Assess Driver Behaviour through Work Zones using Driving Simulation: Comparison between Drivers Sensitized Using Virtual Reality and General Driving Population

SAFETY RESEARCH USING SIMULATION
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16. Abstract

Temporary traffic control in work zones (TTC) has different challenges in terms of safety for both workers in the work zone and drivers, whether in rural or urban settings. Ensuring the safety of workers and drivers in the work areas is important due to the complex geometry of the work areas, which includes modification of the configuration of the road, reduction of lanes, temporary presence of signs, channeling devices, and lane changes. In 2017, the Fatal Analysis Reporting System (FARS) reported 710 fatal crashes in work zones in the United States, out of which 132 involved construction workers. A study conducted by the Associated General Contractor (AGC) in 2019 showed that 67% of workers reported that motor vehicles had crashed into their work zone, and 8% of these crashes ended in fatalities. The study also indicates that 73% of the construction workers feel greater risk now than a decade ago. Work zone workers are increasingly concerned about the risks they face due to the location of their work zones on the roads, and it is a problem they perceive as serious due to the high level of danger they experience. The opposite is the case for road users, as they tend to be less aware of these risks since most of them have not been directly exposed to these dangers as construction workers.

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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AGC	Associated General Contractors
DOT	Department of Transportation
FARS	Fatal Analysis Reporting System
FHWA	Federal Highway Administration
GPS	Global Positioning System
IRB	Institutional Review Board
IVE	Immersive Virtual Environments
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Transportation Safety Administration
PRHTA	Puerto Rico Highway and Transportation Authority
PRT	Perception and Reaction Time
RTI	Real Time Technologies
SDLP	Standard Deviation of Lateral Position
TA	Typical Application
TCD	Traffic Control Devices
TRB	Transportation Research Board
TTC	Temporary Traffic Control
UPRM	University of Puerto Rico at Mayagüez
USDOT	United States Department of Transportation
UTC	University Transportation Center

Abstract

Temporary traffic control in work zones (TTC) has different challenges in terms of safety for both workers in the work zone and drivers, whether in rural or urban settings. Ensuring the safety of workers and drivers in the work areas is important due to the complex geometry of the work areas, which includes modification of the configuration of the road, reduction of lanes, temporary presence of signs, channeling devices, and lane changes. In 2017, the Fatal Analysis Reporting System (FARS) reported 710 fatal crashes in work zones in the United States, out of which 132 involved construction workers. A study conducted by the Associated General Contractor (AGC) in 2019 showed that 67% of workers reported that motor vehicles had crashed into their work zone, and 8% of these crashes ended in fatalities. The study also indicates that 73% of the construction workers feel greater risk now than a decade ago. Work zone workers are increasingly concerned about the risks they face due to the location of their work zones on the roads, and it is a problem they perceive as serious due to the high level of danger they experience. The opposite is the case for road users, as they tend to be less aware of these risks since most of them have not been directly exposed to these dangers as construction workers.

To increase road users' awareness about the danger construction workers are exposed to in work zones, the general public should develop empathy. Empathy is defined in the Cambridge dictionary as “the ability to share someone else's feelings or experiences by imagining what it would be like to be in that person's situation.”

The research objective is to investigate if exposing drivers to the work hazards that construction workers typically encounter in work zones influences their behavior while driving through work zones. Our study compares driver behavior between drivers that were sensitized using virtual reality (VR) and a driving simulator to drivers who were not sensitized using VR.

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

1. Introduction

1.1 Problem Statement

Ensuring workers' and drivers' safety in highway work zones is a challenge due to the complex change in road access for the drivers, including the temporary presence of signs, channeling devices, lane reduction, lane changes, and modified road configuration. In 2017, the Fatal Analysis Reporting System (FARS) reported 710 fatal crashes in work zones in the United States, out of which 132 involved construction workers (1). A study conducted by the Associated General Contractor (AGC) in 2019 showed that 67% of workers reported that motor vehicles had crashed into their work zone, and 8% of these crashes ended in fatalities. The study also indicates that 73% of the construction workers feel greater risk now than a decade ago (2).

Recently, construction workers have been increasingly concerned about the risks in work zones due to their exposure to hazards in their everyday work. The general public is often not as aware of these risks due to not having said exposure. The general public needs to develop empathy to heighten awareness regarding the risks to construction workers in work zones. Empathy is defined in the Cambridge dictionary as “the ability to share someone else's feelings or experiences by imagining what it would be like to be in that person's situation.”

The research objective is to investigate if exposing drivers to the work hazards that construction workers typically encounter in work zones influences their behavior while driving through work zones. Our goal is to investigate if exposing the general public to safety risks that construction workers face in work zones increases empathy and leads to risk perception and behavior changes. Our proposal includes a behavior and risk perception survey, the use of VR to immerse general drivers in virtual work zones environments where they have to perform typical work zone tasks, and the use of the UPRM driving simulator to evaluate drivers’ behavior in terms of speed, lateral position, and reaction time in a high-speed divided freeway work zone.

This research will contribute to understanding the impact of work experience in the work zone and the drivers’ risk perception and behavior in work zones. If the research results indicate a difference in perception between drivers who perform virtual tasks in work zones to increase empathy and drivers who only drive work zones, an educational module will be developed to increase empathy and awareness about the risks that workers face in construction work zones. The goal of the educational module would be to provide information so that the general public can visualize themselves in the construction workers' situation and modify their behavior while driving through highway construction work zones.

1.2 Research Objectives

The research objectives associated with the study are three-fold:

- To investigate whether exposing drivers to workplace hazards construction workers commonly encounter in work zones influences their behavior when driving through work zones. As well as investigating whether exposing the general public to the safety hazards construction workers face in work zones increases empathy and leads to risk perception and behavior changes.
- To evaluate driving behavior when approaching different highway work zone conditions on a two-lane road segment that included a lane closure.
- To Identify if subjecting the driver to a VR environment, designed from the worker's perspective in a highway construction work zone, generates the driver's empathy and improves safety.

1.3 Report Organizational Structure

The organizational structure of this research report consists of six chapters. Chapter 1 provides an introduction to the research project, problem statement, research objectives and the overall organization on the report. Chapter 2 includes a comprenhensive literature review on relevant topics that includes crash statistics, distraction while driving, temporary traffic control, lane closure on a two-lane road, legal uses and restrictions on cell phones while driving, empathy, driving simulators and VR. Chapter 3 describes the research methodology followed in this study, the experimental design and scenarios development, as well a the use of the driver simulator and VR. In Chapter 4 the analysis performed on the subject matters using the driver simulator and the observation study are discussed, specifically the effect of the average speed, position and empathy of the subject drivers. Chapter 5 provides a comparison with a previously highway work zone study with drivers without the VR experience. Chapter 6 summarizes the pertinent conclusions, recommendations and future research. Lastly, the cited references list is presented followed by appendices that includes the informed consent, pre-simulation and post-simulation questionnaire.

2. Literature Review

A comprehensive literature review was performed as part of this research project. Seven major areas were reviewed which are pertinent to the study. These are national crash statistics, distracted driving, temporary traffic control, lane closure on a two-lane, legal uses and restrictions of cell phones while driving, empathy, driving simulators and VR. This chapter summarizes the relevant literature related to these topics.

2.1. National Crash Statistics

In 2019, the National Highway Traffic Safety Administration (NHTSA) reported a total of 3,142 deaths because of distracted driving (11), and 842 of those fatalities occurred in construction work zones (12). The NHTSA defines distracted driving as any activity diverting attention from driving, including texting or talking on a cell phone, drinking, eating, talking to vehicle occupants, playing with the navigation, entertainment, or stereo system (13). A distracted driver and increased workload due to the presence of the TTC can potentially increase the risk of crashes because drivers may not be aware of changes in road geometry and the presence of workers performing tasks on the road zone.

2.2. Distracted Driving

Distractions on the road while driving can generate high potential risks for drivers, construction workers, and the general public. The GPS directions given to the driver to reach their destination can, in many cases, provide contradictory information due to the lack of real-time GPS updates when there are eventualities and changing road conditions such as construction zones.

In 2016, research conducted by State Farm shows that drivers are aware of the dangers of using smartphones while driving but continue to engage in such behavior. Of the drivers surveyed, 50% indicated using a cell phone to talk while driving and 35% sending text messages while driving. Forty-nine percent of respondents indicated that time efficiency was the main reason for using smartphones, and 34% of respondents say they send text messages while driving because it has become a habit (15).

It has been found in multiple studies that using smartphones while driving, negatively affects the following actions of the driver:

- Reaction time to perceive an event: Drivers distracted with smartphones take 42% longer to detect an event in their peripheral vision in conditions of hands-free and hand-held telephones (16).
- Aggressive braking: Drivers who are distracted by smartphone conversations brake more aggressively than drivers who are not distracted to reduce their initial speed when an unexpected event occurs (16). The aggressive braking to slow down for distracted drivers is primarily associated with rear-end collisions; this is the most common type of collision in highway works areas (17).
- Longer perception and reaction time (PRT): A study associated with PRT by Bellinger et al. conducted for twenty-seven young adults in a simulated environment, drivers distracted by smartphone conversations were found to have a 7.1% longer PRT.
- Unconscious time compensation: Bellinger et al. concluded that distracted drivers employ unconscious time compensation with faster brake pedal movement, resulting in stronger braking deceleration.
- Slower response and more intense braking when performing dual tasks: Bellinger et al. observed a slower response and more intense braking of dual-task drivers compared to single-task drivers (17).

2.3. Temporary Traffic Control

According to the Manual on Uniform Traffic Control Devices (MUTCD), the national reference for installing and maintaining traffic control devices in highway work zones, Temporary Traffic Control (TTC) plans are used to ensure optimal and efficient functionality for road users. The TTC is intended to assist highway users to safe and efficient movement when the normal function of a highway is temporalily suspended as well as to protect road users, workers, and first responders, traffic incidents and equipment (18). TTC are plans that guarantee the safety and continuity of the movement of motorized vehicles, pedestrians, bicyclists, and transit services throughout the work zone and provide access to the property and adjacent public services. Traffic control devices (TCDs) typically employed throughout the work zone to warn and inform users about changing road conditions and channel traffic are: warning signs, cones or drums, temporary markings on the pavement, and flaggers.

The MUTCD also provides Typical Applications (TA) that can be used depending on road configuration, volume, speed of road users, work activity, location of the work zone, and the combination of road vehicles. The MUTCD defines a TTC zone as an area of a road where the conditions of road users change due to a work zone, an incident zone or a special event planned through the use of TTC devices, uniformed police officers, or other authorized personnel. The four areas of a temporary highway work zone as defined in the MUTCD are:

- **Advance warning area:** “The advance warning area is the section of the road where road users are informed of the next work zone or incident area.”
- **Transition area:** “The transition area is the section of the road where road users deviate from their normal path. The transition areas usually involve the strategic use of cones ”.
- **Activity area:** “The activity area is the section of the road where the work activity occurs. It consists of the workspace, the traffic space, and the buffer space”.
- **Termination area:** “The termination area is the section of the road where road users return to their normal driving route. If posted, the termination area extends from the downstream end of the work area to the last TTC device, such as END ROAD WORK signs”.

2.4. Lane Closure on Two-Lane Road

Figure 6H-10. Lane Closure on Two-Lane Road Using Flaggers (TA-10)

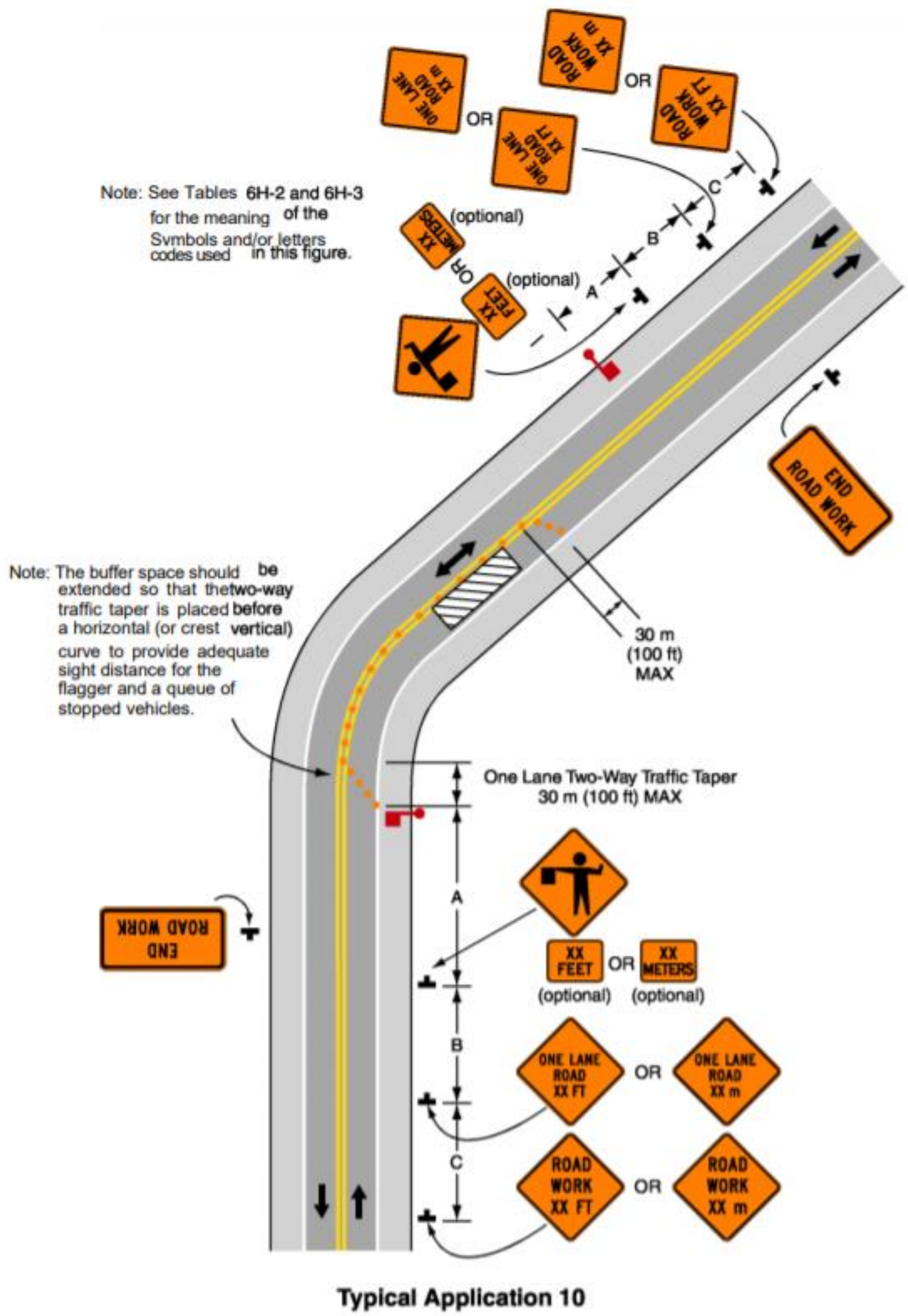


Figure 1 Lane Closure on a Two-Lane Road Using Flaggers (MUTCD, 2009)

2.5. Legal Uses and Restrictions of Cell Phones while Driving.

In Puerto Rico, while driving, the use of smartphones is prohibited by the law. Except for some circumstances:

- When the vehicle is completely stopped, and traffic is not obstructed, drivers can use a smartphone without a hands-free mode.
- When calls or communications are made to law enforcement or related agencies, drivers can use a smartphone.
- Drivers can use a smartphone in medical or safety emergencies, in situations of immediate risk to life, health, or property damage, when using GPS or when starting or ending a call.

It should be noted that the law does not apply to drivers of official vehicles who are attending emergencies (Esq Migdalia Millet 2012; “Puerto Rico Vehicle and Traffic Law '[Law 22-2000, as amended]” 2017) (14).

2.6. Empathy

Empathy is the natural capacity that human beings develop in interacting with other people (3). It is the ability to understand what other people need, feel and think to the point of feeling as if those needs and thoughts were their own (4). Empathy is a fundamental axis for successful social interactions (3). Many studies have shown that empathy increases understanding and encourages pleasant social behaviors. A study related to homeless populations was conducted to determine if empathy varies when people know the situation from the narrative and experience. The study used VR and compared behaviors. The results concluded that the people who had the experience with VR signed more petitions supporting initiatives towards homeless people than those without the VR experience (5). VR in 2015 was named the "ultimate empathy machine" as it allows people to experience any situation, even from another person's point of view (6).

The interest in VR as an empathy-promoting instrument has increased to the point that there are many productions of immersive virtual environments (IVE), which are computer-generated 3D environments where people can move freely in environments designed exclusively to increase empathy. These settings give people the opportunity to experience a specific situation from another person's perspective (7). Other studies show that taking another person's perspective can effectively promote empathy and achieve successful social interactions (8,9). For instance, in 2018, a study by Stanford University revealed that VR environments could help make people more compassionate compared to other media (10).

2.7. Driving Simulators and Virtual Reality (VR)

Driving simulators are a research tool used to evaluate drivers' behavior in multiple research fields, psychology, transportation, medicine, human factors, computing, education, training, and other driving activities (20). Driving simulators have been used to evaluate scenarios with different events, e.g., physical damage or potential crashes, and eliminate the level of danger by not exposing individuals. Using driving simulators, researchers can anticipate, evaluate, and provide possible solutions to road safety problems by analyzing the behavior of subjects in the face of simulated events and existing conditions. In addition to driving simulators, the research project presented in this report also uses a VR simulator.

The use of VR provides a unique experience to people because it allows the participant to play various roles and personifications. VR can provide a role-playing situation with almost complete sensory immersion in a controlled environment. The VR system characteristics include immersion, allowing the user to experience activities from an internal perspective, and reactiveness, respective to observable variations based on the user’s actions (21).

These simulation technologies have become a valuable tool in transportation research to study human factors and behavior; the most remarkable examples are driving simulators that reproduce customized scenarios and manage the parameters under investigation (22).

3. Research Methodology

The research methodology consists of six tasks. The first task was the literature review that included relevant information on driving distractions and their impacts, construction work zones on rural two-lane highways, empathy, and the use of driving simulators. The second task was the approval of the Institutional Review Board (IRB) for the simulation study. The third task was developing the scenario of a two-lane rural road, similar to the existing road conditions of the PR-108 highway, located in the western region of Puerto Rico. The design of the scenario included the closure of one of the traffic lanes using suitable temporary traffic control devices, with the design of the TTC plan following the guidelines provided by the MUTCD and the VR scenario recreated so that the driver can assume the role of a worker in a construction work zone on a highway. This was done for the driver to experience the risks associated with road safety to which the worker inside the work zone on the highway is exposed and finally assess whether the driver felt or had no empathy for the worker. The fourth task was data collection, a total of 24 subjects between 18 and 70 years old, with a valid driver's license and more than 18 months of driving experience, were recruited to assume the role of the worker in the construction zone of a road in the VR device and to drive in the simulator. The drivers' awareness of the risks associated with road safety faced by the construction zone worker was evaluated using the VR device. The driving simulator was used to assess the driver's behavior in terms of speed, lateral position, and reaction time in the two-lane highway work zone. In addition to the data collected using the driver simulator, a researcher noted the subjects' reactions as they drove in each scenario. Focusing on the reactions before, during, and after the subjects' encounters with each of the two work areas presented per scenario. The fifth task consisted of carrying out the statistical analysis of the driver's behavior in both situations, both for VR and for the driving simulator. Finally, the sixth task was to write the final report that includes all the findings related to the study.

Figure 2 Research Methodology

3.1 Driving Simulator Equipment

The driving simulator located at the UPRM consists of a portable cockpit simulator with three main components: driving cockpit, visual display, and computer system. The driver's cab contains the car seat, steering wheel, gear lever, two turn signals, and the accelerator and brake pedals. The base is made of wood and has six wheels for mobile applications. The visual screen consists of three overhead projectors and three screens that generate 120 degrees of visibility on the road with a resolution of 1080p. And finally, the computer system uses a laptop and desktop computer with SimCreator / SimVista simulation software from Real Time Technologies, Inc. (RTI) and an audio system that simulates vehicle and surrounding noises.

3.2 Experimental Design

Four experimental scenarios will be created using a roadway of a four-lane freeway. The scenarios will show the roadway conditions and an active GPS navigation application with visual and auditory instructions to the drivers. In the scenarios without traffic, a worker will encroach the 3.8 m right lane and the 3.0 m deceleration lane perpendicular to traffic at a walking speed of 1.07 m per second.

Independent Variables

Table 1 Independent Variables

Variable Name	Factor or Block	Numerical or Categorical	Fixed or Random	Levels
Age	Block	Numerical	Fixed	18-25,26-45,46-70
Gender	Block	Categorical	Fixed	Female, Male
Traffic	Factor	Categorical	Fixed	Yes, No
Type of Work Zone	Factor	Categorical	Fixed	Right Lane, Left Lane, Right Should
VR use	Factor	Categorical	Fixed	Yes, No

Dependent Variables

Five dependent variables, namely, mean speed, deceleration, speed variance, reaction time, and lateral position, were evaluated to assess and compare the drivers' behavior. These variables were measured in the four areas that compose a work zone, namely: advanced warning area, transition area, activity area, and termination area.

3.3 Scenarios Development

3.3.1 Driving Simulator

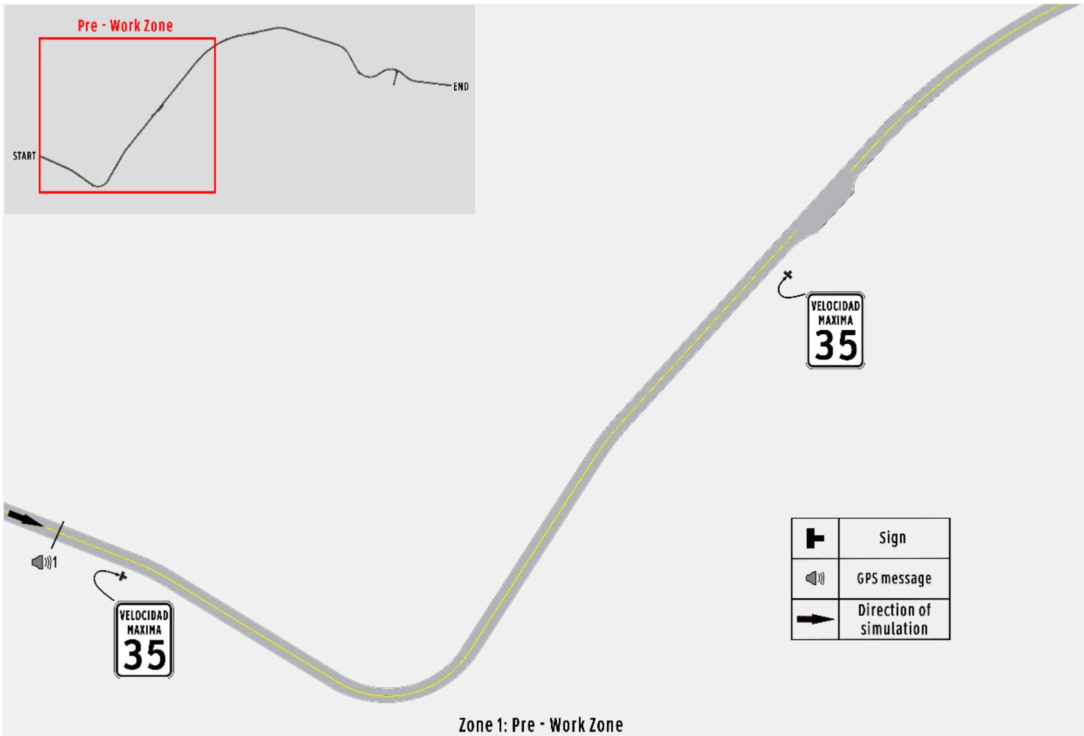
The existing two-lane rural highway PR-108, located in the western region of Puerto Rico, served as the base scenario for the driving simulator. The geometric and operational characteristics are:

- length of highway section: 1.8 km
- number of horizontal curve segments: 9
- roadway cross-section width: 7.7 m
- lane width: 3.2 m
- posted speed limit: 35 mph

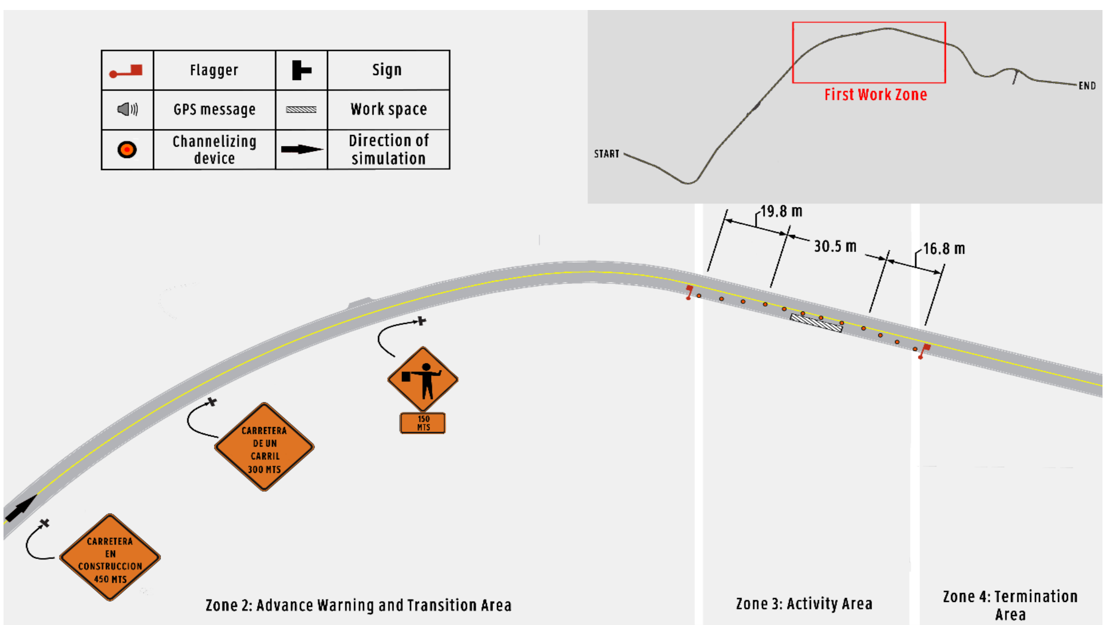
Once the simulation begins, the driver will be located 1.2 km away from the beginning of the work zone. The four scenarios mentioned above were developed using a base road scene with the characteristics previously presented. Figure 3 shows an example of the simulated cross-section scenario.

Figure 3 View of the Simulated Roadway with Active GPS and Flagger Condition

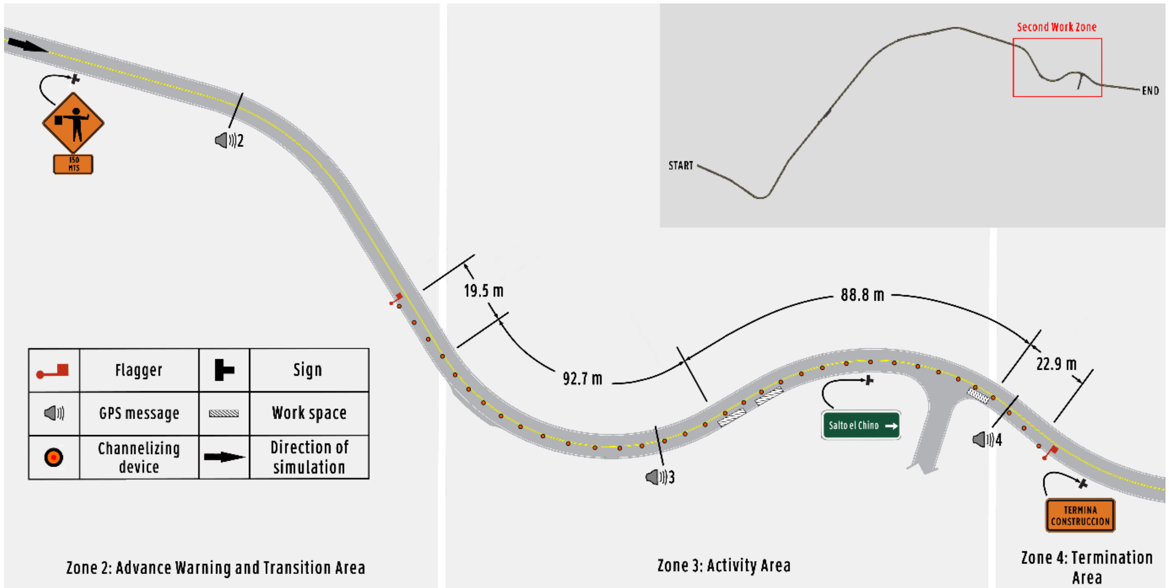
A segment preceding the work zone and two continuous work zones are presented in plan view sketches of the base scenario in Figure 4. These sketches illustrate the scenario with the corresponding work zone components. As shown in the pre-work zone in Figure 4(a), the first GPS message and posted speed limit are used to help the driver maintain a normal driving condition before reaching the advance and transition areas of the first one-lane closure work zone. The utilized workspace has a series of channelizing devices separating the available lane for vehicles coming from both directions, which in turn is defined by the presence of workers and the equipment located in the right lane. Both TTC plans in Figure 4(b) and Figure 4(c) complied with the MUTCD TA-10. The only difference with the typical application is that the text messages in the signs are in Spanish instead of English due to the location of the simulated highway.



a) Pre – Work Zone alignment



b) TTC Plan for the First Work Zone



c) TTC plan for the second work zone

Figure 4 Plan View of the Roadway and Work Zone Conditions

In scenarios where a GPS message was used for directions, four-voice instructions were provided to the driver in different locations, directing them towards an exit blocked by the work zones. The locations used in the simulation are shown in Figure 3. The instructions provided by the GPS are:

- "Continue on PR-108 for a kilometer and a half."
- "After 300 meters, turn right towards Salto el Chino."
- "Turn right towards Salto el Chino."
- "Recalculating… head north on PR-108 towards Camino las Hortensias… after 300 meters turn right towards Camino las Hortensias."

The research established a conflicting decision for the drivers to determine the effect of the GPS as a distraction. The GPS was not updated with information on road conditions; therefore, the voice message would still indicate the driver to take the exit that was blocked by the work zone. On the other hand, drivers without a GPS had already been given instructions to start driving and head to the exit which corresponds to the "Salto del Chino" road. The drivers had to decide if they would follow the GPS instructions and take the exit, thus encroaching into the TTC workspace or ignore the GPS directions and continue driving along the road without taking the exit.

3.3.2 Virtual Reality (VR) Simulation

VR can provide a role-playing situation with almost complete sensory immersion in a controlled environment. The system characteristics include immersion, allowing the user to experience activities from an internal perspective, and reactiveness to observable variations based on the user's actions (21). Simulation technologies have become a valuable tool in transportation research to study human factors and behavior; the most remarkable examples are driving simulators. Simulators allow the reproduction of standardized scenarios and manage the parameters under investigation (22). Pedestrian simulators that help envision virtual roadway scenarios from the perspective of pedestrians are currently being used as a powerful transportation safety research tool. Recent advances in VR technology now present opportunities for researchers to develop and carry out new realistic and engaging pedestrian studies that have significant safety, costs, or complexity implications (23). The essential elements of VR are interactive simulation, implicit interaction, and sensory immersion, as mentioned above. The user observes the environment through small monitors attached to a lightweight head-mounted device known as glasses. The technology provides the option of adding controls or handles for a more reliable experience. The fidelity of the VR devices refers to the accuracy with which actual sensory cues are reproduced (24). Nevertheless, current VR setups will differ from recreating perfect real-world scenarios because computer display technologies are still imperfect. Not all the perceptual and contextual cues needed to recreate a real-world experience are known yet (24). These VR devices are usually promoted commercially for gaming and entertainment purposes, but they are also applied in medicine, architecture, defense, and art. The primary senses activated during the performance of a VR scenario are sight and hearing, allowing the user to experience roadway situations that, in real life, could be risky or even fatal. Even with the current limitations, VR technologies can study the human brain and its reactions to sensory and cognitive cues (24). Enabling pedestrians to encounter complex situations by being immersed in a virtual environment would allow researchers to study human factors, the differences in behavior and performance between pedestrians, roadway safety issues, the effects of new road design strategies, or new traffic control devices, among other benefits.

(23) used an HTC Vive VR headset and a Unity 5 virtual environment to recreate an urban downtown setting with two-lane streets and a four-leg intersection with pedestrian crosswalks. The objective of their study was to obtain objective and subjective measures of subjects crossing the intersection at one of the 5.5-meter-long crosswalks. The average walking speed found for the 26 subjects in their study was 1.07 m/s. The experiment observed that the subjects were hit by a vehicle in 10.8% of the crossing simulation runs. They concluded the fidelity of VR simulation allows obtaining objective measures of pedestrian behavior, such as average walking speeds, that match those measured in real-world situations.

Methodology

The testing and training phase was initially made with the HTC Vive Pro Eye headset and a desktop computer readily available for the research team. The HTC Vive Pro Eye headset provides a detection area of up to 33 ft^2 and includes eye-tracking and wireless capabilities. The specifications of the two VR headsets, gaming laptop, and desktop computer are provided in Section Equipment.

The next step included the development and programming of the simulation scenarios created with the Unity 2019.4.2f1 platform. A base scenario that represented a construction zone segment in a rural context was created. Moving traffic was programmed in two directions in the simulation. The task required the subject to serve as a surveyor's assistant, carrying a stadia rod. The subject performed the activities that a survey technician would do to help a chief surveyor take measurements of the terrain's topography. The subject had to cross the open lane to perform their activities; therefore, they had to observe the gaps in the incoming traffic and cross the road safely to the other side. In addition, the subject was confronted with different typical sounds of construction areas that may affect their performance. That process was repeated four times at various points in the work zone.

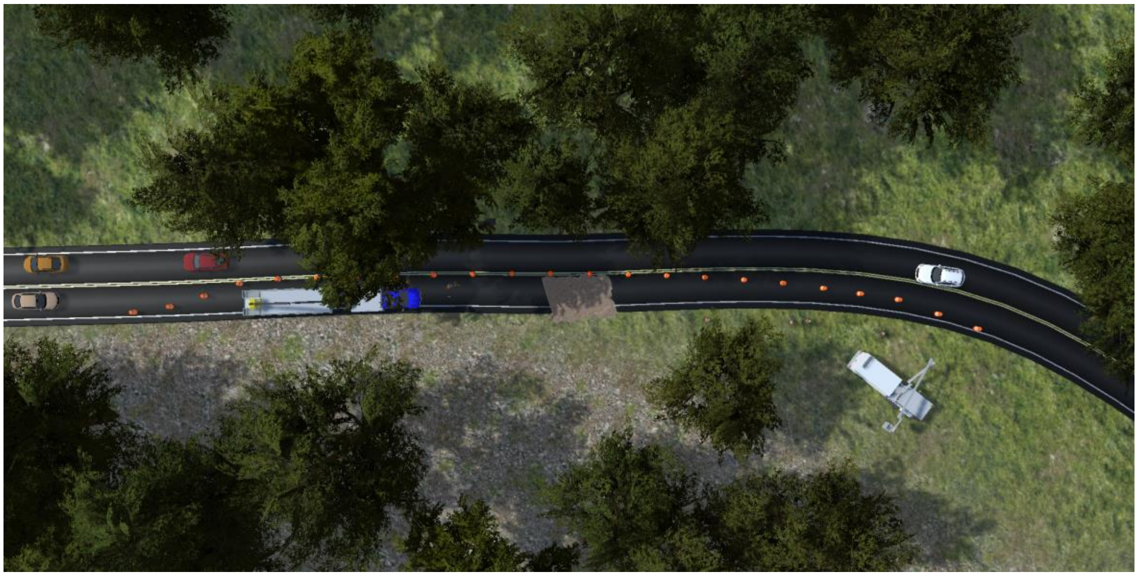


Figure 5 Plan view of the simulated Virtual Reality scenario

Scenarios Development

The VR stage is based on the second construction zone configuration developed in the driving simulator. The characteristics and geometry of the virtual scenario are similar to a section of the existing two-lane rural highway PR-108 located in the western region of Puerto Rico. The stage consists of a two-lane rural segment covering an area of 300 square meters. Figure 5 shows a plan view of the simulated VR scenario. The vehicular flow is reduced to one lane within a construction zone that is 100 meters long. Figure 6 shows the main section of the construction area. Given the spatial limitations of the virtual simulator, the working area of each subject consists of a 6 square meter area. The subject performs the task right in the middle of the traffic-controlled construction area. Figure 7 shows the area of interest and vehicular flow from the subject's point of view.

Figure 6 Area of interest for the subject's tasks

Figure 7 Area of interest and vehicular flow from the subject's point of view

Equipment

The UPRM research team has the HTC Vive Eye Pro VR headset, shown in Figure 8. This new VR headset, released to consumers in 2019, is an expanded version of the HTC Vive Pro headset and includes native, built-in eye-tracking capabilities. The basic setup consists of the VR headset, two handles, and two sensors, but this system has expansion capabilities to improve the VR simulation. The headset also comes with detachable headphones to reproduce sounds inside the VR simulation.

Figure 8 HTC Vive Eye Pro Headset, Controllers, and Base Stations

The headset has foveated rendering capabilities that produce higher fidelity VR images while requiring less processing power by rendering the parts of the scene that the subject is looking at in high resolution while lowering the resolution on images located on the peripheral vision (Hollister, 2019). Besides providing better resolution for the VR graphics and eye-tracking capabilities, the HTC Vive Pro Eye VR headset can add more sensors to expand the detection box to an area of 32.8 ft x 32.8 ft. Also, the headset can add a mountable antenna to replace the cable that communicates with the computer. This option eliminates the mobility restriction and safety concerns of the connecting cable. The larger detection area allows the experiment to expand the rural roadway context. Table VR2 presents the technical specifications for the HTC Vive Eye Pro VR headset.

Table 2 Technical Specifications of the HTC Vive Eye Pro VR Equipment.

Screen	Dual OLED 3.5-in diagonal
Resolution	1440 x 1600 pixels per eye (2160 x 1200 pixels combined)
Refresh rate	90 Hz
Field of view	110 degrees
Audio	Hi-Res-certified headset, Hi-Res-certified headphones (removable), high-impedance headphone support, and enhanced headphone ergonomics
Safety features	Chaperone play area boundaries and front-facing camera
Sensors	SteamVR Tracking, G-sensor, gyroscope, proximity, eye comfort setting (IPD) and eye-tracking
Connections	USB-C 3.0, DP-1.2, Bluetooth
Eye Relief	Lens distance adjustment
Controllers	SteamVR Tracking 2.0, Multifunction trackpad, Grip buttons, dual-stage trigger, System button, Menu button, and Micro-USB charging port
Room-scale	Up to 32.8 ft x 32.8 ft using four SteamVR Base Station 2.0
Base Stations	Includes two 2.0 base stations, and two more were acquired to achieve the area's full capacity

One desktop computer and one gaming laptop computer were available to set up the VR simulator and conduct the experiments. The desktop computer is a Rave-PC model with an Intel Core i7-4770S processor, 16 GB of RAM, and an NVIDIA GeForce GTX 1080 graphics processor with 8 GB.

4. Analysis of Driving Simulation

4.1. Subjects

Twenty-four subjects participated in the study, all with a valid motor vehicle driver's license in Puerto Rico and with an age range of 18 to 70 years. The study followed the ethical standards of the Institutional Review Board (IRB) of the UPRM.

All subjects participated in 4 different scenarios. At the beginning of the simulation, they received visual instructions on where to go. Upon reaching the work zone, the driver had to decide between continuing or stopping to assess whether a vehicle was approaching from the opposite direction. In the flag bearer scenarios, the participant had to wait for the order to pass through the area. Within each stage, approximately 1.6 km away, a destination sign tells the driver which exit to take. The work zone blocks this exit on purpose. The driver must recognize the changes in the road by the presence of the work zone and decide whether to continue (the most correct and safest decision) or encroach the work zone (the wrong and dangerous decision). In scenarios where a GPS gives directions to the driver without considering the temporary modification of the road through the work zones, the driver receives sound instructions to take the exit, simulating that the GPS is not updated with information on existing road conditions. Since the workspace blocks the exit, the driver is faced with the dilemma of whether to encroach the workspace to take the exit indicated by the GPS. The expected correct behavior would be to continue the road and look for alternative ways to get to your destination.

4.2. Experimental Results and Data Analysis

4.2.1. Observational study

After collecting the necessary information for the study, the data is analyzed in detail using the Power BI program. In addition, the observational data were recorded in Excel to be used in the analysis.

Figure 9 shows the percentage of participants who entered the lane in the opposite direction upon reaching the first construction zone without stopping. The horizontal axis shows the order in which the researchers ran the scenarios. In this case, the order is important. As can be seen, reflected in the figure, there is evidence of a difference between the first time the drivers face the simulation and the subsequent executions. When the subjects drove through the work zone for the first time, 29% of those who reached the first work zone encroached the opposite lane without stopping. These subjects arrived at the work zone and, instead of stopping to check if a vehicle was coming from the other direction, they continued straight ahead. In the second work zone, only 21% encroached the highway work zone without taking adequate precautions. The percentage of drivers who encroached the work zone was much lower for subsequent runs. This indicates that drivers were driving as usual when they approached the first work zone for the first time without noticing the signs. Still, they were more cautious in subsequent runs, noting that oncoming traffic was not going to stop because they were encroaching their lane. The learning curve was fast in most cases. However, some subjects still encroached the opposite lane without stopping even in their fourth run.

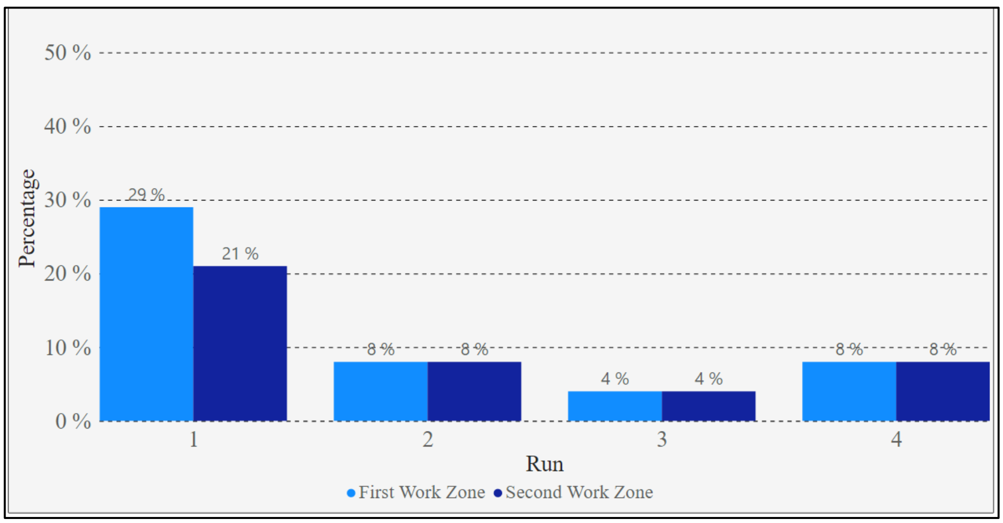


Figure 9 Percentage of Drivers encroaching the Opposite Lane Without Stopping

The three most common reactions of drivers once they faced the work zone include first to continue without stopping as shown in Figure 9; second, to crash with the vehicle coming from the opposite direction when encroaching the lane; and finally, the third reaction was at the moment that drivers realized that they encroached the opposite lane and a vehicle was coming, they stopped and backed up. The percentage of drivers who crashed when encroaching the opposite lane adjacent to the work zone is shown in Figure 10. The highest percentage (17%) of drivers who crashed with the vehicle coming in the opposite direction was the first time they ran the scenario, but this figure decreases for the subsequent runs. However, this situation continued even when the subjects knew that a vehicle could be coming in the opposite direction.

Figure 11 shows that 17% of drivers backed up when they entered the opposite lane, and a vehicle was coming from the opposite direction. In runs one and four, some subjects tried to encroach the opposite lane without adequate precaution, but their immediate reaction was to back up when they saw the vehicle coming from the opposite direction.

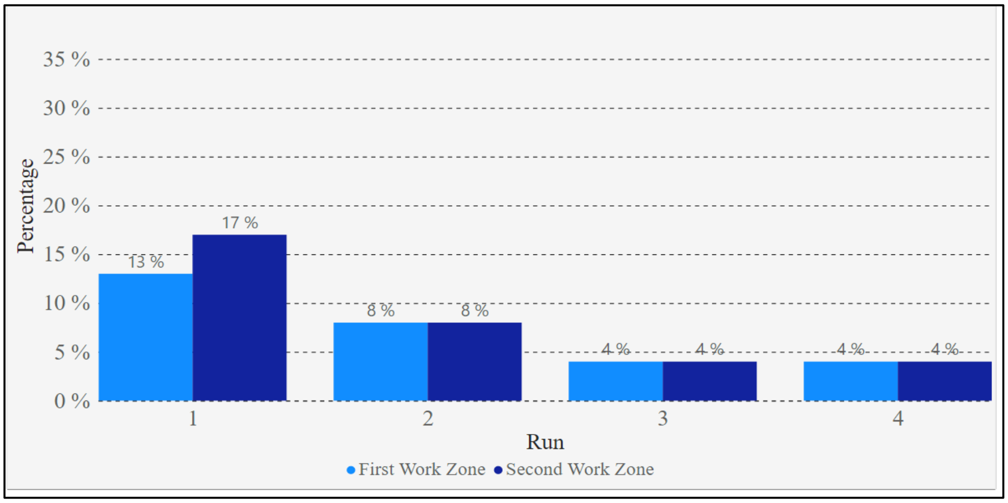


Figure 10 Percentage of Crashes after encroaching the Opposite Lane

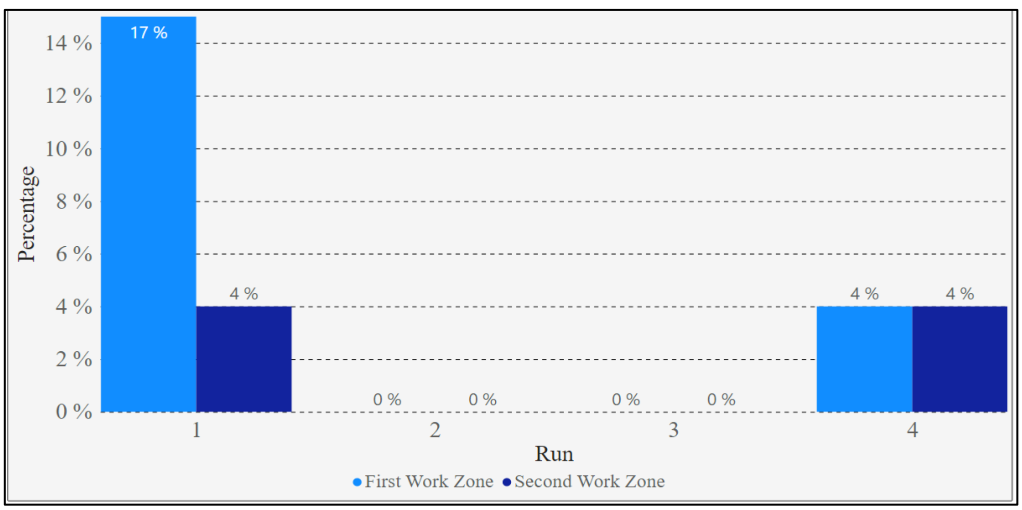
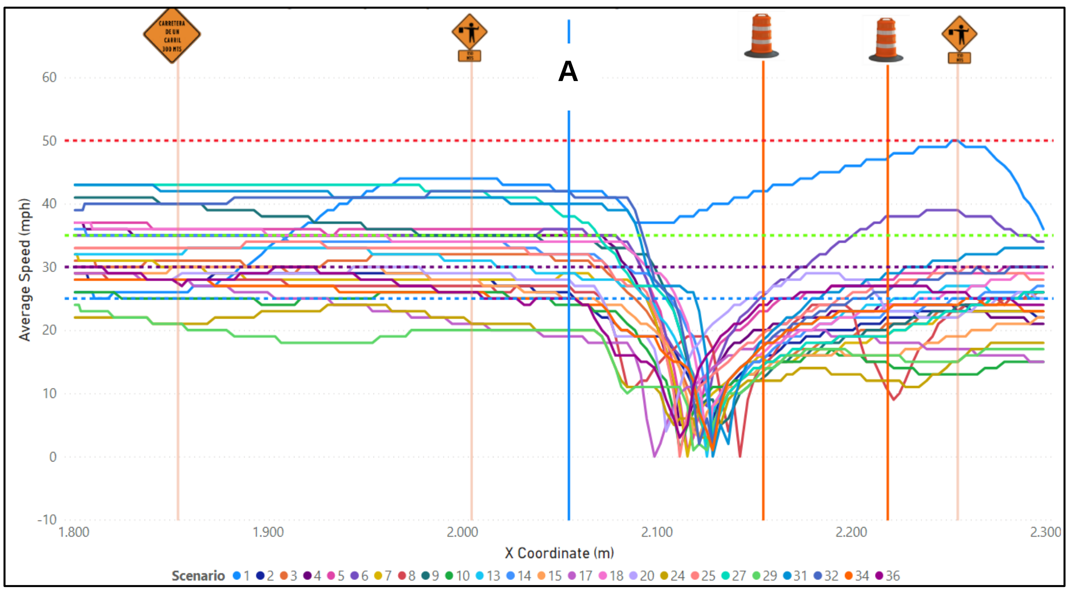


Figure 11 Percentage of Reverse Maneuvers after encroaching the Opposite Lane

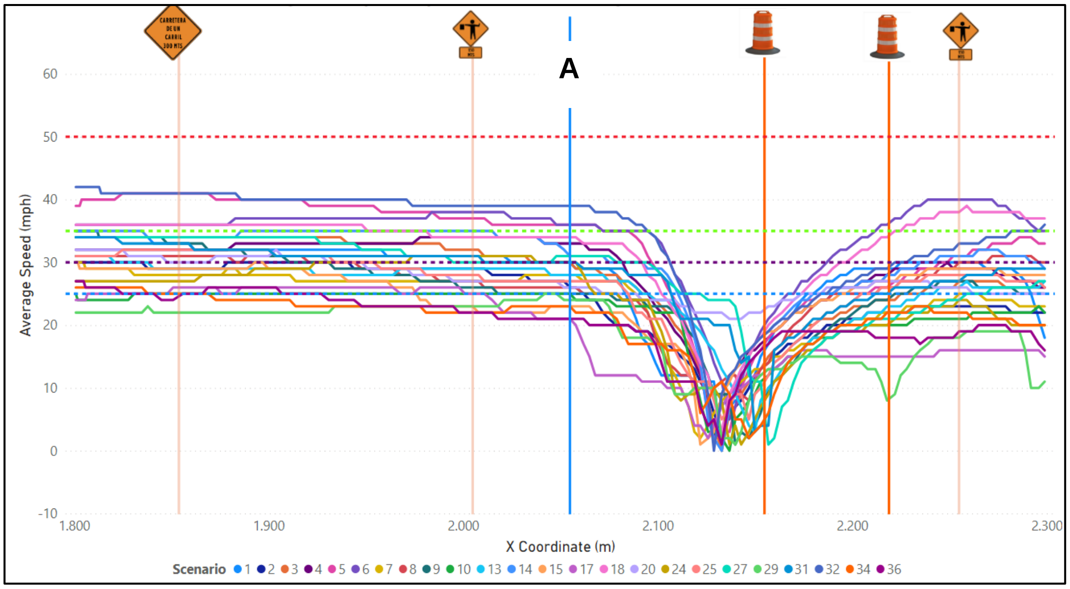
4.2.2. Average Speed

The speed profile of the drivers through the first work zone in each of the evaluated scenarios is shown in Figure 12 (A, B, C, D), which correspond to scenarios 1, 2, 3, and 4, respectively. In scenarios 1 and 3, a flagger with a STOP / SLOW paddle is positioned at the beginning of the merging zone. The vertical line "A" in the figures specifies the visual point where the drivers perceive the work zone for the first time; this point is approximately 100 meters before the first drum. According to the figures, most drivers stop when they reach the work zone. However, one of the drivers did not stop even with the flagger and the TTC devices shown in the figures.

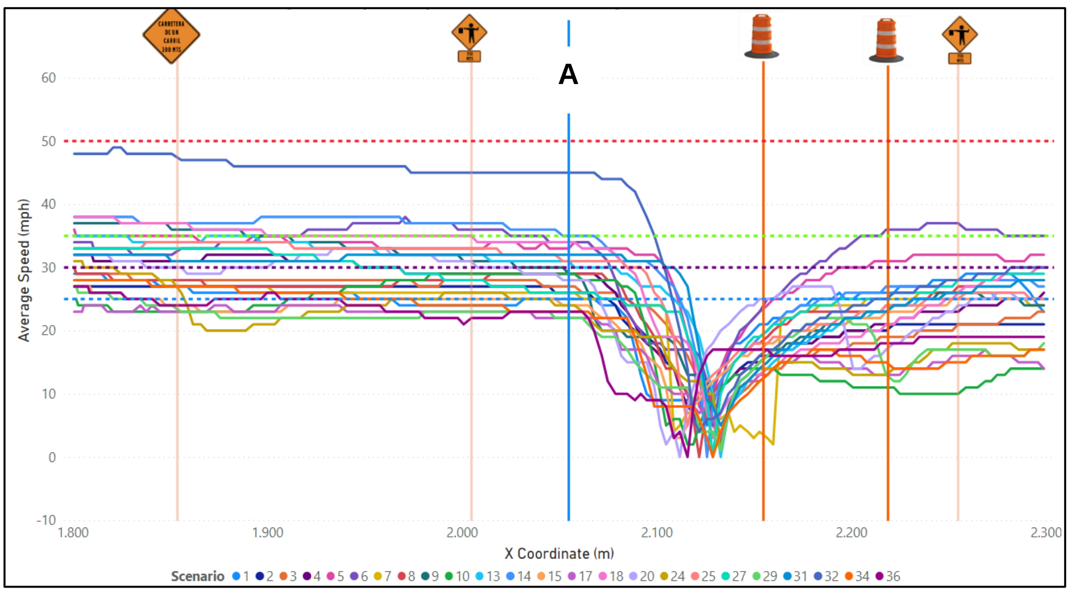
Figures B and D, corresponding to scenarios 2 and 4, show that three drivers reduced their speed but did not stop completely. It should be noted that on some occasions, the drivers stopped at different points on the run before reaching the work zone.



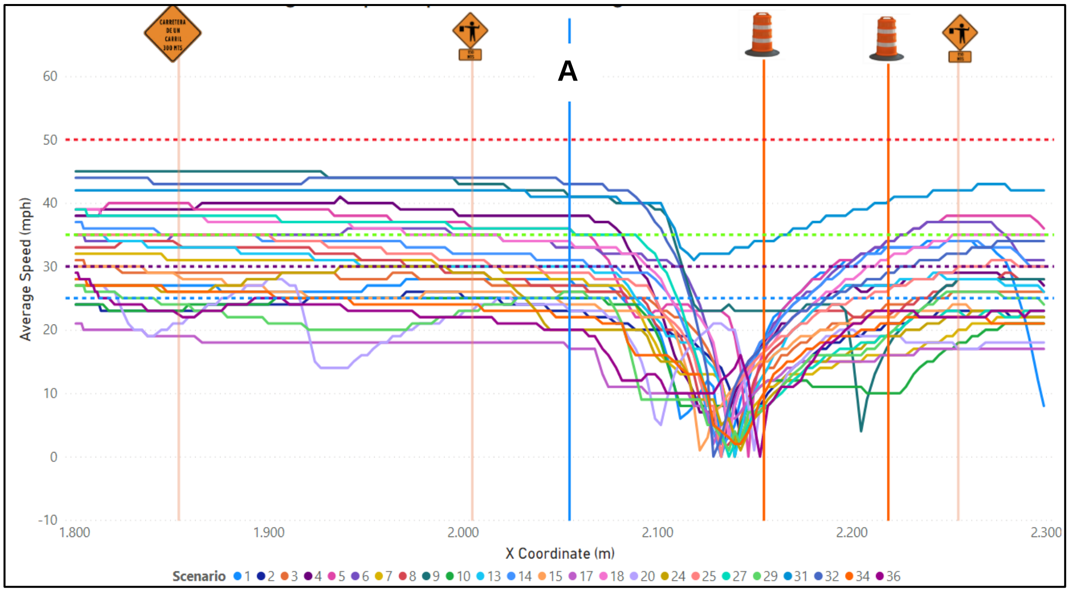
A. Average Speed Profile - Scenario 1



B. Average Speed Profile – Scenario 2



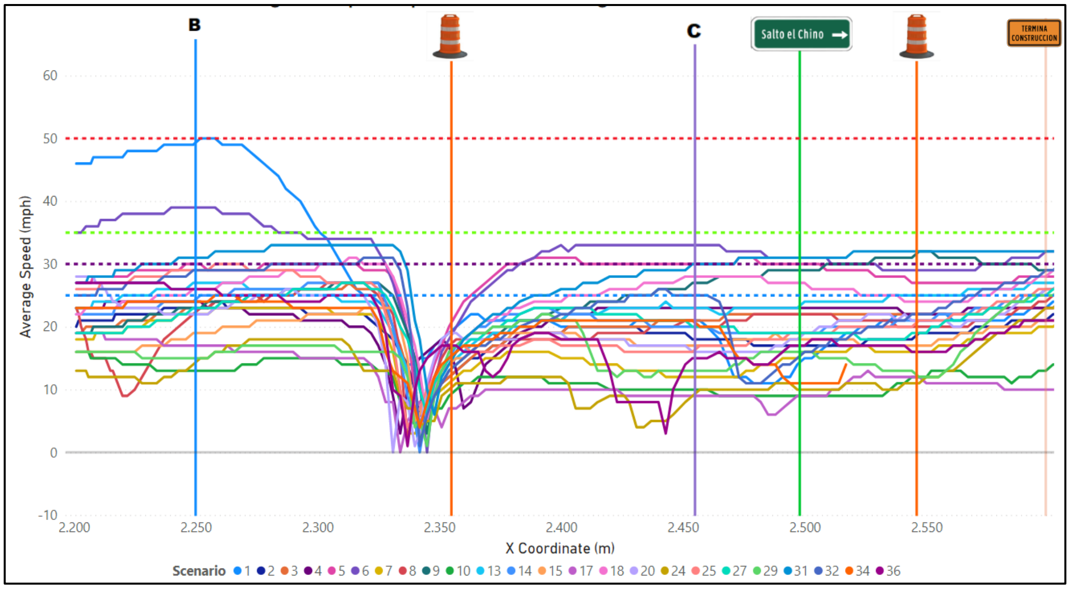
C. Average Speed Profile – Scenario 3



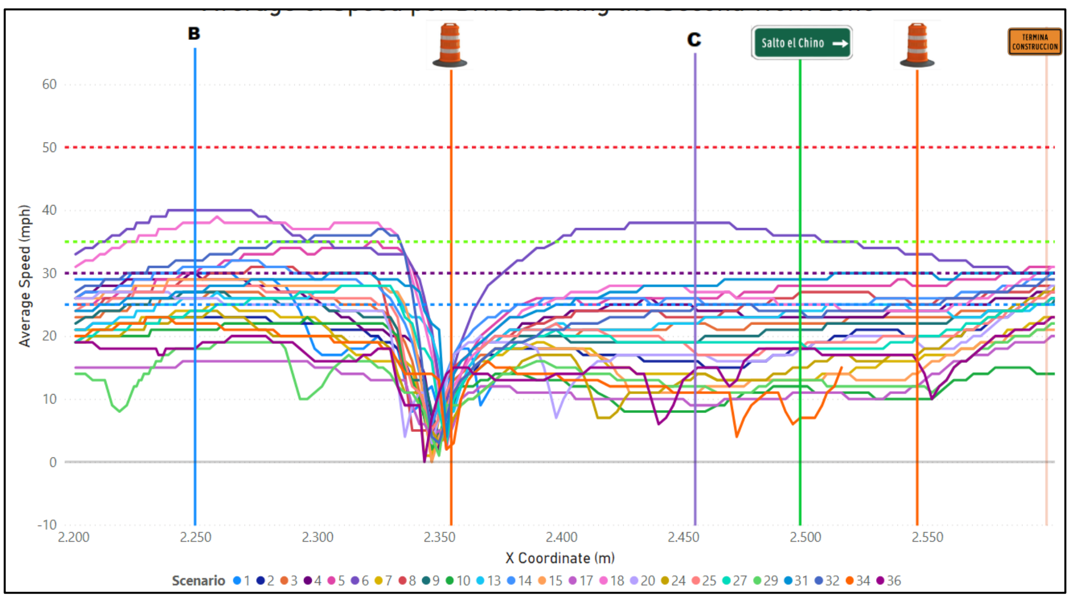
D. Average Speed Profile – Scenario 4

Figure 12 Speed Profiles Along the First Work Zone.

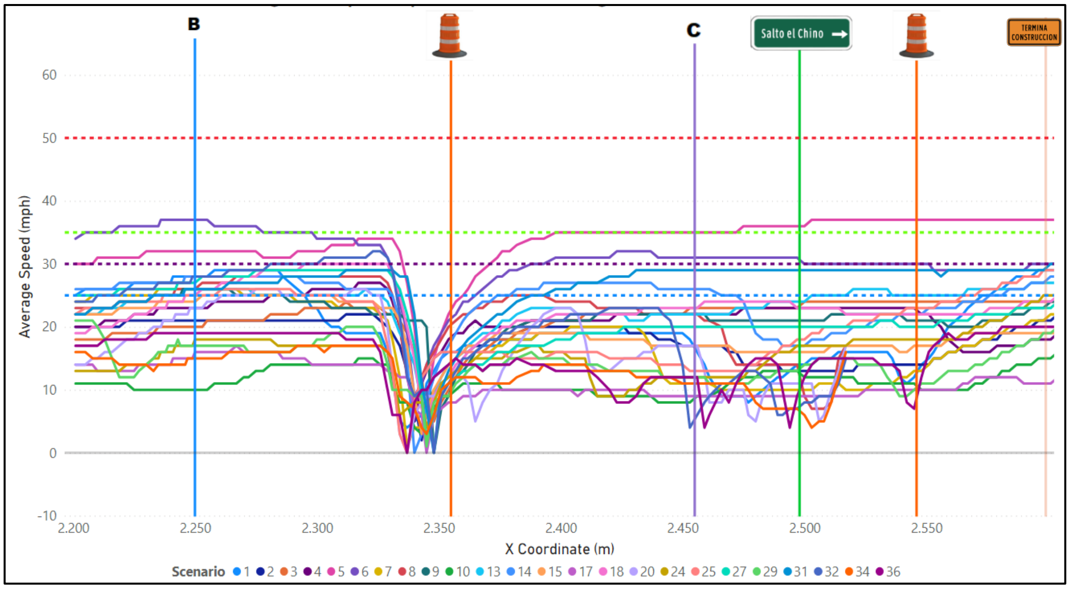
Figure 13 shows the speed profiles for the four scenarios in the second work zone. A line "B" within the figures indicates the point from which the start of the channeling devices or the flagger in the second work area is visible. Line "C" is the point from which you can see the sign indicating the exit to "Salto del Chino," which is the exit that drivers were instructed to take. The figures show that when the subjects observe the sign that indicates the destination to "Salto del Chino," they slow down. Some drivers stop, others enter the lane encroaching the workspace, but most drivers continue looking for an alternative route. It was observed that during the first run, 21% of the subjects encroached the second construction zone; in other words, they took the exit "Salto el Chino" as instructed at the beginning of the simulation.



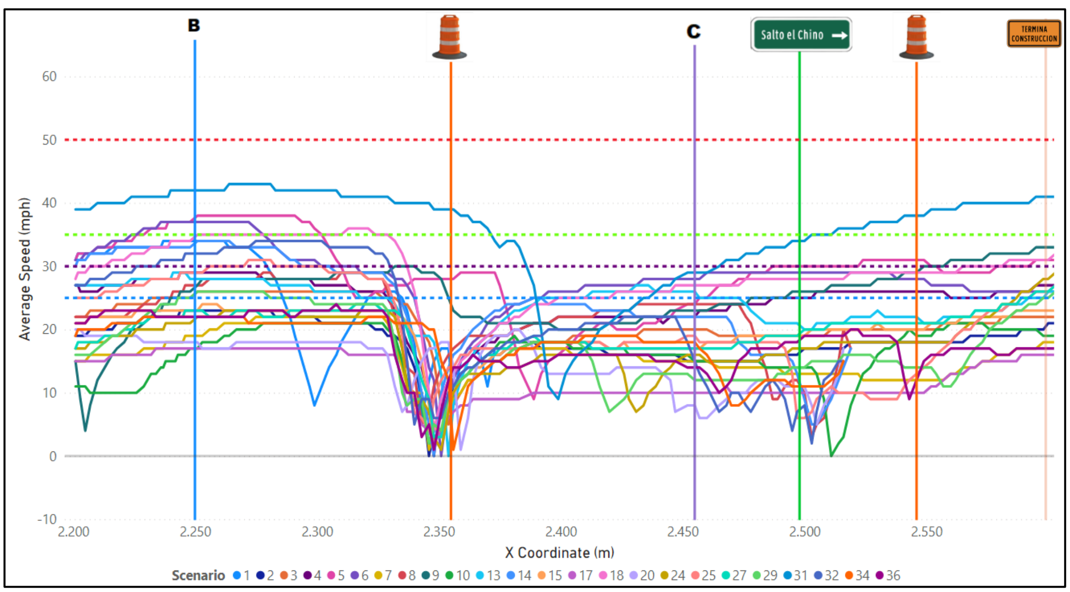
A. Average Speed Profile - Scenario 1



Average Speed Profile - Scenario 2



B. Average Speed Profile - Scenario 3



C. Average Speed Profile - Scenario 4

Figure 13 Speed Profiles Along the Second Work Zone

The average speed by gender is presented in Figure 14. As shown in Figure 15, there is no significant difference in average speed based on the driver´s gender.

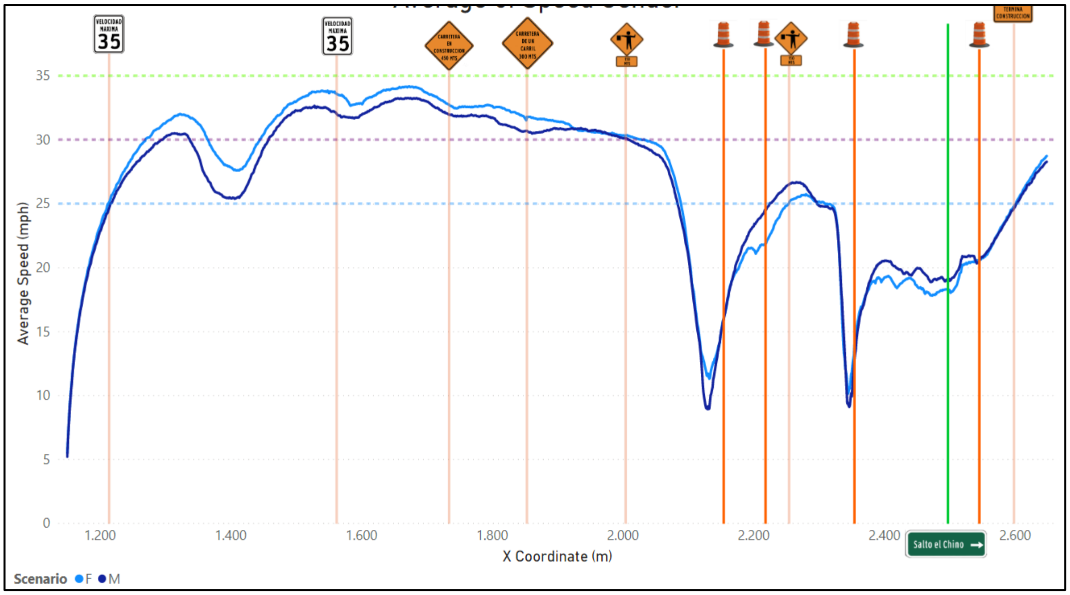


Figure 14 . Average Speed by Gender

Average speed profiles for each of the scenarios are presented in Figure 15. When drivers begin the trip, their average speed is below the posted speed limit of 35 mph. Due to a steep horizontal curve of approximately 90 ° (see figure 4) at the beginning of each scenario, a reduction in average speed is noted due to the complexity of the curve. Afterward, there is a sequence of smoother, tangent curves before reaching the first work zone. This first workspace is shown in sections along with the signs corresponding to the anticipated zone and the beginning of the first work zone. There is a decrease in the average speed to 8 mph. It is important to note that individual drivers come to a complete stop. Still, because they stop at different points on the road before reaching the point where the lane is blocked, the average speed is significantly reduced, but it does not reach zero.

After drivers pass the first work zone, the average speed increases to approximately 28 mph. However, the second work zone is very close, so the speed reduction is quite noticeable, approaching at a speed of 5 mph, which is less than the average speed in the previous work zone (8 mph). After stopping in the second work zone and continuing their run, the drivers find the sign that indicates the exit to "Salto el Chino" is ahead. As shown in Figure 15, the average speed is slightly reduced due to the conflict faced by the driver that needs to decide whether or not to take the exit. Most of the subjects continued their run without taking the exit and increased their speed at the end of the construction work zone.

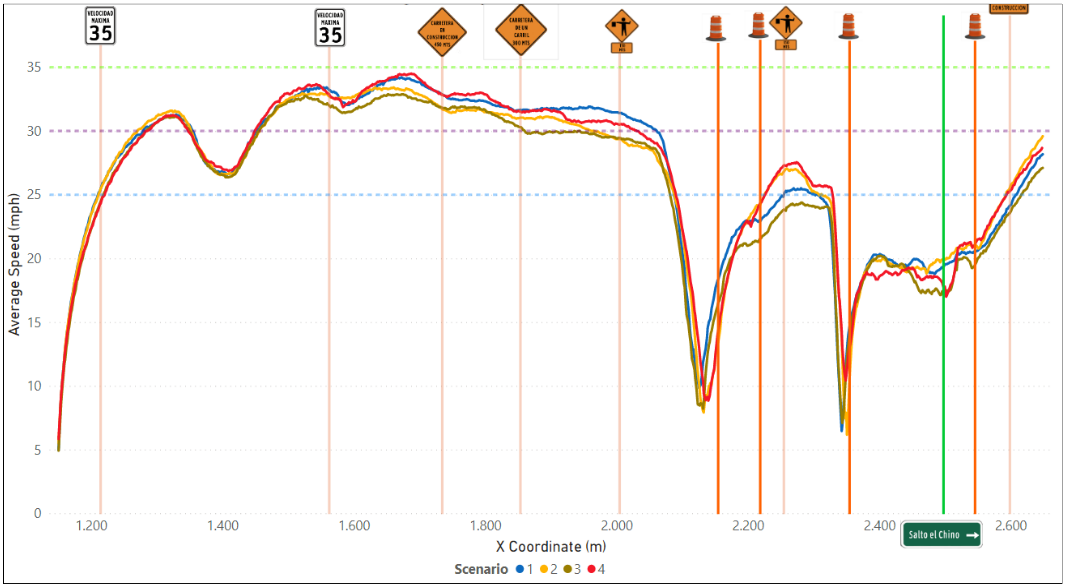
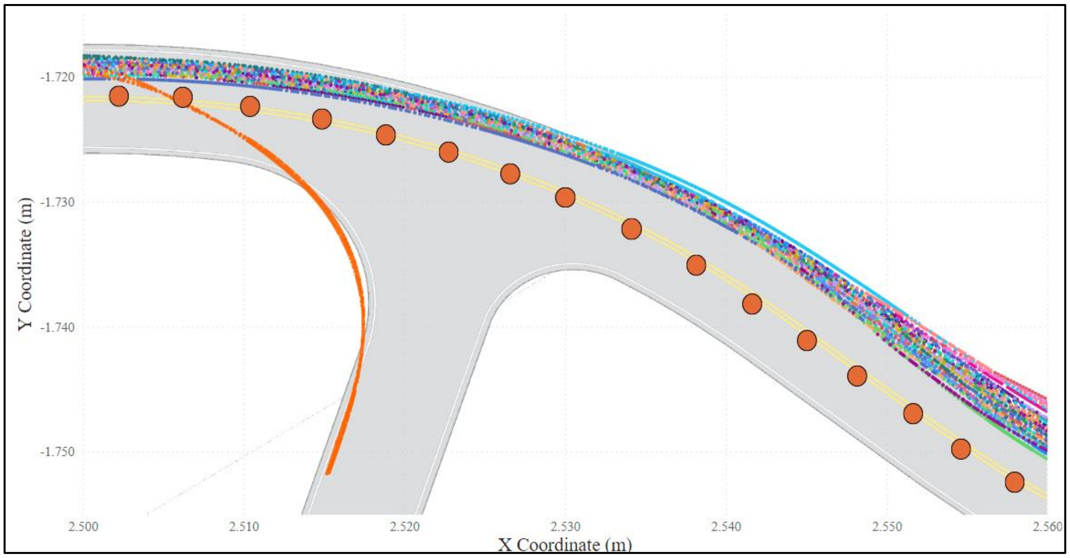


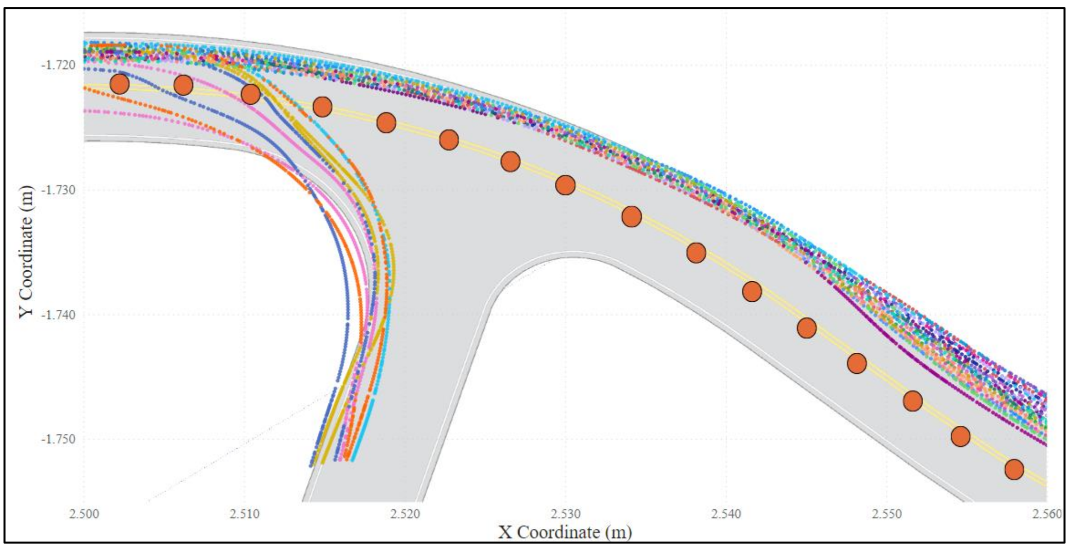
Figure 15 Average Speed Profiles per Scenario

4.2.3. Position

Figure 16 shows the trajectories of the vehicles related to the routes with GPS and without GPS. Figure 16 A corresponds to scenarios 1 and 2 without active GPS, and figure 16 B corresponds to scenarios 3 and 4 with active GPS. There were 24 subjects for each scenario (48 total runs), represented in each figure. Only 4% (one subject) left the road to encroach the workspace in both scenarios that did not have the GPS device active. In comparison, 21% of the subjects with active GPS encroached the workspace at least once. Therefore, in this case, the use of GPS has an additional negative effect, an increase of 17% corresponding to the runs in which the participants encroached the work zone caused by the distraction provided by the GPS.



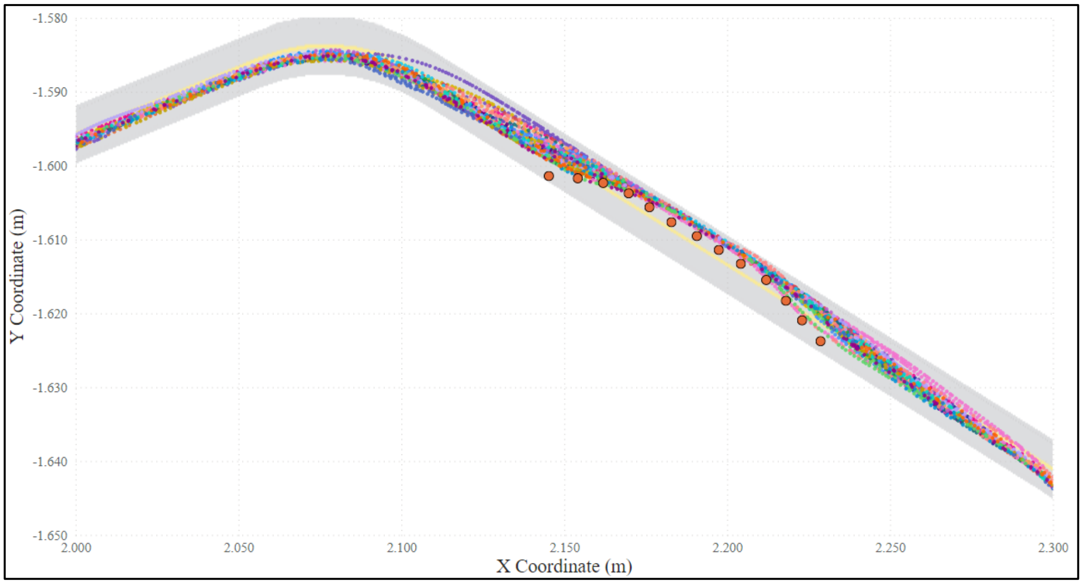
A. Trajectories of the vehicles corresponding to the runs without GPS



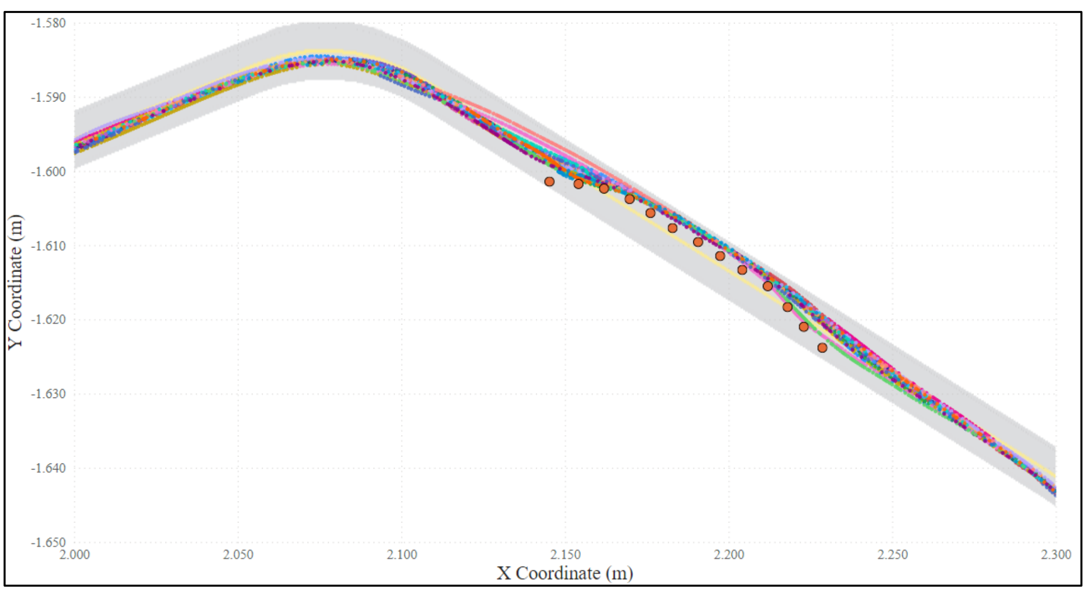
B. Trajectories of the vehicles corresponding to the runs with GPS

Figure 16 Vehicle Trajectories at the Location of the Exit Road

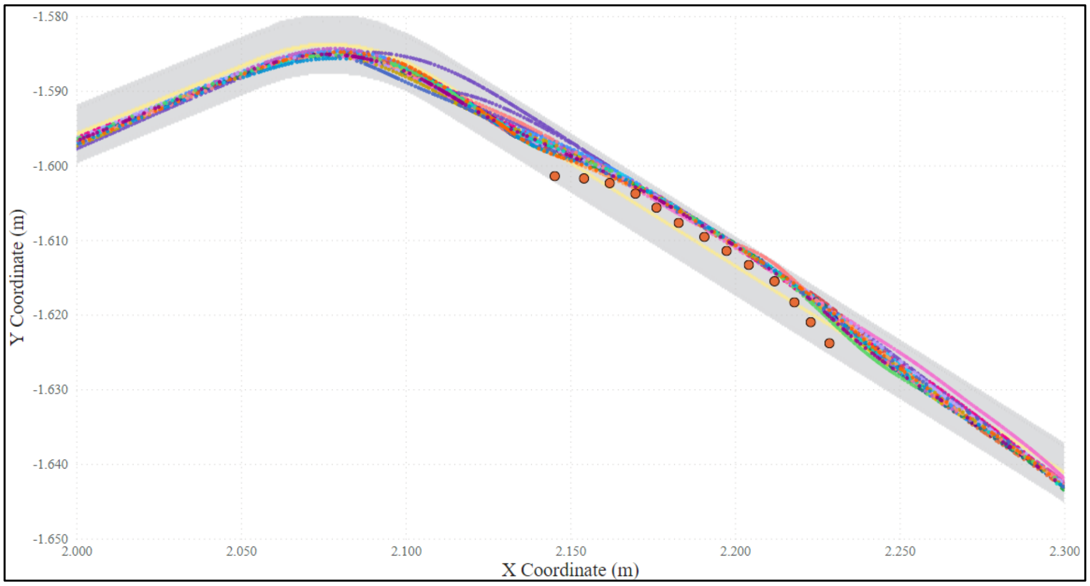
Figure 17 is divided into five figures (A, B, C, D, and E) and corresponds to the trajectory of the vehicles according to the coordinates registered in the simulator for the first work area of each scenario. The figures show how some of the drivers entered the opposite lane. Some of the drivers stopped before the lane closure, which was the desired behavior. However, other drivers did not stop, which caused them to encroach the opposite lane and therefore were faced with the following consequences: crash, back up or go off the road. Figure 17 E shows how a driver performs some collision avoidance movements and applies reverse. In addition, in Figures 17 A, C, and D that some of the drivers, due to excessive speed, mishandle the horizontal curve located at the beginning of each scenario, causing them to encroach the opposite lane before reaching the work zone.



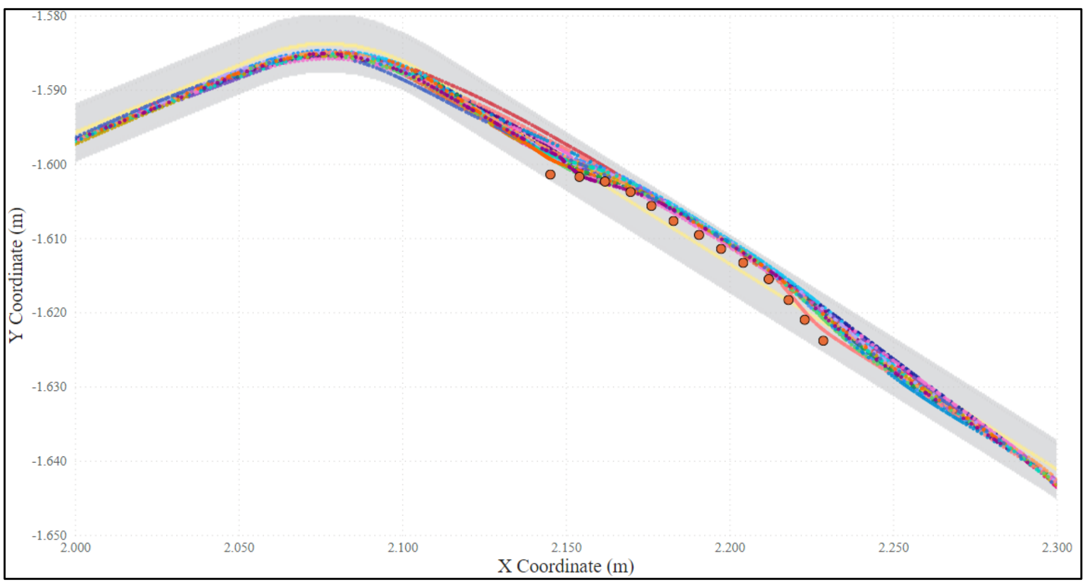
A. Plan view of the first work zone - Scenario 1



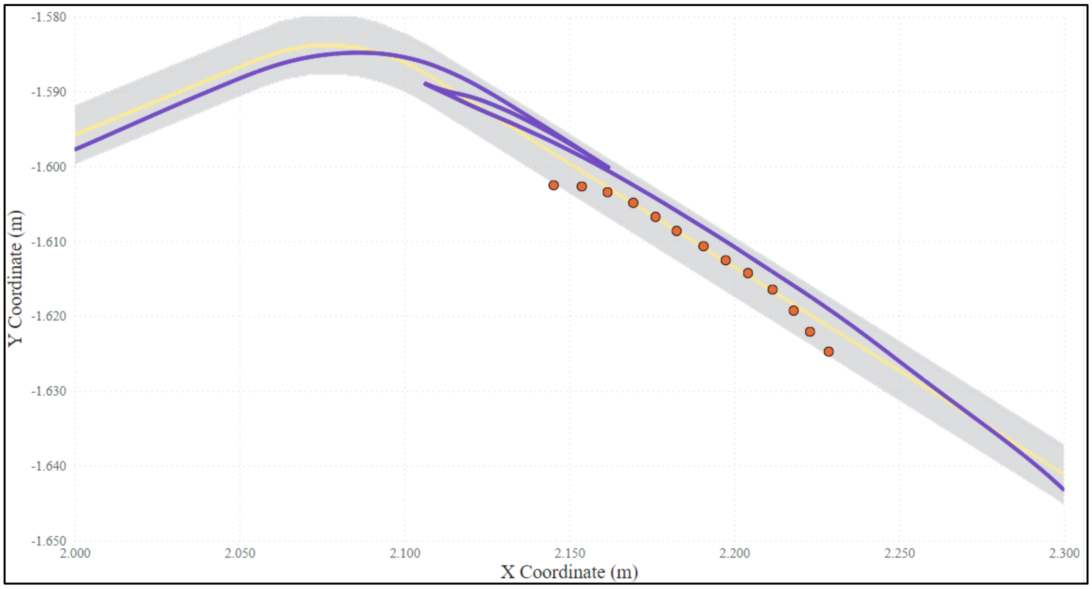
B. Plan view of the first work zone - Scenario 2



C. Plan view of the first work zone - Scenario 3



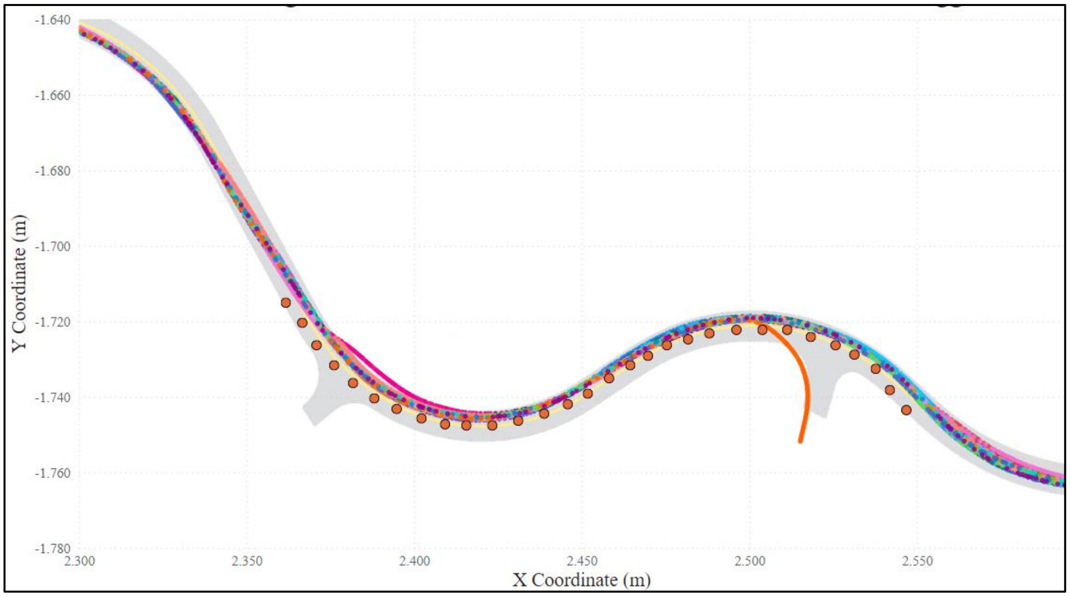
D. Plan view of the first work zone - Scenario 4



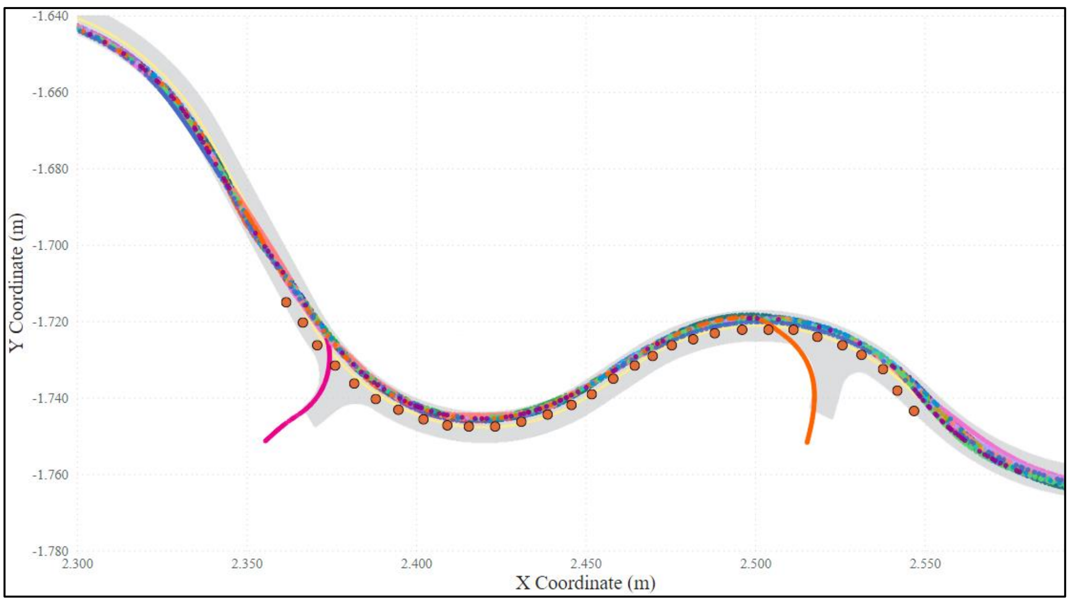
1. Subject reversing to avoid collisions

Figure 17 Plan View of the First Work Zone for the Scenarios

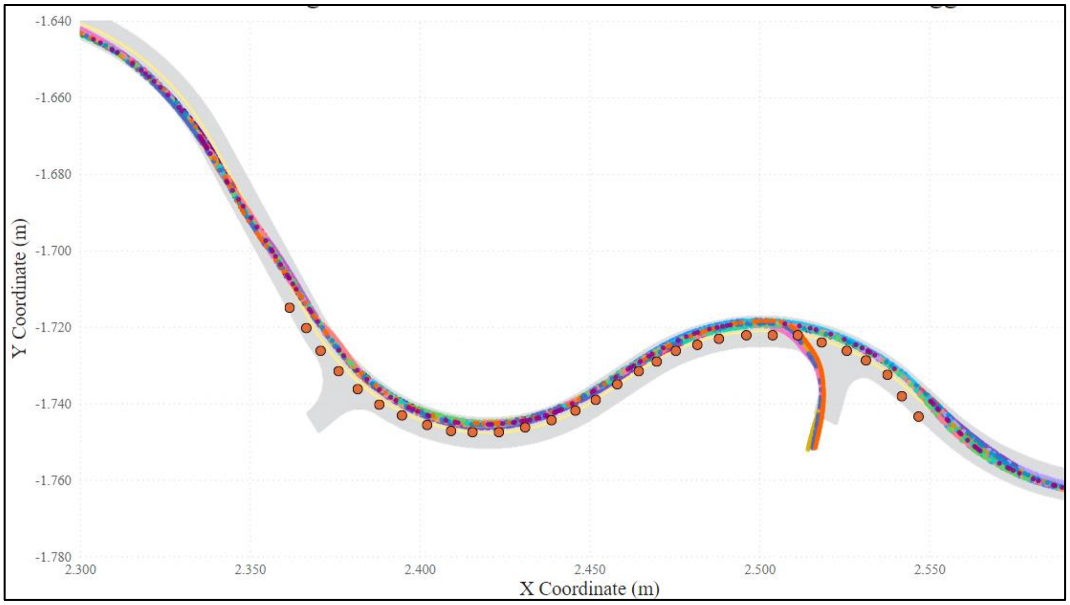
The trajectories of the vehicles according to the coordinates registered by the driving simulator in the second work area are shown in Figure 18. In this area, the exit to "Salto el Chino" is located, which is the exit instructed to the driver to take when they start the driving simulation. These instructions in the scenarios with GPS are auditory and visual and in the scenarios without GPS are only visual. Some drivers encroached the workspace despite having the signaling and channeling of the lane that delimited the second construction zone and having passed through the first construction zone previously. Figures C and D show that when the GPS instructed the drivers to take the exit, and the TTC indicated that the exit was closed, they decided to follow GPS instructions and took the exit to "Salto el Chino," resulting in a hazardous situation.



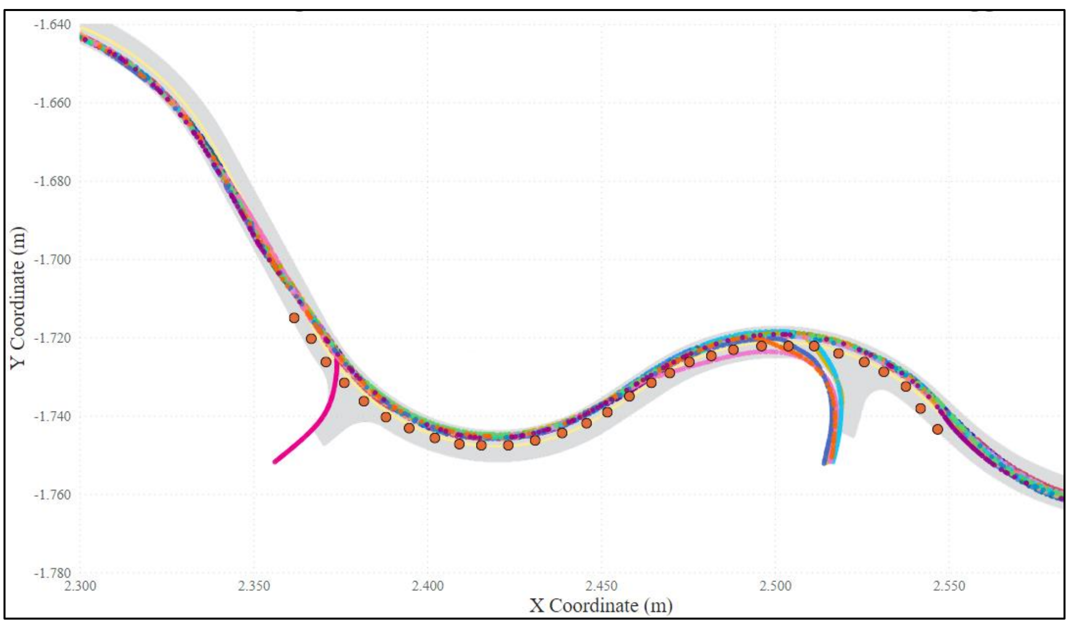
A. Plan view of the second work zone - Scenario 1



B. Plan view of the second work zone - Scenario 2



C. Plan view of the second work zone - Scenario 3



D.

D. Plan view of the second work zone - Scenario 4

Figure 18 Plan View of the Second Work Zone for All Scenarios

4.2.4. Empathy

Illustration 1 Subjects in the virtual reality experience

The VR experience involved observing gaps in oncoming traffic and cross safely to the other side of the road to perform surveying-related activities typically conducted by construction workers. During the crossing, the subjects listened to typical road noise conditions that simulated an actual construction site. Subjects had to cross the road four times to perform surveying measurements. At the end of the VR experience, subjects were asked to run the scenarios in the driving simulator. Afterward, subjects were asked about how these experiences modified their perceptions. The results indicate that 79% of the subjects perceive to have more empathy for the workers in the work zones after experiencing, through VR, their work environment. An additional 17% of the subjects indicated that they perceived themselves as having a high degree of empathy before the experiment. Out of all the subjects, 50% indicated that they would modify their driving behaviour when driving through construction work zones after participating in the study. Forty-two percent (42%) of subjects indicated that they perceive that their driving through work zones is adequate; thus, there is no need to modify their behavior. Finally, 8% say they would not drive differently.

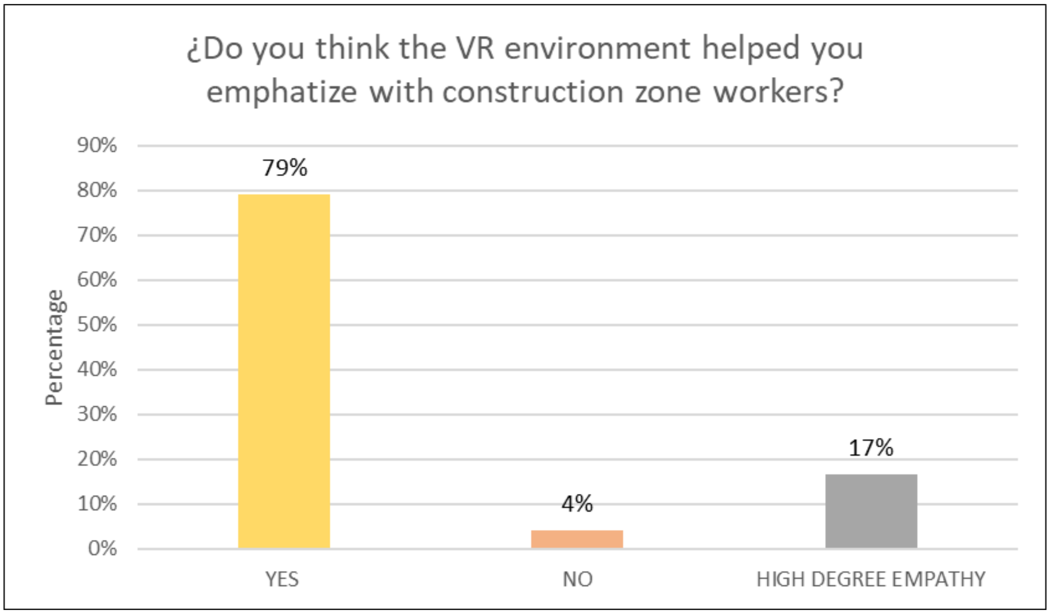


Figure 19 Virtual reality perception question

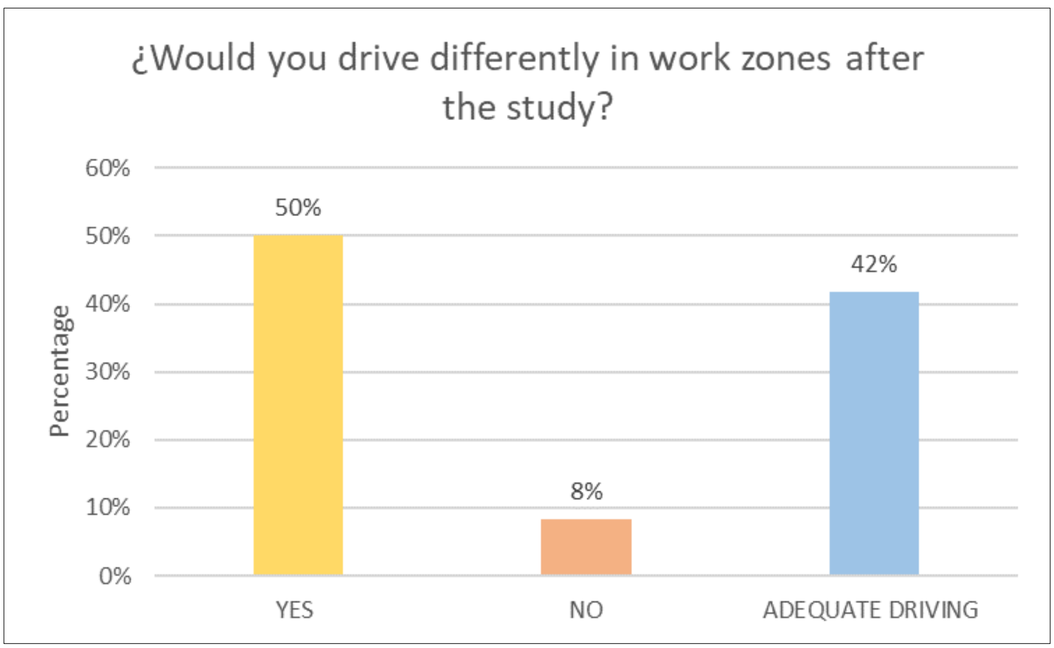


Figure 20 Driving perception question

5. Comparison with drivers without the VR experience

In 2020, our research team conducted a study to investigate the effects of distractions generated by audible GPS messages when approaching or entering the TTC advanced warning area on two-lane rural roads. The study did not include a VR component. It involved analyzing drivers' responses in four different scenarios: with and without the presence of flaggers and with and without GPS instructions to follow. In addition, an observational study was carried out to determine the subjects' reactions when approaching and crossing the work areas. In the scenarios with active GPS, two out of four audible prompts directed the participants to encroach the closed workspace due to the presence of TTC. Subjects had to decide to follow the GPS directions or ignore the GPS; 25% of the participants encroached the work zone, while 17% of the participants encroached the work zone in the scenarios without active GPS. In scenarios with flagging, the subjects, upon noticing their presence, stopped completely when they reached the construction area. Only two of 24 subjects did not stop, and in scenarios without flaggers, 8 of 24 subjects continued without stopping. In terms of lane position, when approaching the lane closure due to the construction zone, 46% of the participants stopped when they reached the closing of the work zone lane, and 54% continued driving in a straight line without noticing any signs in the work zone. Out of the subjects who continued without stopping, 38% continued to drive straight ahead and collided with oncoming traffic; 13% of the subjects who continued to drive when they noticed traffic coming in the opposite direction immediately backed up, and only one subject (4%) performed a different maneuver to avoid colliding with oncoming traffic. The information provided by the GPS can be contradictory when the TTC plan is present since it made the subjects doubt what decision to make (follow the GPS indications or not), which can result in a series of dangerous maneuvers by the drivers. In addition, the lack of real-time GPS updates in the short term on lane closure due to the TTC plan on the rural two-lane highway provided conflicting information to drivers, generating potential risks related to the participant's safety and other users of the road and workers in the construction zone.

The present study replicates the scenarios but adds a VR experience that allows the subjects to put themselves in the construction workers' shoes and perform surveying tasks that enable them to experience the working conditions that construction workers typically face in work zones. The goal is to evaluate if there are differences in behavior due to this immersive experience. The information obtained in both studies is presented, and the participants' behaviors are compared using the following two configurations: with a VR experience and without it.

The research team collected information by observing and measuring each participants' performance and behavior throughout each scenario. The following cases were observed and documented: the percentage of participants who encroached the lane in the opposite direction, the percentage of drivers who collided when encroaching the opposite direction, and the percentage of subjects who backed up when noticing that they had encroached the opposite lane with oncoming traffic.

As shown in Figure 21, participants who did not have the VR experience encroached the opposite lane during the first work zone in their first run at a significantly higher rate (54%) than participants who had the VR experience (29%). The results also indicate that participants who had the VR experience performed better (21% encroached the opposite lane) than participants who did not have the VR experience (35% encroached the opposite lane) during the second construction zone in the first run. In runs two and three, both construction zones also reflected a reduction in the percentage of drivers who had the VR experience compared to drivers who did not.

Figure 21 Subjects who encroached the opposite lane without virtual reality and with virtual reality

As shown in Figure 22, during the first work zone in the first run, the percentage of participants who crashed with incoming traffic was 38% for drivers without VR compared with 13% of drivers with VR.

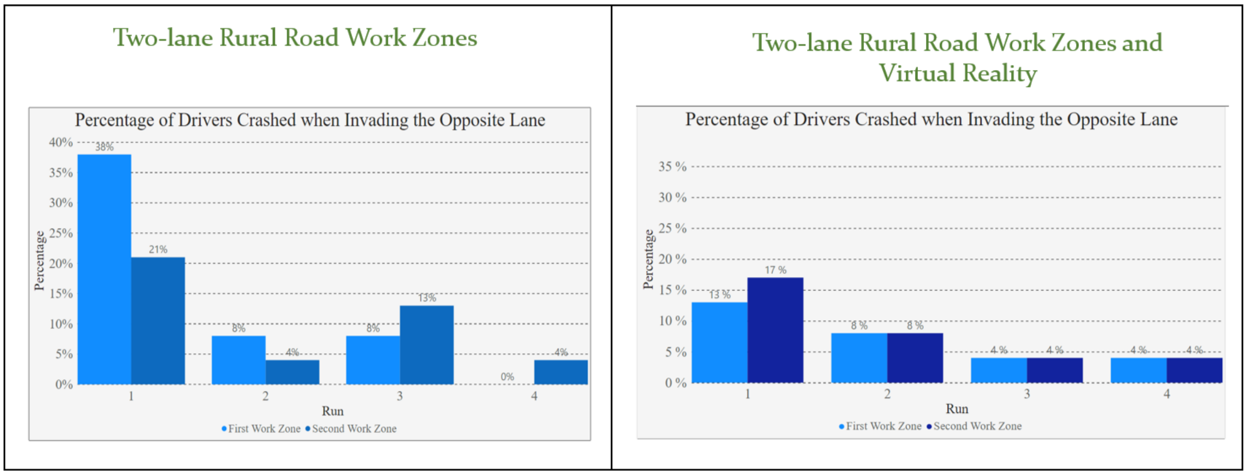


Figure 22 Subjects that crashed when encroaching the opposite lane without virtual reality and with VR

As shown in Figure 23, some of the drivers who encroached the opposite lane realized what they did and backed up. It can be observed that the percentage of drivers who backed up is similar with and without VR.

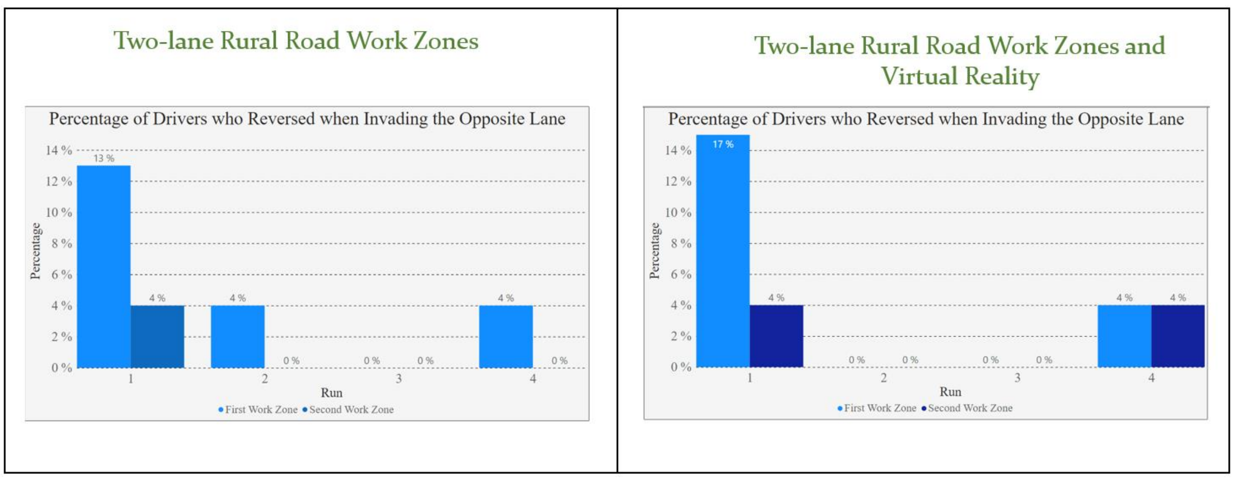


Figure 23 Subjects who reversed when encroaching the opposite lane without virtual reality and with VR

According to Figure 24, the highest average speed corresponding to the study without VR is close to 40mph. Compared to the study that included the VR experience, the highest average speed was lower than 35mph.

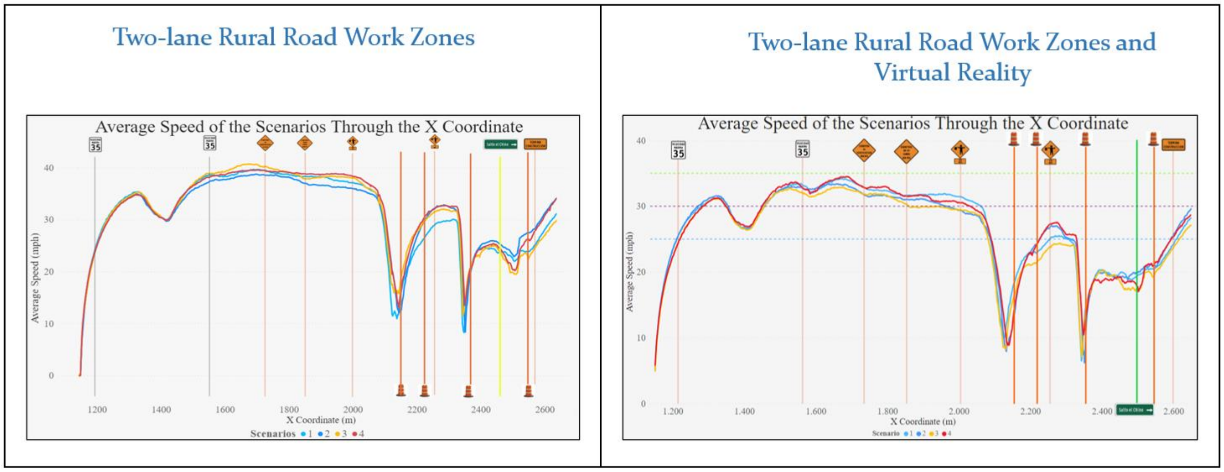


Figure 24 Average speeds of the scenarios without virtual reality and with virtual reality

The positions of the subjects who encroached the construction zone to enter the exit "Salto el Chino" without the distraction of the GPS are shown in Figure 25. As seen in the study without VR, 17% of the subjects who drove through the scenes without active GPS continued their journey and entered the "Salto el Chino" exit, which closed due to construction. Compared with the study that included the VR experience with 4% of subjects took the exit.

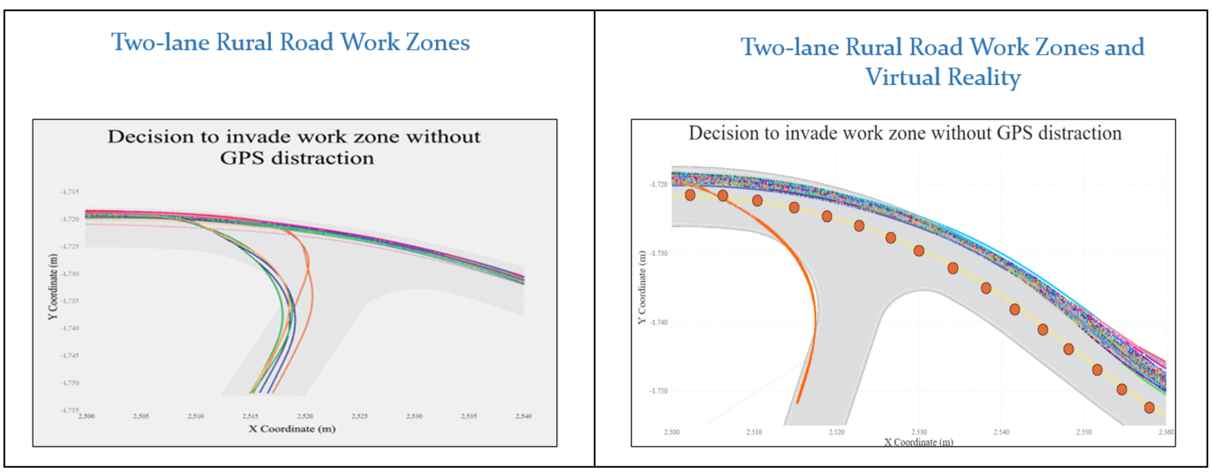


Figure 25 "Salto el Chino" position without GPS distraction. Without virtual reality and with virtual reality

When the subjects drove through the scenarios that had the GPS active, 25% of the study participants without the VR experience entered the “Salto el Chino” following the instructions provided by the GPS. In comparison, 21% of the subjects who participated in the study with VR encroached the highway construction area to enter the exit indicated by the GPS.

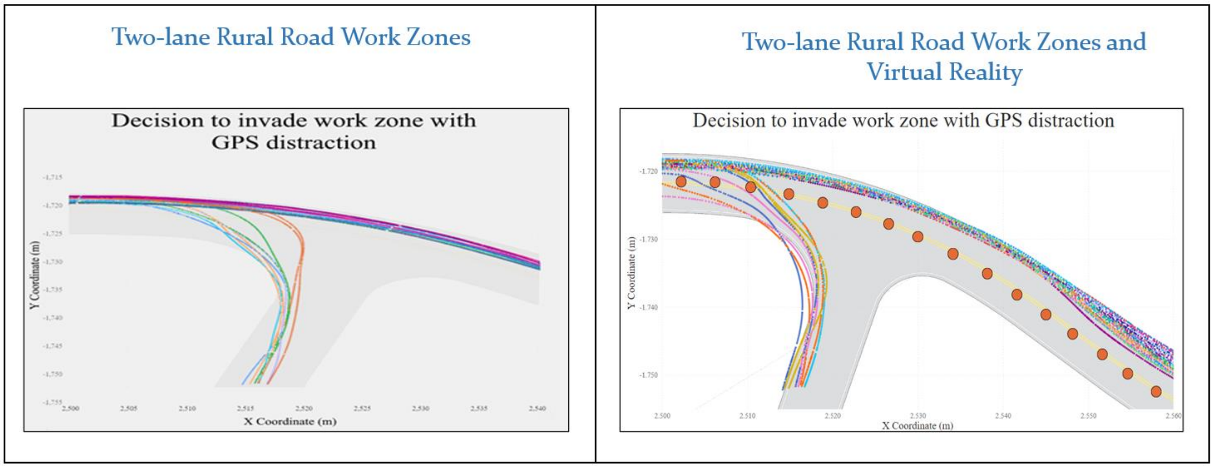


Figure 26 "Salto el Chino" position with GPS distraction. Without virtual reality and with virtual reality

6. Conclusions and Recommendations

6.1 Conclusions

This research study concentrated on examining the effect of exposing drivers to the work hazards that construction workers typically encounter in work zones and how it influences their behavior while driving through work zones. The study compares driver behavior between drivers that were sensitized using virtual reality (VR) and a driving simulator to drivers who were not sensitized using VR.

The primary conclusions of this research study are summarized bellow:

1. When a comparison was made of the participants who had completed both the VR experience and the driving simulation to those with only the driving simulation, it showed that the VR experience allowed participants to contextualize the risks commonly faced by construction workers. Being able to put themselves in the construction workers' shoes allowed them to realize the importance of following safety precautions. Having the VR experience before the driving simulator develops empathy from the participants towards the construction workers, resulting in a safer driving experience for both drivers and construction workers.

2. Participants without VR had a significantly higher percentage of drivers encroaching the opposite lane during the first work zone in the first run.

3. The percentage of participants who crashed with incoming traffic in runs two and three was significantly higher for drivers without VR than drivers with VR. Based on these results, it can be concluded that the use of VR has a positive impact on driving behavior.

4. In both configurations, namely with and without VR, the first-time participants that encountered a highway work zone are more likely to encroach the opposite lane when compared to subsequent runs. Based on this finding, it can be concluded that prior experience with work zones in the driving simulator leads to an increased

awareness of the challenges presented by this situation, resulting in an adjustment in driving behavior to avoid committing the mistake of encroaching the opposite lane without taking adequate precaution.

5. Similar to the behavior modification observed for drivers in the lane invasion situation, drivers learned to take precautions in subsequent runs to avoid crashing with vehicles coming in the opposite direction.

6. A group of drivers are cautious when crossing the work zone and stop at the beginning of the lane closure. However, as soon as they realize that their vehicle has entered the opposite lane and vehicles are coming in the opposite direction, they decide to back up. This hazardous situation occurs more frequently during the first run but appears at a lower percentage in subsequent runs. This leads us to conclude that many drivers are still risking their lives and the lives of other drivers and construction workers by not taking adequate precautions.

7. Based on the results of the scenarios with and without flaggers, it can be concluded that the use of TTC along with flaggers in highway construction work zones increases compliance with work zone regulations. The use of GPS in construction zones without real-time updates to current road conditions creates a hazardous situation by making drives hesitate to follow GPS instructions or follow what the TTC is indicating.

6.2 Recommendations

Based on the conclusions that resulted from this research study, it is evident that empathy is a powerful emotion that can be simulated and can be used to raise awareness of road drivers in work zones, reducing operating speed and potentially saving the lives of highway crew workers.

It is recommended that in order to increase driver compliance in TTCs interventions be designed to raise awareness about the importance of being able to put yourself in another person's situation. This can be achieved through the use of VR. This study highlights the advantage of using VR to raise awareness of hazards to which drivers and construction workers are exposed. The increased awareness leads to behavior modification, resulting in a safer work environment for drivers and construction workers.

Based on the research findings, it is also recommended that the Puerto Rico Vehicle and Traffic Law (Law 22.) be ammended to restrict the use of GPS in highway temporally work zones unless the information provided by the GPS is updated to reflect where construction work is being performed. This offers positive guidance to drivers traversing a work zone which leads to safety improvements.

6.3 Future Research

The current research study has demonstrated the benefits of using VR to promote empathy with the construction workers in work zones to improve driver behavior when facing this kind of situation along their routes. VR experiences would be used in the future to sensitize drivers in hazardous driving conditions.

In the short term, it is recommended to explore additional simplified empathy-building strategies to improve driver behavior in highway construction work zones that could be incorporated directly as a requirement to obtain or renew the drivers' license.

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APPENDICES

a. Informed Consent

ESTUDIO DE SIMULACIÓN

FORMULARIO DE CONSENTIMIENTO INFORMADO

Investigador Principal: Didier M. Valdes Diaz

Título de Proyecto: Assess Highway Construction Workers Behavior while Driving through Work Zones in Comparison to General Drivers Sensitized Using Virtual Reality and a Driving Simulator

1. **¿QUÉ ES ESTE FORMULARIO?**
   Esto es un Formulario de Consentimiento Informado. Le proveerá información acerca de este estudio para que usted pueda tomar una decisión informada sobre su participación. Usted debe tener 18 años de edad o más para dar *consentimiento* informado.

2. **¿QUIÉN ES ELEGIBLE PARA PARTICIPAR?**
   Individuos que se encuentran entre las edades de 18 a 70 años y han tenido una licencia de conducir por al menos 18 meses. Conductores que han experimentado cinetosis (mareo por movimiento), ya sea en su propio vehículo como pasajero o conductor, o en otros modos de transporte, no deberían participar.

3. **¿CUÁL ES EL PROPÓSITO DE ESTE ESTUDIO?**
   El propósito de este estudio es evaluar si exponer a los conductores a los peligros laborales que los trabajadores de la construcción suelen encontrar en las zonas de trabajo influye en su comportamiento al conducir por las zonas de trabajo.

4. **¿DÓNDE ESTE ESTUDIO TOMARÁ LUGAR Y CUÁNTO DURARÁ?**
   Esta sesión de estudio se llevará a cabo en el Laboratorio de Ingeniería de Transportación de la Universidad de Puerto Rico en Mayagüez, localizado en el Edificio de Ingeniería Civil y Agrimensura, salón 102-F. El estudio durará aproximadamente 45 minutos por participante e incluirá cuestionarios y uso del simulador.

5. **¿QUÉ SE ME PEDIRÁ HACER?**

i) Se le pedirá que llene un breve cuestionario antes y después del experimento.

ii) El investigador le enseñará cómo manejar el simulador y le proveerá instrucciones generales para los escenarios de simulación. Durante la simulación, usted deberá operar los controles del simulador del vehículo de la misma manera que usted manejaría los de cualquier otro vehículo, y manejar por el mundo simulado como corresponde. Usted debe de seguir los límites de velocidad y las reglas estándares de la carretera y tener un cuidado razonable cuando utilice los frenos.

iii) Usted se sentará en el simulador, y se le dará una simulación de práctica para familiarizarse con el simulador de conducción. Una vez usted se sienta cómodo con el simulador, usted manejará a través de un trayecto que tomará cerca de 2 a 5 minutos para cada escenario virtual en que conducirá. Si en algún momento del trayecto siente molestia o cinetosis/mareo, informe al investigador de inmediato para que se detenga la simulación. No habrá ningún tipo de penalidad, o efecto adverso al estudio porque su participación no pueda ser completada.

6. **¿EXISTE ALGÚN RIESGO O BENEFICIO ASOCIADO CON LA PARTICIPACION?**

En términos de la operación del simulador de conducción, existe un leve riesgo de cinetosis (mareos). Un pequeño porciento de los participantes que manejan el simulador podrían experimentar sensación de náuseas o náusea actual. El experimento ha sido trabajado para minimizar el riesgo. Se recomienda que si usted ha experimentado cinetosis (mareos) anteriormente mientras viaja o maneja un vehículo real, usted no debería participar en este experimento.

Si durante el trayecto de la simulación, usted siente malestar o náuseas, debería de informar al investigador inmediatamente para que la simulación pueda ser detenida. La interrupción de la simulación debería reducir la molestia rápidamente. Si usted no se siente mejor tan pronto la simulación es interrumpida, los investigadores pueden gestionar para que alguien los guíe a su hogar o a buscar atención médica si es necesario.

Los beneficios de participar en este estudio incluyen aprender potencialmente como ser un conductor más precavido/seguro y a familiarizarse con los cambios de configuración de plazas de peaje.

7. **¿QUIÉN VERÁ LOS RESULTADOS Y/O MI DESEMPEÑO EN ESTE ESTUDIO?**

Los resultados de esta investigación serán publicados en revistas de investigación científica y serán presentados en conferencias y simposios de entidades científicas profesionales. Los resultados podrían ser utilizados por los investigadores aprobados para propósitos internos. Ningún participante será identificable en los reportes o publicaciones ya que ni el nombre ni las iniciales de ningún participante serán utilizados. Para mantener la confidencialidad de los archivos, los investigadores utilizarán códigos para identificar a cada sujeto, en vez de nombres, para toda la data colectada mediante cuestionarios y la data colectada durante su utilización del simulador. La data será asegurada en el Laboratorio de Ingeniería de Transportación de la Universidad de Puerto Rico en Mayagüez y solo será accesible por el investigador principal, y cualquier otro investigador aprobado para el estudio.

Es posible que su archivo de investigación, incluyendo información sensitiva y/o información de identificación, pueda ser inspeccionado y/o copiado por agencias federales o del gobierno estatal, en el curso del desempeño de sus funciones. Si su archivo es inspeccionado por alguna de estas agencias, su confidencialidad será mantenida en la medida permitida por la ley.

8. **¿RECIBIRÉ ALGÚN TIPO DE COMPENSACIÓN MONETARIA POR PARTICIPAR DE ESTE ESTUDIO?**

No. Su participación en este estudio es completamente voluntaria.

9. ¿QUÉ PASA SI TENGO UNA PREGUNTA?

Si tiene alguna pregunta sobre el experimento o cualquier otro asunto relativo a su participación en este experimento, o si sufre de alguna lesión relacionada a la investigación como resultado del estudio, puede llamar al investigador, Edgardo Concepcion Carrasco, al (787) 248-9634 o vía correo electrónico a edgardo.concepcion2@upr.edu o al Dr. Didier Valdés, al (787) 832-4040 ext. 2179 o didier.valdes@upr.edu. Si, durante el estudio o después de, usted desea discutir su participación o preocupaciones en cuanto al mismo con una persona que no participe directamente en la investigación puede comunicarse con el Comité para la Protección de los Seres Humanos en la Investigación del Recinto Universitario de Mayagüez al (787) 832-4040 ext. 6277 ó 6347 o cpshirum@uprm.edu. En caso de que el participante lo desee, una copia de este formulario de consentimiento informado será proveída para que la guarde en sus archivos.

10. ¿QUÉ PASA SI ME NIEGO A PROVEER MI CONSENTIMIENTO?

Su participación es voluntaria, por lo tanto, usted puede negarse a participar o puede retirar su consentimiento y dejar de participar en el estudio en cualquier momento y sin penalidad alguna.

***11.* ¿QUÉ SI ME LESIONO?**

Como usted es parte de la comunidad del Recinto Universitario de Mayagüez (ya sea empleado o estudiante) el seguro médico del Recinto le cubre en caso de tener algún riesgo o incomodidad.

12. DECLARACIÓN DE CONSENTIMIENTO VOLUNTARIO DEL SUJETO

Al firmar abajo, yo, el participante, confirmó que el investigador me ha explicado el propósito de la investigación, los procedimientos del estudio a los que voy a someterme y los beneficios, así como los posibles riesgos que puede experimentar. También se han discutido alternativas a mi participación en el estudio. He leído y entiendo este formulario de consentimiento.

______________________________________ ____________
Nombre en letra de molde del participante Fecha

____
Firma del participante

13. DECLARACIÓN DEL EXPERIMENTADOR

Al firmar abajo, yo, el investigador, indicó que el participante ha leído este Formulario de Consentimiento Informado y yo le he explicado a él/ella el propósito de la investigación, los procedimientos del estudio a los que él/ella va a someterse y los beneficios, así como los posibles riesgos que él/ ella puede experimentar en este estudio, y que él/ella ha firmado este formulario de consentimiento informado.

____ ____________
Firma de la persona que obtiene el consentimiento informado Fecha

b. Pre-Test Questionnaire

11/30/2020 CUESTIONARIO ANTES DEL ESTUDIO

CUESTIONARIO ANTES DEL ESTUDIO

El cuestionario es confidencial, lo que usted provea no será utilizado para conseguir su identidad. Usted será identificado con un número asignado por el investigador, De esta manera se podrá validar la información obtenida durante la simulación. De sentirse incomodo/a contestando una o más preguntas tiene el derecho de no contestar la pregunta.

*Obligatorio

1. # asignado: *

Seccion 1: Datos demograficos

2. Apellidos:

3. Nombre:

4. Correo Electrónico:

https://docs.google.com/forms/d/1CzltvSL7cU1NOjxUbaFvB4sis3yullU_vEJlB22zPX8/edit 1/8

11/30/2020 CUESTIONARIO ANTES DEL ESTUDIO

5. Sexo:

   Marca solo un óvalo.

   - Mujer
   - Hombre

6. Edad:

Marca solo un óvalo.

- 18
- 19
- 20
- 21
- 22
- 23
- 24
- 25
- 26
- 27
- 28
- 29
- 30
- 31
- 32
- 33
- 34
- 35
- 36
- 37
- 38
- 39

11/30/2020 CUESTIONARIO ANTES DEL ESTUDIO

- 65
- 66
- 67
- 68
- 69
- 70

7. Fecha de Nacimiento:

Seccion 2: Historial de conduccion

8. Edad aproximada a la cual obtuvo la licencia de conducir:

9. País donde obtuvo la licencia de conducir:

10. País donde aprendió a conducir:

11. País donde a conducido la mayor parte de su vida:

12. Restricciones en su licencia de conducir:

Marca solo un óvalo.

- Ninguna
- Espejuelos
- Lentes de contacto
- Otra

13. Si su respuesta fue otra, indique:

c. Post-Test Questionnaire

CUESTIONARIO LUEGO DEL ESTUDIO

El cuestionario es confidencial, lo que usted provea no será utilizado para conseguir su identidad. Usted será identificado con un número asignado por el investigador, De esta manera se podrá validar la información obtenida durante la simulación. De sentirse incomodo/a contestando una o más preguntas tiene el derecho de no contestar la pregunta.

*Obligatorio

1. *

____

Seleccione la opción que mejor describa su experiencia.
Siendo 5 excelente y 0 deficiente.

2. Proyección de la simulación

Marca solo un óvalo.

- 5
- 4
- 3
- 2
- 1
- 0

3. Se siente como si fuera un vehiculo real

Marca solo un óvalo.

- 5
- 4
- 3
- 2
- 1
- 0

4. Aceleración

Marca solo un óvalo.

- 5
- 4
- 3
- 2
- 1
- 0

5. Freno

Marca solo un óvalo.

- 5
- 4
- 3
- 2
- 1
- 0

6. Audio

Marca solo un óvalo.

- 5
- 4
- 3
- 2
- 1
- 0

7. Simulación en general

Marca solo un óvalo.

- 5
- 4
- 3
- 2
- 1
- 0

Gracias por participar de este estudio! Nos ayuda a mejorar la seguridad en la carretera.

Este contenido no ha sido creado ni aprobado por Google.

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