Assessing the Impact of Smartphone Usage while Driving in Work Zones

SAFETY RESEARCH USING SIMULATION

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A Report on Research Sponsored by

SAFER-SIM University Transportation Center

Federal Grant No: 69A3551747131

December 2018

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASCE	American Society of Civil Engineers
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
IRB	Institutional Review Board
ITE	Institute of Transportation Engineers
MSP	Mobility Service Providers
MUTCD	Manual on Uniform Traffic Control Devices
NADS	National Advance Driving Simulator
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Transportation Safety Administration
O/M	Operations and Maintenance
PEW	Pew Research Center
PR-22	Puerto Rico Highway #22
PRHTA	Puerto Rico Highway and Transportation Authority
PRT	Perception and Reaction Time
RSS	Road Safety and Simulation
RTI	Real Time Technologies
SDLP	Standard Deviation of Lateral Position
TA	Typical Application

TCD	Traffic Control Devices
TNC	Transportation Network Companies
TRB	Transportation Research Board
TTC	Temporary Traffic Control
UPRM	University of Puerto Rico at Mayagüez
US-DOT	United States Department of Transportation
UTC	University Transportation Center

Units Conversion

Unit	Equivalence
1 km	1000 m
1 ft	0.3048 m
1 mile	1.609 km

Abstract

The use of smartphones has been increasing over the last decade. The increase of smartphone usage by drivers is particularly concerning in highway work zones when operations and maintenance activities are being performed. This research aims to investigate the impact of using smartphone applications, such as a global positioning system (GPS), when driving through a work zone. Initially, a survey was conducted to evaluate drivers' understanding of the typical components of a work zone and their preferences regarding safe operation conditions in a temporary traffic control setting. Afterward, 24 subjects were selected to participate in the study using the driving simulator at the University of Puerto Rico at Mayagüez. The scenarios had three different workspaces located at the left lane, right lane, and right shoulder. Furthermore, they had the presence of an inattentive worker invading the traffic space. The standard deviation of lateral position and mean speed were obtained in four different locations along the work zone. The results showed that at least 16.7% of subjects encroached the workspace while using an active GPS when the work zone was located in the right lane with the exit ramp closed. Also, the results demonstrated that 67% of the subjects avoided impacting the worker by performing an evasive maneuver.

Keywords: Driving Behavior, Driving Simulation, Distractions, Work Zones, Temporary Traffic Control, Highway Safety, Human Factors.

1 Introduction

1.1 Background

A total of 781 fatalities occurred in highway work zones in 2016 in the United States, and 143 of those were workers [1]. In 2016, 77% of adults in the United States owned a smartphone compared to 35% in 2011 [2], and 3,450 road users were killed in traffic crashes due to distracted driving [3]. According to Bai and Li [4], the most recurrent driver error that leads to fatal and non-fatal crashes in work zones is associated with driver distractions. Distracted driving occurs when the drivers focus their attention on activities in the vehicle other than the driving tasks. These distractions can be caused by a variety of factors, classified into three groups: visual, manual, and cognitive distractions. As a unifying distraction, cell phones or other electronic devices impair all drivers by causing higher mental workloads [5].

The use of a cell phone while driving was related to 14% of the 3,450 fatalities associated with distracted driving in the United States in 2016 [6], and inattentive drivers using a cell phone is one of the principal driver-related factors associated with work zone collisions [7]. The effect of using cell phones (talking or texting) on driver performance has been previously studied [6]. However, during the last decade, there has been a significant increase in smartphone ownership, which has led to an increased use of cell phone applications while driving, such as road navigation systems with a global positioning system (GPS). In a survey performed by State Farm [8], 65% of participants stated that listening to directions from a navigation system/GPS was one of the activities they engaged in while driving. Drivers experience many distractions while driving, such as operating the radio, eating food, and interacting with other passengers. In addition, cell phones and portable devices like a GPS are considered a source of distraction. These devices have complex interfaces that may need to interact with the driver to operate. When drivers perform this activity, they must touch and interact with the device to visualize the route, may change an address or change the route, and may get distracted by the voice navigation [9].

A study performed by Tymvios and Oosthuysen [10] investigated the difference in speed between distracted drivers and non-distracted drivers while passing work zones. This study was conducted in an urban area of a two-lane road with one lane temporarily closed. The results showed that distracted drivers and non-distracted drivers had no difference in speed when traveling around work zones. This behavior is of concern because several researchers have found that distracted drivers have a slower reaction time than non-distracted drivers, meaning that they would need a longer stopping sight distance since speed is often a contributory factor in crashes [9, 10, 11].

The worldwide revolution of transportation network companies (TNC), also known as mobility service providers (MSPs), has changed the way people move from origin to destination. One of the main TNCs reports 15 million transactions per day [12]. In many cases, drivers must use the GPS to conduct their business. Drivers' dependence on the GPS has the potential to create a new level of distraction, threatening the safety of road users in urban settings, and road construction zones in particular. These drivers, who have the flexibility of using their private vehicles for a paid job, have an increased complexity in their driving task, particularly in the navigational component. In many instances, they are unfamiliar with the driving environment, have unknown occupants in their cars, must listen to instructions, and must look at the GPS app in their vehicles while driving along a construction zone, therefore creating a potential safety problem.

Driving simulators have been used to study driver performance on emerging technologies in temporary traffic control (TTC) in highway work zones, particularly in evaluating alternate scenarios aimed to improve road user and worker safety. The use of this advanced technology to research the impact of different work zone conditions provides several advantages over real road driving scenarios. These include easier data collection, lower cost, higher controllability, higher reproducibility, and standardization of the experiments with no crash risk imposed on subjects when studying very dangerous driving tasks or road conditions.

1.2 Problem Statement

In recent years, the use of mobile phones has evolved from talking and texting to other applications such as looking at GPS location maps, looking at pictures on social media, and playing interactive games. The increase of smartphone usage by drivers is particularly concerning in work zones when operations and maintenance (O/M) activities are being performed and/or workers are present. Distracted drivers put O/M workers particularly at risk for injuries and fatalities while they are performing moving operations such as pavement testing, pavement marking, painting, shoulder work, mowing, signage repair, guardrail work, and maintenance of electric poles or an electrical distribution network, among others. The focus of this research is to investigate the impact of smartphone use involving distractions by GPS navigation, texting, and other applications in drivers' errors and reaction times to avoid crashes in work zones. This research uses driving simulation scenarios to investigate drivers' errors and speeding while using their smartphones through work zones. This research contributes to the body of knowledge on distracted driving by increasing the understanding of the impact of smartphone usage while driving under challenging conditions. The goal is to reduce the frequency and severity of loss events (personal injury, fatality, and property damage) in work zones.

1.3 Research Objectives

The main objective of this study is to evaluate driver performance on highway work zone conditions with and without the influence of a GPS-navigation smartphone application. The specific objectives of this research are the following:

- Perform an online survey to gather the stated preferences of road users about distractions while driving and their understanding of TTC conditions on highway work zones.
- Evaluate driving behavior when drivers approach different work zone conditions on a freeway segment that includes either a traffic lane or a shoulder closure.
- Provide conclusions and recommendations about whether having an active GPS while traversing the freeway work zones affects driver performance and road safety.

1.4 Report Organization

This report consists of six chapters. Chapter 2 contains a review of published literature related to crash statistics, cell phone restrictions and legal uses while driving, distracted driving, temporary traffic control, and driving simulators. Chapter 3 explains the methodological procedure used in this investigation, and Chapter 4 provides the results of the online survey. Chapter 5 presents the results of the statistical analysis of the driving simulator, and Chapter 6 provides conclusions and research recommendations. References, acknowledgments, and appendixes are included at the end of the report.

2 Literature Review

2.1 Crash Statistics

A National Highway Traffic Safety Administration (NHTSA) report states that in 2016, 3,450 people died as a result of distracted driving, including 339 distracted teen drivers (ages 15-19) [13]. NHTSA defines distracted driving as any activity that diverts attention from driving, including: talking or texting on one's phone, eating and drinking, talking to people in one's vehicle, fiddling with the sound, entertainment or navigation system, or anything that takes one's attention away from the task of safe driving [14].

In 2016, a total of 687 fatal crashes occurred in work zone areas. Compared to 2015, an increase of 4% was found in fatal crashes. Of the 781 fatalities, 598 of them were on interstate and arterial highways [15]. The use of a smartphone while driving in a highway work zone is potentially hazardous because the distracted driver might not be fully aware of or attentive to modifications in the roadway geometry or operating conditions and the presence of equipment and workers performing construction or maintenance activities. The level of road condition adjustments (e.g., speed limit, number and width of lanes, etc.) and the complexity of the TTC plan (e.g., position and length of tapers, location of the workspace, entry and exit of work vehicles, etc.) are varying factors that could provide high workload and unexpected situations to unfamiliar and distracted drivers, thus increasing the crash risk.

2.2 Legal Uses and Restrictions of Cell Phones while Driving

Many state governments have implemented laws that limit the use of cell phones while driving to reduce the number of related fatalities and crashes. In the United States, laws about cell phone usage while driving vary by state or territory. Sixteen states, Washington D.C., Puerto Rico, Guam, and the U.S. Virgin Islands have completely banned the use of handheld cell phones while driving. Likewise, 47 states, Washington

D.C., Puerto Rico, Guam, and the U.S. Virgin Islands prohibit text messaging for all drivers [16].

The Vehicle and Traffic Law of Puerto Rico, Law 22 of January 7, 2001, specifically its amendment in Article 10.25 implemented in 2013, restricts the use of a cell phone (without a hands-free mode) while driving. This law has the following exceptions: drivers can use a cell phone without a hands-free mode when the vehicle is completely stopped and is not impeding traffic; when calls or communications are generated to law enforcement or related agencies in cases of medical or safety emergencies, including situations of immediate risk to health, life, or property; when using the GPS; or when starting or ending a call. The law does not apply to drivers of official vehicles who are attending emergency situations [17].

Despite the existence of laws that limit cell phone usage while driving, the results of a survey conducted by State Farm in 2016 show that drivers use their cell phones while driving even though they are aware that it is distracting and increases the likelihood of crashes. The results also indicate that 50% of the drivers talk on a handheld cell phone while driving, whereas 35% of drivers send text messages while driving. Forty-nine percent of the drivers reported that the main reason for talking on a cell phone was that it was an efficient use of time, and 34% of drivers reported the reason for text messaging was that it is a habit [8].

2.3 Distracted Driving

Haque and Washington [18] found that drivers distracted by having cell phone conversations take longer to detect an event in their peripheral vision, either in hands-free or handheld phone conditions. The study concluded that the reaction time for distracted drivers was 42% longer than for drivers without the cell phone distraction. The same researchers also found that drivers distracted by cell phones press the brakes more aggressively to reduce their initial speed when an unexpected situation appears [18].

Bellinger et al. [19] studied driver perception and reaction time (PRT) for 27 young individuals using a simulated environment. Results showed that drivers distracted by cell phone conversations had a 7.1% longer PRT. These authors defined PRT as the sum of the reaction time and the movement time (the time between the initial movement of the foot from the accelerator and the initial application of pressure to the brake pedal). They also found that, on average, distracted drivers' reaction time was 15.2% slower, but their movement time was 9% faster. Bellinger et al. concluded that distracted drivers used an unconscious time compensation with a faster movement to the brake pedal, resulting in a more intense braking deceleration.

Hancock et al. [20] tested the response time of 42 drivers who needed to respond to an in-vehicle phone while facing a stopping decision at a traffic signal. They concluded that drivers faced with the dual task (answering the phone and complying with the red signal) had a slower response and more intense braking than those who faced only one task. Aggressive braking to decelerate by inattentive drivers is a factor highly associated with rear-end collisions [18], which is the main crash type occurring in highway work zones [7].

2.4 Temporary Traffic Control

Temporary traffic control plans are used in highway work zones to provide optimal functionality of the roadway as well as safe and effective movement to road users when the normal function of a roadway is suspended. They also protect road users, workers, responders to traffic incidents, and equipment. The Manual on Uniform Traffic Control Devices (MUTCD) is the national reference guide that includes information related to the typical TTC settings that can be applied depending on road configuration, work activity, road user volume and speed, the location of the work, and the road vehicle mix. The implementation of a TTC plan must guarantee the safety and continuity of movement for motor vehicles, cyclists, pedestrians, and transit services along the work zone and provide access to adjacent property and utilities [21].

The MUTCD defines four main areas for a highway work zone: advance warning area, transition area, activity area, and termination area. A TTC plan may require signs, cones or drums, temporary pavement markings, and other traffic control devices (TCDs). The TCDs are elements used to warn and inform users of the changing road conditions and channel traffic along the work zone. These can be easily placed and removed and do not give workers full protection from all the vehicles that are near the workspace. Considering the lack of full protection of some TCDs, it is of great importance to know and understand drivers' behavior in a work zone to increase worker safety. The laws that regulate the use of cellphones while driving were written based on data collected over the years from road crashes related to distracted driving and may not specifically address the hazardous conditions that may be present in current work zones.

2.5 Driving Simulators

Driving simulators are used to anticipate and evaluate road safety issues by analyzing the behavior of subjects in simulated scenarios and existing conditions. Driving simulators have been used as an innovative and cost-effective research tool to evaluate drivers' behavior in a wide variety of research fields, such as human factors, transportation, psychology, medicine, computer science, training, and other driving activities [22]. They allow evaluating scenarios that include existing or emerging transportation treatments without exposing subject drivers to physical harm in situations where a potential crash may occur. Several driving simulator studies have used speed, lane position, and acceleration data as measures to evaluate driving behavior.

3 Hypothesis

The general hypothesis in this study was the following:

Drivers subjected to a driving distraction (i.e., navigation task) while traversing a highway work zone will exhibit worse performances (more unsafe behavior) than those who do not have a distraction while driving the same highway work zone conditions [24,25].

This hypothesis was stablished based on the importance of understanding the relationship of work zone safety, associated with driving distraction, and the alarming use of smart phones in our highway system with their potential distraction associated with the audio, video, ringtones, and different languages. The use of smartphone to use GPS applications is permitted by law.

4 Methodology

The general hypothesis in this study was the following:

Drivers subjected to a driving distraction (i.e., navigation task) while traversing a highway work zone will exhibit worse performances (more unsafe behavior) than those who do not have a distraction while driving the same highway work zone conditions.

The research methodology started with a literature review that included topics related to the safety effects of driving distractions, particularly while driving along highway work zones. The data included information collected from an online survey of road users and driver performance data obtained from a driving simulator. The online survey was developed to gather information about the perception and attitude of road users about the significance and frequency of distractions while driving and their general knowledge and understanding of TTC conditions on highway work zones. Licensed drivers were asked to navigate road scenarios that showed a simulated freeway work zone. The work activities shown on the road scenarios were related to utility work of repairing light poles located on the median or roadside. The vehicle position and speed data obtained from the simulator were recorded for the different road scenarios. Each scenario was divided into four zones to analyze the following driver performance measures: standard deviation of lateral position (SDLP), average speed, and speed variability. Comparisons were made between drivers of different scenarios based on these performance measures to detect safe/unsafe driving behavior along the work zones.

4.1 Driving Simulator Equipment

The driving simulator equipment used in the study is configured as a driving cockpit simulator with three primary parts: the vehicle, the projectors, and screens. It also includes the computer hardware and software. The vehicle consists of a car seat, a gear shifter, a steering wheel, and the brake and accelerator pedals placed in a wood frame with six wheels to make it versatile for mobile application. The gear shifter is located on the right-hand side of the car seat. The steering wheel with a turn signal control is placed in front of the car seat and rests on a wooden countertop that serves as a dashboard. The brake and accelerator pedals are fixed on the floor below the countertop. The simulator has three overhead projectors, each with their respective screen, with a 10° deflection angle between them to create a panoramic view of the roadway. The audio from the simulation comes through a sound-bar system that is in the simulator's wooden frame. Regarding hardware and software, the simulator has connected desktop and laptop computers with NVIDIA graphics and the RTI SimCreator/SimVista simulation software.

4.2 Experimental Design

Twelve road simulation scenarios were created. The factors used for the scenarios were three different work zones, with or without traffic, and with or without GPS distraction. The roadway setting used for the simulation was a four-lane rural freeway. The scenarios were grouped in two configurations. The first included six scenarios showing the roadway conditions and the effect of distracted driving by having an active GPS-navigation application provide visual and auditory instructions to the driver. In the scenarios without traffic, a worker encroached the 3.8 m right lane and the 3.0 m deceleration lane perpendicular to traffic at a walking speed of 3.5 ft per second. The scenario descriptions are shown in Table 4.1.

Table 4.1 – Scenario descriptions

Scenario	Traffic	GPS	Type of Work Zone
1	Yes	Yes	Right Lane
2	No	Yes	Right Lane
3	Yes	Yes	Left Lane
4	No	Yes	Left Lane
5	Yes	Yes	Right Shoulder
6	No	Yes	Right Shoulder
7	Yes	No	Right Lane
8	No	No	Right Lane
9	Yes	No	Left Lane
10	No	No	Left Lane
11	Yes	No	Right Shoulder
12	No	No	Right Shoulder

A Latin square design was used to randomly assign the viewing order of the scenarios within each configuration. This experimental design helped ensure that the effects of fatigue and learning curve in the simulator could be considered insignificant. Therefore, the results from the simulated scenarios are independent from the order in which the participants saw them. In addition, only half of the participants completed Scenarios 1-6, while the others drove through Scenarios 7-12 to ensure that the effect of the GPS did not influence scenarios that did not have the GPS.

4.3 Survey Development

A web-based survey was developed and distributed online to local Puerto Rican drivers who held a valid driver's license. The survey was prepared online in Spanish and distributed via e-mail and social media. The purpose of the survey was to identify the perceptions and attitudes of Puerto Rican drivers about the level of distraction caused by performing different activities while driving, such as using smartphones, GPS navigation systems, or social media. The survey also inquired about the participants' understanding of typical components of a work zone and their preference regarding safe operating conditions in a TTC setting. A total of 216 voluntary subjects participated in the survey, of which 53% were female and 47% were male. The average age of the participants was 30 years, with a range from 18 to 73 years old. All participants were asked to be licensed drivers to participate in the survey.

The survey consisted of 19 questions divided into four sections. The first section asked for the respondents' demographic information. The second section included questions about how frequently respondents performed the following actions while driving: writing and reading text messages or email, searching for an address or listening to/looking at the GPS, and taking pictures and videos. The third section asked responders for their perceptions about the level of distraction caused by the actions mentioned above in a scale from 1 to 5 (1 = no distraction, 5 = high distraction). The last section of the survey included questions about the level of knowledge about the components of a work zone with an active TTC plan. This section included a figure showing a typical TTC application from the MUTCD and asked respondents about their understanding of when to start reducing speed and where they believed the work zone began.

4.4 Scenario Development

A group of experimental scenarios was developed based upon a four-lane, median-divided freeway, comparable to existing roadway conditions of freeway PR-22 in the northern region of Puerto Rico. The scenarios consisted of a 2.6 km (1.62 mi) level and straight segment of the freeway and included a right-side exit ramp located 2.1 km (1.30 mi) ahead. The road cross-section has 3.8 m (12.5 ft) wide lanes and 3.05 m (10 ft) wide shoulders. The segment has a posted speed limit of 65 mph and includes median and roadside longitudinal barriers. Figure 4.1 shows three cross-sections of the simulated scenarios, where the general roadway conditions can be observed, including part of the TTC plan and work areas.

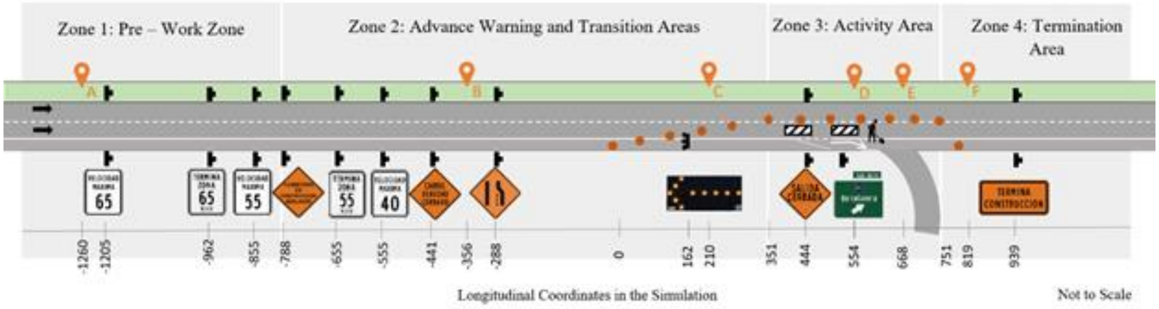
(a) Workspace located on the right lane with surrounding traffic and GPS

(b) Workspace located on the left lane at free-flow conditions and without GPS

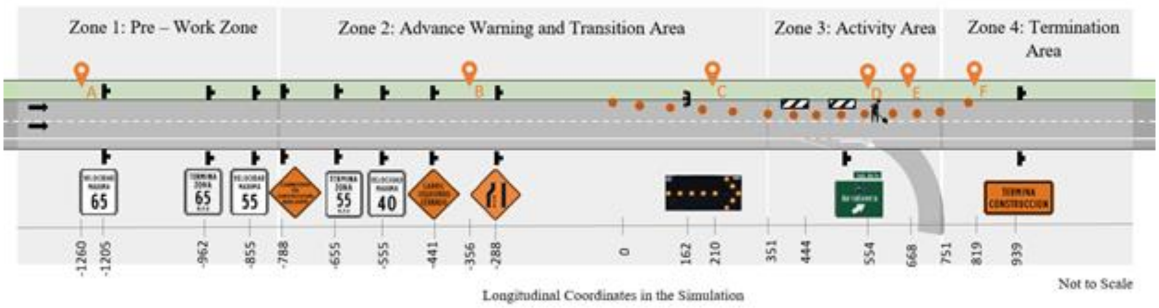
(c) Workspace located on the right shoulder with surrounding traffic and GPS

Figure 4.1 – Sample roadway and work zone conditions in simulation scenarios

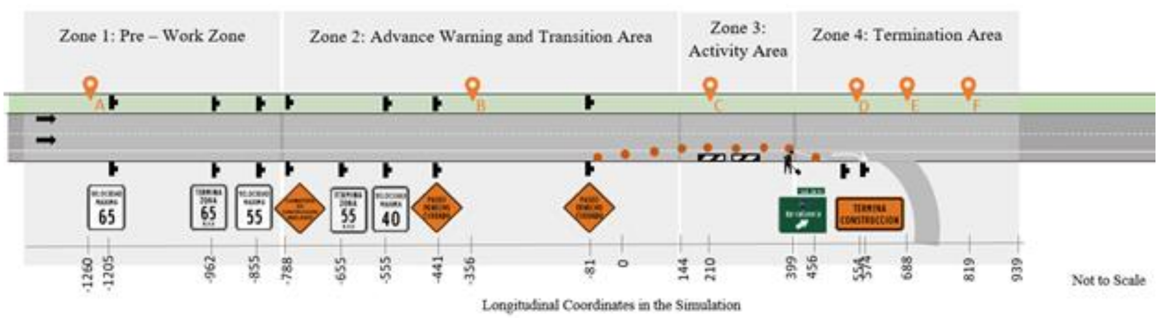
All the simulation scenarios included a work zone showing short-term utility work of repairing light poles on either the left or right side of the road. Figure 4.2 illustrates a plan sketch of the three TTC plans with the corresponding work zone components that were created by locating the workspace either on the right lane (3.2a), left lane (3.2b), or right shoulder (3.2c). The workspace in the TTC plans was defined by the presence of workers and trucks with baskets parked in one of the three locations. The TTC required a reduced speed limit of 40 mph prior to the transition and activity areas. The three road work activity scenarios and corresponding TTC plans were designed in compliance with the MUTCD [22] and the local signage manual [24], which provides supplementary symbols, signs, and legends in Spanish, as used by the Puerto Rico Highway and Transportation Authority (PRHTA). The TTC plan shown in Figure 4.2a is based primarily on the MUTCD TA-33, but with Spanish-text signs and additional reduced speed limit signs.



(a) TTC plan with the workspace occupying the right lane and closing the exit ramp (Scenarios 1, 2, 7, and 8)



(b) TTC plan with the workspace occupying the left lane with exit ramp open (Scenarios 3, 4, 9, and 10)



(c) TTC plan with the workspace occupying the right shoulder with an open exit ramp (Scenarios 5, 6, 11, and 12)

Legend						
		GPS message		Point in which the worker appears		Work space
						Arrow panel
		Channelizing device		Sign		Direction of traffic

Figure 4.2 - Simulation scenarios of roadway and work zone conditions

The driving distraction element was represented in the simulation using active GPS commands that instructed the driver to take an exit ramp located on the right side of the freeway segment while the exit was closed due to construction work. In the scenario that had GPS, a window similar to a GPS application appeared on the right side of the screen showing a roadmap with the recommended route. The roadmap in the GPS window was being updated on the screen while the vehicle was in movement along the scenario, and voice commands were also provided on the recommended route. The six voice instructions that were provided by the GPS during the simulated scenarios are shown below:

A. "Keep driving in PR-22."
B. "In approximately 1 km stay in the right lane."
C. "In approximately 500 m, take exit 55 in the direction to PR-2."
D. "In approximately 200 m, take Exit 55 on the right."
E. "Turn to the right."
F. "Recalculating" (activated when the driver passed the exit).

Figure 4.2 shows the approximate location where each message was activated along each road scenario. Also, at the beginning of the simulations (Zone 1) there was no traffic adjacent to the subject vehicle to allow for initial acceleration and lane position. In the scenarios where traffic was included, the surrounding vehicles were present only from Zone 2 to Zone 4. Message F was only given if the subject did not take the exit ramp and continued straight on the freeway.

In addition, all simulation scenarios that were shown under free-flow conditions included an unexpected (and potentially hazardous) event where a worker walks out from behind one of the trucks, exits the workspace (perpendicular to the traffic lane), and enters the traffic space in the TTC. The scenarios with the presence of traffic did not include this event.

An additional hurdle that was only present in the simulations created with the TTC plan, shown in Figure 4.2a (closed right lane), was that the activity area blocked access to the deceleration lane and the exit ramp. This blockage created a conflict for driver subjects who were directed to exit the freeway segment either by the GPS visual and auditory commands or by the initial instructions given by the proctor. The exit ramp was open in the other two TTC plans.

5 Online Survey

The survey was administered in Puerto Rico during April and May of 2018. A total of 227 respondents completed the survey, of which 53.3% were female and 46.7% were male. 62% of the respondents were between the ages of 18 and 25 years old, while 19% were between the ages of 26 and 45 years old and 19% were older than 46 years old.

When asked about cell phone ownership, 99.6% of respondents indicated that they own a cell phone, out of which 98.7% reported that their cell phone is a smartphone. Table 5.1 compares the results of the respondents' perceived level of distraction caused by the action of using the cell phone while driving vs. the frequency with which they performed the action. The level of distraction was indicated on a scale from 1 to 5, where 5 corresponds to high distraction and 1 to no distraction. The frequency with which an action was performed was indicated on a scale from 1 to 5, where 5 corresponds to always and 1 to never.

The activity that drivers perceived as most distracting while driving was writing a text or e-mail message (79% of respondents considered it very distracting), followed closely by reading a message or viewing information on social media networks (78% considered it very distracting). 40% of the respondents perceived that talking to passengers while driving is not very distracting, and 36% of respondents perceived that talking on the phone with a hands-free device is not very distracting. At the end of the survey, an open-ended question asked respondents to indicate other types of distractions that were not included in the survey; respondents identified eating, putting on makeup, and fiddling with the radio as distracting activities while driving. Based on the survey results, most respondents are aware that cell phone usage causes a distraction, but they choose to perform the action regardless.

The action that respondents indicated performing most frequently while driving was talking to other people in the vehicle (45% of respondents), followed closely by talking on the phone with a hands-free device (33.6% of respondents). 50% of respondents indicated that they search the internet while driving; this number is followed closely by 43% of respondents who indicated that they read messages or view information on social media while driving.

Table 5.1 - Summary of survey responses to specific actions and distractions

Scale	Action(%)	Distraction(%)	Action(%)	Distraction(%)
	Write Text Messages and/or Emails		Read Text Messages and/or Emails	
5	5.8	78.9	8.9	62.2
4	8.9	12.1	16.5	23.4
3	31.7	4.5	33.5	9.9
2	31.7	2.7	25.4	3.6
1	21.9	1.8	15.6	0.9
	Action(%)	Distraction(%)	Action(%)	Distraction(%)
Scale	Listen and Look at the GPS (Maps, Waze, etc.)		Search for an Address in the GPS (Maps, Waze, etc.)	
5	9.9	28.7	8.6	46.6
4	20.2	29.6	16.7	25.6
3	39.0	24.2	33.8	19.3
2	19.7	15.7	22.1	7.2
1	11.2	1.8	18.9	1.3
	Action(%)	Distraction(%)	Action(%)	Distraction(%)
Scale	Read Messages or View Information on Social Media Networks		Talk on the Phone with "Hands-Free"	
5	6.4	78.0	33.6	9.9
4	6.4	10.8	26.5	17.5
3	15.5	4.9	19.7	25.1
2	26.8	3.6	9.0	35.9
1	45.0	2.7	11.2	11.7
	Action(%)	Distraction(%)	Action(%)	Distraction(%)
Scale	Talk with the Phone in your Hands		Take Photos and/or Videos	
5	6.8	38.6	5.0	67.6
4	13.5	26.5	2.8	16.2
3	23.4	19.3	14.7	7.7
2	32.9	12.1	33.9	5.0
1	23.4	3.6	43.6	3.6
	Action(%)	Distraction(%)	Action(%)	Distraction(%)
Scale	Write Text Messages and/or Emails		Read Text Messages and/or Emails	
5	5.8	78.9	8.9	62.2
4	8.9	12.1	16.5	23.4
3	23.4	19.3	14.7	7.7
2	32.9	12.1	33.9	5.0
1	23.4	3.6	43.6	3.6

Figure 5.1 shows survey responses to three questions related to drivers' actions when reaching or traversing along a highway work zone. The situation that was analyzed in the UPRM driving simulator consisted of a four-lane freeway segment with two lanes per direction and a posted speed limit of 65 mph, with a temporary road construction work zone simulating MUTCD Typical Application 33. The scenarios that were generated consisted of closing the right lane of the representative tangent segment of the four-lane freeway and a gradual reduction of the posted speed limit to 45 mph.

The questions addressed drivers' actions when approaching a work zone and whether they differed based on the presence of personnel or heavy equipment. Respondents were also asked questions about their knowledge of the work zone; namely, where the beginning of the work zone was located, where they would start reducing their speed, and where they would perform the lane change.

The survey results show that respondent behavior in and around highway work zones varies depending upon the activities being performed. Most of the respondents (87.1%) indicated that if no workers or heavy equipment were present, they would reduce their speed slightly but not enough to be under the posted speed limit. On the other hand, when workers or heavy equipment were present, most of the respondents (more than 50%) indicated that they would reduce their speed to below the posted limit.

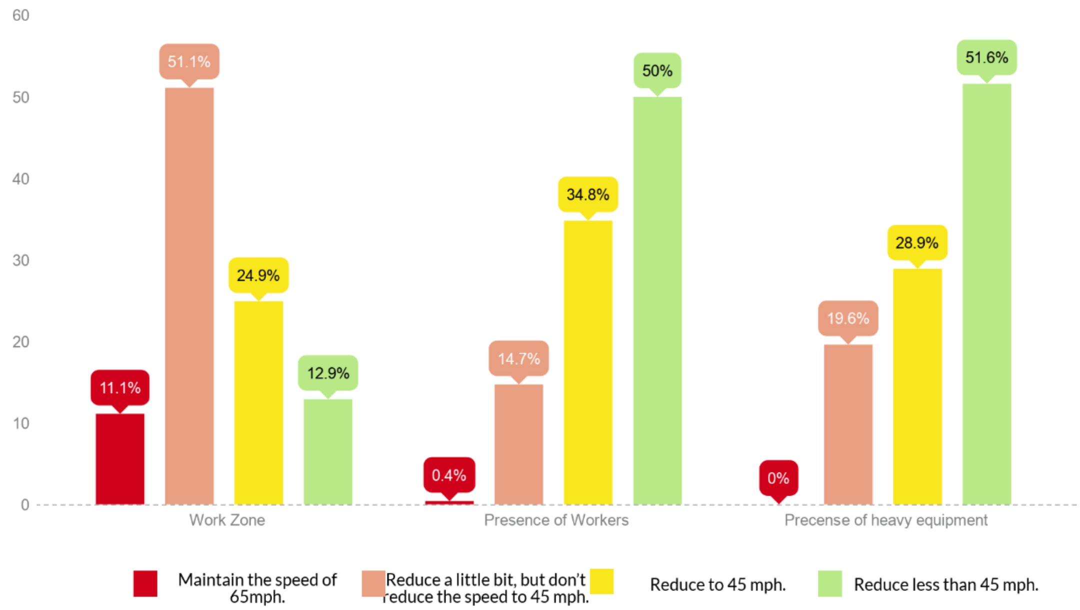


Figure 5.1 - Survey responses to three situations to which a driver could be exposed in a freeway construction work zone

In order to understand drivers' knowledge regarding the work zone's (TTC's) primary components, a survey was conducted in which a sketch of a typical application closing the right lane was presented (see Figure 5.2). Lines A, B, C, and D delineated the beginning of each zone. The three pertinent questions asked were: where does the construction work zone begin, where do you usually start to slow down, and at what instance do you perform a lane change if you are traveling on the right lane. The results of this survey are shown in Table 5.2. Almost two-thirds of the respondents (64.81%) did not recognize where the work zone/TTC started. In terms of when the respondents decided to slow down, 58.33% preferred to wait until they reached a point between the last advance warning sign and the merging taper (Lines B and C). These two answers indicate drivers' tendency to wait until the last moment (lane closing) to adjust their speed. Nevertheless, 80.56% of the respondents indicated that they prefer to change lanes and therefore adjust their path at the beginning of the TTC (Lines A and B), which may indicate that they may decide to accommodate their vehicles along the open travel lane but continue without reducing their speed until the last moment. This behavior is recognized by the MUTCD; it states that the design of the TTC should use the same design principles as for regular conditions considering that drivers will not adjust their speed until they perceive it is necessary [21].

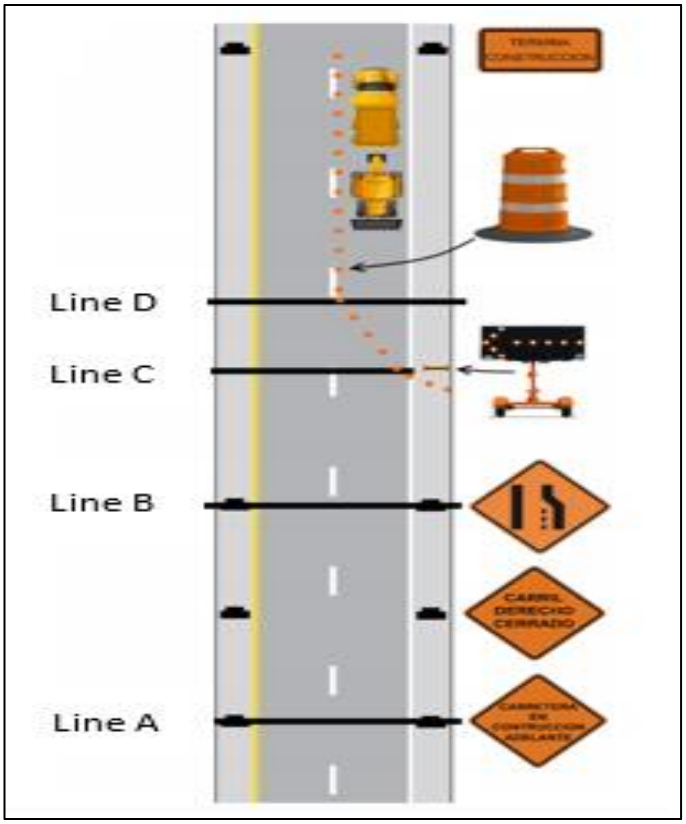


Figure 5.2 - Typical application closing the right lane

Table 5.2 - Survey questions related to smartphone use and distractions

Survey Questions	Scale	Drivers Actions			
		Read text messages and/or emails	Listening to or looking at the GPS	Search an address in the GPS	Perform a search on the internet
How frequent have you performed the following actions while driving?	Sometimes, Often or Always (%)	59.27	70.37	59.72	26.85
	Rarely or Never (%)	40.73	29.63	40.28	73.15
How distracting are the following actions while driving?	Extremely, Moderate or Some (%)	94.44	81.02	90.75	91.21
	Slightly or None (%)	5.56	18.98	9.25	8.79

6 Driving Simulator Study

6.1 Subjects

All subjects that participated in the study met the following criteria: they had a valid motor vehicle driver license and were between the ages of 18 and 70. The study followed the UPRM Institutional Review Board (IRB) ethics regulations.

A total of 24 participants took part in the driving simulations. In the first group, 12 participants drove using a GPS. In the second group, 12 participants drove without a GPS. Participants in both groups were instructed verbally before starting the simulation that they needed to exit the freeway segment at approximately 2 km from the start of the simulation run. The workspace of the TTC plan extended beyond the exit ramp; therefore, the drivers needed to recognize that there were modified operating conditions in the freeway due to the presence of a temporary work zone that prevented them from taking the exit ramp. For the scenario with the active GPS, the application was unaware of both the work zone and the closed exit ramp, therefore increasing driver workload and becoming a distraction for the driver, who was trying to follow visual cues from the GPS window and listen to the voice commands in the simulation.

6.2 Effects of GPS on Exit Ramp Maneuver

Figure 6.2 shows the lateral position of each subject in TTC Scenarios 1, 2, 7, and 8. Scenarios 1 and 2 have an active GPS. All subjects were instructed by the simulator proctor prior to starting the simulation to take exit ramp 55, but only those under scenarios with the GPS were instructed by the system during the simulation. The results of the simulation demonstrate that 16.7% of the subjects encroached upon the workspace in scenarios with an active GPS, compared to 8.3% of the subjects who did so in scenarios without an active GPS. Even though the exit ramp was protected by channelizing devices, these subjects encroached upon the workspace in their intent to use the exit ramp while following instructions. This behavior can be seen in Figure 6.1 additional figures are provided in Appendix C. Contradictory instructions of the audible messages of the active GPS in a segment with a TTC and all the components (advance warning, transition, activity, and termination area) resulted in a higher probability of error maneuvers by subjects. This conflict was not present in the other two work zones, as the exit ramp was not closed by the workspace.

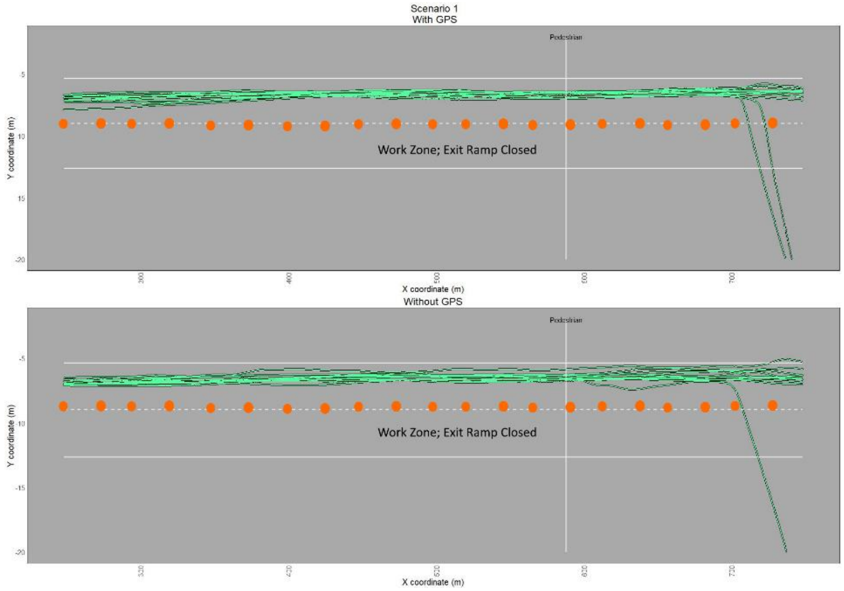


Figure 6.1 - Position of subject while driving in scenario 1(with GPS) & scenario 7(without GPS)

In the case of the two work zones with the open ramp, there were subjects that did not follow the instructions of taking the ramp (See Appendix A). In the case where the workspace occupied the left lane, the results of the scenario without GPS show that 16.6% proceeded through the main lanes without taking the exit. In the two scenarios with an active GPS, all drivers correctly followed the instruction of taking the exit. In the scenario without GPS and where the workspace occupied the right shoulder, 25% of the subjects continued straight without taking the exit ramp. One of the subjects remained on the left lane and never changed to make the exit maneuver. In the two scenarios with an active GPS, all drivers correctly followed the instruction of taking the exit. As expected in two of the scenarios without GPS, there is a higher probability of subjects missing taking the exit ramp.

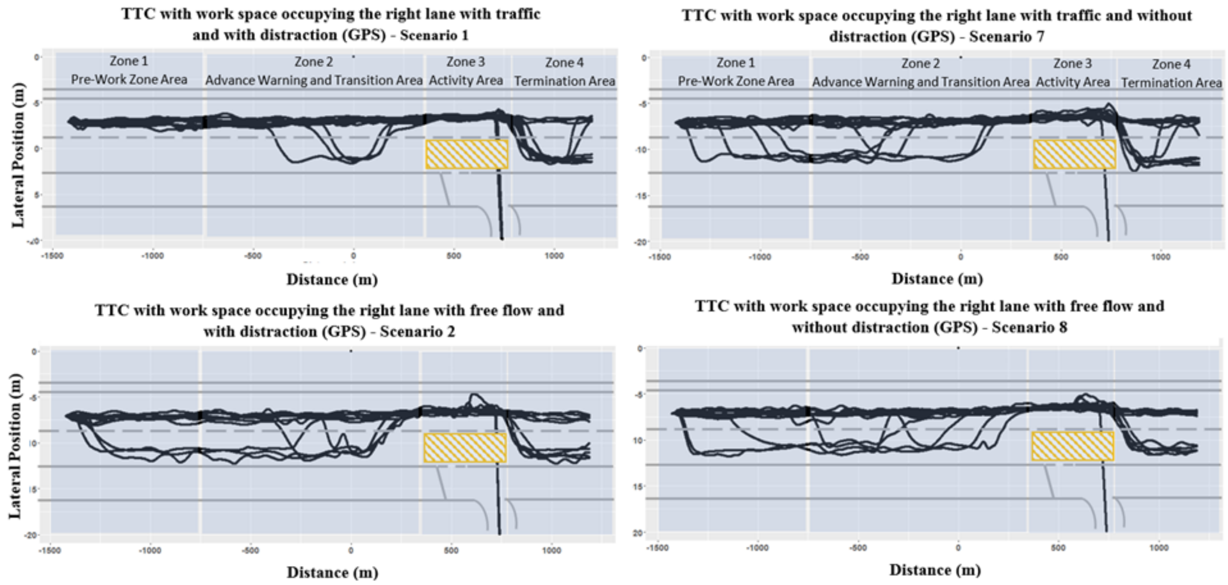


Figure 6.2 - Position of subject vs. distance of scenarios with workspace in the right lane

6.3 Effect of GPS on Lane-Changing Maneuver

To determine the effects on lane-changing maneuvers, a comparison was performed between the scenarios with and without GPS, as shown in Table 6.1. The F-Test with a P-value less than 0.05 and a Bonferroni correction were used to eliminate the familywise error associated with the significant differences in the SDLP between the two scenarios. The P-value for each comparison between each pair of scenarios evaluated should be less than 0.002083. The column named “General” considers the SDLP for all the evaluated zones. Therefore, Scenarios 3 and 9, as well as Scenarios 6 and 12, are statistically significant with respect to the SDLP for all the evaluated zones. Furthermore, in four out of six comparisons, the GPS is statistically significant in Zone 1. Therefore, the subjects with GPS tend to drive more smoothly before entering the work zones. In the work zone (Zone 3), one of the comparisons (Scenarios 3 and 9) was statistically significant. The GPS did not have an effect on the roadway position in the advance warning, transition, workspace, and termination areas. The comparison of Scenarios 1 and 7 can be observed in Figure 6.2; note that there are more lane changes in the scenario without GPS (Scenario 7).

Table 6.1 - P-values of F-test for standard deviation of mean of road position X

Configuration 1 (with GPS)	Configuration 2 (without GPS)	General	Zone 1	Zone 2	Zone 3	Zone 4
1	7	0.977	<0.001	0.550	0.643	0.901
2	8	0.191	0.736	0.598	0.226	0.716
3	9	<0.001	<0.001	0.673	<0.001	N/A
4	10	0.547	<0.001	0.087	0.187	N/A
5	11	0.413	0.317	0.036	0.366	0.317
6	12	<0.001	<0.001	0.459	0.934	<0.001
	P-Value<0.002083 with Bonferroni Correction					

Appendix A includes the graphical representation of the lane position variable for each scenario. Appendix B shows the ANOVA results for the principal effects of the SDLP and its interactions, with configuration, traffic and type of work zone as factors.

6.4 Effect of GPS on Mean Speed and Speed Variability

Figure 6.3 shows the mean speed exhibited by individual subjects for each of the six scenarios under the free flow condition. As can be observed on the graphs, the initial 500 meters in the simulation were used for the initial driver acceleration to attain a speed close to the posted 65 mph speed limit.

In the scenarios with an active GPS, the driver behavior observed during the entire segment was relatively homogenous, showing an initial acceleration approaching the posted speed limit followed by a gradual reduction in speed when approaching the work zone and continuously reducing speed until reaching the exit ramp. The trend observed in the first speed reduction approaching the work zone is most likely associated with the reduced posted speed limit of 40 mph (after position -555 m). This trend was robust for 75% to 83% of the subjects. The second obvious speed reduction is related to the presence of the worker who encroached into the traffic space in Zone 3.

In the scenarios without an active GPS, driver behavior is more heterogeneous, reflecting the customs and traditions of individual drivers who are not exposed to a new set of instructions associated with the GPS.

A t-test revealed that mean speed differences found in comparisons with and without GPS were not significant at a 0.05 significance level. Nevertheless, mean speed differences with and without GPS were significant at a 0.10 significance level with a p-value of 0.065. The results of the ANOVA are shown in Appendix B. In the case of traffic influence, a significant difference was found with a p-value of 0.042. These results, and the principal effects associated with them, are shown in Appendix B.

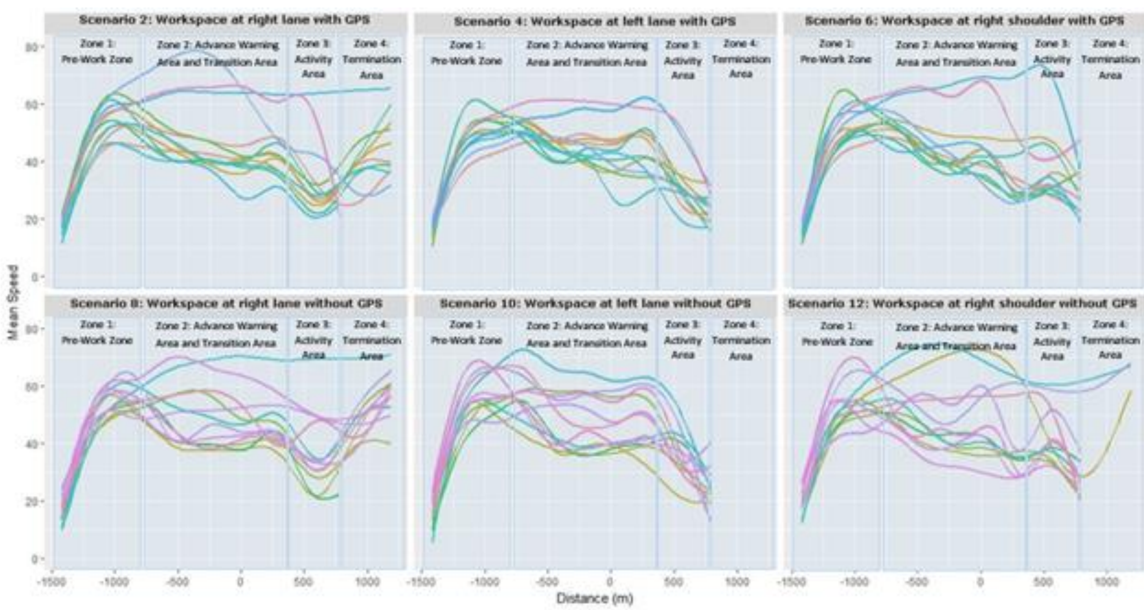


Figure 6.3 - Mean speed and subject trajectories for Scenarios 2, 4, 6, 8, 10, and 12

Figures 5.3, 5.4, and 5.5 show the comparison between mean speeds and the standard deviation of the mean speeds for the three TTCs with and without an active GPS. The observed patterns in scenarios with an active GPS tend to be lower than those without an active GPS, particularly for Zones 2 and 3. Although visually there appears to be a difference due to the presence of GPS, a t-test revealed that those differences were not significant at a 0.05 significance level. Table 6.2 presents the results of such a test.

Table 6.2 - P-values of T-test for mean speed

Configuration 1 (with GPS)	Configuration 2 (without GPS)	General	Zone 1	Zone 2	Zone 3	Zone 4
1	7	0.512	0.924	0.885	0.726	0.308
2	8	0.265	0.768	0.719	0.244	0.039
3	9	0.483	0.666	0.003	0.166	N/A
4	10	0.259	0.310	0.444	0.797	N/A
5	11	0.599	0.732	0.937	0.793	0.732
6	12	0.462	0.215	0.672	0.553	0.215
	P-Value<0.05					

The trends observed for the standard deviation of the speeds need to be explained by the events happening within the zones in each scenario. For the TTC with the right lane closed, the standard deviation is higher with the active GPS (Scenario 2) than in the scenario without GPS (Scenario 8). This situation can be observed from the start of the simulation (-1375 m) until the end of the advance warning area (-250m) and inside the activity area (+350m). The largest difference in standard deviation in the activity area can be attributed to the fact that additional audible instructions sent by the GPS contradict the rationale of an effective TTC, which is a control that gives adequate time for a proper response and channelizes traffic to travel on the left lane, whereas the GPS is instructing the subject driver to make a right turn encroaching a controlled segment. Hence, selecting a reasonable driving behavior under conflicting instructions requires more time to digest the information and is dependent upon age and gender. This large difference in standard deviation presents a potential for higher crash frequency in a work zone due to the conflicting GPS instructions. This large difference in standard deviation is also observed in Figure 6.5 associated with Scenarios 4 and 10.

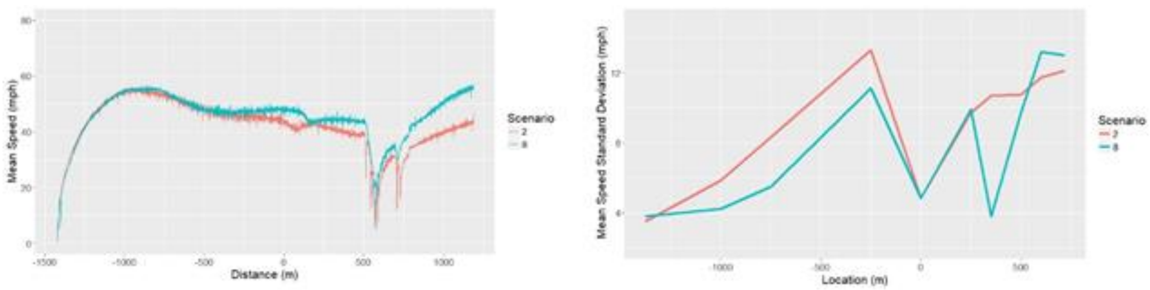


Figure 6.4 - Mean speed and standard deviation comparison (Scenarios 2 and 8)

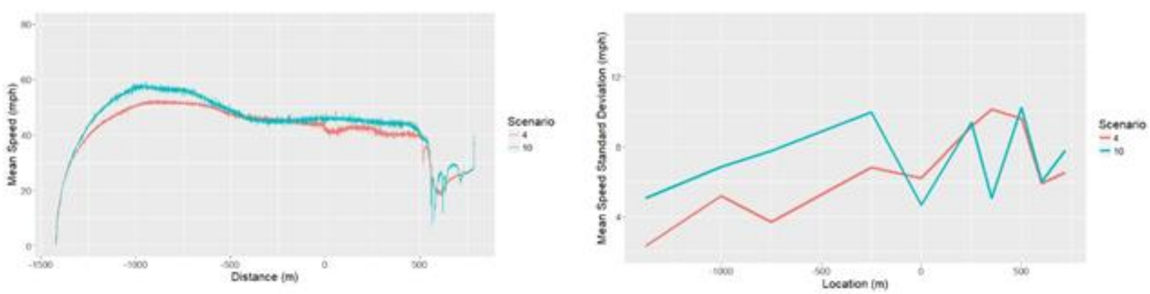


Figure 6.5 - Mean speed and standard deviation comparison (Scenarios 4 and 10)

In the scenarios with the active GPS, four out of the five audible messages (80%) were instructions given to drivers that required encroaching the right lane that was closed due to the TTC. These contradictory GPS instructions, activated at -356 m, 210 m, 554 m and 668 m, are also reflected in the peaks of the standard deviation graphs. In terms of gender, the mean speed of female subjects, during the entire trajectory for all scenarios with and without GPS, was 4.4 mph lower than the mean speed of male drivers.

Figure 6.6 corresponds to Scenarios 6 and 12 in which both traveling lanes are opened to traffic and the TTC is performed in the right shoulder. As can be observed, there is no large difference in the standard deviation of the mean speed at location +350 m as was the case in Scenarios 2 and 8 and 4 and 10. The largest difference in standard deviation is observed at +500 m where the downstream taper in the shoulder ends and starts the deceleration lane to the exit ramp.

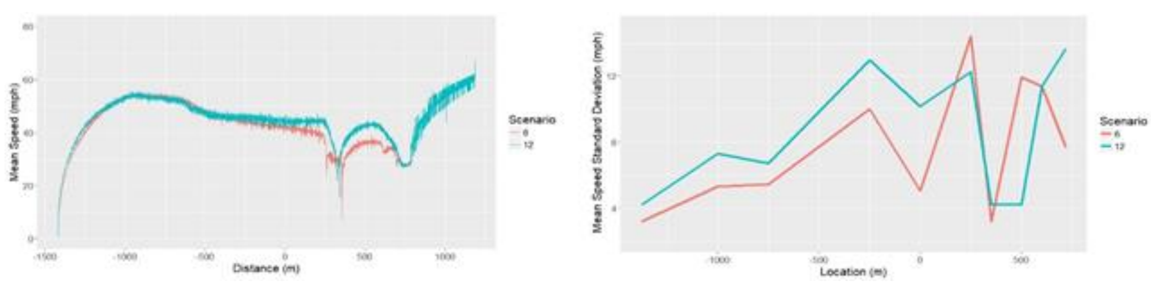


Figure 6.6 - Mean speed and standard deviation comparison (Scenarios 6 and 12)

6.5 <u>Effect of Worker Presence</u>

Figure 6.7 shows the trajectories of subjects 100 m prior to and after the inattentive worker (590 m) that crossed 50% of the open left lane (Scenarios 2 and 8). The subject driver trajectories at 100 m prior to the worker for both scenarios showed a lateral variability of 0.6 m within a 3.8 m lane width. For Scenario 2, where the workspace was in the right lane with traffic and without GPS, 25% of the subjects performed an evasive maneuver to the left to avoid impacting the worker. The largest evasive maneuver was 2.7 m. The remaining 75% of the subjects did not perform an evasive maneuver. The speed reduction for the 100 m distance prior to the worker in the driving lane ranges from -0.3 to 31.7 mph, with an average difference of 14.4 mph.

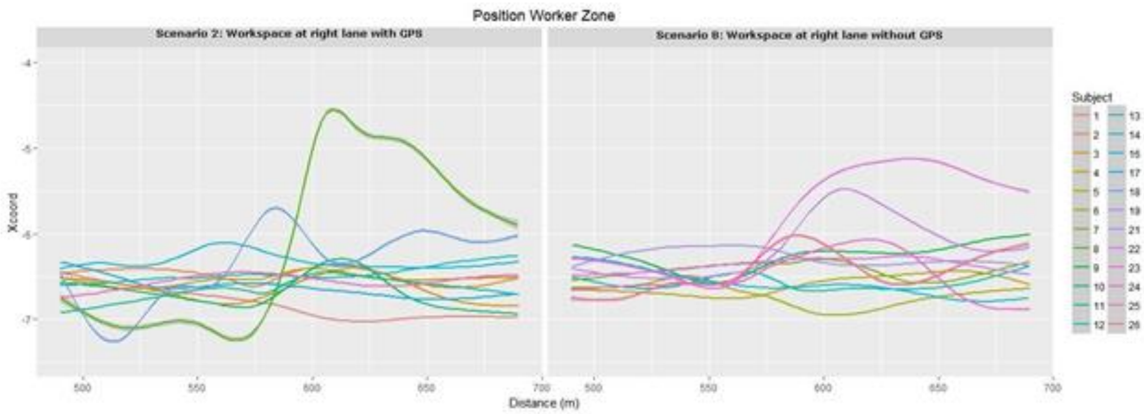


Figure 6.7 - Lateral position of subjects near the inattentive worker (Scenarios 2 and 8)

In Scenario 8, with the workspace in the right lane and traffic but without GPS, 42% of the subjects performed an evasive maneuver, with the largest maneuver distance of approximately 1.5 m. The speed reduction for the 100 m distance prior to the worker in the driving lane ranges from -0.29 to 31.5 mph, with an average difference of 14.6 mph, and with no significant impact on speed behavior in scenarios with or without GPS. The worker walks out of the safe zone at 590m. It can be noticed that at least 5 subjects stop for the worker at scenario 2 (with GPS) and 2 subjects stop at scenario 8 (without GPS). This can be seen in Figure 6.8.

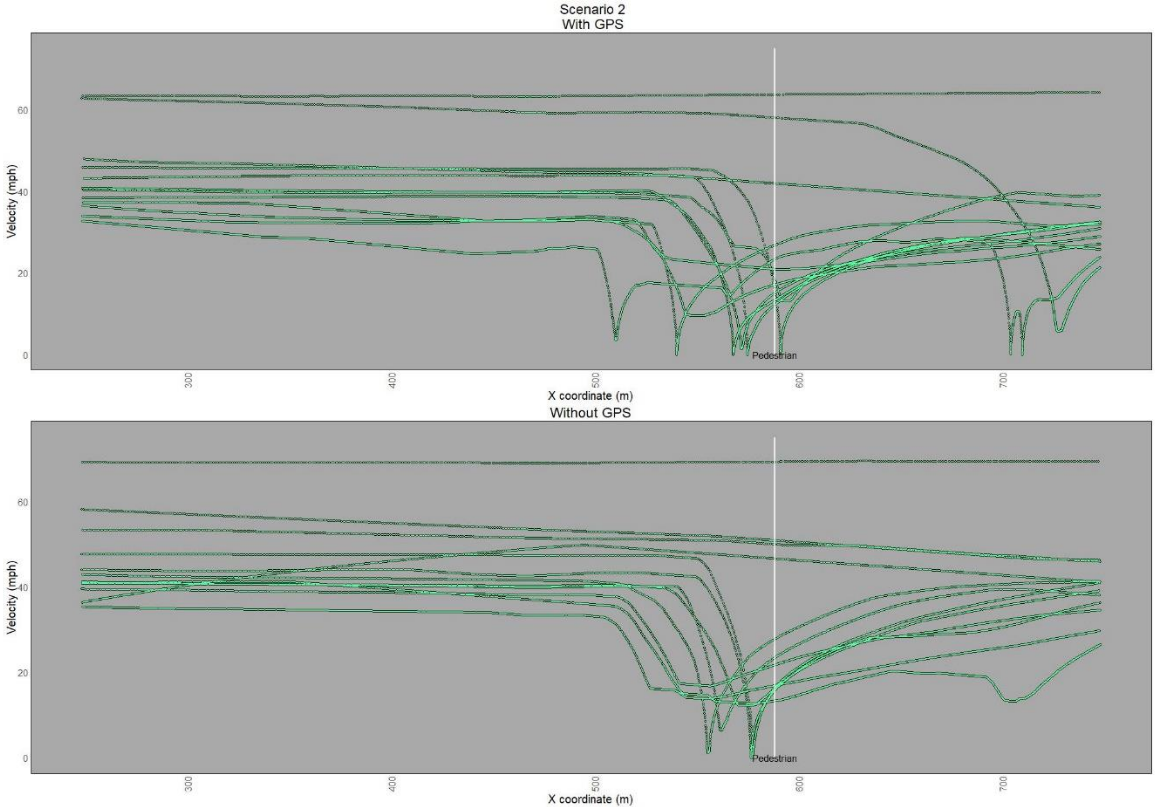


Figure 6.8 - Position of subject vs. Speed of scenarios 2 (with GPS) & 8 (without GPS)

In Scenario 4, where the workspace was in the left lane with traffic with active GPS, and in which the TTC was on the left lane and the inattentive worker was present, 67% of the subjects avoided impacting the inattentive worker by performing an evasive maneuver to the left and returning to the original trajectory as shown in Figure 6.9. The instant the evasive maneuver started depended upon the speed the subject driver was traveling when the worker appeared on the driving lane, crossing perpendicularly towards the deceleration lane and roadside barrier. In Scenario 10, where the workspace was in the left lane with traffic and without GPS, the same percentage of evasive maneuvers by subjects was observed (67%) with the difference that 50% of the subjects were in the right driving lane and the other 50% in the deceleration lane.

Figure 6.9 - Lateral position of subjects near the inattentive worker (Scenarios 4 and 10)

In Scenario 6, where the workspace was in the right shoulder with traffic and with active GPS, 16% of the subjects avoided impacting the inattentive worker by performing an evasive maneuver to the left and returning to the original trajectory, as shown in Figure 6.10. In Scenario 12, where the workspace was in the right shoulder with traffic and without GPS, 33% of the subjects performed an evasive maneuver while 75% drove on the left lane.

Figure 6.10 - Lateral position of subjects near the inattentive worker (Scenarios 6 and 12)

6.6 Acceleration Noise

An ANOVA analysis was conducted to evaluate the acceleration noise. The results of ANOVA indicate that only the traffic and the constant, as is expected in the traffic and no traffic cases, have a significant effect (see Appendix B). The results of the t-test also revealed that there are significant differences between the configuration with GPS and without GPS in Zones 2 and 3, Scenarios 3 and 9, with the activity area in left lane as shown in Table 6.3. This situation may have occurred because of the influence of ambient traffic, the lane-changing maneuvers, or the GPS message.

Table 6.3 - P-values of T-test for acceleration noise

Configuration 1 (with GPS)	Configuration 2 (without GPS)	General	Zone 1	Zone 2	Zone 3	Zone 4
1	7	0.159	0.068	0.179	0.588	0.260
2	8	0.658	0.799	0.330	0.538	0.622
3	9	0.354	0.017	0.030	0.703	N/A
4	10	0.103	0.084	0.584	0.293	N/A
5	11	0.909	0.259	0.092	0.859	0.259
6	12	0.873	0.525	0.172	0.081	0.525
	P-Value<0.05					

7 Conclusions

7.1 Major Findings

This research assesses the impact of GPS usage in smartphones while driving in a work zone/TTC using a driving simulator. Twelve scenarios were evaluated considering three major factors: with and without GPS, with and without traffic, and three different work zones (right lane closed, left lane closed, and shoulder closed) in a high-speed divided highway. The presence of an inattentive worker crossing the traffic space was also evaluated. The major conclusions associated with the driving simulator are as follows:

- Comparing the scenarios with the TTC in the left lane, it can be observed that the GPS was very effective in conveying the message of exiting correctly at the ramp. Comparing Scenarios 3 and 9, more variability of the lateral position is observed in the scenario without GPS (Scenario 9). In the two scenarios with an active GPS (Scenarios 3 and 4), all drivers correctly followed the instructions of taking the exit.

- In scenarios with the active GPS, 80% of the audible messages were instructions given to drivers that required encroaching the right lane that was closed due to the presence of the TTC. These contradictory GPS instructions are reflected in the peaks of the standard deviation graphs.
- In terms of the presence of a worker in the TTC (Scenarios 4 and 10), 67% of the subjects avoided impacting the inattentive worker by performing an evasive maneuver to the left and returning to the original trajectory (Scenario 4, where the workspace was in the left lane with traffic with active GPS). In Scenario 10, where the workspace was in the left lane with traffic and without GPS, the same percentage of evasive maneuvers by subjects was observed (67%) with the difference that 50% of the subjects were still in the right driving lane and the other 50% in the deceleration lane.
- In Scenarios 1 and 2 (active GPS), 16.7% of the subjects encroached the workspace, while 8.3% of the subjects did so in Scenarios 7 and 8 (without GPS). Even though the exit ramp was protected by channelizing devices, these subjects encroached the workspace in their intent to use the exit ramp following the GPS or proctor instructions. Contradictory instructions of the audible messages of the active GPS in a segment with a TTC and all the components resulted in a higher probability of error maneuvers by subjects. This conflict was not present in the other two work zones as the workspace did not close the exit ramp.
- In terms of subjects exposed to a driving distraction while traversing a highway work zone (audible GPS instructions), there was not a significant difference in mean speed. Nevertheless, trends were observed in mean

speed differences and the standard deviation of the mean speed in the activity area.

- In terms of speed variability, there is less dispersion of subject drivers with GPS than without GPS.
- In terms of initial lane position, subject drivers beginning the simulation trajectory in the left lane and changing to the right lane to exit the freeway, more subject drivers with GPS encroached onto the TTC to use the closed than did drivers without GPS.
- In terms of driver behavior within the elements of the TTC, there was less variability in the advance warning area when the subject drivers used the GPS.
- In the ordinary situation, when the subject drivers listened to or watched the GPS instructions displayed on the smartphone device, they tended to drive more uniformly across the construction work zone segment.
- In the ordinary situation, drivers' most likely drove faster on freeway segments when they felt more acquainted with the assistance provided by the GPS in reducing the uncertainty of the trip's destination.
- The driving complexity associated with a TTC makes GPS a feasible alternative in reducing uncertainty if the technology is continuously updated in real time. The lack of real-time TTC short-term closure updates in high-speed facilities such as freeways provides contradictory information to drivers, which results in a potential safety-related risk to road users and workers.

The findings of the survey conducted to identify the perceptions and attitudes of Puerto Rican drivers about the level of distraction caused by performing different activities while driving using smartphones and GPS navigation systems are also documented in this project report. Specifically, the participants' understanding of the typical components in a work zone and their preferences regarding safe operating conditions in a TTC setting are presented. The main conclusions associated with the survey are:

- Almost two-thirds of the respondents (64.8%) did not recognize where the work zone/TTC started.
- 58.3% of the respondents who decided to slow down preferred to wait until they reached a point between the last advance warning sign and the merging taper (Lines B and C in the typical application presented in Figure 5.2).
- Most respondents were aware that cell phone usage causes a distraction, but they chose to use it regardless of the distraction and its effect on drivers, vehicle occupants, pedestrians, workers, or other road users.
- The two actions that respondents perceived as most distracting while driving a motor vehicle and that are pertinent to highway safety perception and reaction time were:
    - Writing a text or e-mail message: 79%
    - Reading a text message or viewing information on social networks: 78%
- The two actions that respondents perceived as not very distracting and that are pertinent to highway safety perception and reaction time are:
    - Talking in the vehicle with passengers: 40%
    - Talking on the phone with a hands-free device: 36%
- Other distractions while driving provided by the respondents included eating in the vehicle, putting on makeup, and fiddling with the radio.
- Regarding the freeway construction work zone (TTC),

- Most of the respondents (87.1%) indicated that if no workers or heavy equipment were present, they would reduce their speed slightly but would not slow down enough to be under the posted speed limit.
- When workers or heavy equipment were present, most of the respondents (more than 50%) indicated that they would decrease their speed below the posted speed limit

7.2 Recommendations and Future Research

Assessing the impact of GPS usage in smartphones while driving in a highway work zone/TTC is a complex process in which the driving task and particularly the navigational component is greatly influenced by gender, age group, and the driving environment. Driving simulation was used in this study to evaluate driver performance while using emerging technologies in work zones with the presence of workers, particularly in assessing alternate scenarios aimed at improving road user and worker safety.

This study provided an excellent first step in integrating all these components with three representative TTCs in high-speed facilities. This study incorporated the effects of a navigation component similar to those typically used by TNCs and MSPs. However, these new forms of mobility, which in some cases combine various service providers in a vehicle with multiple tablets and gadgets that also serve as a distraction to the driver, represent a new reality of transportation mobility. The TNCs and MSPs may be associated with a new level of distraction that has the potential to affect the safety of road users in urban settings and in road construction.

It is recommended that scenarios be generated to evaluate GPS and smartphone technologies used by TNCs in urban settings with a variety of geometric and operational characteristics such as roundabouts, mini-roundabouts, road diets, divergent interchanges, and segments without lane balance. In these scenarios, the driving and navigational tasks become more complicated for an unfamiliar driver who will receive audible instructions from an external source such as a smartphone, and there is an additional distraction when the driver has to look to the device for information in these emerging complex settings, which affects the PRT.

Also, it is recommended that the public and private sector entities associated with the implementation of GPS technology in TTC act to solve this safety-related condition due to the potential liability implications associated with the lives of road users and workers.

Finally, it is recommended that the existing Law 22 - Vehicle and Traffic Law of Puerto Rico be amended to address specific situations where the use of a smartphone with GPS may need to be restricted if it has the potential to affect road users' safety. Potential examples include, but are not limited to, temporary highway and freeway construction, lane and ramp exit closures, and other configurations where high speeds and sudden decelerations will be present. These temporary highway construction scenarios (i.e., with the existing temporary signage, pavement marking, and devices of the TTC plan) affect the ordinary perception and reaction times of reasonable and prudent drivers. This situation, combined with a GPS instruction that has not been updated with the current condition of the road, can affect driver's decision. This needs to be resolved to avoid potential severe and fatal crashes that can result in future tort liability claims.

This research study contributes to the state of the art in the area of safety and simulation, specifically addressing the effect of smart usage and transportation network companies and its effects in contributing in driving distractions in work zones. The research findings demonstrate the importance of adequate signage and improvements in voice messages associated with smartphones to improve safety during temporary control conditions.

In terms of the hierarchy of instructions that a reasonable and prudent driver must follow to safely traverse a TTC, the following issue must be solved:

MUTCD guidance- “To be effective, a traffic control device should meet five basic requirements…C. Convey a clear, simple meaning…”, should prevail over audible messages provided by transportation network companies in the smart phones?

In the opinion of the researchers the answer is “YES”. The consistent driver confusion observed in the different TTC-TA scenarios evaluated show the importance of revisiting the use of smartphone and the hierarchy on TTC’s.

Acknowledgments

The authors would like to express their gratitude to the University Transportation Centers (UTC) Program for providing funding to the SAFR-SIM UTC that supported this research project. Also, we would like to acknowledge Johnathan Ruiz Gonzalez and Bryan Ruiz Cruz for their collaboration in developing the experimental scenarios, as well as Dr. Saylisse Davila for her technical assistance with the experimental design and statistical analysis. We would like to acknowledge Andrea Valdés Valderrama for her assistance in the edition process of this manuscript. And the Civil Infrastructure Research Center at UPRM for their administrative support with our research.

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Zones" To be presented at the Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, Atlanta, 2019.

Appendix A: Position Graphics

The following figures present the position of subjects in each scenario.

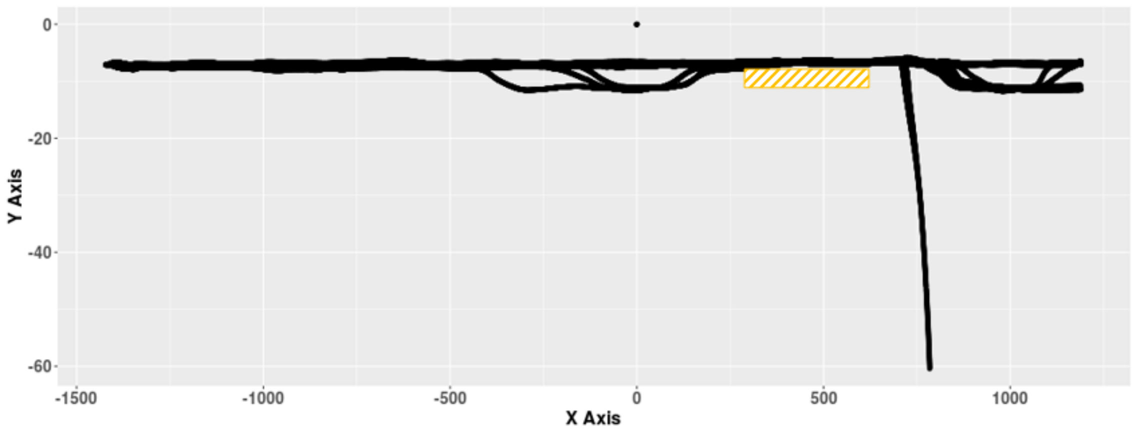

Figure A.1- Scenario 1 with GPS

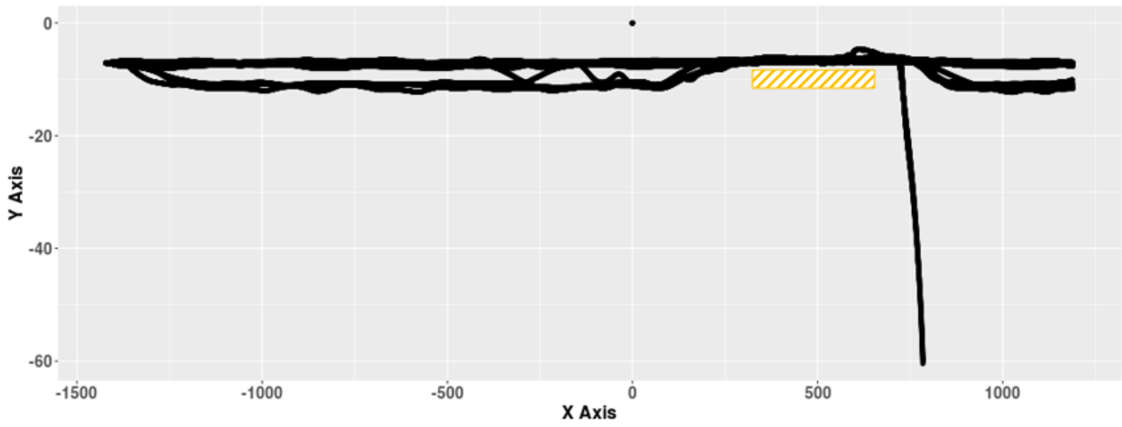

Figure A.2- Scenario 2 with GPS

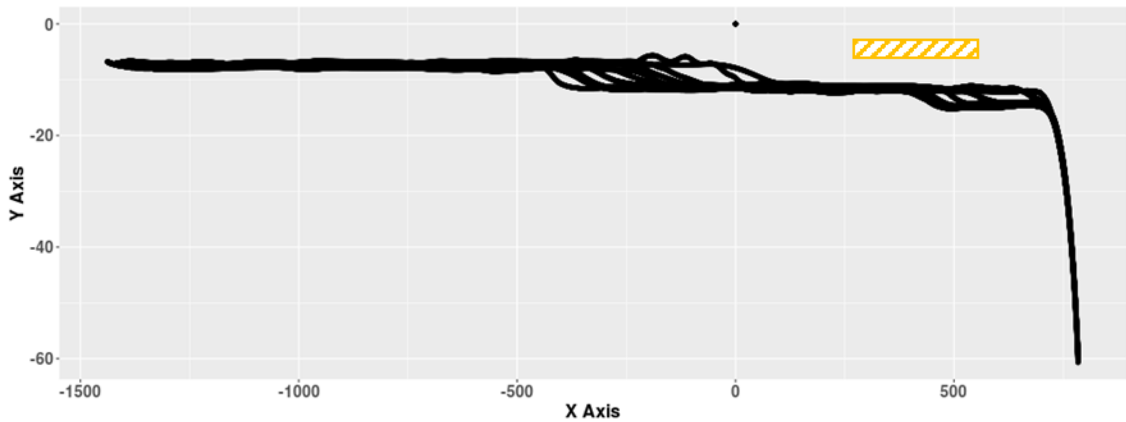

Figure A.3- Scenario 3 with GPS

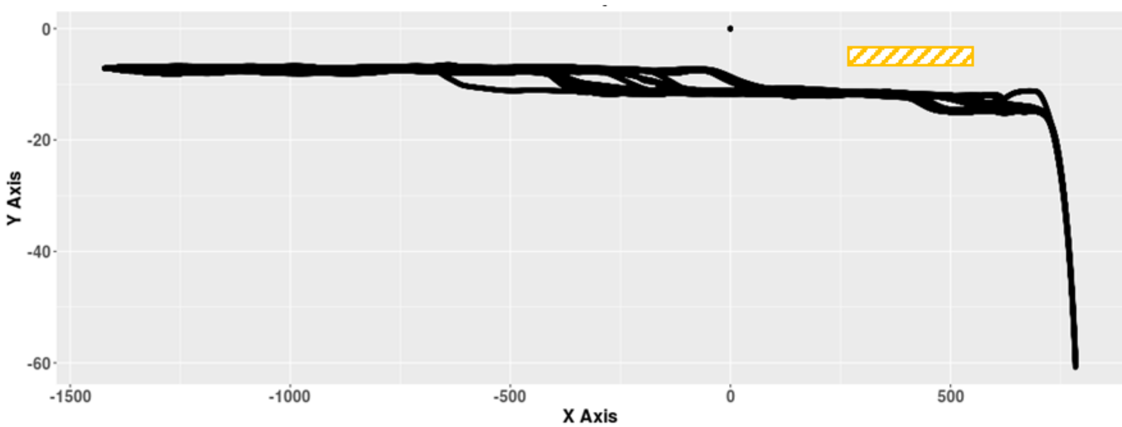

Figure A.4- Scenario 4 with GPS

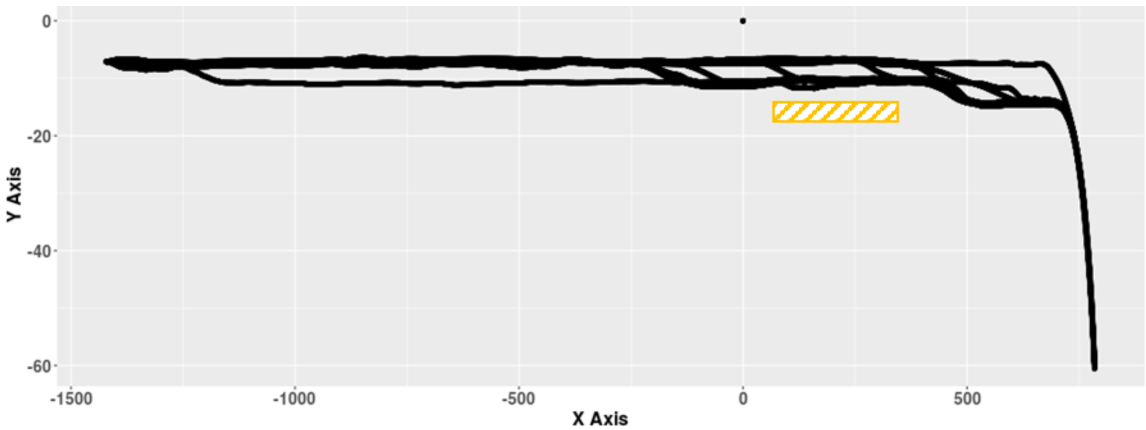

Figure A.5- Scenario 5 with GPS

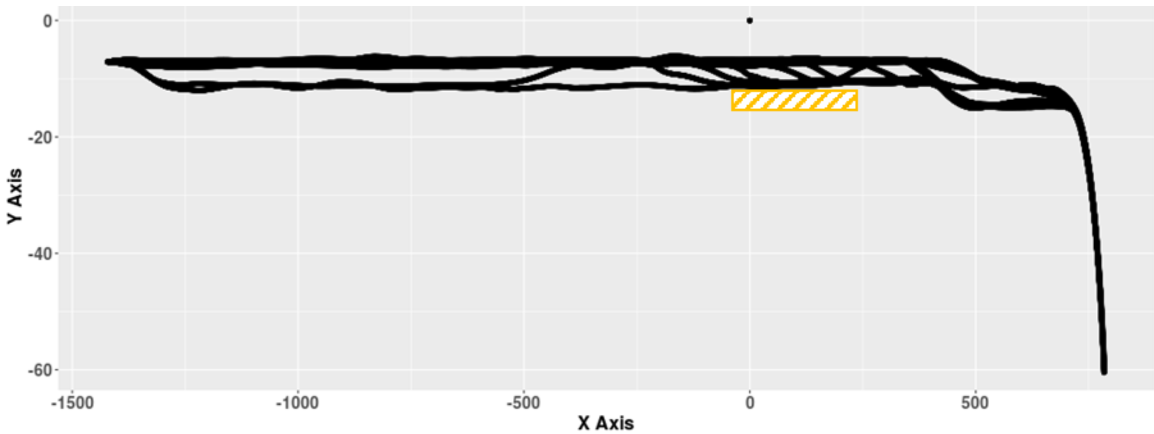

Figure A.6- Scenario 6 with GPS

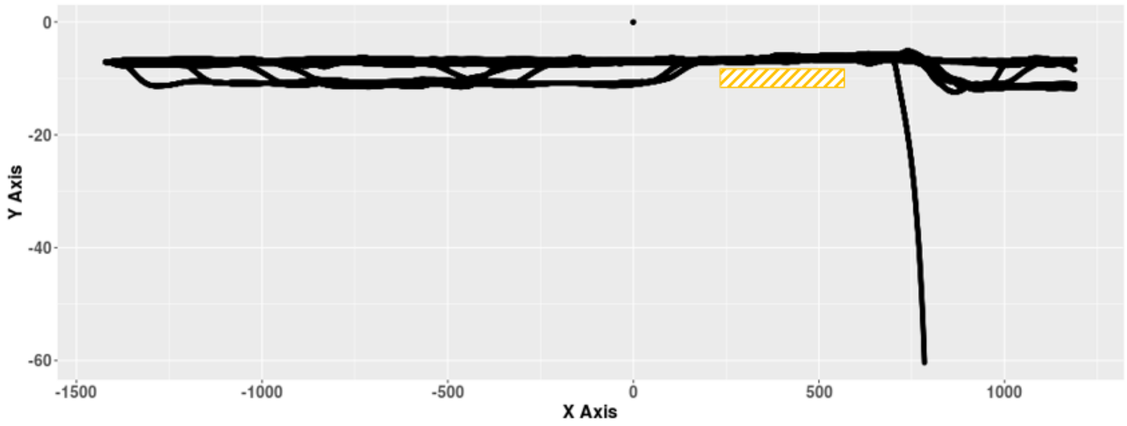

Figure A.7- Scenario 7 without GPS

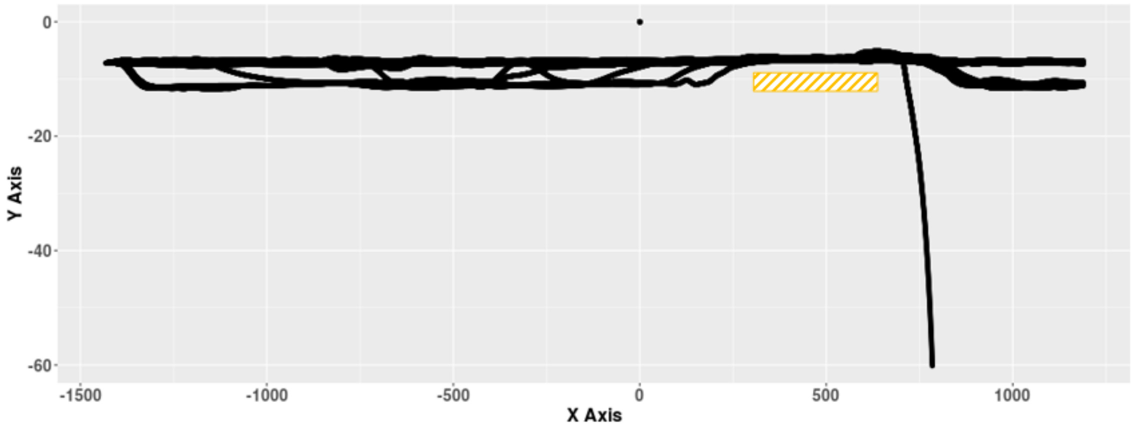

Figure A.8- Scenario 8 without GPS

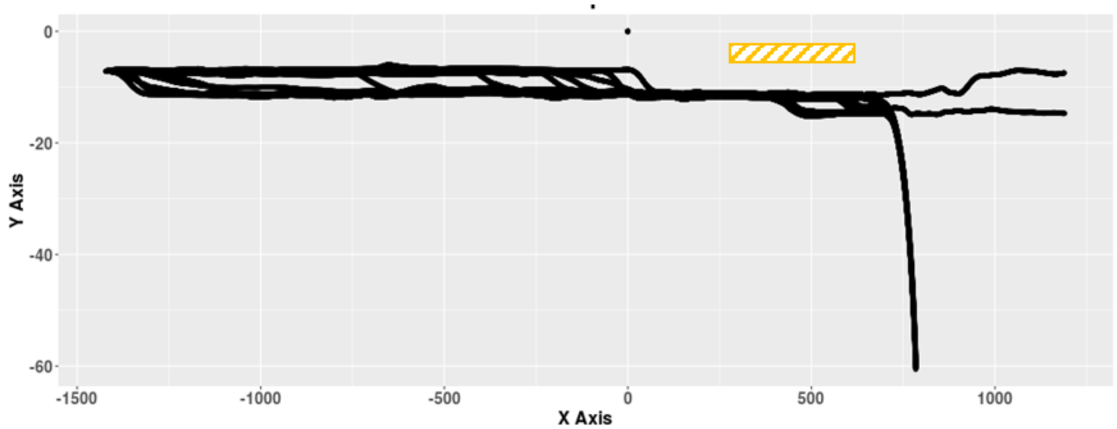

Figure A.9- Scenario 9 without GPS

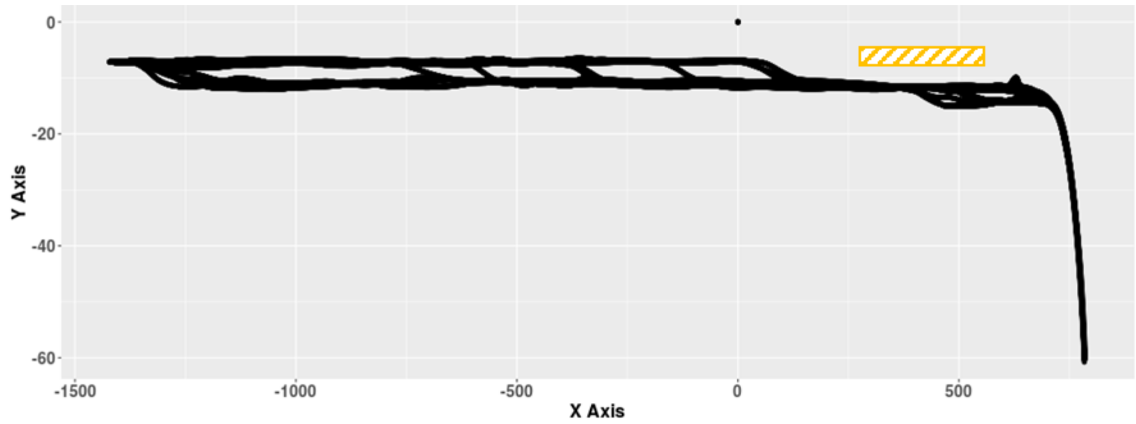

Figure A.10- Scenario 10 without GPS

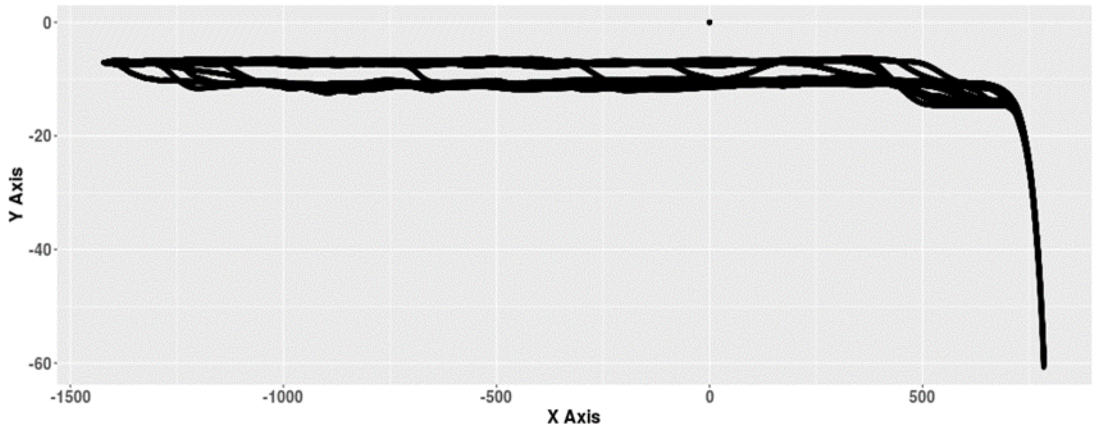

Figure A.11- Scenario 11 without GPS

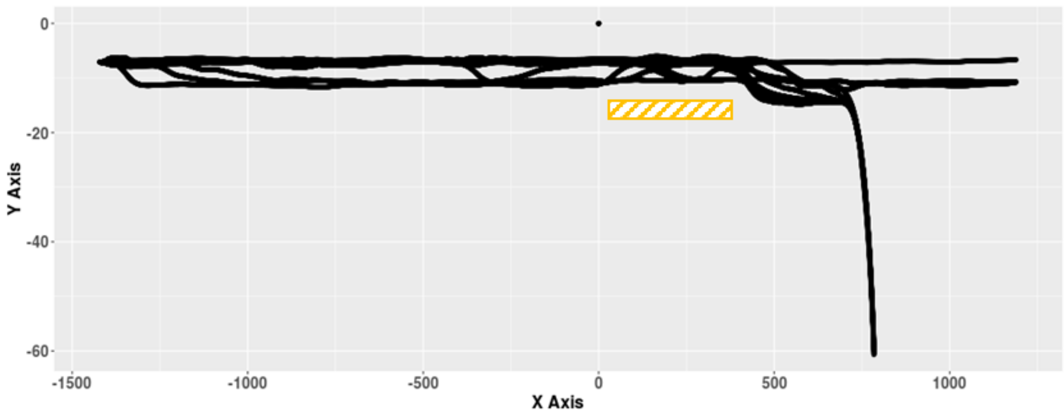

Figure A.12- Scenario 12 without GPS

Appendix B: ANOVA Results

General Linear Model: MeanSpeed versus Config; Type Work Zone

Method

Factor coding (-1; 0; +1)

Factor Information

Factor	Type	Levels	Values
Config	Fixed	2	1; 2
Type Work Zone	Fixed	3	1; 2; 3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Config	1	95.25	95.253	3.47	0.065
Type Work Zone	2	90.80	45.402	1.65	0.195
Error	140	3844.73	27.462		
Lack-of-Fit	2	3.43	1.713	0.06	0.940
Pure Error	138	3841.31	27.836		
Total	143	4030.79			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.24046	4.62%	2.57%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	34.748	0.437	79.57	0.000	
Config					
1	-0.813	0.437	-1.86	0.065	1.00
Type Work Zone					
1	-0.104	0.618	-0.17	0.867	1.33
2	-0.917	0.618	-1.48	0.140	1.33

Regression Equation

MeanSpeed = 34.748 - 0.813 Config_1 + 0.813 Config_2 - 0.104 Type Work Zone_1
- 0.917 Type Work Zone_2 + 1.020 Type Work Zone_3

Fits and Diagnostics for Unusual Observations

Obs	MeanSpeed	Fit	Resid	Std Resid	
4	19.919	33.831	-13.912	-2.69	R
22	48.641	33.831	14.810	2.87	R
23	46.885	33.831	13.054	2.53	R
24	44.759	33.831	10.928	2.11	R
30	22.582	33.018	-10.436	-2.02	R
48	47.155	33.018	14.137	2.74	R
70	50.865	34.955	15.910	3.08	R
90	48.343	35.458	12.885	2.49	R
94	49.496	35.458	14.039	2.72	R
97	19.997	34.645	-14.648	-2.83	R
138	48.052	36.582	11.470	2.22	R
139	49.485	36.582	12.903	2.50	R

R Large residual

Figure B.1- ANOVA mean speed

```
. mvreg meanspeed meanacel meanposx sdposx sdacel = config traffic typeworkzone
```

Equation	Obs	Parms	RMSE	"R-sq"	F	P
meanspeed	144	4	4.766714	0.2108	12.46643	0.0000
meanacel	144	4	.0426584	0.1524	8.387874	0.0000
meanposx	144	4	1.521793	0.3827	28.92528	0.0000
sdposx	144	4	2.356736	0.5145	49.44856	0.0000
sdacel	144	4	.3159283	0.0542	2.674192	0.0497

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
meanspeed						
config	1.626626	.7944524	2.05	0.042	.0559514	3.197302
traffic	-4.485172	.7944524	-5.65	0.000	-6.055847	-2.914497
typeworkzone	.5619348	.4865008	1.16	0.250	-.3999033	1.523773
_cons	33.42678	1.637806	20.41	0.000	30.18875	36.66481
meanacel						
config	.0017182	.0071097	0.24	0.809	-.0123381	.0157746
traffic	-.0251386	.0071097	-3.54	0.001	-.0391949	-.0110822
typeworkzone	-.0154565	.0043538	-3.55	0.001	-.0240642	-.0068488
_cons	.1521154	.0146571	10.38	0.000	.1231375	.1810932
meanposx						
config	.034924	.2536322	0.14	0.891	-.4665204	.5363685
traffic	-.1454939	.2536322	-0.57	0.567	-.6469383	.3559506
typeworkzone	-1.443932	.1553174	-9.30	0.000	-1.751003	-1.136861
_cons	-7.197042	.5228761	-13.76	0.000	-8.230796	-6.163288
sdposx						
config	-.5615838	.3927894	-1.43	0.155	-1.338149	.214982
traffic	.101989	.3927894	0.26	0.796	-.6745767	.8785548
typeworkzone	2.908706	.2405334	12.09	0.000	2.433158	3.384253
_cons	.8638146	.8097561	1.07	0.288	-.7371167	2.464746
sdacel						
config	.0772014	.0526547	1.47	0.145	-.0268998	.1813026
traffic	-.109593	.0526547	-2.08	0.039	-.2136942	-.0054918
typeworkzone	-.0400253	.0322443	-1.24	0.217	-.103774	.0237234
_cons	.7902194	.1085505	7.28	0.000	.5756093	1.00483

Figure B.2- ANOVA mean speed with factors

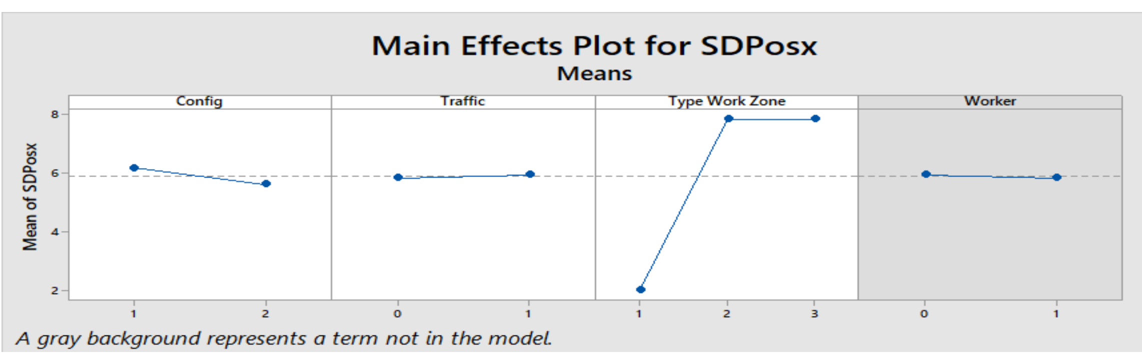

Figure B.3- Main effect plot for standard deviation of Position X

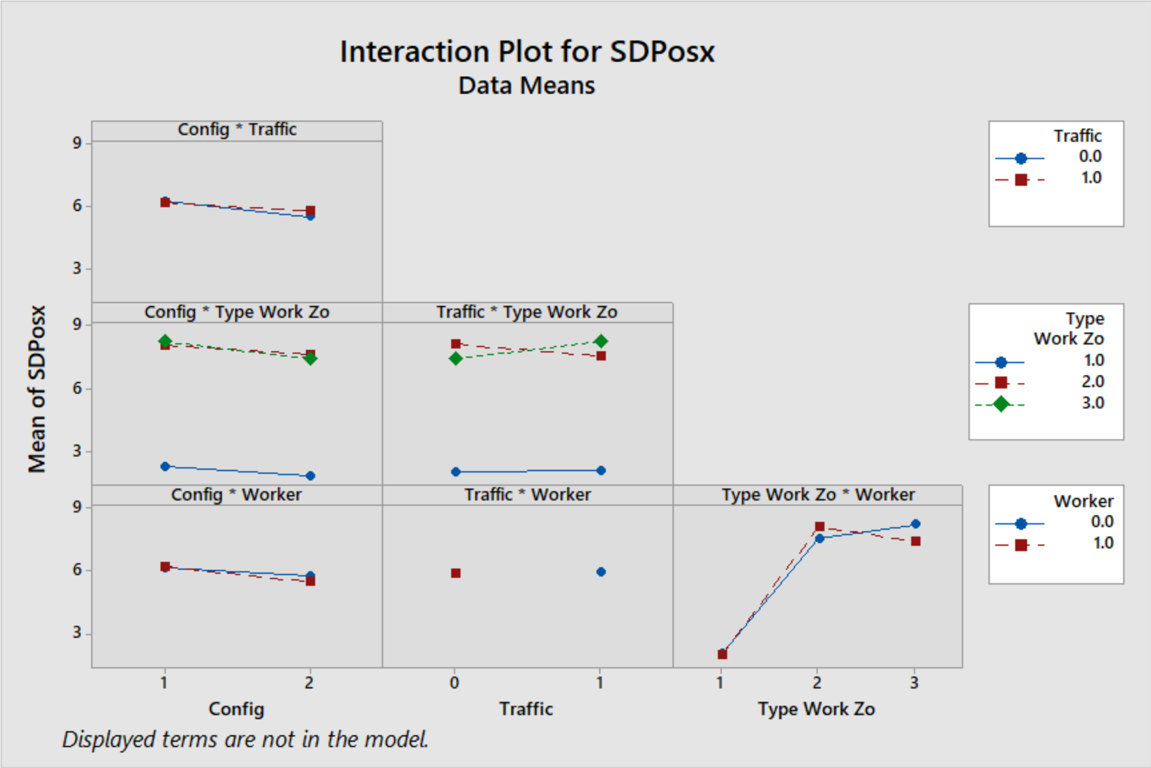

Figure B.4- Interaction plot for standard deviation of Position X

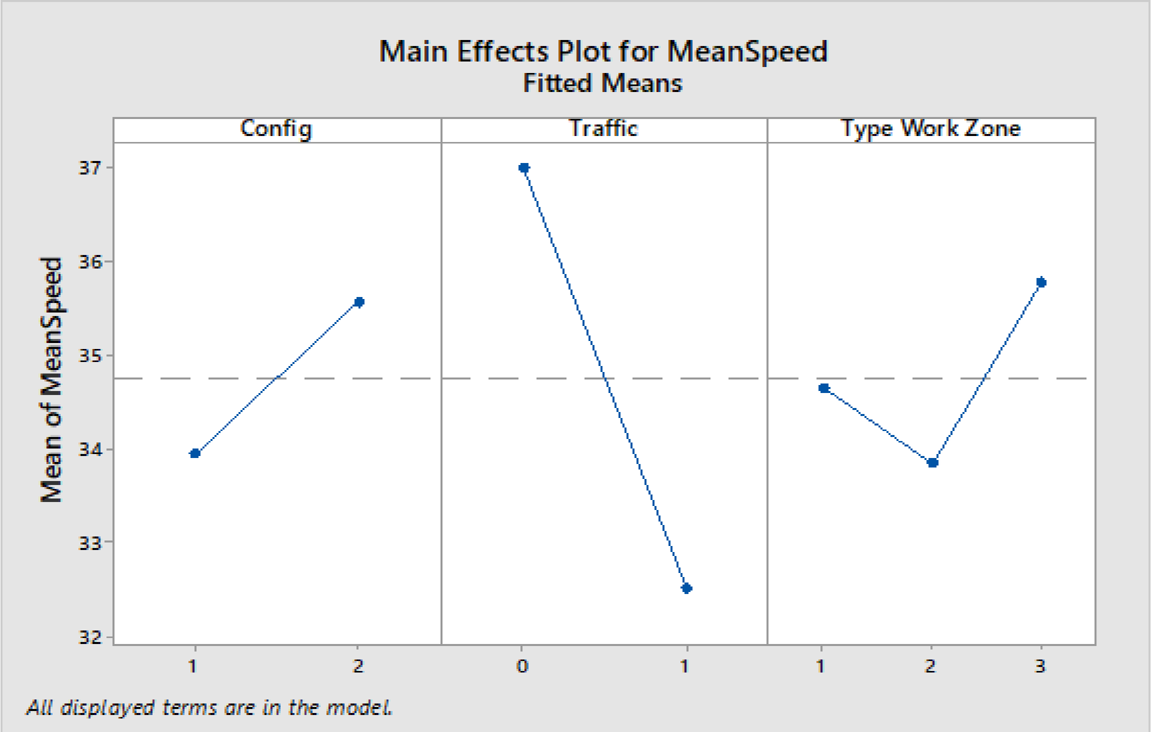

Figure B.5- Main effect plot for mean speed

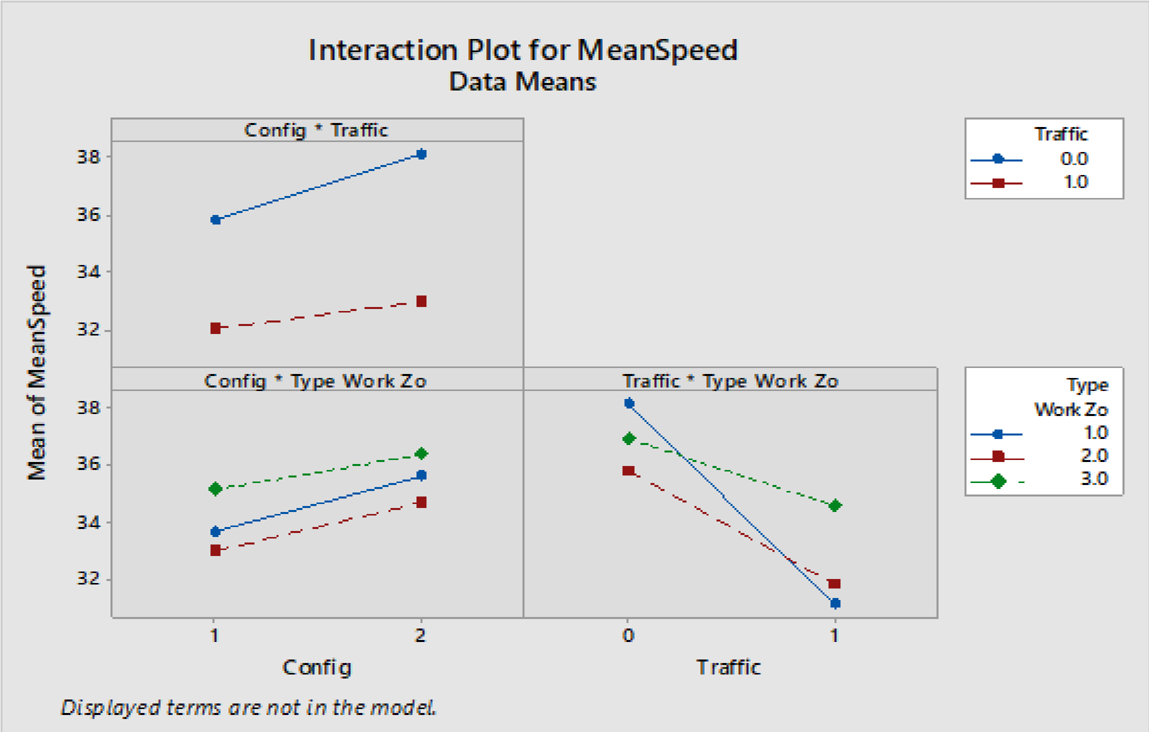

Figure B.6- Interaction plot for mean speed

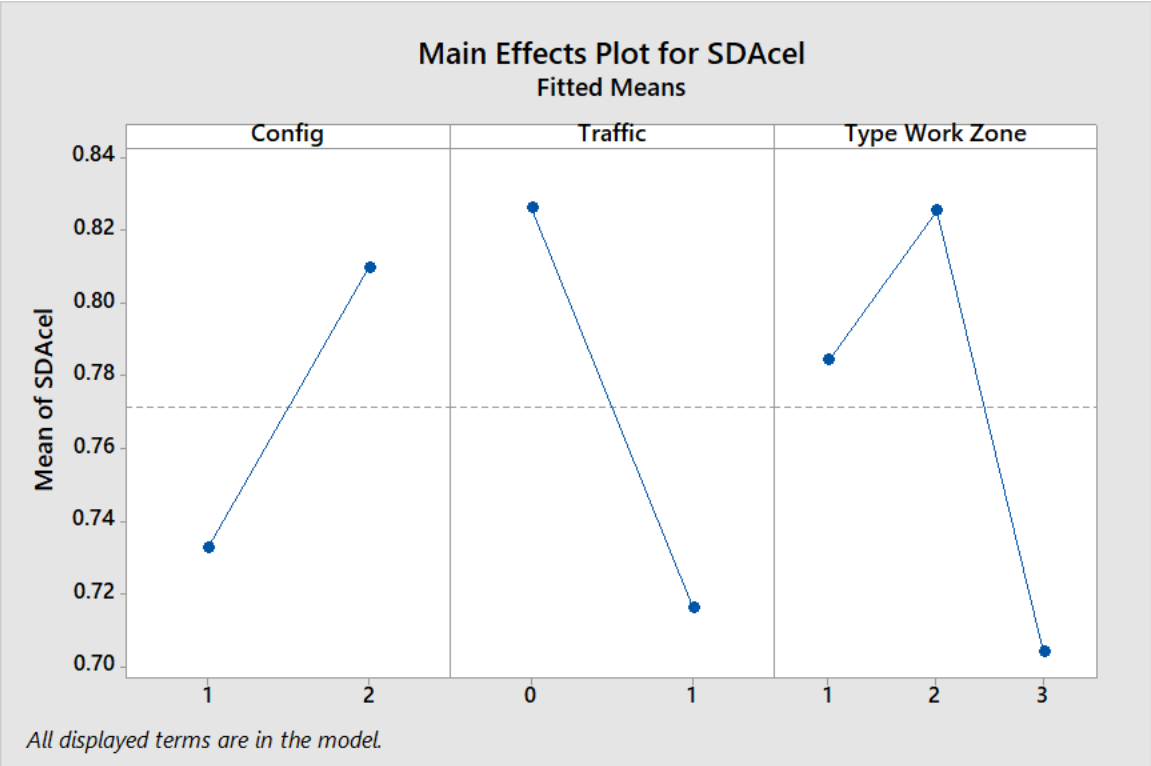

Figure B.7- Main effect plot for acceleration noise

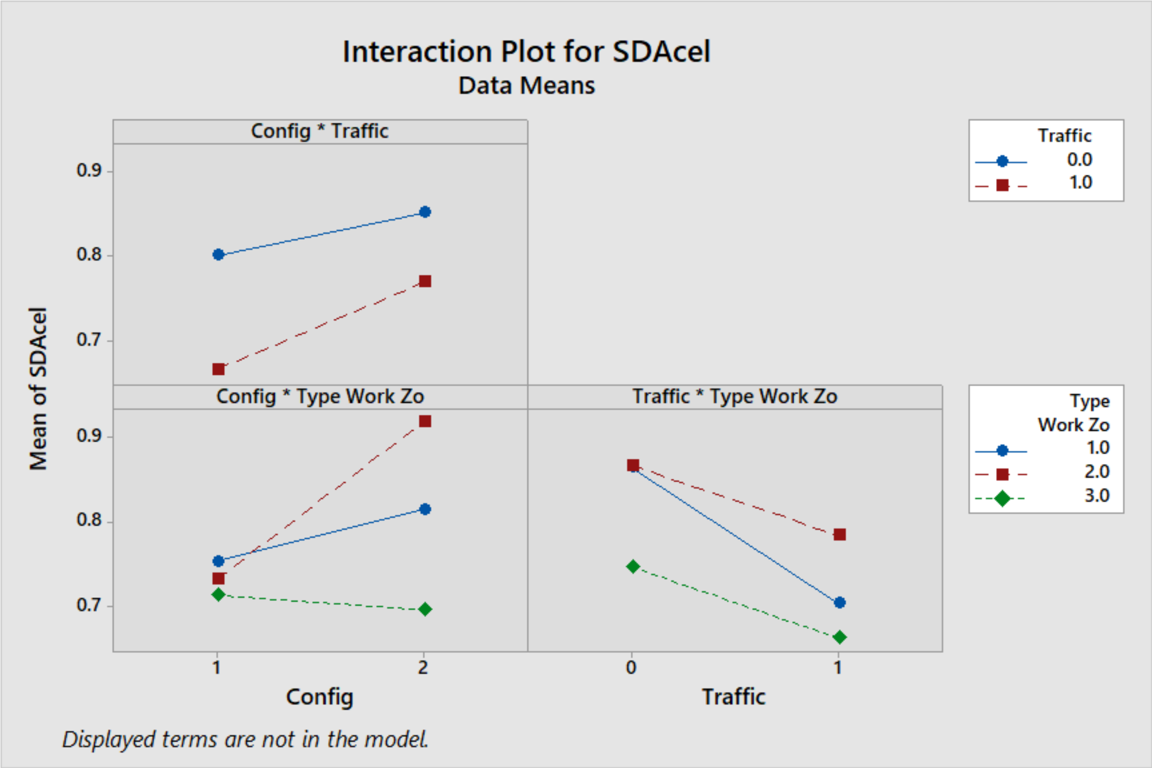

Figure B.8- Interaction plot for acceleration noise

Appendix C: Subjects location

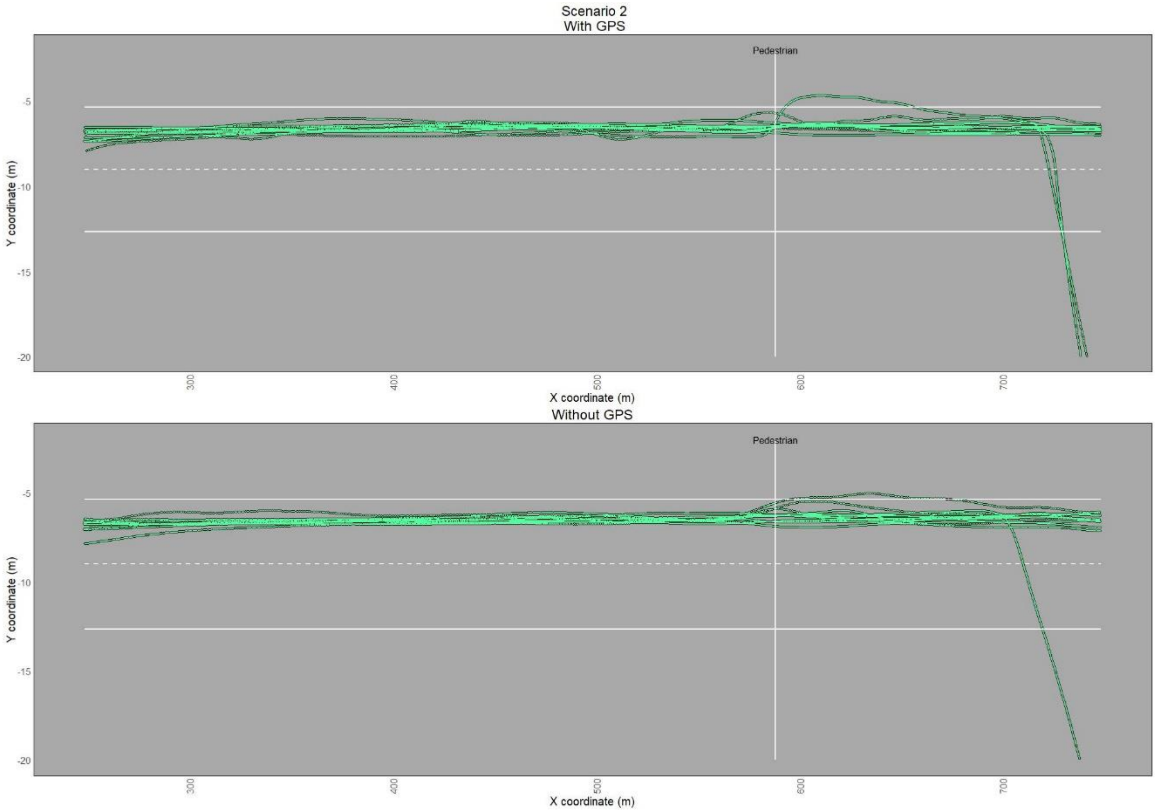

Figure C.1- Subject Position Scenarios 2 & 8

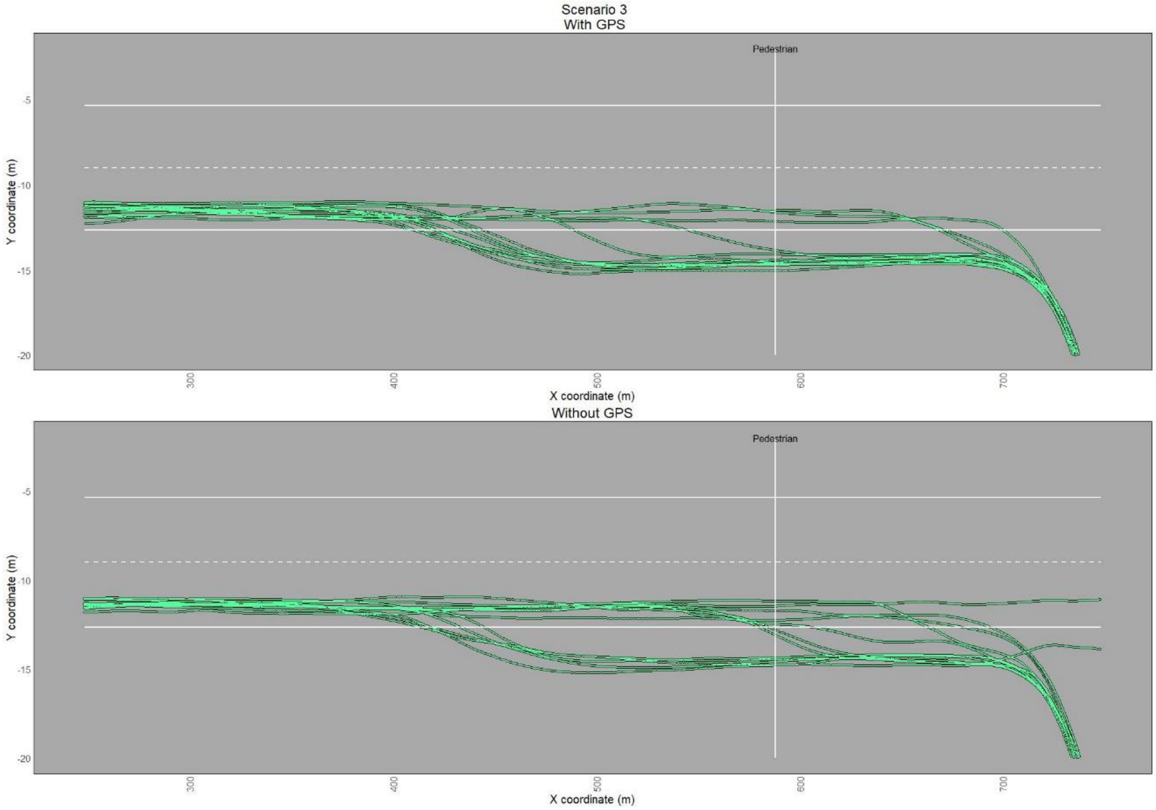

Figure C.2- Subject Position Scenarios 3 & 9

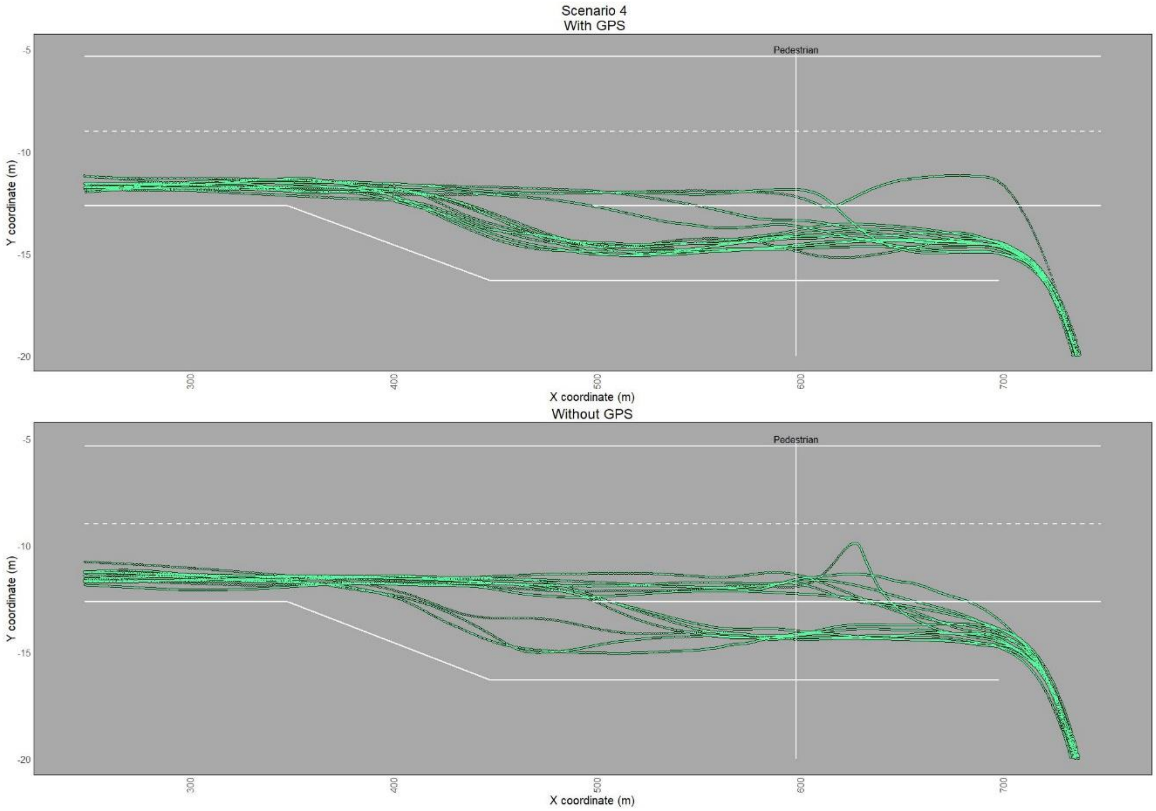

Figure C.3- Subject Position Scenarios 4 & 10

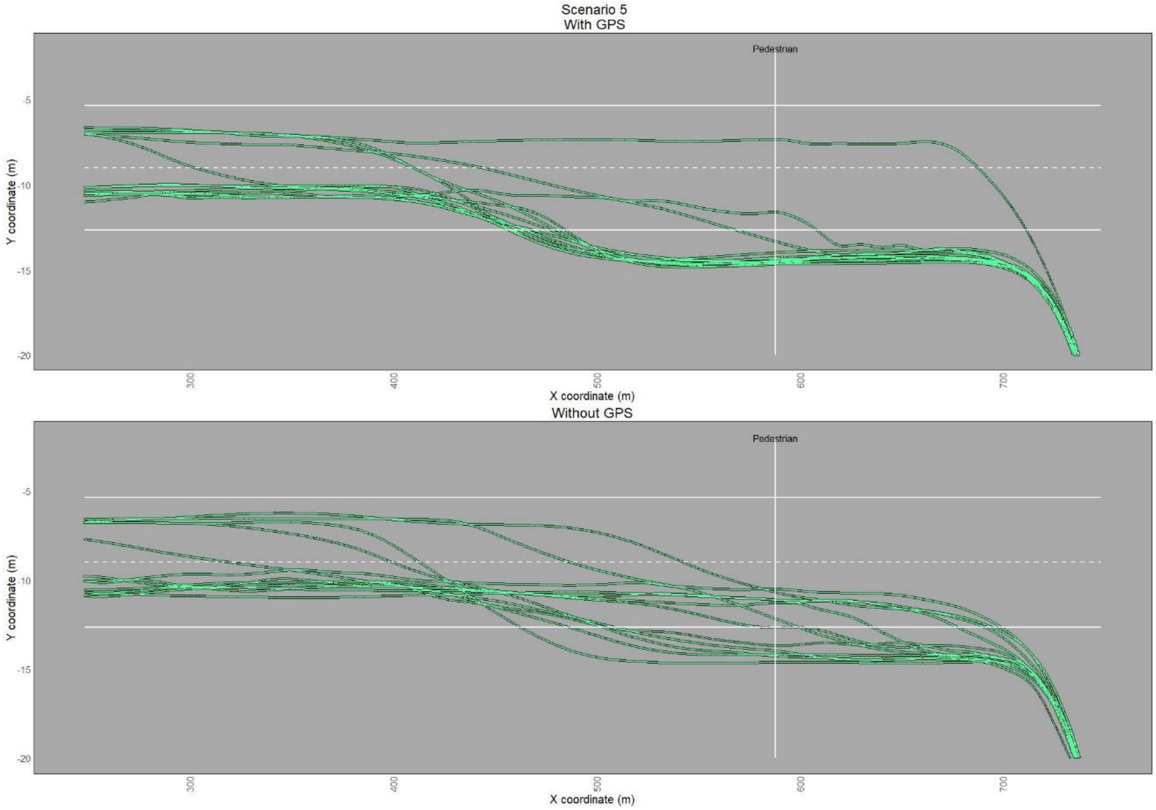

Figure C.4- Subject Position Scenarios 5 & 11

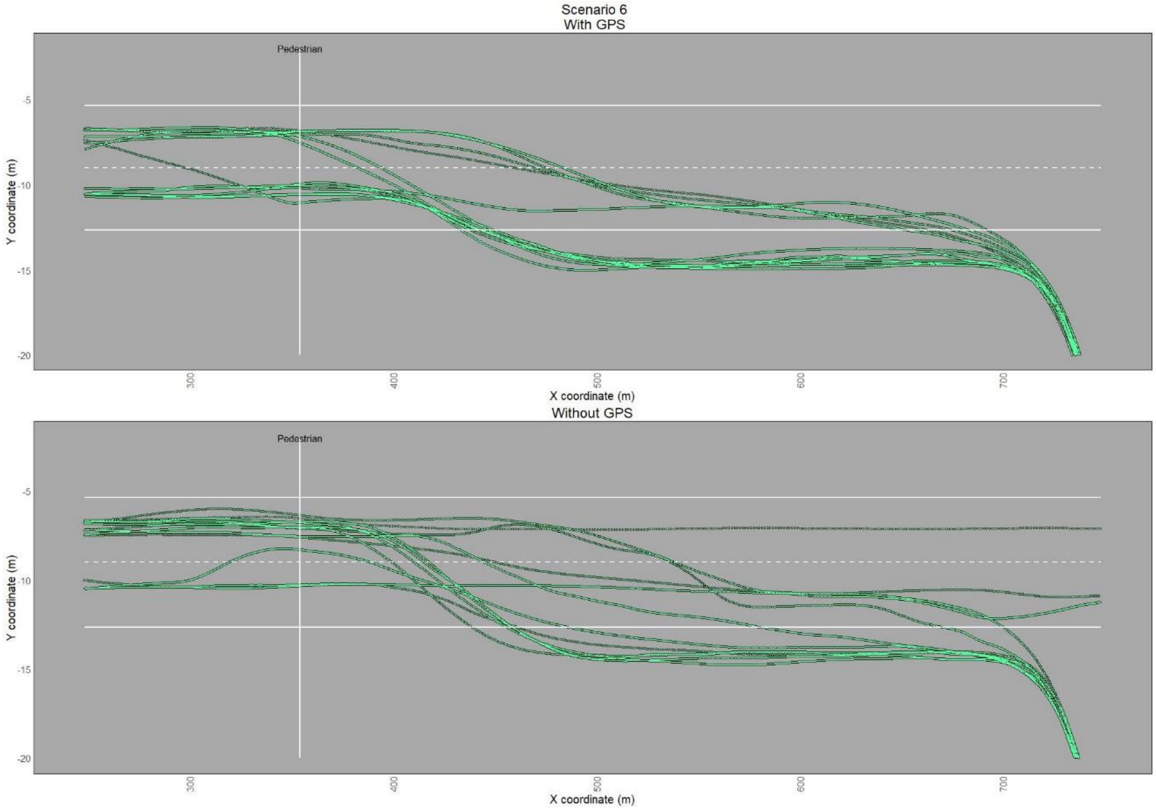

Figure C.5- Subject Position Scenarios 6 & 12