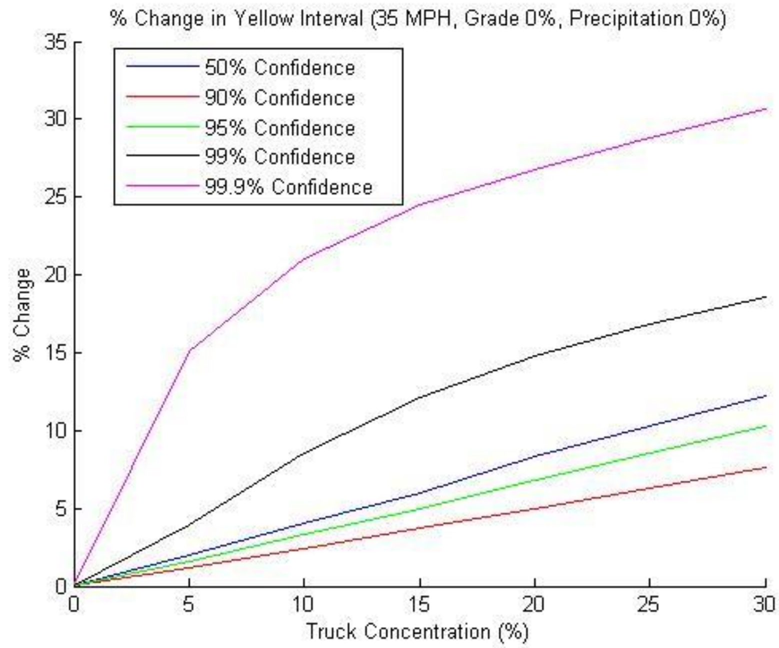

Figure 3-17: Percent Change in Yellow Interval Duration (35 MPH, Grade 0%, Precipitation 0)

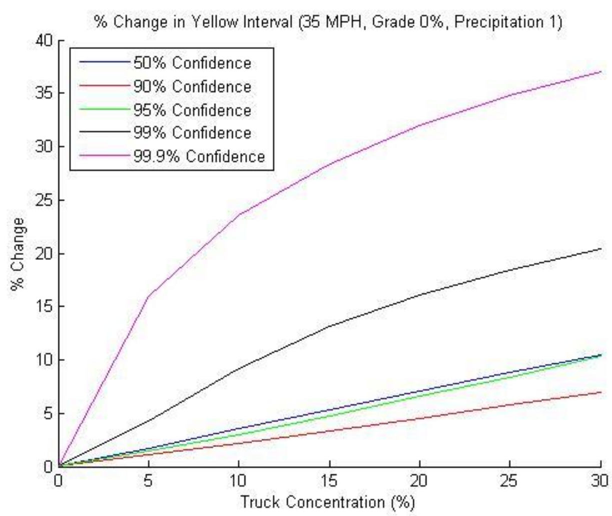

Figure 3-18: Percent Change in Yellow Interval Duration (35 MPH, Grade 0%, Precipitation 1)

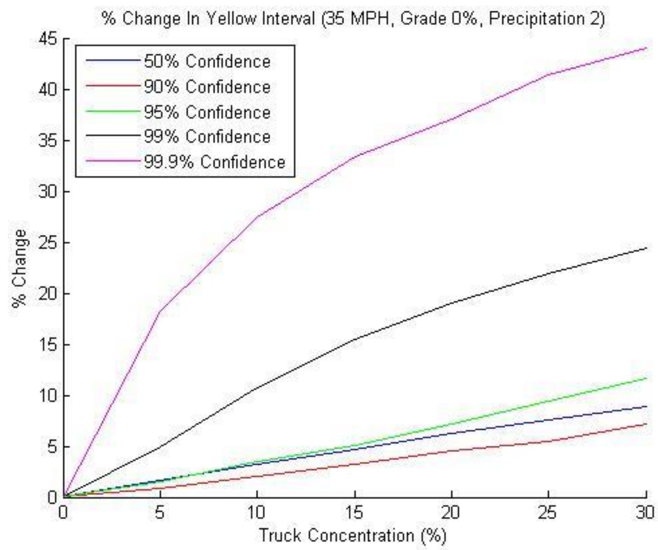

Figure 3-19: Percent Change in Yellow Interval Duration (35 MPH, Grade 0%, Precipitation 2)

Additionally it was observed that as the confidence level increased the percent change in yellow interval duration produced plot that remained relatively stable before increasing rapidly, suggesting that trucks do not have a significant impact on yellow interval durations until reaching confidence levels of 98% or greater. Figures 3-20 and 3-21 demonstrate this observation at several combinations of approach speed, grade, precipitation, and truck concentration.

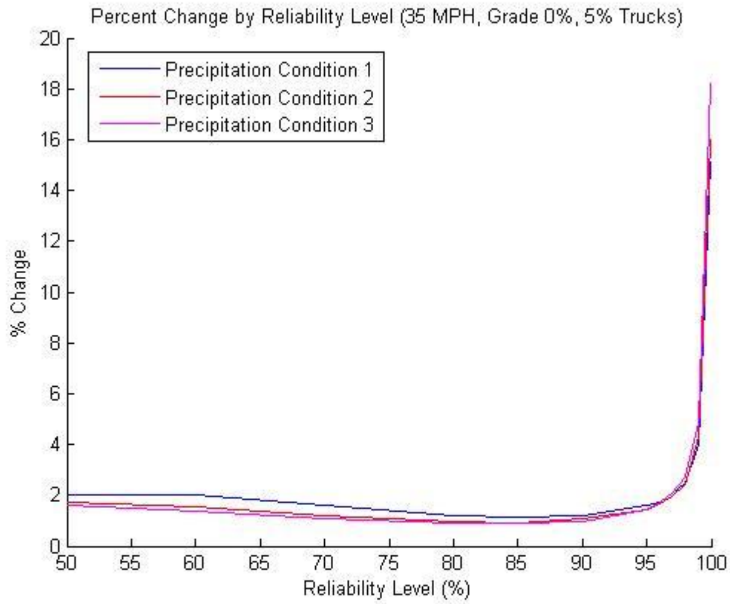

Figure 3-20: Percent Change by Reliability Level (35 MPH, Grade 0%, 5% Trucks)

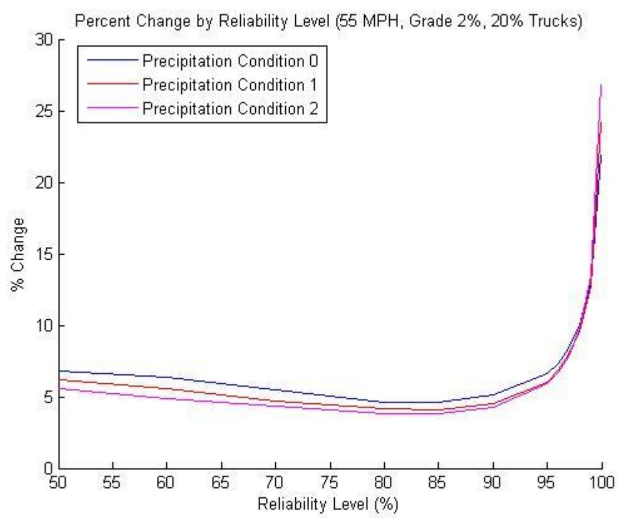

Figure 3-21: Percent Change by Reliability Level (55 MPH, Grade 2%, 20% Trucks)

As previously discussed, the goal of this study was to identify and quantify the difference in the dilemma zone for trucks and passenger cars. It is believed that truck drivers may behave differently when placed in platooning situations as they approach traffic signals. Additionally, the effects of precipitation on truck stopping behavior in this study were assumed to be the same as the effects of precipitation on passenger cars. It is recommended that further field tests are conducted to investigate the impacts of both platooning and precipitation conditions on truck stopping behavior. Additionally, as the field experiments conducted in this study were completed using a truck driving simulator, it is recommended that this study be repeated using a real truck on a test track such as the Smart Road at VTTI in order to validate the conclusions reached in this study.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

4.1 CONCLUSIONS

This thesis has presented 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 results. The experiment was designed and conducted to identify and quantify the dilemma zone for truck drivers and to investigate the factors that cause this dilemma zone to be different than the dilemma zone for passenger cars. Analysis of the data presented demonstrates a significant difference between the dilemma zone for trucks and passenger cars. Compared to passenger cars the differences in the truck dilemma zone can be summarized:

- The dilemma zone boundary for trucks is approximately 1.5 seconds TTI back from the boundary for passenger cars at 45 MPH (72.42 KPH), this is approximately a difference of 99 feet at an approach speed of 45 MPH (72.42 KPH). This value is longer than the 1.0 second adjustment proposed by Bonneson and Zimmerman [13], and is consistent with the 1.5 second adjustment proposed by Zimmerman in 2007 [14]. These consistencies validate the use of the CTAP simulator for testing purposes.
- The PRTs for truck drivers that were measured in the simulated experiment had an average of 1.15 seconds. The ITE uses a PRT value of 1.0 seconds for calculation of yellow times. This value is assumed to be the 85th percentile PRT for all drivers, by comparison, the 85th percentile PRT for truck drivers was observed to be 1.5 seconds, which is consistent with the value published in the Missouri Department of Transportation's Commercial Driver's License Manual

[10]. The observation of a longer perception reaction time for truck drivers is consistent with the recommendation of the Missouri Department of Transportation's Commercial Driver's License Manual [10].

- Deceleration levels for trucks are lower than those for passenger cars. This is due to inefficiencies of air braking systems versus newly-designed hydraulic braking systems.
- When considering trucks for the development of yellow times, even at the highest evaluated concentration of 30% trucks, it is possible to provide dilemma zone protection for 98% of all vehicles without adversely affecting the operations of the intersection.
- It is necessary to consider trucks when designing all-red times in order to provide adequate time for trucks to clear the intersection before giving the right of way to conflicting traffic.

As previously discussed, the goal of this study was to identify and quantify the difference in the dilemma zone for trucks and passenger cars. It is believed that truck drivers may behave differently when placed in platooning situations as they approach traffic signals. Additionally, the effects of precipitation on truck stopping behavior in this study were assumed to be the same as the effects of precipitation on passenger cars. It is recommended that further field tests are conducted to investigate the impacts of both platooning and precipitation conditions on truck stopping behavior. Additionally, as the field experiments conducted in this study were completed using a truck driving simulator, it is recommended that this study be repeated using a real truck on a test track such as the Smart Road at VTTI in order to validate the conclusions reached in this study.

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. As demonstrated in this study, the dilemma zone for trucks starts significantly further back than the dilemma zone for standard passenger cars. If yellow times were increased to provide this protection at all times the delay induced into the system would cause an obvious decrease in the level service at intersections. With vehicle to infrastructure communications an intersection will be able to know when a truck is approaching and is at risk at being caught in a dilemma zone and can adjust yellow times accordingly for that situation, thus avoiding introducing unnecessary delay when there are no trucks present.

4.2 RECOMMENDATIONS FOR FUTURE RESEARCH

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

- Examine the impact of platooning conditions (such as truck following car, car following truck) on truck driver behavior at the onset of yellow.
- Investigate the impact of precipitation factors and roadway conditions on truck driver behavior at the onset of yellow.
- Conduct an experiment similar to the one described in this thesis using a real truck in a controlled environment to validate and refine the findings and conclusions presented in this thesis.

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APPENDIX A

VIRGINIA TECH INSTITUTIONAL REVIEW BOARD APPROVAL LETTER AND INFORMED CONSENT FORM

VirginiaTech

Office of Research Compliance
Institutational Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, VA 24060
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE:	April 3, 2013
TO:	Hesham A Rakha, Ihab E Elshawarby, Michael Baird, Craig William Bryant
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)
PROTOCOL TITLE:	Inclement Weather Yellow Timing
IRB NUMBER:	**09-712**

Effective April 3, 2013, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Amendment 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 2, 2012**
Protocol Expiration Date:	**October 1, 2013**
Continuing Review Due Date*:	**September 17, 2013**

*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?
08/21/2012	06207204	Virginia Center for Transportation Innovation & Research	Compared on 06/29/2010
08/21/2012	10043708	Virginia Center for Transportation Innovation & Research	Not required (Not federally funded)

* 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.

Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: Truck Simulator Study

Investigator(s): Hesham Rakha, Ihab El-Shawarby, Michael Baird, Craig Bryant, Scott Tidwell

Section I. Purpose of this Research/Project:

The purpose of this study is to look at traffic signal timing involving large trucks. 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 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. Show a current commercial driver's license (CDL).
4. Complete a questionnaire regarding your truck driving history, medical history and demographic survey, as well as an optional emergency contact form.
5. Drive the orientation drive in the truck simulator and take the accompanying survey.
6. Complete all simulated routes. While you are in the simulator, video cameras will be continuously recording. Recorded views will include your feet.
7. Listen to the instructions regarding any tasks in this study.
8. Come back for a second session as scheduled at the end of the first session.
9. At the end of each session, you will be paid and sign a receipt for payment.

Section III. Risks:

This study does not present more than minimal risk to current commercial drivers. The driving tasks in this experiment will be consistent with your current level of training.

The minimal risks include:

1) Possible discomfort associated with the motion of the simulator, fatigue, headache, eye strain, difficulty focusing, increased salivation, dry mouth, sweating, difficulty concentrating, fullness of head, blurred vision, dizziness, vertigo, and upset stomach. These are similar to those symptoms you might experience with motion sickness.

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

1) Based on screening questionnaires, your inclusion in this study means that you are probably not at high risk for simulator sickness.
2) The researcher and will monitor your use of the simulator and ask you to stop if he/she feels the risks are too great to continue After the first drive of the first visit, a survey will be taken to assess your susceptibility to simulator sickness. If you do not pass this survey, your participation will be terminated, and you will be paid and thanked for the time spent in the experiment.
3) If you experience simulator sickness, you will be provided with a comfortable place to rest until you feel able to drive.
4) The simulator will be have its eye height calibrated, screens aligned, an adequate frame rate, and minimal transport delay.
5) Design scenarios will minimize 90 degree turns, tight curves, abrupt braking, and the roadside will be cleaned of unnecessary objects.
6) The room where the simulator is in will be kept at a cool temperature.
7) You will be required to wear the seat belt restraint while driving the simulator.
8) The simulator is equipped with a fire extinguisher and first-aid kit, which may be used in an emergency.
9) You do not have any medical condition that would put you at a greater risk, including but not restricted to heart disease, epilepsy, balance disorders, and lingering effects of head injuries, stroke, fatigue, effects of a hangover, an upset stomach.
10) You are to comply with the hours of service (HOS) regulations.

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.

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, including the Health Screening Questionnaire, 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 deidentified 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 2 participation sessions, one session per day, taking approximately 2.5 to 3.5 hours per session to complete. Upon completion of each session, you will be paid $40 per hour in cash, prorated in 15 minute intervals, for time spent in the simulator, completing paperwork, and filling out questionnaires. However, if you are to receive payment of $100 or more in any individual visit, university policy requires the payment to be made by check. You may stop at any time. If you decide to stop, you will be paid for the amount of time you actually participated. The maximum total compensation if you participate in the two sessions would be in the range of $220 to $280. 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 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. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained. This form is valid for the period listed at the bottom of the page.

Section IX. 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 posted speed limits and traffic laws.
5. To abstain from any substances that will impair your ability to drive.
6. To drive the simulator in a safe and responsible manner.

Section X. Participant's Acknowledgements

Check all that apply:

☐ I am not under the influence of any substances which may impair my ability to safely participate in this experiment.

- ☐ I am in good health and not aware of any health conditions that would increase my risk including, but not limited to, lingering effects of a heart condition, fatigue, effects of a hangover, an upset stomach, head cold, ear infection, and ear blockages.
- ☐ I have informed the experimenter of any concerns or questions I have about this study.

Section XI. 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

____ Date__________

Experimenter Signature

Test Day	Participant Initials	Experimenter Initials	Date
2			/ /

Section XII. Questions or Concerns

Should I have any pertinent questions about this research I may contact one of the research investigators whose contact information is included below:

Investigators	Telephone/email
Hesham Rakha	540-231-1505 / hrakha@vt.edu
Ihab El-Shawarby	540-231-1577/ shawarby@vt.edu
Michael Baird	mjbarid@vt.edu
Craig Bryant	crbryant@vt.edu
Scott Tidwell	540-231-7761/ stidwell@vt.edu

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

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

APPENDIX B – 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. Once this questionnaire is completed, remove this cover sheet and file separately from the screening questions.

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. I am recruiting participants for a driving study that will take place in the truck simulator. I obtained your contact information from the VTTI internal participant database.

If you choose to participate, you will drive a commercial vehicle in the truck simulator which will simulate a real driving world with realistic signal timings. You will be driving the simulator, however an experimenter will be with you at all times while you are driving. The simulator is equipped with cameras that allow us to collect data. The cameras, however, are very small and are placed out of the way.

The study consists of two distinct parts. The first is filling out the necessary paperwork and testing for simulator sickness. Provided that these tests are passed, you will perform the driving portion of the study. The driving portion will consist of driving a commercial truck on the truck simulator for approximately two hour and forty-five minutes, which includes undertaking an orientation drives and study trials. There will be two sessions on two days to complete participation in this study. The study takes approximately three to three and one half hours per session. 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?

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

Thank you for your time.

If they indicated that they are interested:

That's great. I would like to ask you some questions to see if you are eligible to participate. The information you provide will be kept confidential. Do I have your consent to proceed with the questions? (If yes, proceed).

Questions

1. Are you male?

   □ Yes □ No

   Criteria: Must answer yes

2. *Do you have a valid Class A commercial driver's license?* (Criterion for participation: the response must be *Yes*)

   □ Yes □ No

3. *Do you have a valid DOT medical certificate* (Criterion for participation: response must be Yes)

   □ Yes □ No

4. *Are you eligible for employment in the United States?*

   □ Yes □ No

   Criteria: Must be able to work in the US.

5. *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?*

   □ Yes □ No

   Criteria: Must answer yes

6. *What is your age? ________*

   (Criterion for participation: must be between 21 and 55 at time of experiment)

7. *Are you able to drive a standard manual transmission in a commercial vehicle without assistive devices?*

   □ Yes □ No

   (Criterion for participation: the driver must be able to drive standard ten speed manual transmission commercial vehicle without assistive devices)

8. *How often do you drive a commercial vehicle*?

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

(Criterion for participation: Participants must drive at least 2 times per week)

Note to Researcher:
If a response to any of the first 7 questions does not meet its criterion, read the following:

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

Criteria For Participation

1. **Must be male.**
2. **Must hold a valid Class A commercial driver's license.**
3. **Must hold a valid DOT medical certificate.**
4. **Must be able to drive a manual truck transmission vehicle without assistive devices.**
5. **Must be eligible for employment in the U.S.**
6. **Participants must be between 21 and 55 years old.**
7. **Must drive a commercial vehicle at least 2 times per week.**

If the driver passes the first part of the screening , move onto the second part.

1. Do you have or have lingering effects from heart condition, stroke, or brain tumor?

YES or NO *If yes, please describe:_______________________________________*

2. Do you have or have lingering effects from a head or neck injury?

YES or NO *If yes, please describe:_______________________________________*

3. Do you suffer from epileptic seizures?

YES or NO

4. Do you have any respiratory disorders?

YES or NO *If yes, please describe:*____

5. Do you have dizziness, vertigo, or balance problems?

YES or NO

6. Do you have problems with claustrophobia?

YES or NO *If yes, please describe:*____

7. Are you currently taking any medications that might affect your driving?

YES or NO

8. Do you have an upper respiratory illness?

YES or NO

The criterion for these questions is that if the person answers YES on questions 3, 5, 7, or, 8, they are ineligible. (Note to Researcher: if they answer 1, 2, 4, or 6, please make note of this that they may be of higher risk of simulator sickness, but they are still allowed to participate).

Note to Researcher:
If a response to any of these 8 questions does not meet its criterion, read the following:

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

If they pass the second part, move onto part 3.

Part 3 questions.

Please answer the following statements using the accompanying scale.

0	**1**	**2**	**3**
Never	**Occasionally**	**Often**	**Always**

Simulator-Sickness Criteria	**RATING**
The inability to sit close to a movie screen or watch the movement of a train or carnival ride without nausea, dizziness, or headaches	
Frequent, and sometimes daily, pressure headaches	
Nausea, headache, or dizziness on playground equipment	
Car sickness	
Fatigue, headaches, nausea, or dizziness when reading or sitting in front of a computer screen	
Nausea, headache, or dizziness from riding roller coasters	
Inability to watch rapid movement on a TV or movie screen without getting nausea or dizziness	
Nausea, headache, or dizziness when playing video games	

Seeing the floor or ground as being titled or wavy	
Tendency to become nauseated or dizzy when turning, spinning, or doing rapid movements	
Feeling that something inside the body is in constant motion	
Sensation that print floats at times when reading	

The criterion for this part is that if the participant answers 3 on three or more categories, they are ineligible. Also, if six or more of the categories are 2 or above, they are ineligible. (Note to Researcher: If there are numerous ones and twos, they are eligible, but make a note so that the research team is aware that the participant may be at a slightly higher risk for simulator sickness).

Note to Researcher:

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

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

Once the researcher determines that the participant is eligible for the study:

You are eligible for the study.

I would like to set up a time when you can come to the Moss Building (1900 Kraft Drive) 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-XXX-XXXX.

Here are the directions to the Moss Building (1900 Kraft Drive) in the Corporate Research Center. 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 left onto Industrial Park Dr.
6. Turn right at the second traffic signal, Research Center Drive
7. Continue on Research Center Drive for about 0.3 miles.
8. Turn Left onto Kraft Drive (a Stellar One Bank will be on your left).

9. Continue on Kraft Drive for about 0.4 miles

10. Turn left into the Moss Building (1900 Kraft Drive).

11. Arrive at building.

When you come to the Moss Building you may park in any open space available and walk to Suite 107 on the ground floor. 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. We also need you to be in good health. If you find yourself suffering from fatigue or sleep loss, the effects of a hangover, an upset stomach, a head cold, an ear infection, or ear blockages, please call (540)-231-2528 and leave a message and we will reschedule you for a different day.

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.

APPENDIX C – DRIVER SURVEYS AND QUESTIONNAIRES

Participant #:

Truck Simulator Study

Instructions: For these questions, answer yes or no by circling one option. On certain questions, if you answer yes, please answer the supplemental question.

1. Do you have or have lingering effects from heart condition, stroke, or brain tumor?

    YES or NO   If yes, please describe:_______________________________________

2. Do you have or have lingering effects from a head or neck injury?

    YES or NO   If yes, please describe:_______________________________________

3. Do you suffer from epileptic seizures?

    YES or NO

4. Do you have any respiratory disorders?

    YES or NO   If yes, please describe:_______________________________________

5. Do you have dizziness, vertigo, or balance problems?

    YES or NO

6. Do you have problems with claustrophobia?

    YES or NO   If yes, please describe:_______________________________________

7. Are you currently taking any medications that might affect your driving, or suffering from fatigue, effects of a hangover, an upset stomach, a head cold, an ear infection, or ear blockages?

    YES or NO

8. Directions: Please answer the following statements using the accompanying scale.

0	1	2	3
Never	Occasionally	Often	Always

Simulator-Sickness Criteria	RATING
The inability to sit close to a movie screen or watch the movement of a train or carnival ride without nausea, dizziness, or headaches	
Frequent, and sometimes daily, pressure headaches	
Nausea, headache, or dizziness on playground equipment	
Car sickness	
Fatigue, headaches, nausea, or dizziness when reading or sitting in front of a computer screen	
Nausea, headache, or dizziness from riding roller coasters	
Inability to watch rapid movement on a TV or movie screen without getting nausea or dizziness	
Nausea, headache, or dizziness when playing video games	
Seeing the floor or ground as being titled or wavy	

Tendency to become nauseated or dizzy when turning, spinning, or doing rapid movements	
Feeling that something inside the body is in constant motion	
Sensation that print floats at times when reading	

Instructions: This form is **optional**. Filling out or not filling out this form will not affect your standing in the study in any way. This form will be stored separately from the other data collected today and will only be looked at if needed to contact the person you list. It will be destroyed at the end of data collection for this study.

Participant Name: ____

Emergency Contact Information

Name: ____

Telephone Number: ____________________________

_________________________________ _____________________________

Signature Date

Test Day	Initials	Date
2		/ /

Participant #: Date:

Truck Simulator Study

Demographic Questionnaire

1. What is your age?

2. How long have you been driving a commercial vehicle? _______ years

3. What is the make, model, and year of the primary commercial vehicle you drive (include details on type of transmission)?

4. What is the make, model, and year of the secondary commercial vehicle you drive (include details on type of transmission)?

5. What is the typical trailer that you pull?

6. In your estimate, how much time in a typical week do you drive on roadways with signalized intersections?

   _________%

7. Have you ever had a traffic ticket or crash involving a signalized intersection while driving a commercial vehicle?

   Yes No

   7a. If yes, please describe

APPENDIX D – SIMULATOR SICKNESS QUESTIONNAIRE

VIRGINIA TECH TRANSPORTATION INSTITUTE

Simulator Orientation Post Screening Questionnaire

Truck Simulator Study

Participant #:

Please answer the following statements using the accompanying scale.

0 **1** **2** **3**

None **Slight** **Moderate** **Severe**

SYMPTOM	Rating
General Discomfort	
Fatigue	
Headache	
Eye Strain	
Difficulty Focusing	
Increased Salivation	
Dry Mouth	
Sweating	
Nausea	
Difficulty Concentrating	
Fullness of Head	
Blurred Vision	
Dizzy (eyes open)	
Dizzy (eyes closed)	
Vertigo	
Stomach Awareness	

Burping	

Symptoms Score: .... (after weighting)

SIMULATOR SICKNESS SCORING

The SSQ is based on three components: nausea, oculomotor problems, and disorientation. These can be combined to produce a total SSQ score, as described below.

Computation of SSQ Scores

	Weight		
SSQ Symptom	*Nausea*	*Oculomotor*	*Disorientation*
General discomfort	1	1	0
Fatigue	0	1	0
Headache	0	1	0
Eye strain	0	1	0
Difficulty focusing	0	1	1
Increased salivation	1	0	0
Dry Mouth	1	0	0
Sweating	1	0	0
Nausea	1	0	1
Difficulty concentrating	1	1	0

Fullness of head	0	0	1
Blurred vision	0	1	1
Dizzy (eyes open)	0	0	1
Dizzy (eyes closed)	0	0	1
Vertigo	0	0	1
Stomach awareness	1	0	0
Burping	1	0	0

Participants report the degree to which they experience each of the above symptoms as one of "None", "Slight'", "Moderate'" and "Severe'". These are scored respectively as 0, 1, 2, and 3. To compute the scale scores for each column, the reported value for each symptom is multiplied by the weight in each column and then summed down the columns. The total SSQ score is obtained by adding the scale scores across the three columns and multiplying by 3.74. Weighted scale scores for each column individually can be found by multiplying the "Nausea'" scale score by 9.54; the "Oculomotor" subscale by 7.58; and the "Disorientation" subscale by 13.92.

A total score of 40 or higher will eliminate the subject

APPENDIX E – POST TEST SURVEY

Post Test Survey

Participant # _____

Session # _____

1. Was there any signal in this study that you felt unsafe about? If so, what made you feel unsafe?

2. What was the determining factor in whether you stopped or not at a given signal?

3. Is there anything in the driving world or simulation that could be changed to make the test more realistic to the driving you encounter every day?

APPENDIX F – YELLOW TIME LOOKUP TABLES

Speed Limit	***35 MPH***																				
Grade (%)	***0***																				
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	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.7	2.8	2.8	2.9	2.9	3.0	3.0	2.9	2.9	3.0	3.0	3.1	3.1	3.2
60	2.8	2.8	2.9	2.9	3.0	3.0	3.1	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4
70	3.0	3.1	3.1	3.2	3.2	3.2	3.3	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6
80	3.3	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.9
85	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	3.9	4.0	4.0
90	3.5	3.6	3.6	3.6	3.7	3.7	3.8	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
95	3.7	3.7	3.8	3.9	3.9	4.0	4.1	3.9	3.9	4.0	4.1	4.1	4.2	4.3	4.1	4.2	4.2	4.3	4.4	4.5	4.6
96	3.7	3.8	3.9	3.9	4.0	4.1	4.1	3.9	4.0	4.1	4.1	4.2	4.3	4.4	4.2	4.2	4.3	4.4	4.5	4.6	4.7
97	3.8	3.9	3.9	4.0	4.1	4.2	4.3	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.2	4.3	4.4	4.5	4.7	4.8	4.9
98	3.8	3.9	4.0	4.2	4.3	4.4	4.4	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.3	4.4	4.6	4.8	4.9	5.0	5.1
99	3.9	4.1	4.3	4.4	4.5	4.6	4.7	4.2	4.4	4.6	4.7	4.8	4.9	5.0	4.5	4.7	4.9	5.1	5.3	5.4	5.5
99.9	4.2	4.9	5.1	5.3	5.4	5.4	5.5	4.5	5.3	5.6	5.8	6.0	6.1	6.2	5.0	5.9	6.3	6.6	6.8	7.0	7.1

Speed Limit	***35 MPH***																				
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	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.7	2.7	2.8	2.8	2.9	2.9	3.0	2.9	2.9	2.9	3.0	3.0	3.1	3.1
60	2.7	2.8	2.8	2.9	2.9	3.0	3.0	2.9	3.0	3.0	3.1	3.1	3.1	3.2	3.1	3.2	3.2	3.2	3.3	3.3	3.3
70	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6
80	3.2	3.2	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8
85	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	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
90	3.4	3.5	3.5	3.6	3.6	3.6	3.7	3.6	3.7	3.7	3.7	3.8	3.8	3.9	3.8	3.9	3.9	4.0	4.0	4.1	4.1
95	3.6	3.6	3.7	3.8	3.8	3.9	4.0	3.8	3.8	3.9	4.0	4.0	4.1	4.2	4.0	4.1	4.1	4.2	4.3	4.4	4.5
96	3.6	3.7	3.8	3.8	3.9	4.0	4.0	3.8	3.9	4.0	4.0	4.1	4.2	4.3	4.1	4.1	4.2	4.3	4.4	4.5	4.6
97	3.7	3.8	3.8	3.9	4.0	4.1	4.2	3.9	4.0	4.0	4.1	4.2	4.3	4.4	4.1	4.2	4.3	4.4	4.5	4.6	4.7
98	3.7	3.8	3.9	4.1	4.2	4.2	4.3	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.2	4.3	4.5	4.6	4.7	4.9	5.0
99	3.8	4.0	4.2	4.3	4.4	4.5	4.5	4.1	4.2	4.4	4.6	4.7	4.8	4.9	4.3	4.5	4.8	5.0	5.1	5.2	5.3
99.9	4.1	4.7	4.9	5.1	5.1	5.2	5.3	4.4	5.1	5.4	5.6	5.7	5.8	5.9	4.8	5.6	6.0	6.3	6.4	6.6	6.7

Speed Limit	35 MPH																				
Grade (%)	2																				
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	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.7	2.7	2.7	2.8	2.8	2.9	2.9	2.8	2.9	2.9	2.9	3.0	3.0	3.1
60	2.7	2.8	2.8	2.8	2.9	2.9	3.0	2.9	2.9	3.0	3.0	3.0	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.3
70	2.9	3.0	3.0	3.1	3.1	3.1	3.2	3.1	3.1	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5
80	3.1	3.2	3.2	3.3	3.3	3.3	3.4	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7
85	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8
90	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.7	3.8	3.8	3.9	3.9	4.0	4.0
95	3.5	3.6	3.6	3.7	3.7	3.8	3.9	3.7	3.8	3.8	3.9	3.9	4.0	4.1	3.9	4.0	4.0	4.1	4.2	4.3	4.3
96	3.5	3.6	3.7	3.7	3.8	3.9	4.0	3.7	3.8	3.9	3.9	4.0	4.1	4.2	4.0	4.0	4.1	4.2	4.3	4.4	4.4
97	3.6	3.7	3.7	3.8	3.9	4.0	4.1	3.8	3.9	3.9	4.0	4.1	4.2	4.3	4.0	4.1	4.2	4.3	4.4	4.5	4.6
98	3.7	3.7	3.9	4.0	4.1	4.1	4.2	3.9	3.9	4.1	4.2	4.3	4.4	4.4	4.1	4.2	4.3	4.5	4.6	4.7	4.8
99	3.7	3.9	4.1	4.2	4.3	4.4	4.4	4.0	4.1	4.3	4.5	4.6	4.6	4.7	4.2	4.4	4.6	4.8	4.9	5.0	5.1
99.9	4.0	4.6	4.8	4.9	5.0	5.0	5.1	4.3	4.9	5.2	5.4	5.5	5.6	5.6	4.6	5.4	5.7	5.9	6.1	6.2	6.3

Speed Limit	35 MPH																				
Grade (%)	3																				
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	2.5	2.5	2.5	2.6	2.6	2.7	2.7	2.6	2.7	2.7	2.7	2.8	2.8	2.9	2.8	2.8	2.9	2.9	2.9	3.0	3.0
60	2.7	2.7	2.8	2.8	2.8	2.9	2.9	2.8	2.9	2.9	3.0	3.0	3.0	3.1	3.0	3.1	3.1	3.1	3.2	3.2	3.2
70	2.9	2.9	3.0	3.0	3.0	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.3	3.2	3.3	3.3	3.3	3.4	3.4	3.4
80	3.1	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.6
85	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.7
90	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9
95	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.6	3.7	3.7	3.8	3.8	3.9	4.0	3.8	3.9	3.9	4.0	4.1	4.1	4.2
96	3.5	3.5	3.6	3.7	3.7	3.8	3.9	3.7	3.7	3.8	3.8	3.9	4.0	4.1	3.9	3.9	4.0	4.1	4.2	4.2	4.3
97	3.5	3.6	3.7	3.7	3.8	3.9	4.0	3.7	3.8	3.8	3.9	4.0	4.1	4.2	3.9	4.0	4.1	4.2	4.3	4.4	4.5
98	3.6	3.7	3.8	3.9	4.0	4.0	4.1	3.8	3.8	4.0	4.1	4.2	4.3	4.3	4.0	4.1	4.2	4.3	4.5	4.6	4.6
99	3.7	3.8	4.0	4.1	4.2	4.3	4.3	3.9	4.0	4.2	4.3	4.4	4.5	4.6	4.1	4.3	4.5	4.6	4.8	4.9	4.9
99.9	3.9	4.5	4.7	4.8	4.8	4.9	4.9	4.1	4.8	5.0	5.2	5.3	5.3	5.4	4.5	5.2	5.5	5.7	5.8	5.9	6.0

Speed Limit	35 MPH																				
Grade (%)	4																				
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	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.6	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.8	2.9	2.9	2.9	3.0
60	2.6	2.7	2.7	2.8	2.8	2.8	2.9	2.8	2.8	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.1	3.2
70	2.8	2.9	2.9	3.0	3.0	3.0	3.1	3.0	3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.4
80	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.5
85	3.1	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.7
90	3.2	3.3	3.3	3.3	3.4	3.4	3.5	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8
95	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.5	3.6	3.6	3.7	3.8	3.8	3.9	3.7	3.8	3.8	3.9	4.0	4.0	4.1
96	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.6	3.6	3.7	3.8	3.8	3.9	4.0	3.8	3.8	3.9	4.0	4.1	4.1	4.2
97	3.4	3.5	3.6	3.7	3.8	3.8	3.9	3.6	3.7	3.8	3.8	3.9	4.0	4.1	3.8	3.9	4.0	4.1	4.2	4.3	4.3
98	3.5	3.6	3.7	3.8	3.9	4.0	4.0	3.7	3.8	3.9	4.0	4.1	4.2	4.2	3.9	4.0	4.1	4.2	4.3	4.4	4.5
99	3.6	3.7	3.9	4.0	4.1	4.2	4.2	3.8	3.9	4.1	4.2	4.3	4.4	4.5	4.0	4.1	4.4	4.5	4.6	4.7	4.8
99.9	3.8	4.4	4.5	4.6	4.7	4.7	4.8	4.0	4.6	4.8	5.0	5.1	5.1	5.2	4.3	5.0	5.3	5.4	5.5	5.6	5.7

Speed Limit	***35 MPH***																				
Grade (%)	***-4***																				
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	2.7	2.7	2.8	2.9	2.9	3.0	3.0	2.9	2.9	3.0	3.0	3.1	3.2	3.2	3.1	3.1	3.2	3.2	3.3	3.4	3.4
60	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.2	3.2	3.3	3.3	3.4	3.4	3.5	3.4	3.5	3.5	3.6	3.6	3.7	3.7
70	3.3	3.3	3.4	3.4	3.5	3.5	3.6	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.8	3.8	3.9	3.9	4.0	4.0
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	4.1	4.1	4.1	4.2	4.2	4.3	4.3
85	3.7	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	4.2	4.3	4.3	4.4	4.4	4.5	4.5
90	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	4.4	4.5	4.5	4.6	4.6	4.7	4.8
95	4.1	4.2	4.2	4.3	4.4	4.5	4.5	4.4	4.4	4.5	4.6	4.7	4.8	4.9	4.7	4.7	4.8	4.9	5.0	5.2	5.3
96	4.2	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	4.7	4.8	4.9	5.1	5.2	5.3	5.5
97	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.5	4.6	4.7	4.8	5.0	5.1	5.2	4.8	5.0	5.1	5.2	5.4	5.6	5.7
98	4.3	4.4	4.6	4.7	4.8	4.9	5.0	4.6	4.7	4.9	5.1	5.2	5.3	5.5	5.0	5.1	5.3	5.5	5.7	5.9	6.1
99	4.5	4.7	4.8	5.0	5.2	5.3	5.4	4.8	5.0	5.3	5.5	5.7	5.8	5.9	5.2	5.5	5.8	6.1	6.4	6.6	6.8
99.9	4.9	5.7	6.1	6.3	6.5	6.7	6.8	5.3	6.3	6.9	7.3	7.6	7.9	8.1	5.9	7.3	8.1	8.8	9.1	9.7	9.9

Speed Limit	***35 MPH***																				
Grade (%)	***-3***																				
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	2.6	2.7	2.8	2.8	2.9	2.9	3.0	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.0	3.1	3.1	3.2	3.2	3.3	3.3
60	2.9	3.0	3.0	3.1	3.1	3.2	3.2	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.3	3.4	3.4	3.5	3.5	3.6	3.6
70	3.2	3.3	3.3	3.3	3.4	3.4	3.5	3.4	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
80	3.5	3.5	3.6	3.6	3.7	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	4.2
85	3.6	3.7	3.7	3.8	3.8	3.8	3.9	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
90	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.3	4.3	4.4	4.4	4.5	4.5	4.6
95	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	4.5	4.6	4.7	4.8	4.9	5.0	5.1
96	4.0	4.1	4.2	4.3	4.3	4.4	4.5	4.3	4.4	4.5	4.5	4.6	4.7	4.8	4.6	4.7	4.8	4.9	5.0	5.1	5.3
97	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	4.7	4.8	4.9	5.0	5.2	5.3	5.5
98	4.2	4.3	4.4	4.5	4.7	4.8	4.8	4.5	4.6	4.7	4.9	5.0	5.1	5.2	4.8	4.9	5.1	5.3	5.5	5.7	5.8
99	4.3	4.5	4.7	4.8	5.0	5.1	5.2	4.6	4.8	5.1	5.3	5.4	5.5	5.7	5.0	5.2	5.6	5.8	6.1	6.2	6.4
99.9	4.7	5.4	5.8	6.0	6.2	6.3	6.4	5.1	6.0	6.5	6.9	7.1	7.3	7.5	5.6	6.9	7.6	8.1	8.4	8.8	9.0

Speed Limit	***35 MPH***																				
Grade (%)	***-2***																				
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	2.6	2.7	2.7	2.8	2.8	2.9	2.9	2.8	2.8	2.9	2.9	3.0	3.1	3.1	3.0	3.0	3.1	3.1	3.2	3.2	3.3
60	2.9	2.9	3.0	3.0	3.1	3.1	3.2	3.1	3.1	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.5	3.5	3.5
70	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8
80	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.6	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
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	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.2
90	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.9	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.4	4.4	4.5
95	3.9	3.9	4.0	4.1	4.1	4.2	4.3	4.1	4.2	4.2	4.3	4.4	4.5	4.5	4.4	4.4	4.5	4.6	4.7	4.8	4.9
96	3.9	4.0	4.1	4.1	4.2	4.3	4.4	4.2	4.2	4.3	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.7	4.8	4.9	5.1
97	4.0	4.1	4.2	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	5.3
98	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.3	4.4	4.6	4.7	4.8	4.9	5.0	4.6	4.7	4.9	5.1	5.3	5.4	5.6
99	4.2	4.4	4.5	4.7	4.8	4.9	5.0	4.5	4.7	4.9	5.1	5.2	5.3	5.4	4.8	5.0	5.3	5.6	5.8	5.9	6.1
99.9	4.5	5.2	5.5	5.7	5.9	6.0	6.1	4.9	5.7	6.2	6.5	6.7	6.9	7.0	5.4	6.5	7.1	7.5	7.8	8.1	8.3

Speed Limit	35 MPH																				
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	2.6	2.6	2.7	2.7	2.8	2.8	2.9	2.7	2.8	2.9	2.9	3.0	3.0	3.0	2.9	3.0	3.0	3.1	3.1	3.2	3.2
60	2.8	2.9	2.9	3.0	3.0	3.1	3.1	3.0	3.1	3.1	3.2	3.2	3.2	3.3	3.2	3.3	3.3	3.4	3.4	3.4	3.5
70	3.1	3.1	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.7	3.7
80	3.3	3.4	3.4	3.5	3.5	3.5	3.6	3.5	3.6	3.6	3.7	3.7	3.7	3.8	3.8	3.8	3.8	3.9	3.9	3.9	4.0
85	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9	3.9	3.9	4.0	4.0	4.0	4.1	4.1
90	3.6	3.6	3.7	3.7	3.8	3.8	3.9	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
95	3.8	3.8	3.9	4.0	4.0	4.1	4.2	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
96	3.8	3.9	4.0	4.0	4.1	4.2	4.3	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.3	4.4	4.5	4.6	4.7	4.8	4.9
97	3.9	4.0	4.0	4.1	4.2	4.3	4.4	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.4	4.5	4.6	4.7	4.8	5.0	5.1
98	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.2	4.3	4.4	4.6	4.7	4.8	4.9	4.5	4.6	4.8	4.9	5.1	5.2	5.3
99	4.1	4.2	4.4	4.6	4.7	4.8	4.8	4.3	4.5	4.7	4.9	5.0	5.1	5.2	4.6	4.8	5.1	5.4	5.5	5.7	5.8
99.9	4.4	5.0	5.3	5.5	5.6	5.7	5.8	4.7	5.5	5.9	6.1	6.3	6.5	6.6	5.2	6.2	6.7	7.0	7.2	7.5	7.7

Speed Limit	45 MPH																				
Grade (%)	0																				
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	3.0	3.1	3.1	3.2	3.3	3.3	3.4	3.2	3.3	3.3	3.4	3.4	3.5	3.5	3.4	3.4	3.5	3.5	3.6	3.6	3.7
60	3.3	3.4	3.4	3.5	3.5	3.6	3.6	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.7	3.8	3.8	3.9	3.9	3.9
70	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.7	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
80	3.8	3.9	3.9	4.0	4.0	4.0	4.1	4.0	4.1	4.1	4.1	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.4	4.4	4.5
85	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.6	4.6
90	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	4.6	4.5	4.6	4.6	4.7	4.7	4.8	4.9
95	4.3	4.3	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.9	4.9	4.8	4.8	4.9	5.0	5.1	5.2	5.2
96	4.3	4.4	4.5	4.6	4.6	4.7	4.8	4.6	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
97	4.4	4.5	4.6	4.7	4.8	4.8	4.9	4.6	4.7	4.8	4.9	5.0	5.1	5.2	4.9	5.0	5.1	5.2	5.3	5.4	5.5
98	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.7	4.8	5.0	5.1	5.2	5.3	5.4	5.0	5.1	5.3	5.4	5.5	5.7	5.8
99	4.6	4.8	5.0	5.1	5.2	5.3	5.4	4.9	5.0	5.2	5.4	5.5	5.6	5.7	5.1	5.3	5.6	5.8	6.0	6.1	6.2
99.9	5.0	5.6	5.9	6.0	6.1	6.2	6.3	5.3	6.0	6.3	6.5	6.7	6.7	6.8	5.6	6.6	7.0	7.2	7.4	7.6	7.8

Speed Limit	45 MPH																				
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	3.0	3.0	3.1	3.2	3.2	3.3	3.3	3.2	3.2	3.3	3.3	3.4	3.4	3.5	3.3	3.4	3.4	3.5	3.5	3.6	3.6
60	3.2	3.3	3.4	3.4	3.5	3.5	3.6	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.6	3.7	3.7	3.7	3.8	3.8	3.9
70	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.7	3.7	3.8	3.8	3.9	3.9	3.9	3.9	3.9	4.0	4.0	4.0	4.1	4.1
80	3.7	3.8	3.8	3.9	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.1	4.1	4.2	4.1	4.2	4.2	4.3	4.3	4.3	4.4
85	3.9	3.9	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.1	4.2	4.2	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.5	4.5
90	4.0	4.0	4.1	4.1	4.2	4.2	4.3	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	4.7
95	4.2	4.2	4.3	4.4	4.4	4.5	4.6	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	5.1
96	4.2	4.3	4.4	4.5	4.5	4.6	4.7	4.5	4.5	4.6	4.7	4.8	4.8	4.9	4.7	4.8	4.8	4.9	5.0	5.1	5.2
97	4.3	4.4	4.5	4.6	4.6	4.7	4.8	4.5	4.6	4.7	4.8	4.9	5.0	5.0	4.8	4.8	4.9	5.1	5.2	5.3	5.4
98	4.4	4.5	4.6	4.7	4.8	4.9	5.0	4.6	4.7	4.8	4.9	5.1	5.1	5.2	4.8	5.0	5.1	5.2	5.4	5.5	5.6
99	4.5	4.6	4.8	5.0	5.1	5.1	5.2	4.9	4.9	5.1	5.2	5.4	5.5	5.5	5.0	5.2	5.4	5.6	5.8	5.9	6.0
99.9	4.8	5.4	5.7	5.8	5.9	6.0	6.1	5.1	5.8	6.1	6.3	6.4	6.5	6.5	5.4	6.3	6.6	6.8	7.0	7.2	7.3

Speed Limit	45 MPH																				
Grade (%)	***2***																				
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	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.3	3.3	3.4	3.4	3.5	3.5	3.6
60	3.2	3.2	3.3	3.4	3.4	3.4	3.5	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.5	3.6	3.6	3.7	3.7	3.8	3.8
70	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.6	3.7	3.7	3.7	3.8	3.8	3.9	3.8	3.8	3.9	3.9	4.0	4.0	4.0
80	3.7	3.7	3.8	3.8	3.8	3.9	3.9	3.9	3.9	3.9	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.2	4.2	4.2	4.3
85	3.8	3.8	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.4	4.4
90	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.2	4.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.6
95	4.1	4.1	4.2	4.3	4.3	4.4	4.5	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.9	4.9
96	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.3	4.4	4.5	4.6	4.6	4.7	4.8	4.6	4.6	4.7	4.8	4.9	5.0	5.1
97	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	4.6	4.7	4.8	4.9	5.0	5.1	5.2
98	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.5	4.6	4.7	4.8	4.9	5.0	5.1	4.7	4.8	5.0	5.1	5.2	5.3	5.4
99	4.4	4.5	4.7	4.8	4.9	5.0	5.1	4.6	4.8	4.9	5.1	5.2	5.3	5.4	4.9	5.0	5.2	5.4	5.6	5.7	5.8
99.9	4.7	5.3	5.5	5.6	5.7	5.8	5.8	4.9	5.6	5.8	6.0	6.1	6.2	6.3	5.2	6.1	6.4	6.5	6.7	6.9	7.0

Speed Limit	***45 MPH***																				
Grade (%)	***3***																				
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	2.9	3.0	3.0	3.1	3.1	3.2	3.2	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.2	3.3	3.3	3.4	3.4	3.5	3.5
60	3.2	3.2	3.3	3.3	3.4	3.4	3.4	3.3	3.4	3.4	3.5	3.5	3.5	3.6	3.5	3.5	3.6	3.6	3.7	3.7	3.7
70	3.4	3.4	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.7	3.8	3.8	3.9	3.9	3.9	3.9
80	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.2
85	3.7	3.8	3.8	3.8	3.9	3.9	4.0	3.9	3.9	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.2	4.2	4.2	4.3	4.3
90	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.2	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.4	4.5	4.5
95	4.0	4.1	4.1	4.2	4.2	4.3	4.4	4.2	4.3	4.3	4.4	4.4	4.5	4.6	4.4	4.5	4.5	4.6	4.7	4.7	4.8
96	4.0	4.1	4.2	4.3	4.3	4.4	4.5	4.2	4.3	4.4	4.5	4.5	4.6	4.7	4.5	4.5	4.6	4.7	4.8	4.8	4.9
97	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.3	4.4	4.5	4.5	4.6	4.7	4.8	4.5	4.6	4.7	4.8	4.9	5.0	5.1
98	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.4	4.5	4.6	4.7	4.8	4.9	4.9	4.6	4.7	4.8	4.9	5.1	5.2	5.2
99	4.3	4.4	4.6	4.7	4.8	4.9	4.9	4.5	4.6	4.8	5.0	5.1	5.1	5.2	4.7	4.9	5.1	5.3	5.4	5.5	5.6
99.9	4.5	5.1	5.3	5.4	5.5	5.6	5.6	4.8	5.4	5.6	5.8	5.9	6.0	6.0	5.1	5.8	6.1	6.3	6.4	6.6	6.6

Speed Limit	***45 MPH***																				
Grade (%)	***4***																				
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	2.9	2.9	3.0	3.0	3.1	3.1	3.2	3.0	3.1	3.1	3.2	3.2	3.3	3.3	3.2	3.2	3.3	3.3	3.4	3.4	3.5
60	3.1	3.2	3.2	3.3	3.3	3.3	3.4	3.3	3.3	3.4	3.4	3.4	3.5	3.5	3.4	3.5	3.5	3.6	3.6	3.6	3.7
70	3.3	3.4	3.4	3.5	3.5	3.5	3.6	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.9
80	3.5	3.6	3.6	3.7	3.7	3.7	3.8	3.7	3.8	3.8	3.8	3.9	3.9	3.9	3.9	3.9	4.0	4.0	4.0	4.1	4.1
85	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.2
90	3.8	3.8	3.9	3.9	3.9	4.0	4.0	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.3	4.3	4.3	4.4
95	3.9	4.0	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.2	4.3	4.3	4.4	4.5	4.3	4.4	4.4	4.5	4.6	4.6	4.7
96	4.0	4.0	4.1	4.2	4.2	4.3	4.4	4.1	4.2	4.3	4.3	4.4	4.5	4.6	4.4	4.4	4.5	4.6	4.6	4.7	4.8
97	4.0	4.1	4.2	4.2	4.3	4.4	4.5	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
98	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.5	4.6	4.7	4.8	4.9	5.0	5.1
99	4.2	4.3	4.5	4.6	4.7	4.8	4.8	4.4	4.5	4.7	4.8	4.9	5.0	5.1	4.6	4.8	4.9	5.1	5.2	5.3	5.4
99.9	4.4	5.0	5.2	5.3	5.3	5.4	5.5	4.7	5.2	5.5	5.6	5.7	5.8	5.8	4.9	5.6	5.9	6.0	6.2	6.3	6.4

Speed Limit	45 MPH																				
Grade (%)	-4																				
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	3.2	3.3	3.4	3.4	3.5	3.6	3.6	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.6	3.7	3.7	3.8	3.9	3.9	4.0
60	3.5	3.6	3.7	3.7	3.8	3.9	3.9	3.7	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.0	4.1	4.1	4.2	4.2	4.3
70	3.8	3.9	4.0	4.0	4.1	4.1	4.2	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	4.6
80	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.4	4.5	4.5	4.6	4.6	4.7	4.7	4.7	4.7	4.8	4.8	4.9	4.9	5.0
85	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.6	4.6	4.7	4.7	4.8	4.9	4.9	4.9	4.9	5.0	5.0	5.1	5.1	5.2
90	4.5	4.6	4.6	4.7	4.8	4.8	4.9	4.8	4.9	4.9	5.0	5.0	5.1	5.2	5.1	5.1	5.2	5.3	5.3	5.4	5.5
95	4.8	4.9	4.9	5.0	5.1	5.2	5.3	5.1	5.1	5.2	5.3	5.4	5.5	5.6	5.4	5.5	5.6	5.7	5.8	5.9	6.0
96	4.8	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	5.5	5.6	5.7	5.8	5.9	6.1	6.2
97	4.9	5.0	5.1	5.2	5.4	5.5	5.5	5.2	5.3	5.5	5.6	5.7	5.8	5.9	5.6	5.7	5.8	6.0	6.1	6.3	6.4
98	5.0	5.2	5.3	5.4	5.6	5.7	5.8	5.4	5.5	5.6	5.8	6.0	6.1	6.2	5.7	5.9	6.1	6.2	6.4	6.6	6.8
99	5.2	5.4	5.6	5.8	6.0	6.1	6.2	5.6	5.8	6.0	6.2	6.4	6.6	6.7	5.9	6.2	6.5	6.8	7.1	7.3	7.4
99.9	5.7	6.5	6.9	7.2	7.4	7.5	7.6	6.1	7.1	7.6	8.0	8.2	8.4	8.6	6.6	8.0	8.7	9.2	9.5	9.8	10.1

Speed Limit	45 MPH																				
Grade (%)	-3																				
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	3.2	3.2	3.3	3.4	3.4	3.5	3.6	3.4	3.4	3.5	3.5	3.6	3.7	3.7	3.5	3.6	3.7	3.7	3.8	3.8	3.9
60	3.5	3.5	3.6	3.7	3.7	3.8	3.8	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
70	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.3	4.3	4.4	4.4	4.5	4.5
80	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.3	4.4	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.6	4.7	4.7	4.8	4.8
85	4.2	4.3	4.3	4.4	4.4	4.5	4.5	4.5	4.5	4.6	4.6	4.7	4.7	4.8	4.7	4.8	4.8	4.9	4.9	5.0	5.0
90	4.4	4.5	4.5	4.6	4.6	4.7	4.7	4.7	4.7	4.8	4.8	4.9	4.9	5.0	4.9	5.0	5.0	5.1	5.2	5.2	5.3
95	4.6	4.7	4.8	4.9	4.9	5.0	5.1	4.9	5.0	5.1	5.2	5.2	5.3	5.4	5.2	5.3	5.4	5.5	5.6	5.7	5.8
96	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.0	5.1	5.2	5.3	5.4	5.4	5.5	5.3	5.4	5.5	5.6	5.7	5.8	5.9
97	4.8	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	5.8	5.9	6.0	6.2
98	4.9	5.0	5.1	5.3	5.4	5.5	5.6	5.2	5.3	5.4	5.6	5.7	5.9	6.0	5.5	5.7	5.8	6.0	6.2	6.3	6.5
99	5.0	5.2	5.4	5.6	5.7	5.8	6.0	5.4	5.6	5.8	6.0	6.2	6.3	6.4	5.7	5.9	6.2	6.5	6.7	6.9	7.1
99.9	5.5	6.2	6.6	6.8	7.0	7.1	7.2	5.9	6.8	7.3	7.5	7.7	7.9	8.1	6.3	7.6	8.2	8.5	8.9	9.1	9.3

Speed Limit	45 MPH																				
Grade (%)	-2																				
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	3.2	3.2	3.3	3.4	3.4	3.5	3.3	3.4	3.4	3.5	3.5	3.6	3.7	3.5	3.5	3.6	3.7	3.7	3.8	3.8
60	3.4	3.5	3.5	3.6	3.6	3.7	3.8	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	4.1
70	3.7	3.7	3.8	3.9	3.9	4.0	4.0	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
80	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.4	4.5	4.5	4.6	4.6	4.7	4.7
85	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.6	4.7	4.7	4.8	4.8	4.9
90	4.3	4.3	4.4	4.5	4.5	4.6	4.6	4.5	4.6	4.6	4.7	4.7	4.8	4.9	4.8	4.8	4.9	5.0	5.0	5.1	5.1
95	4.5	4.6	4.7	4.7	4.8	4.9	5.0	4.8	4.8	4.9	5.0	5.1	5.2	5.2	5.0	5.1	5.2	5.3	5.4	5.5	5.6
96	4.6	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	5.1	5.2	5.3	5.4	5.5	5.6	5.7
97	4.6	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	5.2	5.3	5.4	5.6	5.7	5.8	5.9
98	4.7	4.8	5.0	5.1	5.2	5.3	5.4	5.0	5.1	5.3	5.4	5.5	5.7	5.8	5.3	5.5	5.6	5.8	6.0	6.1	6.2
99	4.9	5.1	5.3	5.4	5.6	5.6	5.7	5.2	5.4	5.6	5.8	5.9	6.1	6.2	5.5	5.7	6.0	6.2	6.5	6.6	6.7
99.9	5.3	6.0	6.3	6.5	6.7	6.8	6.9	5.6	6.5	6.9	7.2	7.3	7.4	7.6	6.0	7.2	7.7	8.0	8.3	8.5	8.7

Speed Limit	45 MPH																				
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	3.3	3.3	3.4	3.4	3.3	3.3	3.4	3.4	3.5	3.5	3.6	3.4	3.5	3.5	3.6	3.7	3.7	3.8
60	3.3	3.4	3.5	3.5	3.6	3.6	3.7	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.7	3.8	3.8	3.9	3.9	4.0	4.0
70	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	4.1	4.0	4.1	4.1	4.2	4.2	4.3	4.3
80	3.9	3.9	4.0	4.0	4.1	4.1	4.2	4.1	4.2	4.2	4.2	4.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.5	4.6
85	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.4	4.4	4.5	4.5	4.5	4.5	4.6	4.6	4.7	4.7	4.8
90	4.2	4.2	4.3	4.3	4.4	4.5	4.5	4.4	4.5	4.5	4.6	4.6	4.7	4.7	4.7	4.7	4.8	4.8	4.9	4.9	5.0
95	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	5.0	5.0	5.1	5.2	5.3	5.4
96	4.4	4.5	4.6	4.7	4.8	4.8	4.9	4.7	4.8	4.9	4.9	5.0	5.1	5.2	5.0	5.0	5.1	5.2	5.3	5.4	5.5
97	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	5.1	5.3	5.4	5.5	5.6	5.7
98	4.6	4.7	4.8	5.0	5.1	5.2	5.2	4.9	5.0	5.1	5.2	5.4	5.5	5.6	5.1	5.3	5.4	5.6	5.7	5.9	6.0
99	4.7	4.9	5.1	5.3	5.4	5.5	5.5	5.0	5.2	5.4	5.6	5.7	5.8	5.9	5.3	5.5	5.8	6.0	6.2	6.3	6.5
99.9	5.1	5.8	6.1	6.3	6.4	6.5	6.6	5.4	6.2	6.6	6.8	7.0	7.1	7.2	5.8	6.9	7.3	7.6	7.8	8.0	8.2

Speed Limit	55 MPH																				
Grade (%)	0																				
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	3.5	3.6	3.6	3.7	3.8	3.8	3.9	3.7	3.7	3.8	3.9	3.9	4.0	4.0	3.9	3.9	4.0	4.0	4.1	4.2	4.2
60	3.8	3.8	3.9	4.0	4.0	4.1	4.1	4.0	4.0	4.1	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.3	4.4	4.4	4.5
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	4.5	4.6	4.4	4.5	4.6	4.6	4.7	4.7	4.7
80	4.3	4.4	4.4	4.5	4.5	4.6	4.6	4.5	4.6	4.6	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.9	4.9	5.0	5.0
85	4.5	4.5	4.6	4.6	4.7	4.7	4.8	4.7	4.7	4.8	4.8	4.9	4.9	5.0	4.9	5.0	5.0	5.1	5.1	5.2	5.2
90	4.6	4.7	4.8	4.8	4.9	4.9	5.0	4.9	4.9	5.0	5.0	5.1	5.1	5.2	5.1	5.1	5.2	5.3	5.3	5.4	5.4
95	4.9	4.9	5.0	5.1	5.2	5.3	5.3	5.1	5.2	5.2	5.3	5.4	5.5	5.6	5.3	5.4	5.5	5.6	5.7	5.8	5.9
96	4.9	5.0	5.1	5.2	5.3	5.4	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
97	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.5	5.6	5.7	5.8	5.9	6.1	6.2
98	5.1	5.2	5.3	5.5	5.6	5.7	5.8	5.3	5.4	5.6	5.7	5.8	5.9	6.0	5.6	5.7	5.9	6.0	6.2	6.3	6.4
99	5.2	5.4	5.6	5.8	5.9	6.0	6.1	5.5	5.6	5.9	6.0	6.2	6.3	6.4	5.8	6.0	6.2	6.4	6.6	6.7	6.8
99.9	5.6	6.3	6.6	6.8	6.9	7.0	7.1	5.9	6.6	7.0	7.2	7.4	7.5	7.6	6.2	7.2	7.6	7.9	8.1	8.2	8.4

Speed Limit	**55 MPH**																				
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	3.5	3.5	3.6	3.6	3.7	3.8	3.8	3.6	3.7	3.7	3.8	3.9	3.9	4.0	3.8	3.9	3.9	4.0	4.0	4.1	4.1
60	3.7	3.8	3.8	3.9	4.0	4.0	4.1	3.9	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.1	4.2	4.2	4.3	4.3	4.4
70	4.0	4.0	4.1	4.2	4.2	4.3	4.3	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	4.6
80	4.2	4.3	4.3	4.4	4.4	4.5	4.5	4.4	4.5	4.5	4.6	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.8	4.9	4.9
85	4.4	4.4	4.5	4.5	4.6	4.6	4.7	4.6	4.6	4.7	4.7	4.8	4.8	4.9	4.8	4.8	4.9	4.9	5.0	5.0	5.1
90	4.5	4.6	4.6	4.7	4.8	4.8	4.9	4.7	4.8	4.9	4.9	5.0	5.0	5.1	5.0	5.0	5.1	5.1	5.2	5.2	5.3
95	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.0	5.0	5.1	5.2	5.3	5.3	5.4	5.2	5.3	5.3	5.4	5.5	5.6	5.7
96	4.8	4.9	5.0	5.0	5.1	5.2	5.3	5.0	5.1	5.2	5.3	5.4	5.4	5.5	5.3	5.3	5.4	5.5	5.6	5.7	5.8
97	4.8	4.9	5.1	5.2	5.3	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.3	5.4	5.5	5.7	5.8	5.9	6.0
98	4.9	5.1	5.2	5.3	5.4	5.5	5.6	5.2	5.3	5.4	5.6	5.7	5.8	5.9	5.4	5.6	5.7	5.8	6.0	6.1	6.2
99	5.1	5.3	5.5	5.6	5.7	5.8	5.9	5.3	5.5	5.7	5.9	6.0	6.1	6.2	5.6	5.8	6.0	6.2	6.4	6.5	6.6
99.9	5.4	6.1	6.3	6.5	6.7	6.8	6.9	5.7	6.4	6.8	7.0	7.1	7.2	7.3	6.0	6.9	7.3	7.5	7.7	7.8	8.0

Speed Limit	**55 MPH**																				
Grade (%)	**2**																				
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	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.6	3.6	3.7	3.7	3.8	3.9	3.9	3.8	3.8	3.9	3.9	4.0	4.0	4.1
60	3.7	3.7	3.8	3.8	3.9	3.9	4.0	3.8	3.9	3.9	4.0	4.1	4.1	4.1	4.0	4.1	4.1	4.2	4.2	4.3	4.3
70	3.9	4.0	4.0	4.1	4.1	4.2	4.2	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	4.5
80	4.2	4.2	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.7	4.7	4.8	4.8
85	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.7	4.7	4.8	4.7	4.7	4.8	4.8	4.9	4.9	5.0
90	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.7	4.8	4.8	4.9	5.0	4.9	4.9	5.0	5.0	5.1	5.1	5.2
95	4.6	4.7	4.8	4.9	4.9	5.0	5.1	4.8	4.9	5.0	5.1	5.1	5.2	5.3	5.1	5.1	5.2	5.3	5.4	5.5	5.5
96	4.7	4.8	4.8	4.9	5.0	5.1	5.2	4.9	5.0	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.6	5.6
97	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.0	5.0	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.4	5.5	5.6	5.7	5.8
98	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.0	5.1	5.3	5.4	5.5	5.6	5.7	5.3	5.4	5.5	5.7	5.8	5.9	6.0
99	4.9	5.1	5.3	5.5	5.6	5.7	5.7	5.2	5.3	5.5	5.7	5.8	5.9	6.0	5.4	5.6	5.8	6.0	6.2	6.3	6.4
99.9	5.3	5.9	6.1	6.3	6.4	6.5	6.6	5.5	6.2	6.5	6.7	6.8	6.9	7.0	5.8	6.6	7.0	7.2	7.4	7.5	7.6

Speed Limit	**55 MPH**																				
Grade (%)	**3**																				
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	3.4	3.4	3.5	3.5	3.6	3.7	3.7	3.5	3.6	3.6	3.7	3.7	3.8	3.9	3.7	3.7	3.8	3.8	3.9	3.9	4.0
60	3.6	3.7	3.7	3.8	3.8	3.9	3.9	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.0	4.0	4.1	4.1	4.2	4.2
70	3.8	3.9	4.0	4.0	4.1	4.1	4.1	4.0	4.1	4.1	4.2	4.2	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.5
80	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.3	4.3	4.4	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.6	4.6	4.7	4.7
85	4.2	4.3	4.3	4.4	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	4.7	4.8	4.8	4.9
90	4.3	4.4	4.5	4.5	4.6	4.6	4.7	4.5	4.6	4.6	4.7	4.7	4.8	4.8	4.7	4.8	4.8	4.9	4.9	5.0	5.1
95	4.5	4.6	4.7	4.7	4.8	4.9	5.0	4.7	4.8	4.9	4.9	5.0	5.1	5.2	4.9	5.0	5.1	5.2	5.2	5.3	5.4
96	4.6	4.6	4.7	4.8	4.9	5.0	5.0	4.8	4.8	4.9	5.0	5.1	5.2	5.2	5.0	5.1	5.2	5.2	5.3	5.4	5.5
97	4.6	4.7	4.8	4.9	5.0	5.1	5.2	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4	5.5	5.5	5.6
98	4.7	4.8	4.9	5.1	5.2	5.3	5.3	4.9	5.0	5.1	5.3	5.4	5.5	5.5	5.2	5.3	5.4	5.5	5.6	5.7	5.8
99	4.8	5.0	5.2	5.3	5.4	5.5	5.6	5.0	5.2	5.4	5.5	5.7	5.8	5.8	5.3	5.5	5.7	5.8	6.0	6.1	6.2
99.9	5.1	5.7	6.0	6.1	6.2	6.3	6.4	5.4	6.0	6.3	6.5	6.6	6.7	6.8	5.7	6.4	6.8	7.0	7.1	7.2	7.3

Speed Limit	55 MPH																				
Grade (%)	4																				
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	3.3	3.4	3.4	3.5	3.5	3.6	3.7	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.6	3.7	3.7	3.8	3.8	3.9	3.9
60	3.6	3.6	3.7	3.7	3.8	3.8	3.9	3.7	3.8	3.8	3.9	3.9	4.0	4.0	3.9	3.9	4.0	4.0	4.1	4.1	4.1
70	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.0	4.0	4.0	4.1	4.1	4.2	4.2	4.1	4.2	4.2	4.3	4.3	4.3	4.4
80	4.0	4.1	4.1	4.2	4.2	4.2	4.3	4.2	4.2	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.6	4.6
85	4.1	4.2	4.2	4.3	4.3	4.4	4.4	4.3	4.4	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.7	4.7	4.7
90	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.5	4.5	4.5	4.6	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.8	4.9	4.9
95	4.4	4.5	4.6	4.6	4.7	4.8	4.9	4.6	4.7	4.8	4.8	4.9	5.0	5.0	4.9	4.9	5.0	5.0	5.1	5.2	5.2
96	4.5	4.6	4.6	4.7	4.8	4.9	4.9	4.7	4.7	4.8	4.9	5.0	5.1	5.1	4.9	5.0	5.0	5.1	5.2	5.3	5.4
97	4.5	4.6	4.7	4.8	4.9	5.0	5.0	4.7	4.8	4.9	5.0	5.1	5.2	5.2	5.0	5.0	5.1	5.2	5.3	5.4	5.5
98	4.6	4.7	4.8	5.0	5.1	5.1	5.2	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.0	5.1	5.3	5.4	5.5	5.6	5.7
99	4.7	4.9	5.1	5.2	5.3	5.4	5.4	4.9	5.1	5.3	5.4	5.5	5.6	5.7	5.2	5.3	5.5	5.7	5.8	5.9	6.0
99.9	5.0	5.6	5.8	5.9	6.0	6.1	6.2	5.2	5.9	6.1	6.2	6.4	6.4	6.5	5.5	6.2	6.5	6.7	6.8	6.9	7.0

Speed Limit	55 MPH																				
Grade (%)	-4																				
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	3.7	3.8	3.9	4.0	4.0	4.1	4.2	3.9	4.0	4.1	4.2	4.2	4.3	4.4	4.1	4.2	4.3	4.3	4.4	4.5	4.5
60	4.1	4.1	4.2	4.3	4.4	4.4	4.5	4.3	4.3	4.4	4.5	4.5	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.8	4.9
70	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.7	4.8	4.9	4.9	5.0	4.9	4.9	5.0	5.0	5.1	5.2	5.2
80	4.7	4.8	4.9	4.9	5.0	5.0	5.1	5.0	5.0	5.1	5.2	5.2	5.3	5.3	5.2	5.3	5.4	5.4	5.5	5.5	5.6
85	4.9	5.0	5.0	5.1	5.2	5.2	5.3	5.2	5.2	5.3	5.4	5.4	5.5	5.5	5.4	5.5	5.6	5.6	5.7	5.8	5.8
90	5.1	5.2	5.3	5.3	5.4	5.5	5.5	5.4	5.5	5.5	5.6	5.7	5.7	5.8	5.7	5.7	5.8	5.9	6.0	6.1	6.1
95	5.4	5.5	5.6	5.7	5.8	5.9	6.0	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.0	6.1	6.2	6.3	6.4	6.6	6.7
96	5.5	5.6	5.7	5.8	5.9	6.0	6.1	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.1	6.2	6.3	6.5	6.6	6.7	6.9
97	5.6	5.7	5.8	5.9	6.1	6.2	6.3	5.9	6.0	6.1	6.3	6.4	6.5	6.6	6.2	6.3	6.5	6.6	6.8	7.0	7.1
98	5.7	5.8	6.0	6.1	6.3	6.4	6.5	6.0	6.1	6.3	6.5	6.6	6.8	6.9	6.3	6.5	6.7	6.9	7.1	7.3	7.5
99	5.9	6.1	6.3	6.5	6.7	6.9	7.0	6.2	6.4	6.7	6.9	7.1	7.3	7.4	6.6	6.9	7.2	7.5	7.7	7.9	8.1
99.9	6.4	7.3	7.7	8.0	8.3	8.5	8.6	6.8	7.8	8.4	8.8	9.0	9.2	9.4	7.3	8.6	9.4	9.8	10.1	10.3	10.6

Speed Limit	55 MPH																				
Grade (%)	-3																				
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	3.7	3.7	3.8	3.9	4.0	4.0	4.1	3.9	3.9	4.0	4.1	4.1	4.2	4.3	4.1	4.1	4.2	4.3	4.3	4.4	4.5
60	4.0	4.1	4.1	4.2	4.3	4.3	4.4	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.4	4.5	4.5	4.6	4.6	4.7	4.8
70	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.5	4.6	4.6	4.7	4.8	4.8	4.9	4.7	4.8	4.9	4.9	5.0	5.0	5.1
80	4.6	4.7	4.7	4.8	4.9	4.9	5.0	4.9	4.9	5.0	5.0	5.1	5.1	5.2	5.1	5.2	5.2	5.3	5.3	5.4	5.4
85	4.8	4.8	4.9	5.0	5.0	5.1	5.2	5.0	5.1	5.2	5.2	5.3	5.3	5.4	5.3	5.4	5.4	5.5	5.5	5.6	5.7
90	5.0	5.0	5.1	5.2	5.3	5.3	5.4	5.2	5.3	5.4	5.4	5.5	5.6	5.6	5.5	5.6	5.6	5.7	5.8	5.9	5.9
95	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.5	5.6	5.7	5.8	5.9	6.0	6.1	5.8	5.9	6.0	6.1	6.2	6.3	6.4
96	5.3	5.4	5.5	5.6	5.7	5.8	5.9	5.6	5.7	5.8	5.9	6.0	6.1	6.2	5.9	6.0	6.1	6.2	6.4	6.5	6.6
97	5.4	5.5	5.6	5.8	5.9	6.0	6.1	5.7	5.8	5.9	6.0	6.2	6.3	6.4	6.0	6.1	6.3	6.4	6.6	6.7	6.8
98	5.5	5.6	5.8	5.9	6.1	6.2	6.3	5.8	5.9	6.1	6.3	6.4	6.6	6.7	6.1	6.3	6.5	6.7	6.8	7.0	7.2
99	5.7	5.9	6.1	6.3	6.5	6.6	6.7	6.0	6.2	6.5	6.7	6.9	7.0	7.1	6.4	6.6	6.9	7.2	7.4	7.6	7.7
99.9	6.2	7.0	7.4	7.7	7.9	8.0	8.2	6.5	7.5	8.0	8.3	8.5	8.7	8.9	7.0	8.2	8.9	9.2	9.5	9.7	9.9

Speed Limit	55 MPH																				
Grade (%)	-2																				
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	3.6	3.7	3.8	3.8	3.9	4.0	4.0	3.8	3.9	3.9	4.0	4.1	4.1	4.2	4.0	4.1	4.1	4.2	4.2	4.3	4.4
60	3.9	4.0	4.0	4.1	4.2	4.2	4.3	4.1	4.2	4.2	4.3	4.4	4.4	4.5	4.3	4.4	4.4	4.5	4.5	4.6	4.7
70	4.2	4.3	4.3	4.4	4.5	4.5	4.6	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.6	4.7	4.8	4.8	4.9	4.9	5.0
80	4.5	4.6	4.6	4.7	4.7	4.8	4.8	4.7	4.8	4.9	4.9	5.0	5.0	5.1	5.0	5.0	5.1	5.1	5.2	5.2	5.3
85	4.7	4.7	4.8	4.9	4.9	5.0	5.0	4.9	5.0	5.0	5.1	5.1	5.2	5.2	5.2	5.2	5.3	5.3	5.4	5.4	5.5
90	4.9	4.9	5.0	5.1	5.1	5.2	5.2	5.1	5.2	5.2	5.3	5.4	5.4	5.5	5.4	5.4	5.5	5.6	5.6	5.7	5.8
95	5.1	5.2	5.3	5.4	5.5	5.5	5.6	5.4	5.4	5.5	5.6	5.7	5.8	5.9	5.6	5.7	5.8	5.9	6.0	6.1	6.2
96	5.2	5.3	5.4	5.5	5.6	5.6	5.7	5.4	5.5	5.6	5.7	5.8	5.9	6.0	5.7	5.8	5.9	6.0	6.2	6.3	6.4
97	5.2	5.4	5.5	5.6	5.7	5.8	5.9	5.5	5.6	5.7	5.9	6.0	6.1	6.2	5.8	5.9	6.1	6.2	6.3	6.5	6.6
98	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	5.9	6.1	6.3	6.4	6.6	6.8	6.9
99	5.5	5.7	5.9	6.1	6.3	6.4	6.5	5.8	6.0	6.2	6.5	6.6	6.7	6.9	6.1	6.4	6.7	6.9	7.1	7.3	7.4
99.9	6.0	6.7	7.1	7.3	7.5	7.7	7.8	6.3	7.2	7.6	7.9	8.1	8.3	8.4	6.7	7.8	8.4	8.7	9.0	9.2	9.3

Speed Limit	55 MPH																				
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	3.6	3.6	3.7	3.8	3.8	3.9	4.0	3.7	3.8	3.9	3.9	4.0	4.1	4.1	3.9	4.0	4.0	4.1	4.2	4.2	4.3
60	3.8	3.9	4.0	4.0	4.1	4.2	4.2	4.0	4.1	4.2	4.2	4.3	4.3	4.4	4.2	4.3	4.3	4.4	4.5	4.5	4.6
70	4.1	4.2	4.3	4.3	4.4	4.4	4.5	4.3	4.4	4.4	4.5	4.6	4.6	4.6	4.5	4.6	4.6	4.7	4.8	4.8	4.8
80	4.4	4.5	4.5	4.6	4.6	4.7	4.7	4.6	4.7	4.7	4.8	4.8	4.9	4.9	4.9	4.9	5.0	5.0	5.1	5.1	5.2
85	4.6	4.6	4.7	4.7	4.8	4.8	4.9	4.8	4.8	4.9	5.0	5.0	5.1	5.1	5.0	5.1	5.1	5.2	5.2	5.3	5.3
90	4.7	4.8	4.9	4.9	5.0	5.1	5.1	5.0	5.0	5.1	5.2	5.2	5.3	5.3	5.2	5.3	5.3	5.4	5.5	5.5	5.6
95	5.0	5.0	5.1	5.2	5.3	5.4	5.5	5.2	5.3	5.4	5.5	5.6	5.6	5.7	5.5	5.6	5.7	5.7	5.8	5.9	6.0
96	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.3	5.4	5.5	5.6	5.7	5.8	5.8	5.6	5.6	5.7	5.9	6.0	6.1	6.2
97	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	5.6	5.7	5.9	6.0	6.1	6.2	6.4
98	5.2	5.3	5.5	5.6	5.7	5.8	5.9	5.5	5.6	5.7	5.9	6.0	6.1	6.2	5.8	5.9	6.1	6.2	6.4	6.5	6.6
99	5.3	5.5	5.8	5.9	6.1	6.2	6.3	5.6	5.8	6.0	6.2	6.4	6.5	6.6	5.9	6.2	6.4	6.7	6.8	7.0	7.1
99.9	5.8	6.5	6.8	7.0	7.2	7.3	7.4	6.1	6.9	7.3	7.6	7.7	7.9	8.0	6.5	7.5	8.0	8.3	8.5	8.7	8.8