Evaluation of Safety Enhancements in School Zones with Familiar and Unfamiliar Drivers

SAFETY RESEARCH USING SIMULATION

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List of Acronyms

AADT	Average annual daily traffic
ASL	Applied Science Laboratories
FHWA	Federal Highway Administration
HSM	Highway Safety Manual
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
PR-2	Puerto Rico Highway #2
RSA	Road safety audit
RTI	Realtime Technologies
SRTS	Safe Routes to School
TCD	Traffic control devices
UMass	University of Massachusetts at Amherst
UPRM	University of Puerto Rico at Mayagüez
UTC	University Transportation Center

Units Conversion

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

Abstract

Traffic crashes in suburban school zones pose a serious safety concern due to a higher presence of school-age pedestrians and cyclists as well as potential speeding issues. A study that investigated speed selection and driver behavior in school zones was carried out using two populations from different topographical and cultural settings: Puerto Rico and Massachusetts. A school zone from Puerto Rico was recreated in driver simulation scenarios, and local drivers who were familiar with the environment were used as subjects. The Puerto Rico school simulation scenarios were replicated with subjects from Massachusetts to analyze the impact of drivers' familiarity on the school-roadway environment. Twenty-four scenarios were built with pedestrians, on-street parked vehicles, and traffic flow used as simulation variables in the experiment. Results are presented in terms of speed behavior, reaction to the presence of pedestrians, speed compliance, mean reduction in speeds, and eye tracker analysis for both familiar and unfamiliar drivers.

1 Introduction

Pedestrian fatalities in the United States increased in the last decade, and traffic crashes in school zones are a serious safety concern. According to the National Highway Traffic Safety Administration (NHTSA), there were an average of 128 fatalities per year in school-transportation-related crashes in the United States (US) and Puerto Rico (PR) from 2007 to 2016 (National Center for Statistics and Analysis, 2018a). School zones are areas with a high presence of vulnerable users of young age, which increases the risk of crashes. Several studies have shown that a significant number of drivers violate the posted speed limit in school zones (Ellison et al., 2011; Lazic, 2003; Valdés-Diaz et al., 2018) and that approximately one-third of the traffic fatalities in 2016 involved speeding behavior (National Center for Statistics and Analysis, 2018b).

In Puerto Rico, there are school zones located in areas adjacent to major arterial streets with a posted speed limit of 40 mph or more. A recent study conducted in school zones in the western region of Puerto Rico show that drivers' mean speeds were higher than the posted speed limit in 63% of the evaluated school zones (González-Compre, 2016). Driving simulators at the University of Puerto Rico at Mayaguez (UPRM) and University of Massachusetts at Amherst (UMass) were used to conduct experiments that aimed to analyze drivers' responses to changes in road infrastructure configuration, school zone speed limits, and roadway signage. The UPRM-UMass collaborative research includes the assessment of temporary control device (TCD) configurations and understanding unfamiliar drivers' behavior along suburban school zone scenarios. Familiar and unfamiliar drivers' behaviors were compared for a school zone in Puerto Rico, not only with the base configuration of signage and pavement markings of the school, but also with a recommended configuration. The recommended pavement marking and signage configuration followed the requirements for school zones specified in the *Manual on Uniform Traffic Control Devices* (MUTCD). The preferred enhanced sign was selected based on the results of an online survey that was conducted at UPRM for a school zone related study that explored the combination of TCDs that better inform drivers of the presence of a school zone (Valdés et al., 2019).

The objective of this collaborative research was to evaluate speed behavior and compliance in school zones for familiar and unfamiliar drivers using driving simulation. The research evaluated the best TCD configuration to maximize drivers' speed limit compliance rate in school zones and tested whether there were any significant differences in behavior between familiar and unfamiliar drivers in the school zone.

2 Literature Review

2.1 Speed in School Zones

School zones typically require a transition from high speed to low speed to comply with the posted speed limits needed to adequately manage pedestrians' presence. The transition zones, in terms of driver expectancy on a suburban road, represent a safety management problem. This transition zone phenomenon is also present in suburban roads with high operating speeds where drivers tend not to adequately comply with the posted speed limit of lower-speed areas (National Roads Authority, 2005).

Different countermeasures have been developed and studied to improve school zone safety. The Safe Routes to School (SRTS) Program was developed by the Federal Highway Administration (FHWA) to promote healthy and equitable mobility for everyone, to increase safety in the vicinity of school zones, and to raise awareness of the benefits of walking and biking. Several research studies have focused on the effects of road environment characteristics on drivers' speed in school zones to increase compliance and improve safety, and those zones with high sign saturation resulted in drivers exhibiting lower speeds and higher compliance (Rahman & Strawderman, 2015). Also, the implementation of speed display devices has yielded positive results in terms of reducing speed violations in school zones and playgrounds (Kattan et al., 2011).

2.2 Unfamiliar Drivers

Throughout the years, human factors research has identified the importance of a driver's familiarity with the road environment. Intini et al. showed that familiarity is an influential factor on crash risk, due to either distraction or over-confidence (Intini et al., 2018). Therefore, new designs should consider unfamiliar as well as familiar users to improve compliance with regulations and enhance safety and mobility.

The MUTCD specifies the standards by which all TCDs in public roads are installed and maintained (Federal Highway Administration, 2012). Part 7 of the MUTCD presents the standards, guidance, and options for TCDs applicable for school zones. In the case of Puerto Rico, TCDs substantially comply with the MUTCD, but with Spanish text. It is pertinent to recognize that for unfamiliar drivers (i.e., tourists and first-time users), the difference in language and general highway environment may generate additional challenges to driving tasks.

2.3 Driving Simulators

Simulators have been used as an innovative and cost-effective research tool to evaluate behavior in a wide range of research fields, including human factors, transportation, psychology, medicine, computer science, training, and driving (Fisher et al., 2011). Simulators are useful for evaluating existing and emerging transportation treatments without exposing subject drivers to physical harm in scenarios where a potential crash may occur.

An area of transportation research that has been studied from different perspectives using a driving simulator is the influence of familiar and unfamiliar conditions in driving behavior. Previous studies have evaluated the effect of the implementation of overhead signage considering familiar and unfamiliar drivers' performance on toll plazas in Puerto Rico and

Massachusetts. The results show that the overhead signage improved driving behavior in 67 percent of familiar drivers and 33 percent of unfamiliar drivers (Valdés et al., 2017).

3 Methodology

The research methodology included a literature review on school zone safety and speeds, TCDs, and how unfamiliar environments affect driver behavior. A base simulation scenario was then constructed by recreating the characteristics of a suburban school zone in Puerto Rico. The school zone was selected using a procedure that included a detailed screening process based on *Highway Safety Manual* (HSM) concepts and a road safety audit (RSA). The conditions at the chosen school zone were then inspected to generate scenarios and define the variables for the simulation scenarios.

A survey conducted among Puerto Rican drivers was used to select the combination of signage and pavement markings that most effectively conveyed the message of speed reduction in a school zone. Based on the 196 responses received, the preferred TCD combination included SCHOOL pavement marking symbols next to the S1-1 school zone warning sign, followed by an overhead sign showing the school speed limit and flashing beacons with the END OF SCHOOL ZONE sign at the end of the school area. Both existing and proposed TCD configurations were tested using simulation experiments conducted with the UPRM and UMass driving simulators. The first phase took place in Puerto Rico with Puerto Rican drivers who were familiar with the roadway environment and the Spanish-based signs and pavement markings. The second phase took place in Amherst, Massachusetts with the UMass driving simulator with English speaking drivers who were unfamiliar with the roadway environment and the Spanish-based signs and pavement markings. Comparisons were made between the behavior of familiar and unfamiliar drivers in the different scenarios.

3.1 Driving Simulator Equipment

The driving simulator located at UPRM consists of a desktop simulator configured as a portable cockpit simulator with three main components: a driving cockpit, visual display, and computer system. The driving cockpit consists of a car seat, steering wheel, gear shifter, two turn signals, and the acceleration and braking pedals all mounted on a wooden base that has six wheels, making it compatible with mobile applications. The visual display consists of three overhead projectors and three screens that generates 120 degrees of road visibility at 1024 x 768 pixels. Finally, the computer system uses a laptop and a desktop computer with the Realtime Technologies Inc. (RTI) SimCreator/SimVista simulation software and an audio system that represents the vehicle and environment noises.

Figure 3.1 - UPRM driving simulator

The driving simulator used by UMass for this study is a fixed-base simulator with a full-body Ford Fusion Sedan model 2013. The visual display for this equipment consists of five main projectors with a resolution of 19020 x 1200 pixels, one rear projector with a resolution of 1400 x 1050 pixels, and six screens that generate a field of view of approximately 330 degrees. The sound system used to recreate the vehicle and environmental noises consists of a five-speaker surround system plus a sub-woofer for exterior noise and a two-speaker system plus a sub-woofer for interior vehicle noise. The computer system uses two desktop computers with the RTI SimCreator/SimVista simulation software.

Figure 3.2 - UMass driving simulator

3.2 Eye-Tracking Equipment

Two different eye-tracking systems were used, the Pupil Labs system at UPRM and the Applied Science Laboratories (ASL) Mobile Eye XG eye tracker system at UMass. The information is used to determine the participant's point of gaze and was recorded for later replay. The Pupil Labs system is a monocular equipment that records eye movement using a 200 Hz camera with a latency of 4.5 ms, and it weighs 34 g. Figure 3.3 presents the eye-tracking equipment used at

UPRM, and Figure 3.4 presents an image of the recorded environment with the detection of the point where the subject is looking.

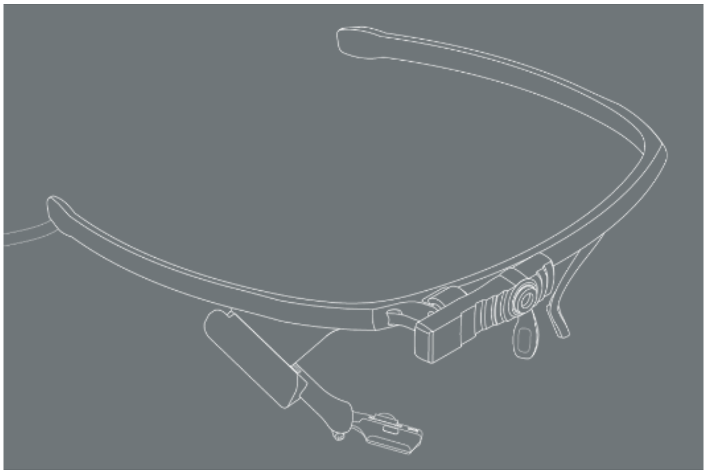


Figure 3.3 - UPRM eye-tracking equipment [image adapted from Pupil Labs]

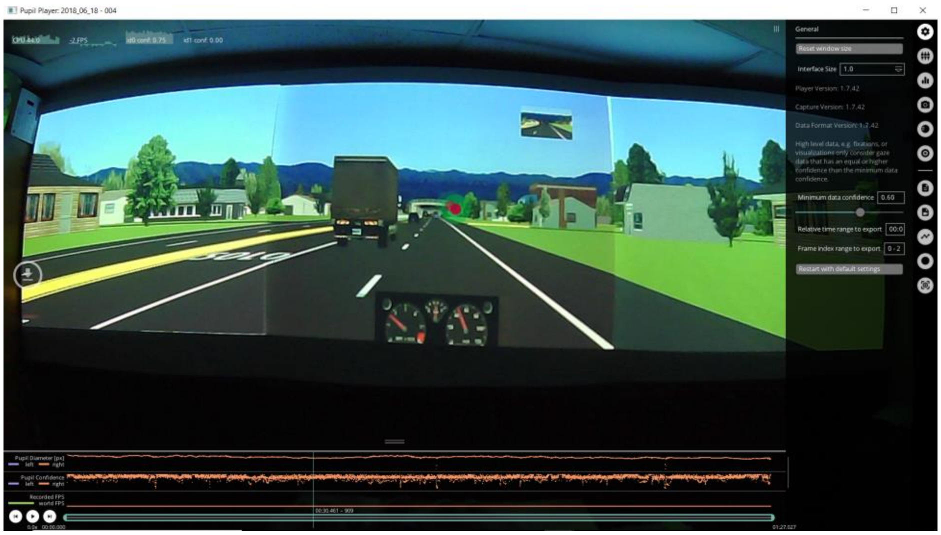


Figure 3.4 - UPRM eye-tracker recording

The ASL Mobile Eye XG eye-tracking system samples the position of the eye at 33 Hz with a visual range of 50 degrees in the horizontal direction and 40 degrees in the vertical direction. The system's accuracy is 0.5 degrees of visual angle. Figure 3.5 shows the eye tracker system used at UMass, and Figure 3.6 presents an image of the recorded environment with the detection point where the subject is looking.

Figure 3.5 - UMass eye-tracking equipment [Source: https://imotions.com/]

Figure 3.6 - UMass eye-tracker recording

3.3 School Zone: Second Unit Samuel Adams

The school zone selected for this study is the Second Unit Samuel Adams in the municipality of Aguadilla in Puerto Rico. This school is in a suburban area and provides a level of education from Pre-Kinder to 9th grade with a student enrollment of approximately 900 children. This school has direct access from the arterial highway Puerto Rico – 2 (PR-2). This highway has two lanes in each direction, an average annual daily traffic (AADT) of 42,900 vehicles per day (vpd), and a posted speed limit of 25 mph in the school zone and 45 mph elsewhere (Valdés-Diaz et al., 2018).

A site inspection performed in this school zone showed that the speed limit and school zone signs had not been updated to the fluorescent yellow-green color indicated in the last version of the MUTCD. Also, it was found that yellow transversal lines were used to delimit the beginning and end of the school zone, as required by Puerto Rico's traffic law. There was no pavement marking with the word "School," and there was no END OF SCHOOL ZONE sign at the end of the school zone as required by the MUTCD.

3.4 Experimental Design

A factorial design with two blocks was used for this experiment. The factors considered in this study were Traffic, Pedestrian Presence, Vehicles Parked in Shoulder, and Configuration. The Traffic factor represents whether or not ambient traffic is included in the scenarios, with two levels: moderate number of vehicles and no vehicles. The Pedestrian Presence factor denotes the presence of pedestrians on the sidewalks near the school zone with three different levels: no pedestrians, adults and children, and only children. The Vehicles Parked in Shoulder factor represents the presence of vehicles parked on the right-side shoulder in front of the school, with two levels: parked vehicles and no parked vehicles. The Configuration factor was used for the blockage: base configuration and recommended configuration.

A total of twelve scenarios for each configuration were developed to evaluate each combination of the factors. Table 3.1 shows a description of the experimental scenarios.

Table 3.1 - Experimental scenarios

Scenario	Pedestrians			Vehicles Parked in Shoulder		Traffic	
	Adults and Children	No Pedestrians	Only Children	Yes	No	Yes	No
1	x			X		X	
2	x			X			X
3	X				X	X	
4	X				X		X
5		X		X		X	
6		X		X			X
7		X			X	X	
8		X			X		X
9			X	X		X	
10			X	X			X
11			X		X	X	
12			X		X		X

A total of 72 subjects participated in the collaborative project. Two groups of 36 subjects were recruited from Puerto Rico and from Massachusetts. Each group at each university was divided in two samples of 18 subjects. Each sample drove in one configuration. The scenarios in each configuration were shown to each subject in random order.

4 Analysis of Results

The analyses of the driving simulation experiments concentrated on the following variables: speed behavior, influence of pedestrian presence, and speed limit compliance. The comparison of the results shown was between the behavior of familiar and unfamiliar drivers between Zone 0 and Zone 3. The familiar drivers correspond to the subjects recruited at UPRM, and the unfamiliar drivers correspond to the subjects recruited at UMass. The local drivers at UPRM were assumed to be familiar with the roadway-school environment and the existing TCDs of

Configuration 1. The UMass drivers were assumed to be unfamiliar with the roadway environment and the Spanish-based signs and were treated as first-time drivers in the existing TCDs of Configurations 1 and 2. A second factor to consider in the evaluation of the differences was the use of Spanish text on the TCDs.

4.1 Zones of Interest

Figure 4.1 shows the comparison between the signage and pavement markings that were used for the configuration of the scenarios and the location of each sign in the school zone area. There are five zones of interest. Zone 0 refers to the segment of the road where the subjects are traveling at free-flow speed, before the school zone signage and pavement markings. Zone 1 is the area prior to the school zone warning sign. Zone 2 corresponds to the area between the school zone warning sign and the school speed limit sign (roadside or overhead, respectively). Zone 3 corresponds to a location in the vicinity of the school driveway where one pedestrian walks on the shoulder near the right travel lane in the direction toward oncoming traffic. Vehicles parked at an angle in the right shoulder are also present in this zone. Zone 4 represents the end of the school zone identified with the last TCD in each configuration.

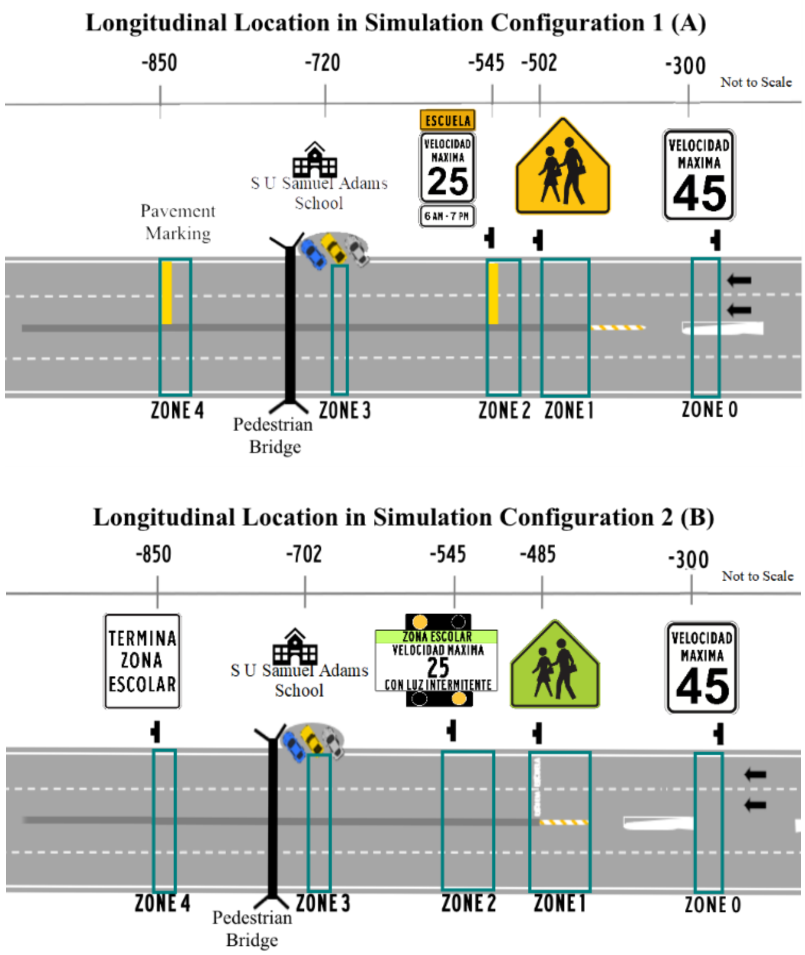


Figure 4.1 - Signage and pavement marking configurations

4.2 Speed Behavior

Table 4.1 shows the results from the statistical test of the difference in mean speeds between each group of subjects (familiar vs. unfamiliar) and for each configuration. The results show that familiar and unfamiliar drivers had similar mean speeds at Zone 0 (before the school zone) for all scenarios in Configuration 1. When comparing speeds at Zone 0 in Configuration 2 with the enhanced TCDs, larger differences were observed between the groups of drivers. In this case, unfamiliar drivers had significantly higher mean speeds at Zone 0 for 67% of the scenarios, in a range of 3.3 to 8.0 mph.

When observing mean speeds in Zone 3, with drivers already inside the school zone, there were significant differences between familiar and unfamiliar drivers at a 5% significance level. These differences were observed in 75% of the scenarios for Configuration 1 with the existing TCDs and in 92% of the scenarios for Configuration 2 with the enhanced TCDs. The overall trend is that familiar drivers selected lower speeds than unfamiliar drivers.

Table 4.1 - Statistical analysis of mean speed for unfamiliar vs familiar drivers

Unfamiliar vs Familiar Drivers Evaluation								
Scenario	Configuration 1 – Existing TCDs				Configuration 2 – Enhanced TCDs			
	P-Values		$Difference_{ij} = A_{ij} - B_{ij}$		P-Values		$Difference_{ij} = A_{ij} - B_{ij}$	
	Zone 0	Zone 3	Zone 0	Zone 3	Zone 0	Zone 3	Zone 0	Zone 3
1	0.493	0.006	1.21	5.45	0.168	0.032	2.30	5.31
2	0.278	<0.001	1.72	9.68	0.001	0.019	8.01	12.66
3	0.235	0.093	-1.74	2.64	0.195	0.007	2.29	6.38
4	0.895	0.002	0.22	6.65	0.027	0.043	3.80	3.56
5	0.710	<0.001	0.62	6.78	0.038	0.018	3.32	8.88
6	0.717	0.002	-0.52	8.25	0.009	0.016	4.47	8.20
7	0.729	0.135	0.62	2.73	<0.001	0.002	4.90	6.87
8	0.759	0.048	-0.31	6.07	0.15	0.478	3.20	2.48
9	0.550	0.032	1.05	4.37	0.011	0.009	4.10	7.25
10	0.238	0.065	1.82	5.12	0.104	<0.001	3.08	12.07
11	0.811	0.046	-0.39	4.41	0.001	0.002	6.11	7.16
12	0.062	0.007	-0.92	6.92	0.002	0.023	6.26	7.52

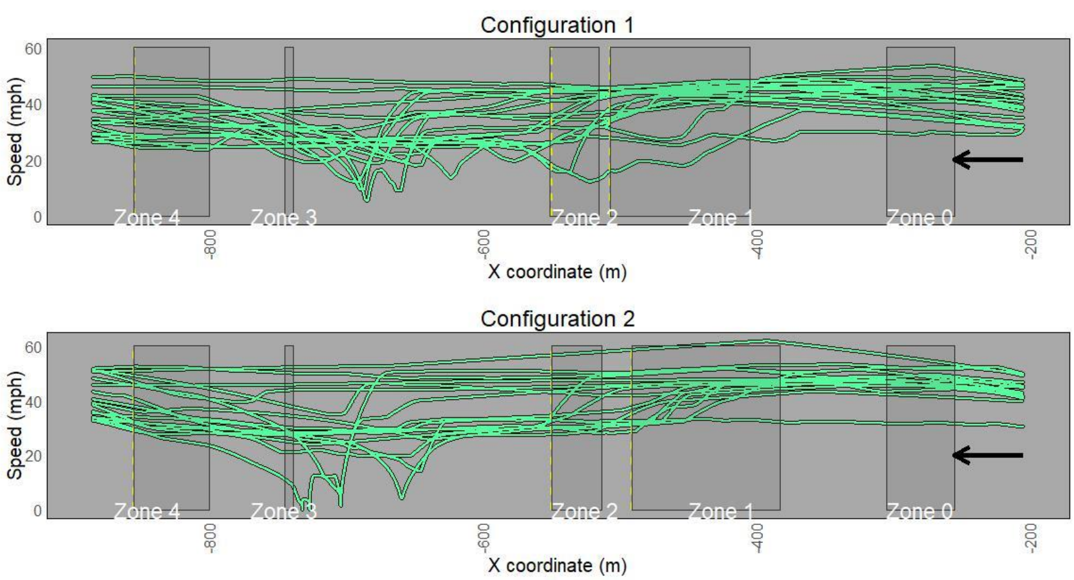
$\boldsymbol{Difference_{ij} = A_{ij} - B_{ij}}$

where A = mean speed for unfamiliar drivers; B = mean speed for familiar drivers; i: 1-12, scenario number; and j: 0 or 3, zone of interest.

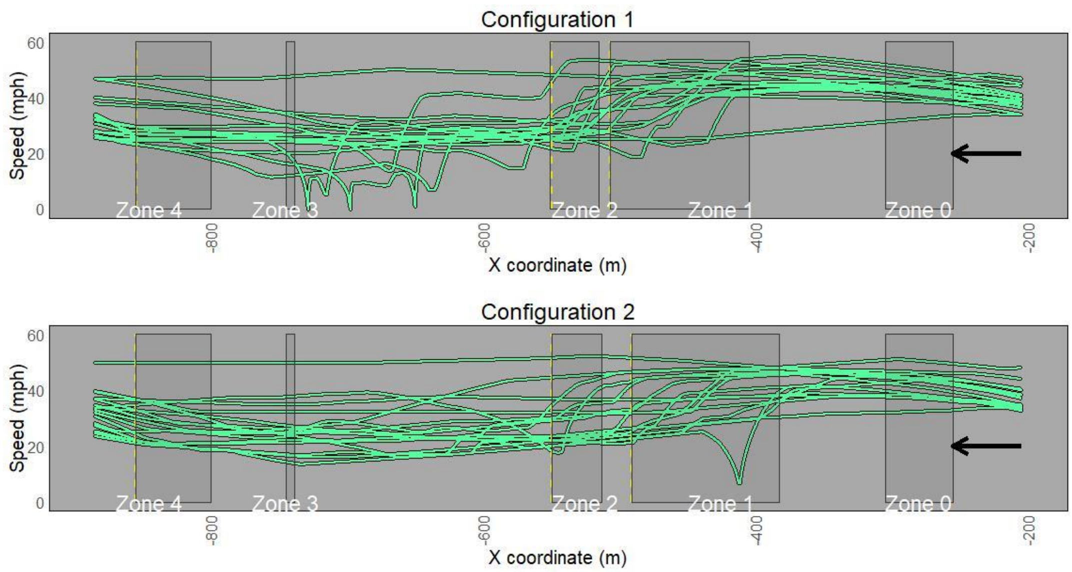
4.3 Reaction to the Presence of Pedestrians

Figure 4.2 shows the trajectories of individual subjects along Scenario 12 for both driver samples at each configuration. Scenario 12 included only the presence of children pedestrians with no vehicles parked on the shoulder and no ambient traffic in the simulation. Besides avatars present on the sidewalks, an additional avatar was walking along the shoulder in the direction toward traffic between Zones 2 and 3. See Appendix A for speed trajectories of familiar and unfamiliar drivers in all experimental scenarios.

The sudden speed reductions observed between Zones 2 and 3 for the individual speed trajectories in the first three graphs of Figure 4.2 reflect that the driver reacted to the presence of the pedestrian on the shoulder. Most of these drivers were traveling at speeds well above the school zone speed limit (over 30 mph) before applying the brakes. Of all unfamiliar drivers traveling in Configurations 1 and 2, 33% and 29% of the drivers, respectively, reduced their speeds in reaction to the presence of the child pedestrian. The trend observed for familiar drivers showed that 33% and 19% of all drivers reduced their speeds between Zones 2 and 3 for Configurations 1 and 2, respectively.



a) Unfamiliar drivers



b) Familiar drivers

Figure 4.2 - Scenario 12 subject speeds by configuration

4.4 Speed Compliance

Table 4.2 shows the speed limit compliance in percentages between familiar and unfamiliar drivers in Zones 0 and 3. For Zone 0, familiar drivers had a higher compliance percentage in 75% of the scenarios. The overall trend in Zone 3 is that familiar drivers always had higher compliance than unfamiliar drivers. In terms of the enhanced TCDs' effectiveness for improving speed limit compliance, the results show that unfamiliar drivers improved their compliance on 25% of the scenarios, whereas familiar drivers improved compliance on 83% of the scenarios. Improvement was defined as an increase of 1% or higher.

Table 4.2 - Speed limit compliance between familiar and unfamiliar drivers

Scenario	Configuration	Unfamiliar Drivers (%)		Familiar Drivers (%)	
		Zone 0	Zone 3	Zone 3	Zone 0
1	1	44.44	5.56	46.67	60.00*
	2	22.22	0.00	43.75	62.50*
2	1	44.44	11.11	53.33*	66.67

	2	29.41	11.76	56.25*	62.50
3	**1**	38.89	0.00*	13.33*	40.00*
	2	22.22	11.11*	43.75*	43.75*
4	**1**	44.44	5.56	33.33*	46.67*
	2	29.41	5.88	37.50*	68.75*
5	**1**	27.78	11.11	33.33*	46.67
	2	22.22	0.00	50.00*	31.25
6	**1**	55.56	5.56*	40.00*	40.00*
	2	17.65	11.76*	43.75*	68.75*
7	**1**	50.00	5.56	20.00*	46.67*
	2	5.56	0.00	25.00*	62.50*
8	**1**	50.00	5.56	26.67	66.67
	2	44.44	0.00	25.00	62.50
9	**1**	33.33	0.00*	33.33*	60.00*
	2	27.78	11.11*	56.25*	62.50*
10	**1**	33.33*	16.67	46.67*	66.67
	2	38.89*	11.11	56.25*	62.50
11	**1**	38.89	16.67	40.00*	53.33*
	2	27.78	16.67	43.75*	68.75*
12	**1**	66.67	16.67	53.33*	73.33*
	2	16.67	16.67	56.25*	81.25*

Table 4.3 shows the mean reduction in speeds for familiar and unfamiliar drivers between Zones 0 and 3 for those scenarios without ambient traffic. The expected minimum reduction in

speeds was 20 mph for this school zone (from 45 to 25 mph). None of the scenarios exhibited the expected speed reduction. In 83% of the scenarios, familiar drivers had larger reductions in mean speeds than unfamiliar drivers. In 67% of the scenarios (4 out of 6), the enhanced TCDs had the expected effect of achieving a higher speed reduction for unfamiliar drivers, even though the speed compliance in Zone 3 was between 0% and 16.67%. The positive effect of the enhanced TCDs for the familiar drivers was only observed in 17% of the scenarios (1 out of 6). However, the range for the compliance rate was between 33% and 81% for familiar drivers.

Table 4.3 - Mean reduction in speeds between Zones 0 and 3

Scenario	**Unfamiliar Drivers**				**Familiar Drivers**			
	Configuration 1		**Configuration 2**		**Configuration 1**		**Configuration 2**	
	P-Values	$\boldsymbol{Diff_i}$	**P-Values**	$\boldsymbol{Diff_i}$	**P-Values**	$\boldsymbol{Diff_i}$	**P-Values**	$\boldsymbol{Diff_i}$
2	<0.001	10.92	0.042	10.45	<0.001	18.89	<0.001	15.10
4	<0.001	11.52	<0.001	17.92	<0.001	17.94	<0.001	17.67
6	0.001	8.91	<0.001	12.43	<0.001	17.68	<0.001	16.15
8	0.003	8.44	<0.001	11.20	<0.001	15.14	0.002	10.48
10	<0.001	11.89	0.001	9.65	<0.001	15.19	<0.001	18.64
12	<0.001	10.75	<0.001	15.60	<0.001	18.59	<0.001	16.87

$Diff_i = Difference_i = C_i - D_i$

where: C = mean speed for Zone 0; D = mean speed for Zone 3; i: 2, 4, 6, 8, 10, 12, scenario number.

4.5 Eye-Tracker Analysis

The eye-tracking data recorded for this project was a binary response of yes (1) or no (0). Considering that the data has a binary format, a Fisher Exact Test was performed for two independent samples (StatsDirect Limited, 2019b, 2019a). This test was used to analyze the proportions of successes in each element of interest. Appendix B presents the outputs of the Fisher Exact Test. The elements of interest are 45 mph sign, school zone sign, school zone speed limit sign, and pavement marking at the beginning of the school area. Success is defined as 1 if the subjects see the element, otherwise it is 0. The Fisher Exact Test consists of comparing the quantity of successes and failures of viewing an element in the simulation.

For the familiar drivers, 183 observations were recorded for 8 subjects for Configuration 1 and for 9 subjects for Configuration 2. When evaluating whether there was a significant difference between the configuration proportions for each of the elements of interest, it was determined that there was a difference for the 45 mph sign and for the school zone sign. The comparison between the speed limit sign of 45 mph located at the side of the road at the beginning of the simulation vs the overhead school speed limit sign in Configuration 2 shows that there is a statistically significant difference in the instances when the subjects saw the overhead sign. This means that subjects looked more at the overhead sign than to the sign at the side of the road.

For the unfamiliar drivers, a total of 216 data were collected for each configuration. When evaluating if there was a significant difference between the configuration proportions for each of the elements of interest, it was determined that there was a significant difference for the 45mph sign, the school zone sign, the school speed limit sign, and the pavement marking at the beginning of the school area. The comparison between the speed limit sign of 45 mph located at the side of the road at the beginning of the simulation vs the overhead school speed limit sign in Configuration 2 shows that there is a statistically significant difference in the instances when the subjects saw the overhead sign. This means that unfamiliar subjects also looked more at the overhead sign than at the sign on the side of the road. A comparison for the 25 mph school speed limit sign for Configuration 2 between familiar and unfamiliar drivers was performed, and the result indicates that there was a significant difference between familiar and unfamiliar drivers; therefore, unfamiliar drivers looked at the overhead sign more than the familiar drivers.

A summary of the responses is presented in Figure 4.3.

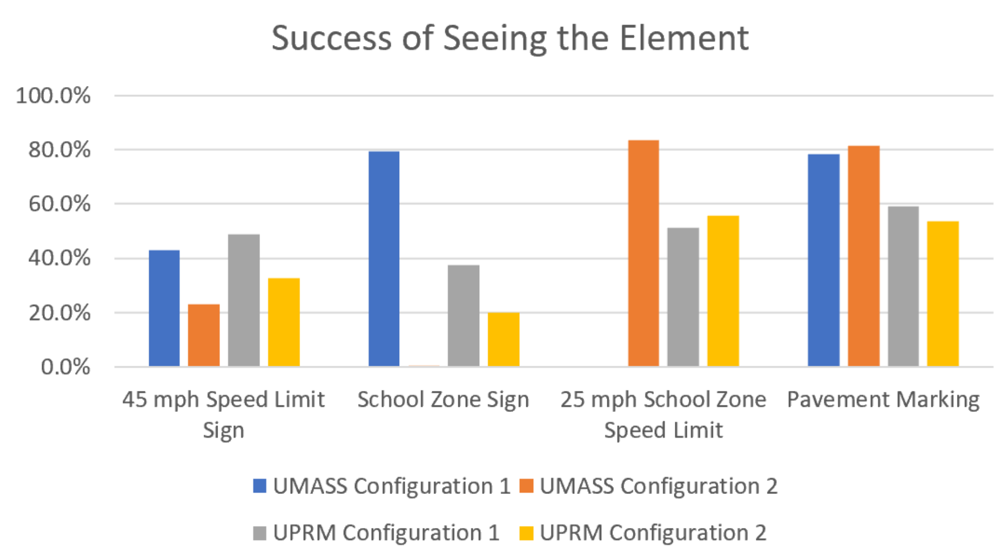


Figure 4.3 - Success of seeing the elements

5 Conclusions

This collaborative study evaluated speed selection and driver behavior in a school zone adjacent to a four-lane arterial highway located in a suburban area in Puerto Rico. The evaluation was performed using driving simulation scenarios with familiar (Puerto Rico) and unfamiliar (Massachusetts) drivers. The study also evaluated the potential effectiveness of enhanced TCD configurations in improving speed compliance in the school zone. The conclusions are presented in three categories: speed behavior, reaction to the presence of pedestrians/avatars, and speed compliance.

In terms of **speed behavior**, the combined effect of Spanish-text and enhanced TCDs, although following MUTCD colors and sizes, was not necessarily apparent to unfamiliar drivers. This finding might be indicative of the need to consider use of symbols rather than text (i.e., legend) messages in areas where there are likely to be unfamiliar drivers on the road. Based on the results of the **reaction to the presence of pedestrians/avatars**, familiar drivers did not show significant speed reductions because they were aware of the environment and were less sensitive to the presence of the pedestrian on the road shoulder.

The **speed compliance** can be improved up to 30% for familiar drivers and up to 11% for unfamiliar drivers with the implementation of the proposed overhead sign. Based on the results of **mean reduction in speeds** between Zones 0 and 3, the enhanced TCDs increased the reduction for unfamiliar drivers, even though the compliance was substantially low (between 0% and 16.67%). For familiar drivers, the mean reduction was lower, but the compliance was higher (between 33% and 81%). This may be indicative of the overall behavior of driver performance in school zones in Massachusetts, where compliance with speed reduction requirements for school zones may be limited regardless of the treatment.

Finally, with the evaluation of the eye-tracker data, it is notable that the proposed overhead signage with flashing beacons captured the attention for unfamiliar and familiar drivers more than the signs used in the current configuration. However, the percentage of unfamiliar drivers that looked at the overhead sign was greater than the percentage of familiar drivers. Nevertheless, looking more at the overhead sign does not translate to greater speed compliance in school zones.

In Puerto Rico, it is not common to use overhead signage for school zones. Therefore, the implementation of this signage should be reinforced with educational campaigns and enforcement.

Acknowledgments

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References

Ellison, A. B., Greaves, S. P., & Daniels, R. (2011). Speeding Behavior in School Zones. *Australasian College of Road Safety Conference*, 1–12. Retrieved from https://acrs.org.au/files/papers/5 Ellison Speeding Behaviour in School Zones.pdf

Federal Highway Administration. (2012). *Manual on Uniform Traffic Control Devices for Streets and Highways*. Retrieved from https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf

Fisher, D. L., Rizzo, M., Caird, J., & Lee, J. D. (2011). *Handbook of driving simulation for engineering, medicine, and psychology*. Boca Raton, FL: Taylor & Francis Group.

González-Compre, J. (2016). *Mejoras en las Medidas para la Seguridad de las Zonas Escolares en el Área Oeste de Puerto Rico*. Universidad de Puerto Rico, Recinto Universitario de Mayagüez.

Intini, P., Berloco, N., Colonna, P., Ranieri, V., & Ryeng, E. (2018). Exploring the Relationships between Drivers' Familiarity and Two-lane Rural Road Accidents. A Multi-level Study. *Accident Analysis and Prevention*, *111*, 280–296. https://doi.org/10.1016/J.AAP.2017.11.013

Kattan, L., Tay, R., & Acharjee, S. (2011). Managing Speed at School and Playground Zones. *Accident Analysis and Prevention*, *43*(5), 1887–1891. https://doi.org/10.1016/J.AAP.2011.04.009

Lazic, G. (2003). School Speed Zones: Before and After Study City of Saskatoon. In *Annual Conference of the Transportation Association of Canada*. Retrieved from http://conf.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2003/pdfs/lazic2.pdf

National Center for Statistics and Analysis. (2018a). *School-transportation-related crashes: 2007-2016 data. (Traffic Safety Facts. Report No. DOT HS 812 476)*. Washington D.C.: National Highway Traffic Safety Administration.

National Center for Statistics and Analysis. (2018b). *Speeding: 2016 data. (Traffics Safety Facts. DOT HS 812 480)*. Washington D.C.: National Highway Traffic Safety Administration.

National Roads Authority. (2005). *Guidelines on Traffic Calming for Towns and Villages on National Routes*. Dublin, Ireland.

Rahman, M. M., & Strawderman, L. (2015). The Effect of Sign Saturation on Driver Speed Limit Compliance in School Zones. In *Human Factors and Ergonomics Society 59th Annual Meeting* (pp. 1612–1615). https://doi.org/https://doi.org/10.1177/1541931215591349

StatsDirect Limited. (2019a). Compare Two Independent Binomial Proportions. Retrieved May 18, 2019, from https://www.statsdirect.com/help/proportions/unpaired.htm

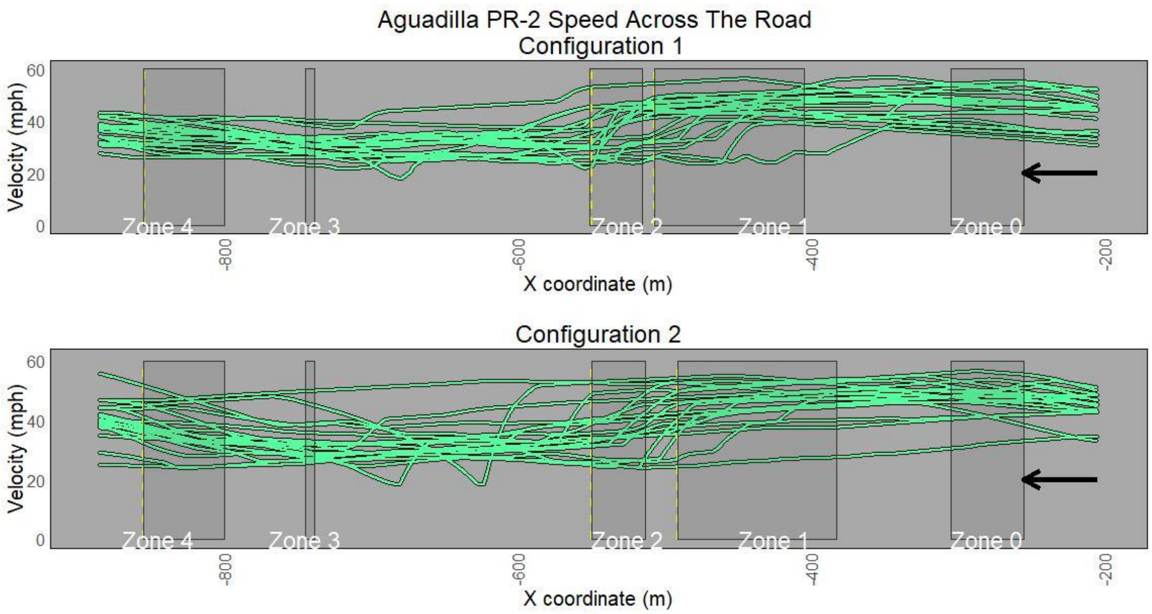
StatsDirect Limited. (2019b). Fisher Exact Test. Retrieved May 18, 2019, from https://www.statsdirect.com/help/exact_tests_on_counts/fisher_exact.htm

Valdés-Diaz, D., Colucci, B., Rojas, M. X., Colón, E., & García, R. (2018). Methodology for the Evaluation of School Zones in a Driver Simulator. *16th LACCEI International Multi-Conference for Engineering, Education, and Technology*. https://doi.org/10.18687/LACCEI2018.1.1.334

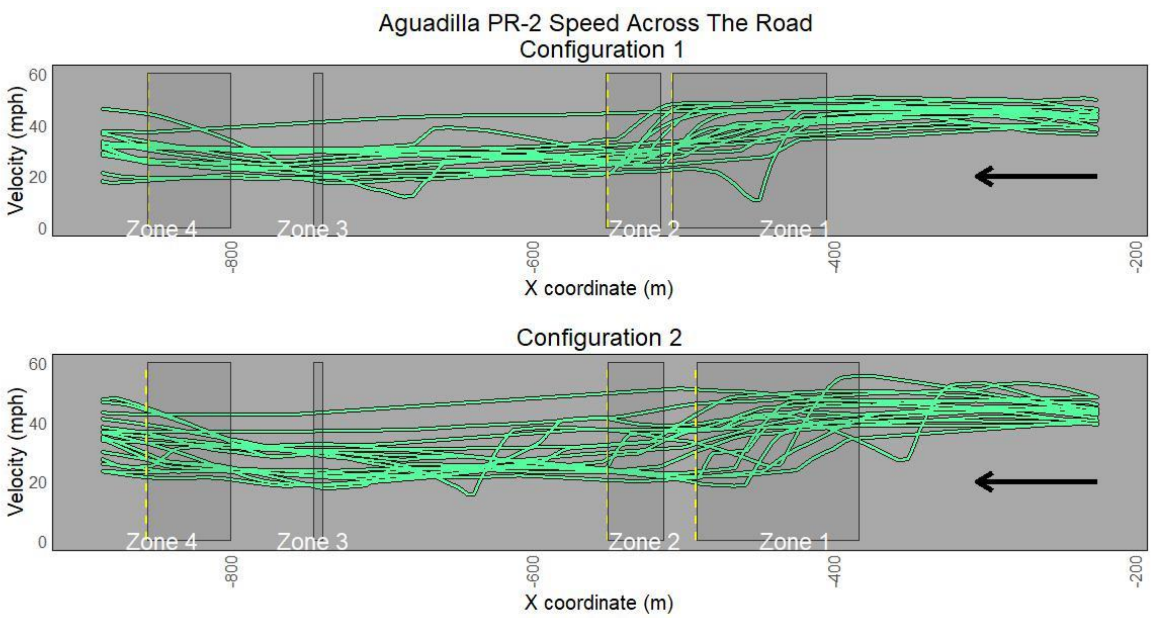
Valdés, D., Colucci, B., Figueroa, A., Colón, E., Rojas, M., García, R., … Arroyo, C. (2019). *Enhancing School Zone Safety: Case Studies in Puerto Rico using Driving Simulation*. Safety Research using Simulation. University Transportation Center.

Valdés, D., Colucci, B., Knodler, M., Fisher, D., Ruiz, B., Ruiz, J., … Hajiseyedjavadi, F. (2017). Comparative Analysis of Toll Plaza Safety Features in Puerto Rico and Massachusetts with a Driving Simulator. *Transportation Research Record: Journal of the Transportation Research Board*, *2663*(1), 1–11. https://doi.org/10.3141/2663-01

Appendix A: Speed Profiles for Familiar Vs. Unfamiliar Drivers

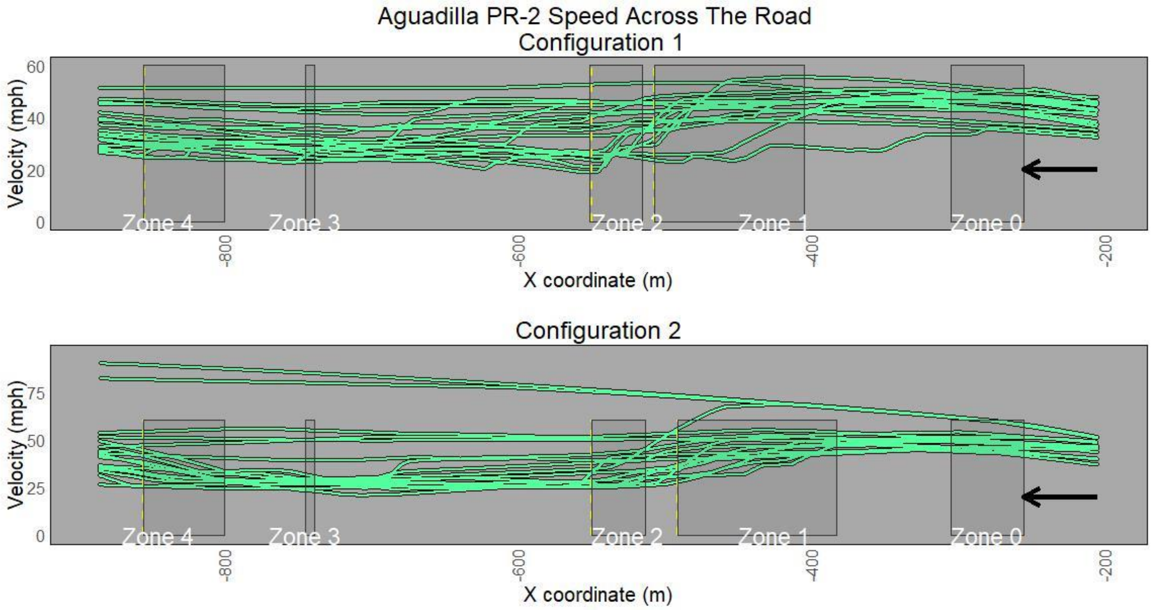


a) Unfamiliar drivers

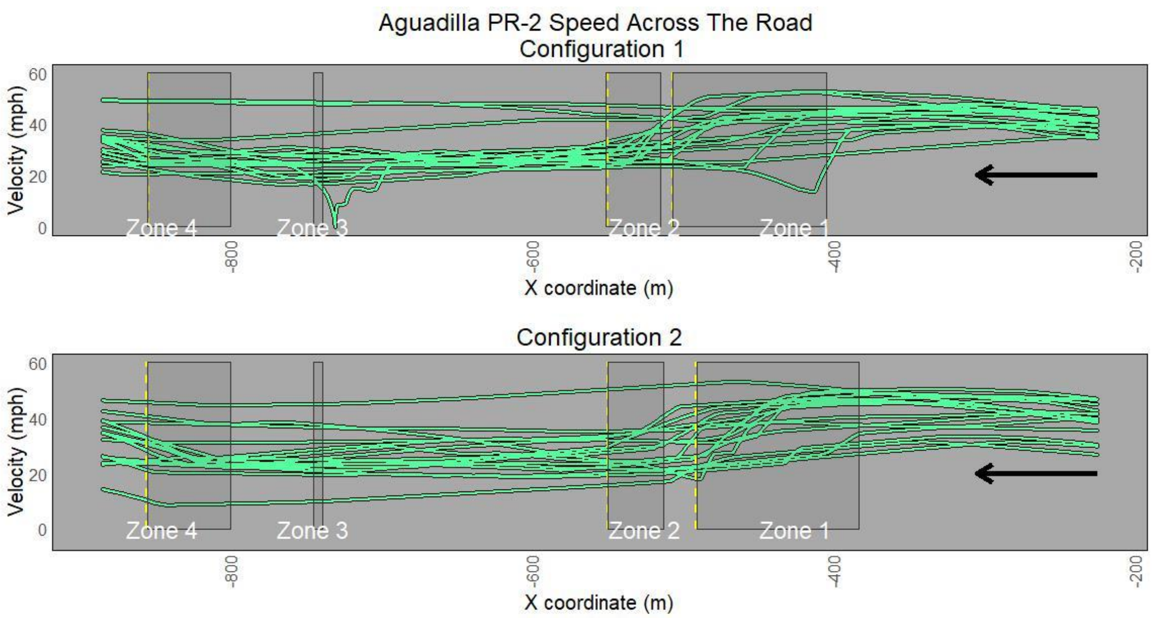


b) Familiar drivers

Figure A.1 - Scenario 1 subjects' speeds by configuration

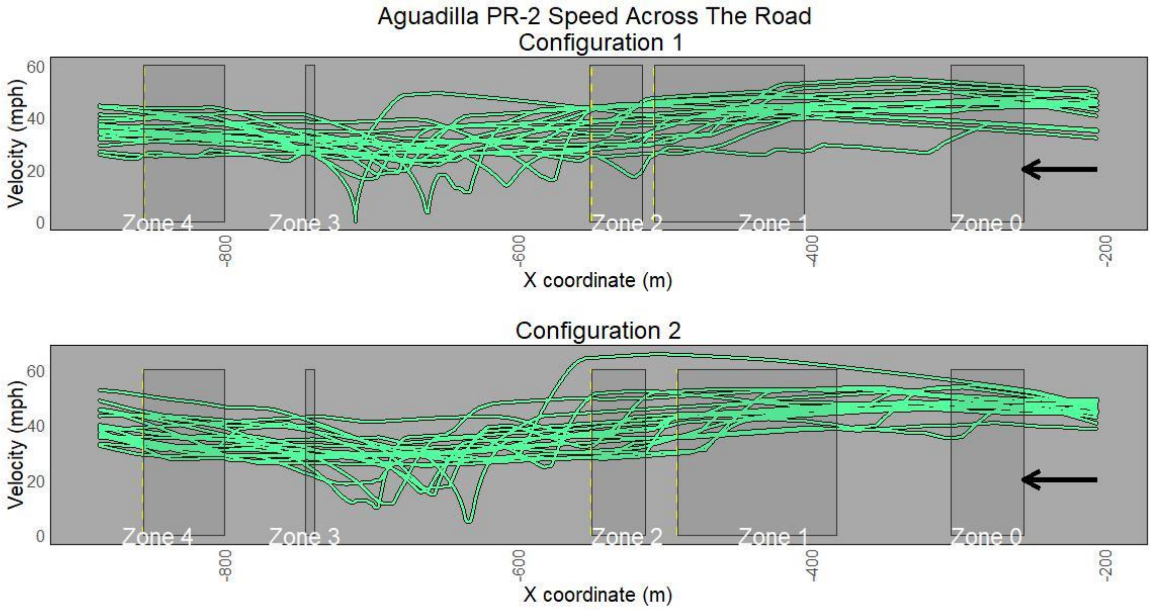


a) Unfamiliar drivers

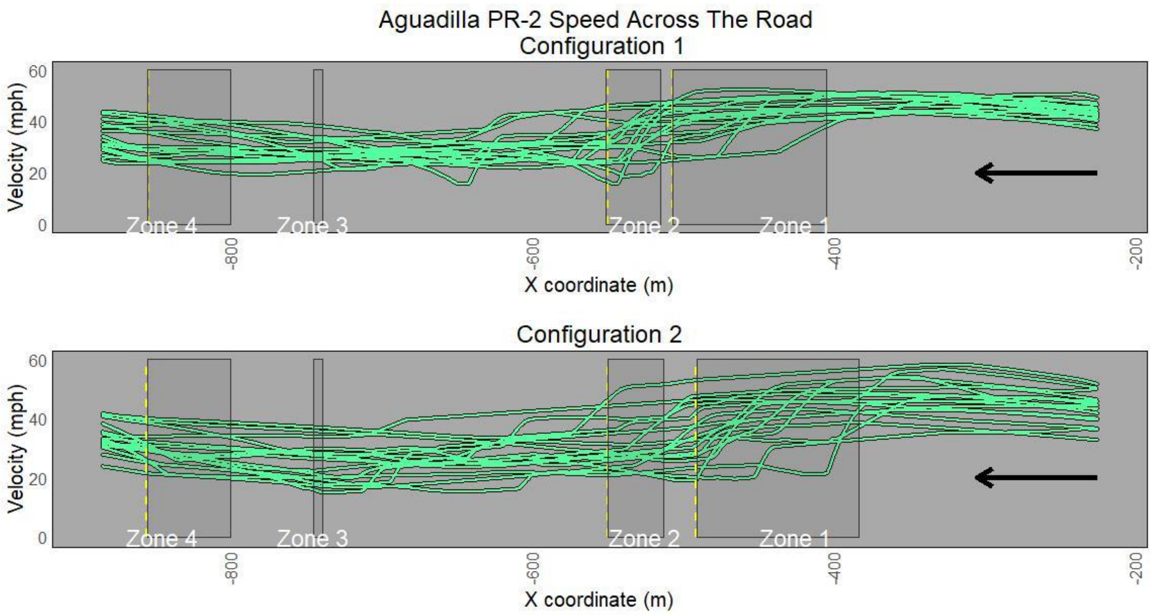


b) Familiar drivers

Figure A.2 - Scenario 2 subjects' speeds by configuration

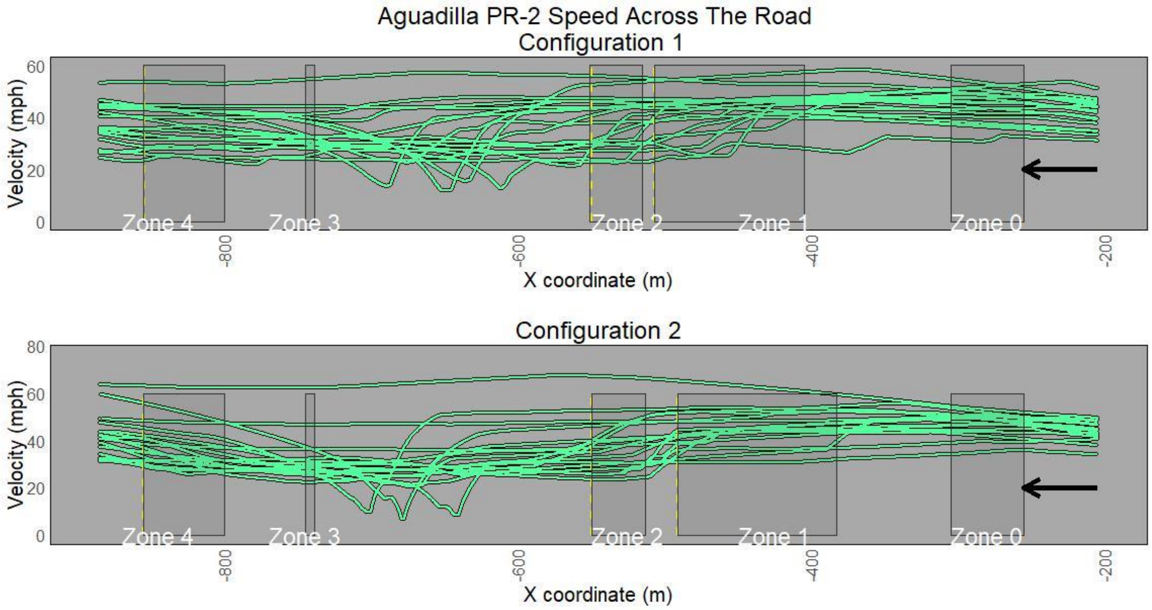


a) Unfamiliar drivers

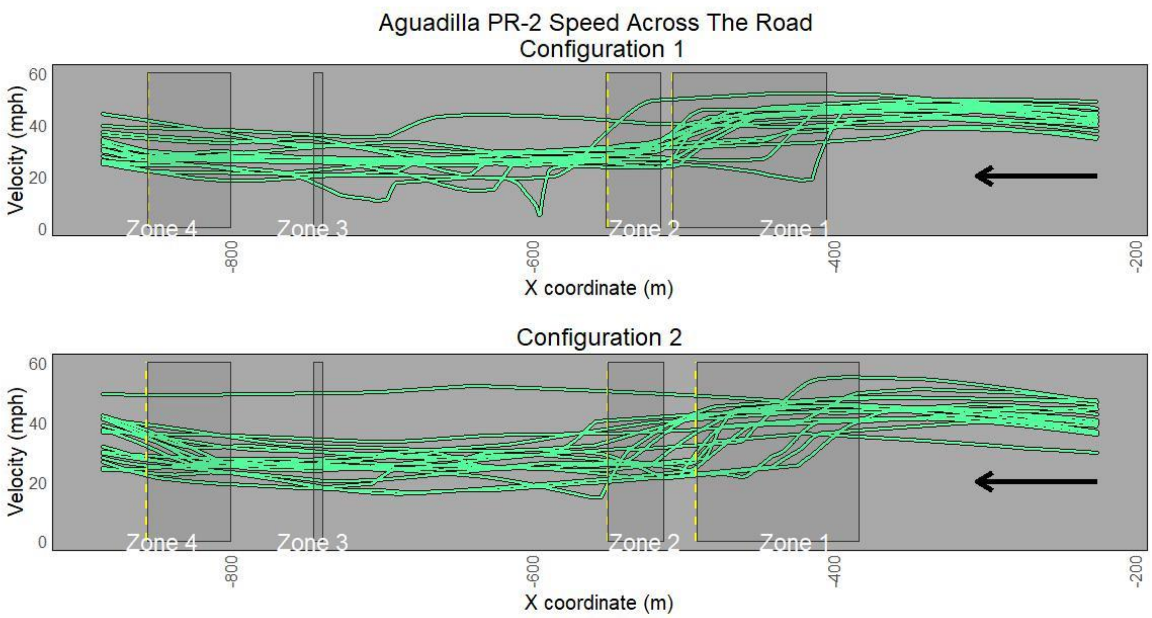


b) Familiar drivers

Figure A.3 - Scenario 3 subjects’ speeds by configuration

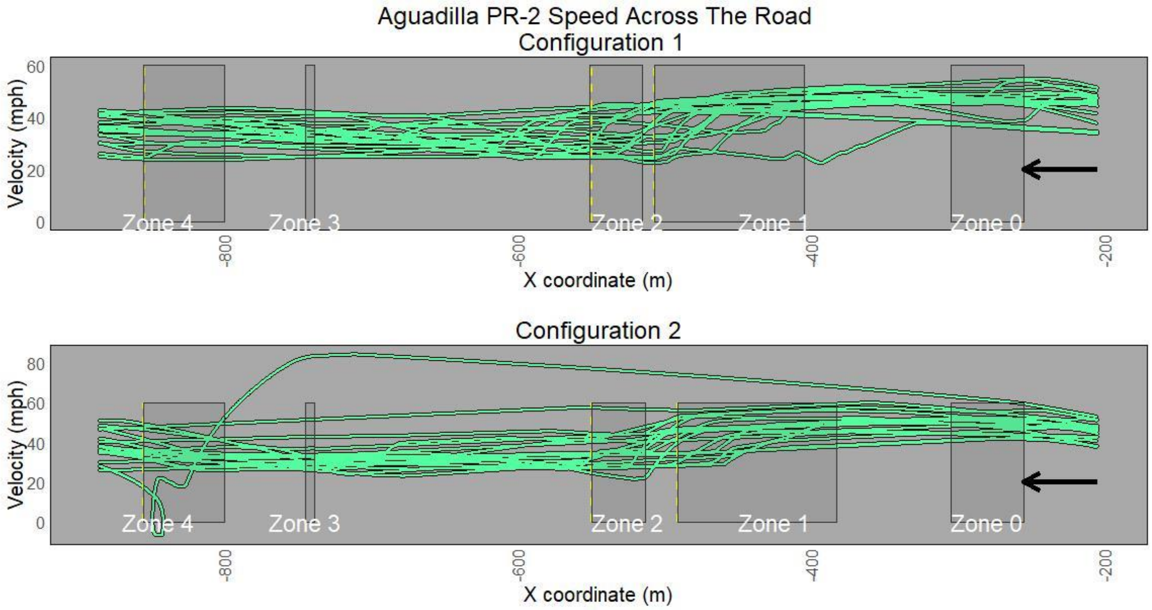


a) Unfamiliar drivers

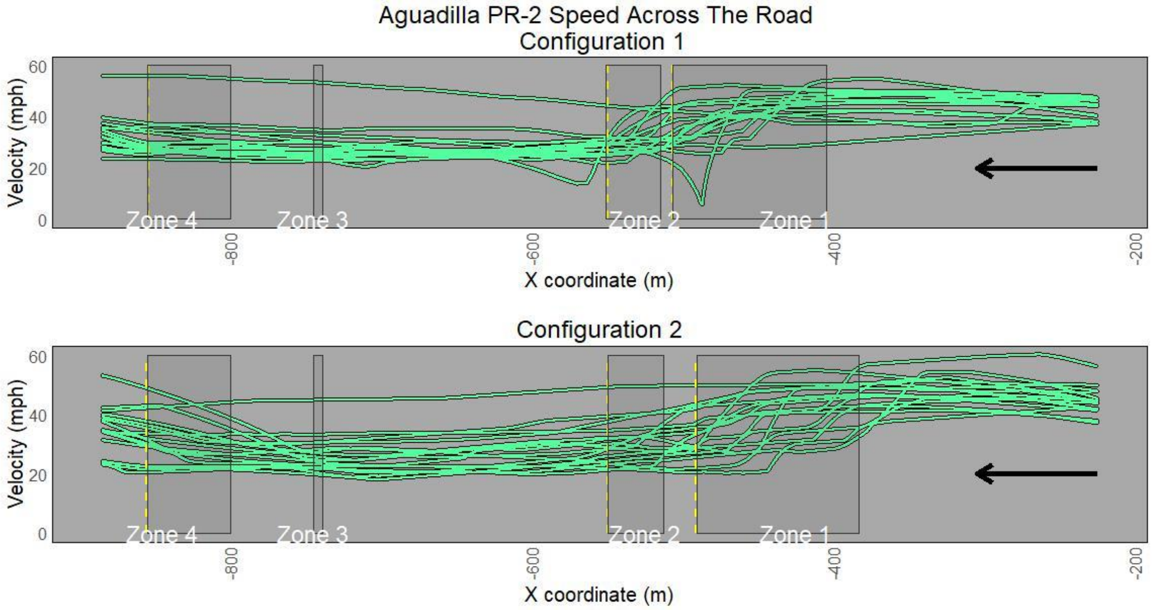


b) Familiar drivers

Figure A.4 - Scenario 4 subjects' speeds by configuration

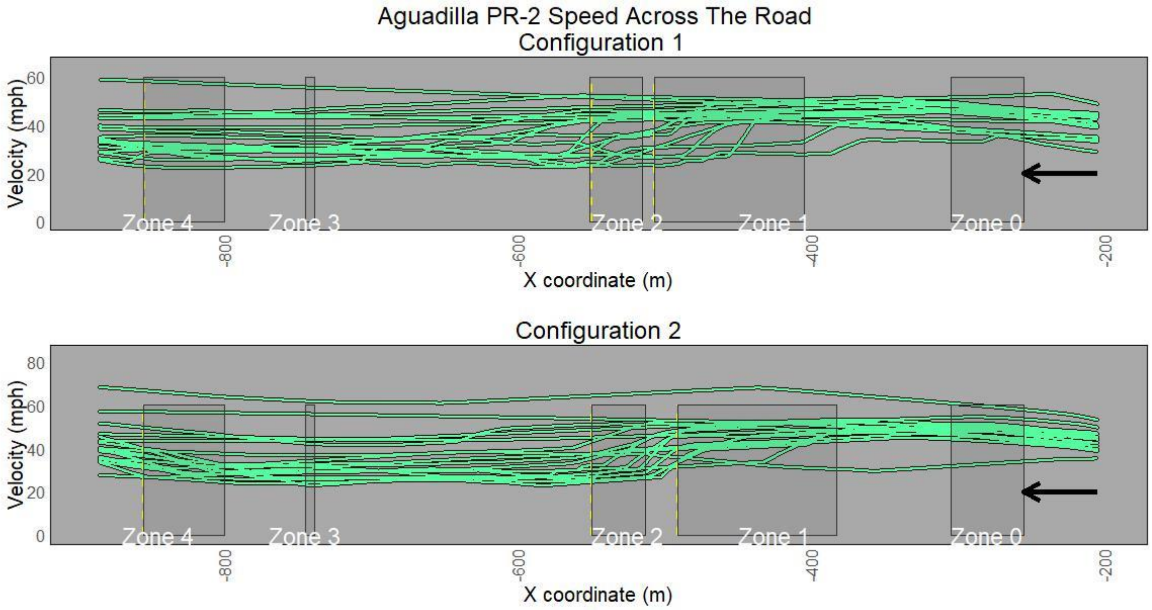


a) Unfamiliar drivers

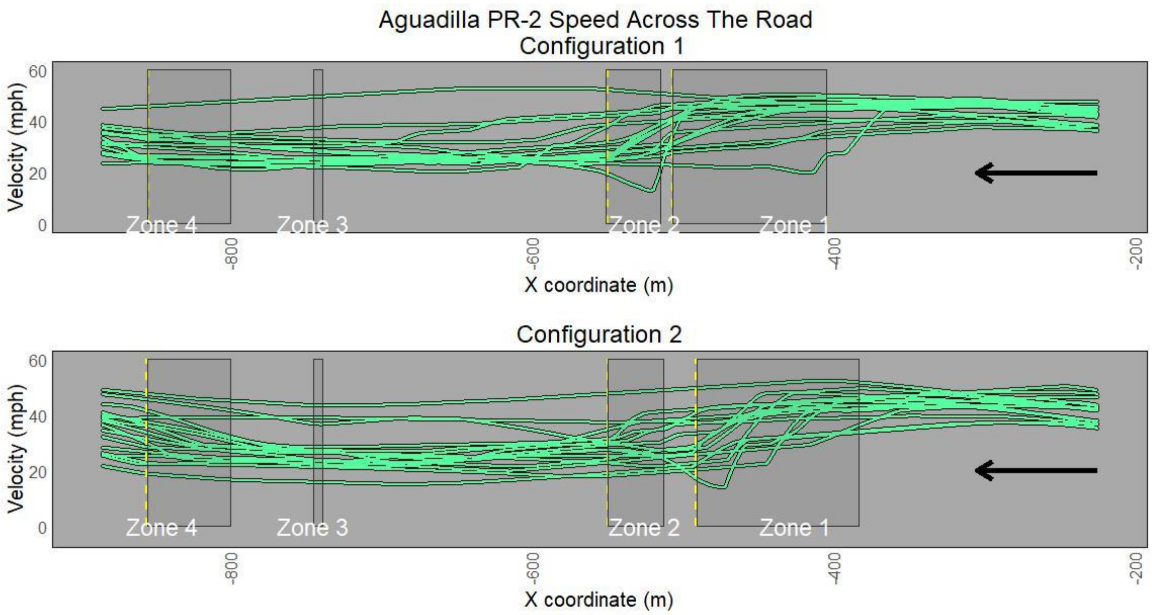


b) Familiar drivers

Figure A.5 - Scenario 5 subjects' speeds by configuration

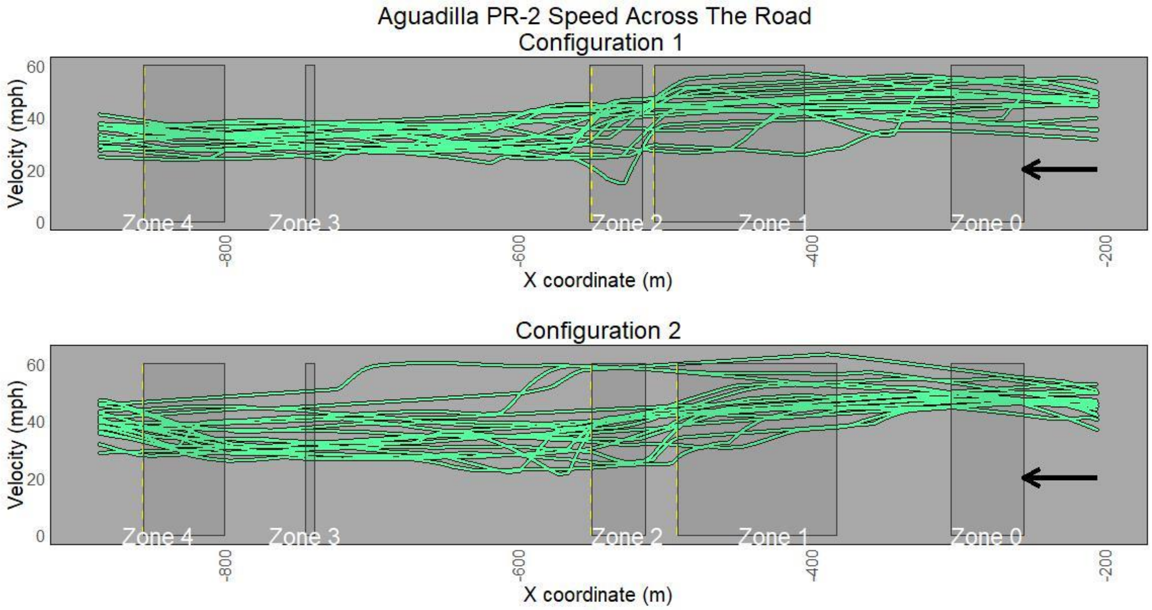


a) Unfamiliar drivers

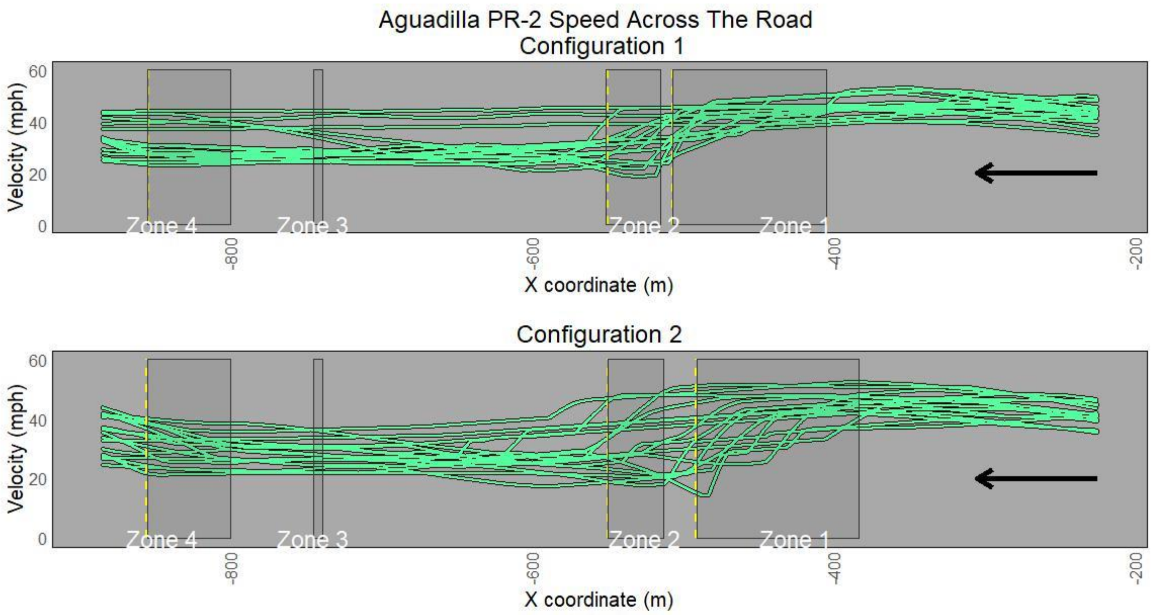


b) Familiar drivers

Figure A.6 - Scenario 6 subjects' speeds by configuration

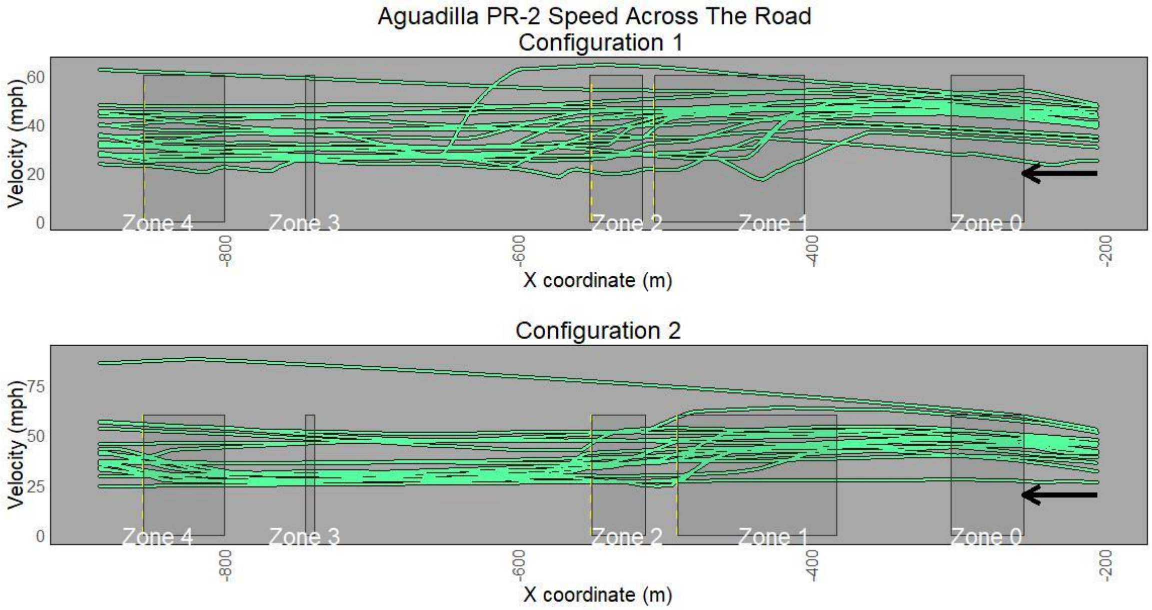


a) Unfamiliar drivers

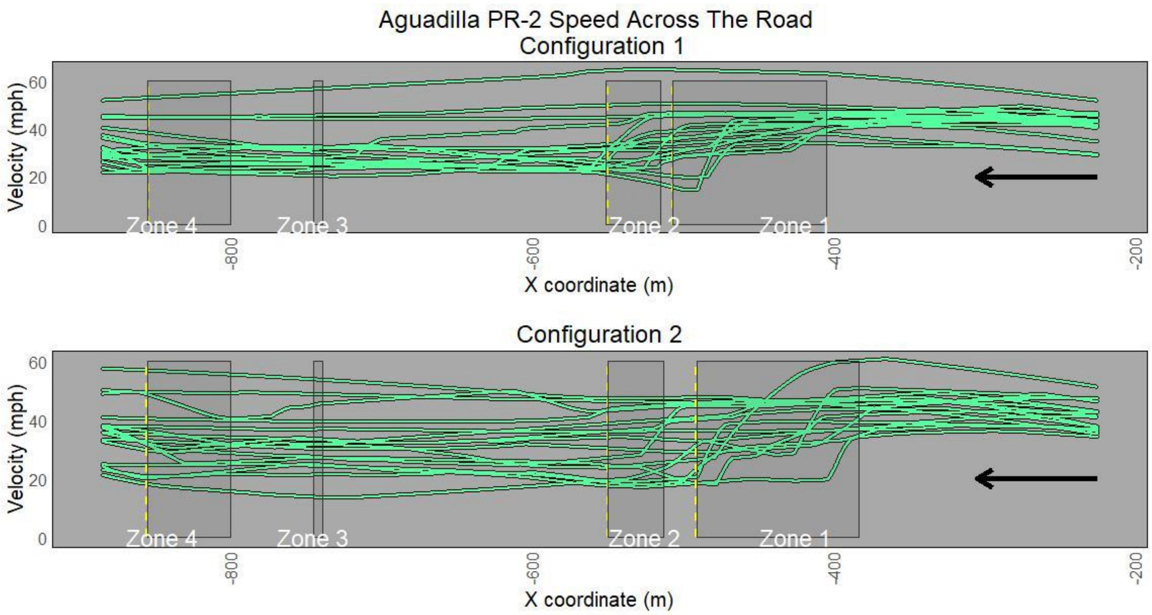


b) Familiar drivers

Figure A.7 - Scenario 7 subjects' speeds by configuration

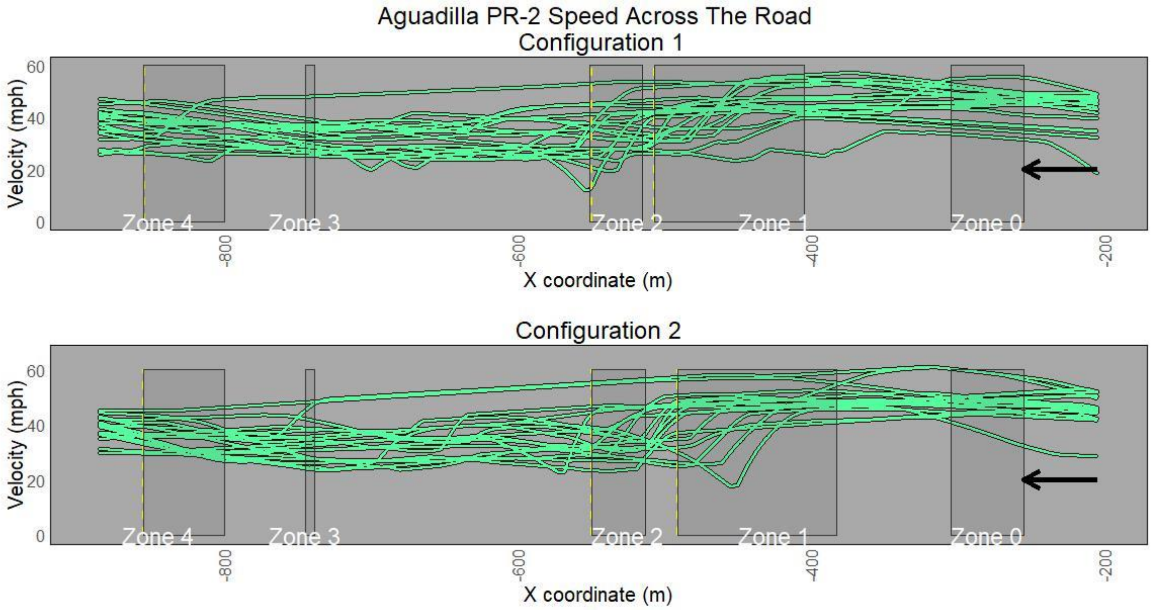


a) Unfamiliar drivers

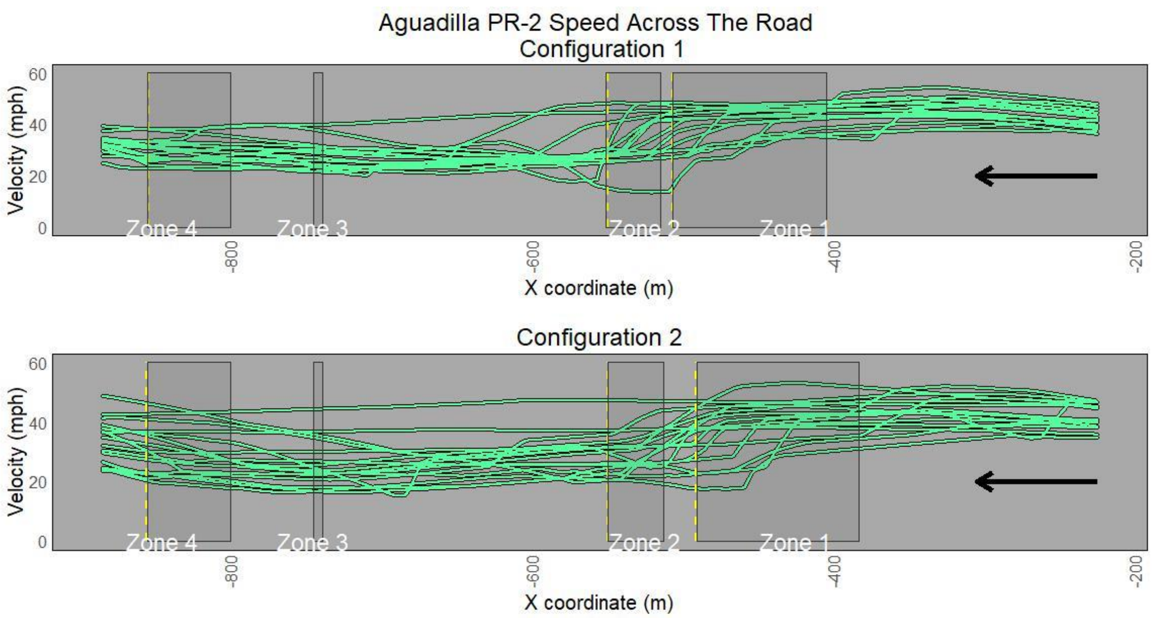


b) Familiar drivers

Figure A.8 - Scenario 8 subjects' speeds by configuration

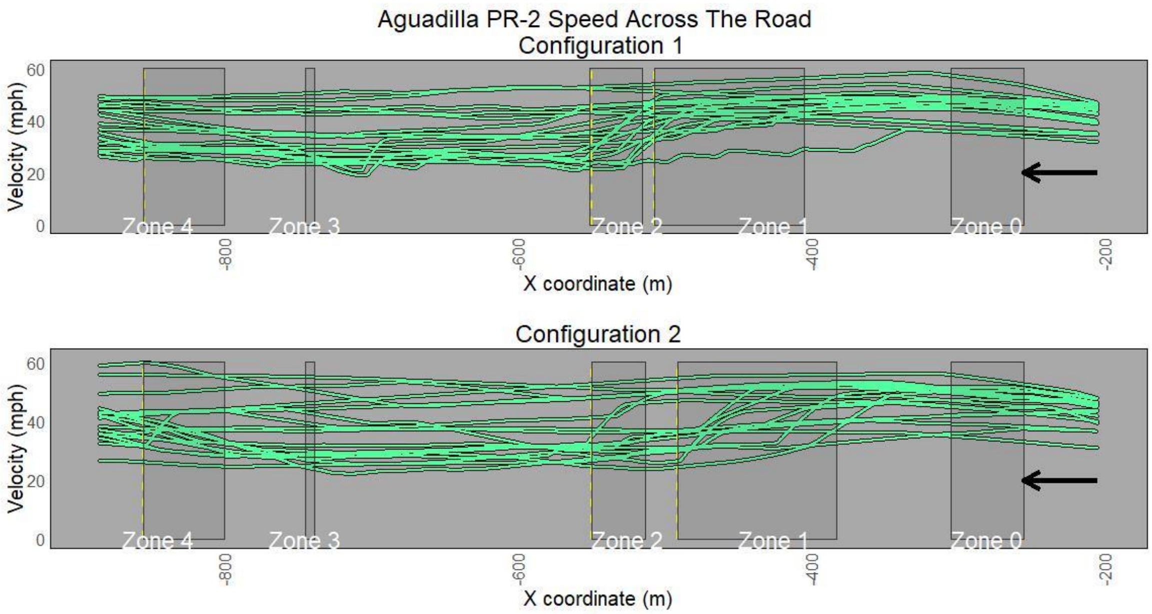


a) Unfamiliar drivers

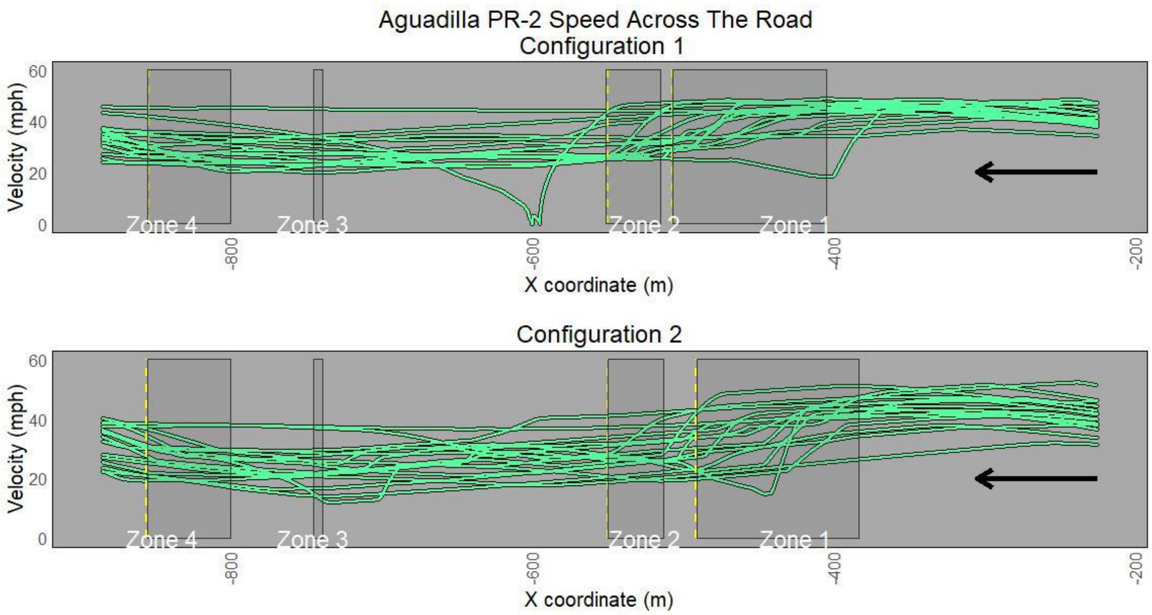


b) Familiar drivers

Figure A.9 - Scenario 9 subjects' speeds by configuration

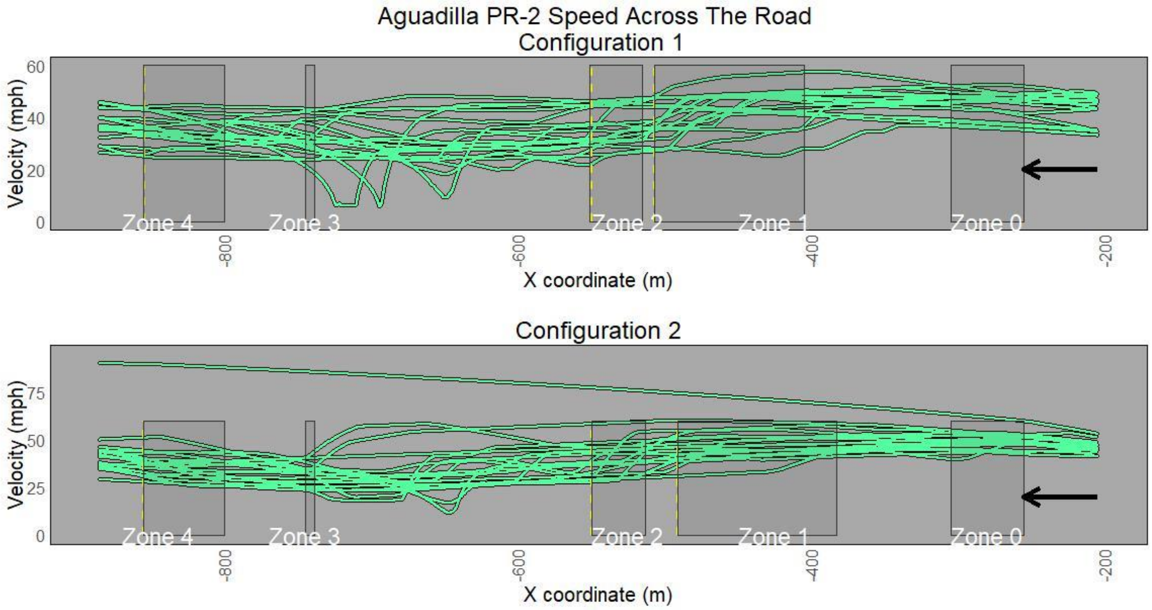


a) Unfamiliar drivers

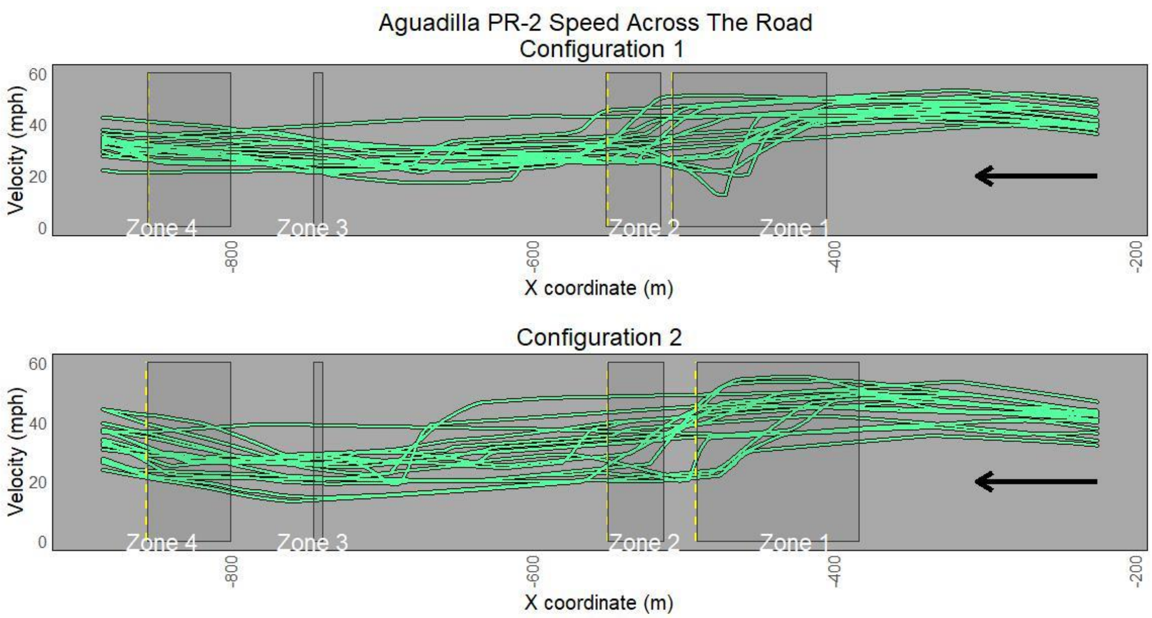


b) Familiar drivers

Figure A.10 - Scenario 10 subjects' speeds by configuration

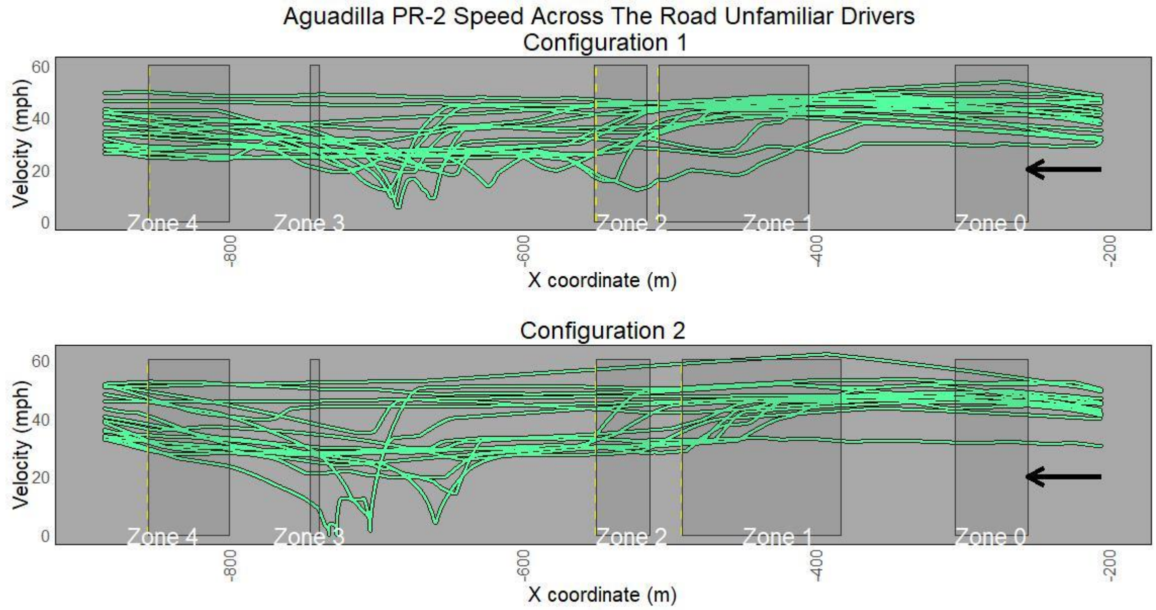


a) Unfamiliar drivers

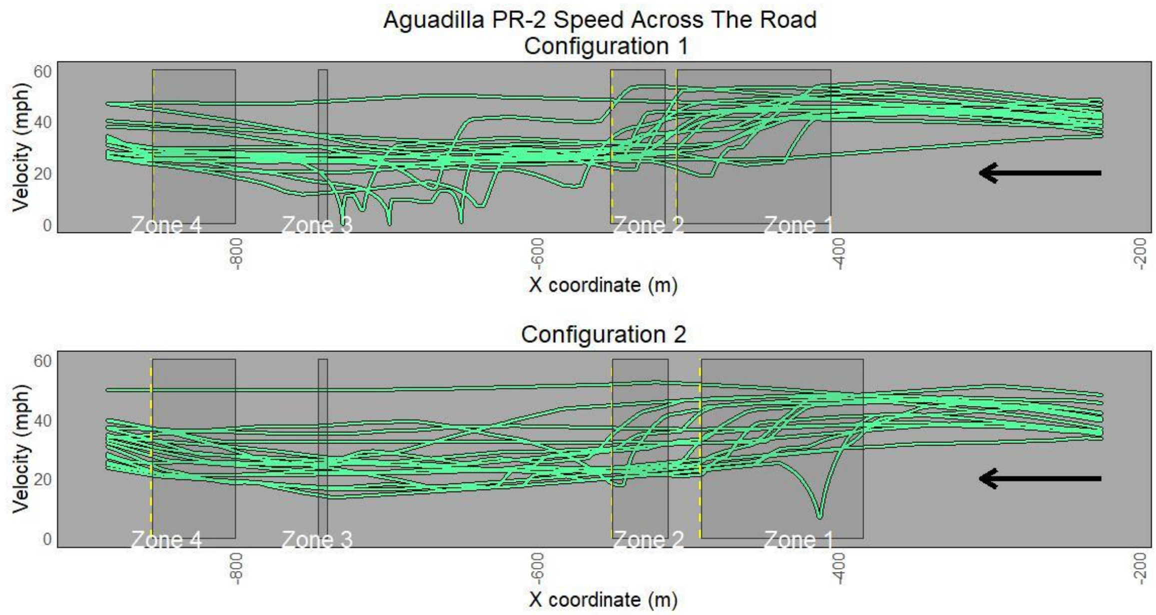


b) Familiar drivers

Figure A.11 - Scenario 11 subjects' speeds by configuration



a) Unfamiliar drivers



b) Familiar drivers

Figure A.12 - Scenario 12 subjects' speeds by configuration

Appendix B: Eye-Tracker Data Analysis

R Notebook

Code

UPRM

Speed Limit Sign 45 mph

Hide

```
fisher.test(matrix(c(43, 45, 31, 64), ncol=2))
```

```
	Fisher's Exact Test for Count Data

data:  matrix(c(43, 45, 31, 64), ncol = 2)
p-value = 0.03457
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 1.038884 3.754473
sample estimates:
odds ratio
  1.965322
```

Side of the Road School Zone Sign

Hide

```
fisher.test(matrix(c(33, 55, 19, 76), ncol=2))
```

```
	Fisher's Exact Test for Count Data

data:  matrix(c(33, 55, 19, 76), ncol = 2)
p-value = 0.01346
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 1.179342 4.946887
sample estimates:
odds ratio
  2.388314
```

Speed School Zone Sign 25mph Side of the Road Vs Overhead

Hide

```
fisher.test(matrix(c(45, 43, 53, 42), ncol=2))
```

```
    Fisher's Exact Test for Count Data

data:  matrix(c(45, 43, 53, 42), ncol = 2)
p-value = 0.5555
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 0.444708 1.546234
sample estimates:
odds ratio
 0.8301661
```

Pavement Marking Yellow line vs Pavement marking School word

Hide

```
fisher.test(matrix(c(52, 36, 51, 44), ncol=2))
```

```
    Fisher's Exact Test for Count Data

data:  matrix(c(52, 36, 51, 44), ncol = 2)
p-value = 0.551
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 0.6657617 2.3357175
sample estimates:
odds ratio
  1.244678
```

UMass

216/12=18 subjects for each configuration

Speed Limit Sign 45 mph

Hide

```
fisher.test(matrix(c(93, 123, 50, 166), ncol=2))
```

```
    Fisher's Exact Test for Count Data

data:  matrix(c(93, 123, 50, 166), ncol = 2)
p-value = 1.584e-05
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 1.624643 3.892696
sample estimates:
odds ratio
  2.504785
```

Side of the Road School Zone Sign

Hide

```
fisher.test(matrix(c(171, 45, 1, 215), ncol=2))
```

```
	Fisher's Exact Test for Count Data

data:  matrix(c(171, 45, 1, 215), ncol = 2)
p-value < 2.2e-16
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
   133.5812 16384.0000
sample estimates:
odds ratio
  794.3812
```

Speed School Zone Sign 25mph Side of the Road Vs Overhead

Hide

```
fisher.test(matrix(c(0, 216, 180, 36), ncol=2))
```

```
	Fisher's Exact Test for Count Data

data:  matrix(c(0, 216, 180, 36), ncol = 2)
p-value < 2.2e-16
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 0.000000000 0.003747111
sample estimates:
odds ratio
         0
```

Pavement Marking Yellow line vs Pavement marking School word

Hide

```
fisher.test(matrix(c(169, 47, 176, 122), ncol=2))
```

```
	Fisher's Exact Test for Count Data

data:  matrix(c(169, 47, 176, 122), ncol = 2)
p-value = 4.605e-06
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 1.648154 3.796153
sample estimates:
odds ratio
  2.488122
```

Speed 45 vs 25 UPRM config 2

Hide

```
fisher.test(matrix(c(31, 64, 53, 42), ncol=2))
```

```
    Fisher's Exact Test for Count Data

data:  matrix(c(31, 64, 53, 42), ncol = 2)
p-value = 0.002072
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 0.2036960 0.7209898
sample estimates:
odds ratio
 0.3858554
```

Speed 45 vs 25 UMASS config 2

Hide

```
fisher.test(matrix(c(50, 166,180,36), ncol=2))
```

```
    Fisher's Exact Test for Count Data

data:  matrix(c(50, 166, 180, 36), ncol = 2)
p-value < 2.2e-16
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 0.03626126 0.09963130
sample estimates:
odds ratio
 0.0607574
```

Speed 25 Config 2 UPRM vs UMASS

Hide

```
fisher.test(matrix(c(53, 42,180,36), ncol=2))
```

```
    Fisher's Exact Test for Count Data

data:  matrix(c(53, 42, 180, 36), ncol = 2)
p-value = 8.052e-07
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
 0.1419449 0.4496242
sample estimates:
odds ratio
 0.2536855
```