In general, scenarios were unimodal upstream from the entrance line to the roundabout. The KS-test statistic results for the scenarios can be seen in Table 3. The mean yielding distances for each pavement marking configuration are shown in parentheses.

The results of the six pairwise KS-tests with the Bonferroni corrections found all scenarios were significantly different from each other clearly illustrating the impact pavement markings have on drivers' understanding of where to yield on the approach to a roundabout. Further, results from ANOVA were also found to be significant (p-value < 2e-16). When the "shark teeth" pavement marking was present, drivers chose to yield approximately five feet further back than if the "shark teeth" were not present. Additionally, in scenarios with the word "YIELD" standard deviations were larger than scenarios without the word "YIELD," particularly for scenarios where only the word "YIELD" was present. Demographic testing results of the yielding locations did not yield significant results across the different demographics for the four pavement marking configurations.

CONCLUSIONS

Past research has found pavement markings at roundabout approaches have an impact on the expected number of rear-end collisions, specifically, the "shark teeth" pavement marking, and the word "YIELD." One hypothesis is the effect pavement markings have on roundabout approach-related rear-end collisions may be due to differences in driver understanding of where they need to yield. To investigate this hypothesis, a driver survey was conducted at five locations in the Madison, Wisconsin area.

In total, 463 surveys were completed. The results found that most drivers had not learned about roundabouts in their driver's education programs. This result was strongly correlated to age, with over three-quarters of younger drivers (18-24) having learned how to navigate roundabouts and nearly none of the senior drivers (65 and older). However, nearly all participants had driven through a roundabout, and over half did so at least once a week. Regardless of a driver's familiarity with roundabouts, drivers overwhelmingly believed they understood how to navigate a roundabout. Just over half of participants thought roundabouts provided a safety benefit, although over three-quarters of participants believed roundabouts had operational benefits.

Concerning drivers understanding of yielding locations, two different pavement markings were tested: "shark teeth" pavement markings and the word "YIELD." A complete factorial design resulted in four scenarios which were randomly presented to the drivers. At scenarios with the "shark teeth" pavement marking participants chose to yield approximately five feet further back from the entrance line than when this pavement marking was not present. The word "YIELD" caused a larger variance amongst participant yield locations. The results suggest the supplemental pavement markings ("shark teeth" and "YIELD") do impact driver yielding behavior at roundabout approaches. Drivers have clear differences in understanding about where they should yield given different pavement marking configurations. The results suggest supplemental pavement markings at roundabout approaches are not intuitive to drivers. Supplemental markings should be taught in drivers' education programs, so drivers understand the messages the supplemental pavement markings convey.

This research takes a preliminary look at quantifying the message these pavement markings convey to drivers from one region in Wisconsin. The results could be bolstered in the future by extending the survey to other regions, or even other states where roundabouts are not as prevalent. While the results of the study do suggest pavement markings have an impact on yield location, the results do not suggest which pavement marking combinations provide drivers with an intuitive message. Future research should examine driver's understanding of pavement markings at other locations in the United States as well as at multilane roundabouts. Additionally, a field study will enable examination of actual driving behavior while a full-scale driving simulator study will provide more accurate insight into driver behavior regarding pavement markings while also controlling for various geometric characteristics.

REFERENCES

Arndt, O. K., and Troutbeck, R. J. (1998). "Relationship between Roundabout Geometry and Accident Rates." *Transportation Research Circular,* 28, 1-16.

Bill, A., Qin, X., Chitturi, M., and Noyce, D. A. X. (2011). "Comprehensive Evaluation of Wisconsin Roundabouts, Volume 2: Safety Findings." Wisconsin Department of Transportation.

Burdett, B., Alshgan, I., Chiu, L., Bill, A. R., and Noyce, D. A. (2016). "Analysis of Rear-End Crashes at Roundabout Approaches." *Transportation Research Record 2585*, 29-38.

Chrysler, S., and Schrock, S. (2005). "Field Evaluations and Driver Comprehension Studies of Horizontal Signing." FHWA/TX-05/0-4471-2. Texas Transportation Institute, College Station, Tx.

Corkle, J., Giese, J. L., and Marti, M. M. (2001). *"Investigating the Effectiveness of Traffic Calming Strategies on Driver Behavior, Traffic Flow, and Speed."* Minnesota Local Road Research Board, Minnesota Department of Transportation, St. Paul, MN..

Elvik, R. (2003). "Effects on Road Safety of Converting Intersections to Roundabouts: Review of Evidence from Non-U.S. Studies." *Transportation Research Record 1847*, 1-10.

Federal Highway Administration (FHWA). (2009a). "Nine Proven Crash Countermeasures." U.S. Department of Transportation. *Safety Compass*, 3(2).

Federal Highway Administration (FHWA). (2009b). *Manual on Uniform Traffic Control Devices*. U.S. Department of Transportation, Washington, D.C.

Fisher, D., and Garay-Vega, L. (2012). "Advance Yield Markings and Drivers' Performance in Response to Multiple-Threat Scenarios at Mid-Block Crosswalks." *Accident Analysis and Prevention*, 44(1), 35-41.

Garder, P. (1998). "The Modern Roundabouts: The Sensible Alternative for Maine." Maine Department of Transportation, Bureau of Planning, Research and Community Services, Transportation Research Division.

Gomez, R. A., Samuel, S., Gerardino, L. R., Romoser, M. R. E., Collura, J., Knodler, M., and Fisher, D. L. (2011). "Do Advance Yield Markings Increase Safe Driver Behaviors at Unsignalized, Marked Midblock Crosswalks?" *Transportation Research Record 2264*, 27-33.

Hallmark, S., Peterson, E., Fitzsimmons, E., Hawkins, N., Resler, J., and Welch, T. (2007). "*Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities*." Center for Transportation Research and Education, Iowa State University.

Khan, G., Bill, A. R., Chiu, L., and Noyce, D. A. (2013). "Safety Evaluation of Wisconsin Roundabouts: Phase 2." Wisconsin Department of Transportation.

Kuge, N., Ueno, H., Ichikawa, H., and Ochiai, K. (1995). "A Study on the Causes of Rear-end Collision Based on an Analysis of Driver Behavior." *JSAE Review*, 16(1), 55-60.

Mandavilli, S., McCartt, A. T., and Retting, R. A. (2009). "Crash Patterns and Potential

Engineering Countermeasures at Maryland Roundabouts." *Traffic Injury Prevention*, 10(1), 44-50.
Persaud, B. N., Retting, R. A., Garder, P. E., and Lord, D. (2001). "Safety Effect of Roundabout Conversions in the United States: Empirical Bayes Observational Before-After Study." *Transportation Research Record 1751*, 1-8.
Retting, R. A., Persaud, B. N., and Garder, P. E. (2001). "Crash and Injury Reduction Following Installation of Roundabouts in the United States." *American Journal of Public Health*, 91(4), 628–631.
Rodegerdts, L., Blogg, M., Wemple, E., Myers, E., Kyte, M., Dixon, M., List, G., Flannery, A., Troutbeck, R., Brilon, E., Wu, N., Persaud, B., Lyon, C., Harkey, D., and Carter, D. (2007). "Roundabouts in the United States." NCHRP Report 572, Transportation Research Board of the National Academies, Washington, D.C.
Rodegerdts, L., Bansen, J., Tiesler, C., Knudsen, J., Myers, E., Johnson, M., Moule, M., Persaud, B., Lyon, C., Hallmark, S., Isebrands, H., Crown, R. B., Guichet, B., and O'Brien, A. (2010). "Roundabouts: An Informational Guide." 2nd ed. NCHRP Report 672, Transportation Research Board of the National Academies, Washington, D.C..
Savolainen, P. T., Kawa, J. M., and Gates, T. J. (2012). "Examining Statewide Public Perceptions of Roundabouts Through a Web-Based Survey." *Transportation Research Record 2312*, 25-33.
Singh, S. (2003). "Driver Attributes and Rear-end Crash Involvement Propensity." DOT HS 809 540. U.S. Department of Transportation.
Wisconsin Department of Transportation (WisDOT). (2015). *Facilities Development Manual*. Chapter 11, Section 26, Madison, Wisconsin.

Influence of Mobile Work Zone Barriers on Driver Behavior on Freeways: A Driving Simulator Study

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ABSTRACT

A work zone crash occurred once every 5.4 minutes in the United States in 2015, according to the Federal Highway Administration (FHWA). This study investigated the impact of work zone barriers (cone pylons, concrete jersey barriers, and metal barriers) on driver behavior on a freeway using a medium-fidelity full-scale driving simulator. Traffic volumes were based on level of service (LOS) C in which 65 individuals participated in the study. A single factor analysis of variance (ANOVA) indicated that there was a statistically significant difference between mean vehicle speeds across all barriers as well as mean vehicle speeds across metal barriers for age groups 35 and above versus other age groups. An interesting observation was that drivers tend to deviate from the center of the lane, away from concrete jersey barriers on a freeway which is in complete contrast to driver behavior on an arterial road, based on a prior study.

INTRODUCTION

Driving is a dynamic process and is largely dependent upon the road's conditions, vehicle performance characteristics, psychological & physical state of the driver and number of vehicles on the road (Cioca and Ivascu 2017). Majority of the drivers avoid risky behavior and adapt to safe driving. The driver’s behavior parameters include individual risk-taking desire, tiredness, distributional attention, lack of driving experience, alcoholic drinks, administered drugs, hearing and visual impairment, mobile phone use and allied health issues (Cioca and Ivascu 2017). Numerous studies have been carried out to determine driver's behavioral changes due to road curves, safety & work zone barriers, cross-sectional features and tangents (Paolo and Sar 2012).

Globally, freeways restrict pedestrians, bicycles, mopeds, motorcycles, all-terrain and slow-moving vehicles. Moreover, there are no stops or intersections and traffic flows in the same direction. Freeways and arterial roads continue to carry increasing numbers of vehicles. Studies have been undertaken to study driver behavior to better calibrate work design models and operational strategies to reduce impacts on mobility and safety by managing traffic flow at freeway and arterial road work zones (Lochrane, Al-Deek et al. 2013).

In 2015, United States reported 96,626 work zone crashes and recorded growth of 7.8% and 42% since 2014 and 2013 respectively (FHWA 2017) as shown in Figure 1. Works zone barriers restrict the movement of vehicles and affect driver behavior in terms of speed, lateral position and reaction times, increasing the risk to other vehicle users and work zone workers (Paolo and Sar 2012). In 2014, US population collectively lost 6.9 billion-man hours due to traffic which amounts to approximately 42 hours a year per rush-hour commuter average. In 2014, work zone barriers accounted for 24% of nonrecurring congestion resulting in 888 million hours loss and 10% of overall congestion resulting in predictable annual fuel loss of approximately 310 million gallons (FHWA 2017).

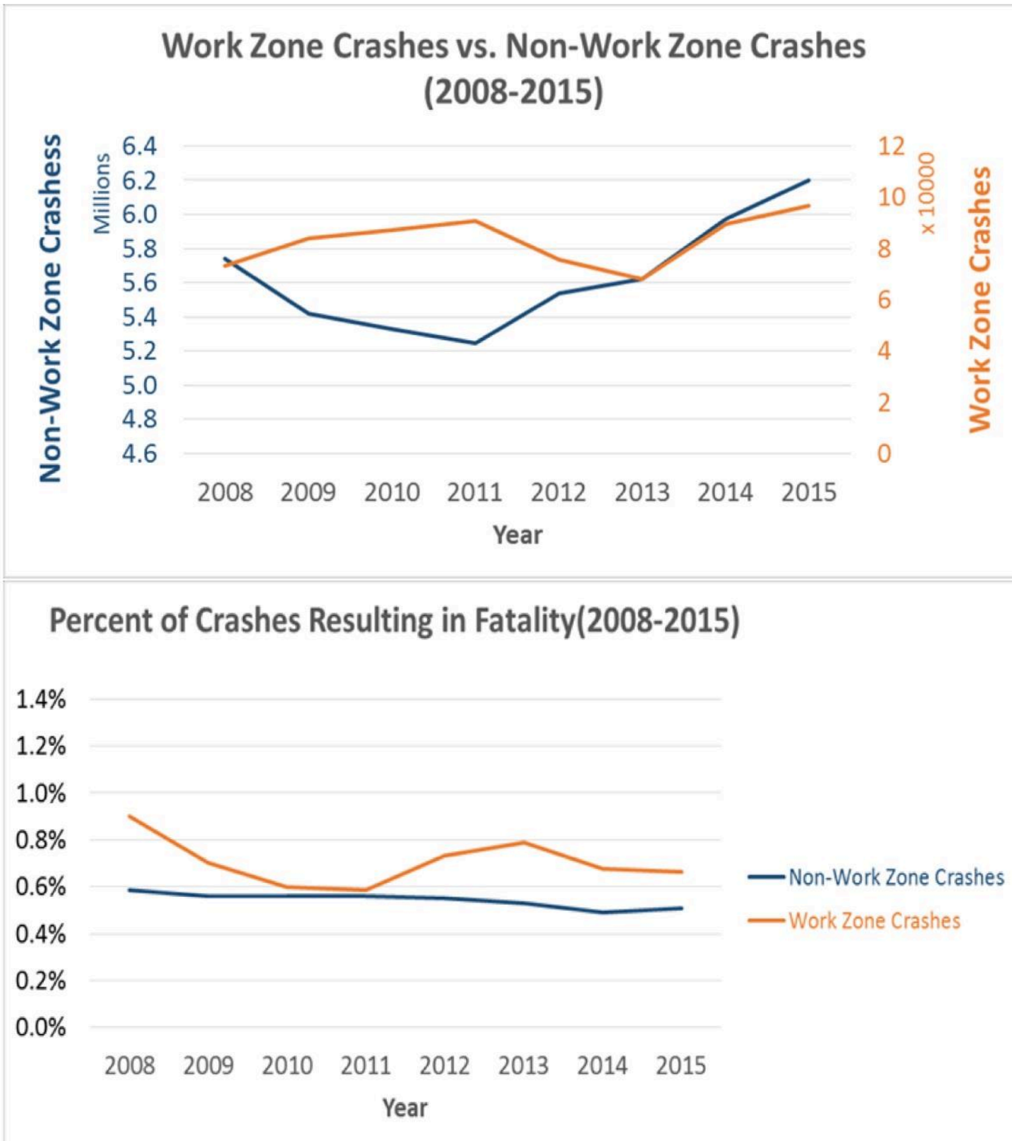

Figure 1. Work zone statistics (FHWA 2017)

Between the years of 2003 and 2010 in the United States, 92 work zone crew members died while directing traffic and 16 workers were run over by intoxicated drivers (Pegula 2013). As a result of these crashes, a detailed investigation into driver's behavioral interaction with work zone geometry and barriers is considered very essential. FHWA statistics reveal that the presence of cones, barrels, and temporary concrete barriers on freeway reduces the 45% driver comfort levels, to "somewhat comfortable". For cones and barrels, 14% of drivers reported "not that comfortable" and for temporary concrete barriers, 32% drivers reported "not that comfortable." Driver comfort level reduces due to common roadside equipment and temporary concrete barriers. This altogether changes driver's normal driving behavior while traveling through a freeway work zone (Lochrane, Al-Deek et al. 2013). Researchers found that most drivers (57%) reported that they remain in the same lane while in a construction zone and maintain unconscious car-following behavior with following speed of the vehicle in front of them. Drivers stated that, when they enter a work zone with a temporary concrete barrier to the left, they drive more slowly and cautiously. This behavioral change reinforces that driver alter their driving behavior in work zones compared to normal freeway conditions (Lochrane, Al-Deek et al. 2013)

The number of drivers on freeway and on arterial roads use their turn signal for a lane change but do not change lanes due to the work zone barriers. This behavior implies a certain indecisiveness of the driver and create confusion for other drivers. As the distance in lane separation decreases, lane changing becomes more critical. So crash rates increase more rapidly in work zones that are shorter in length or of smaller driving duration. Many single and multilane lane closures and frequent lane shifts were associated with an increase in crashes (Waleczek, Geistefeldt et al. 2016).

Concrete and hard barrier separation, cone, plastic drum or other soft barrier separation are used in the highway work zone locations. Drivers feel more comfortable with the soft barriers than the hard barriers. Drivers keep less lateral distance from the edge of travel lane adjacent to the work zone to the soft barrier, barricades, or cones than the hard barriers. Driver behavior is largely driven by barrier type used in work locations. The New Jersey Department of Transportation (NJDOT) study based on the specific work zone on freeway found that the capacity (veh/lane/hour) can be increased by 100 vehicles when a Jersey barrier is protecting the work zone (Li, Faghri et al. 2017) as opposed to lane closures during peak hours.

Reflective materials and striping can help to increase the visibility of workers, signs, barrels, and barriers. However, dust created by construction activities, road debris, and dents and tears in the retro-reflective sheeting over time reduce visibility. Furthermore, previous research has found drivers travel at higher speeds when the edges of the work zone are marked with barrels, compared to marked barrels mounted with lights, suggesting that work zones with increased visibility increase drivers' perceived safety, leading them to drive less cautiously (McAvoy, Schattler et al. 2007, McAvoy, Duffy et al. 2011).

This type of behavioral adaptation may also occur if a driver has had repeated exposure to the same freeway work zone, which may similarly raise his or her comfort level and elicit risky driving behavior. Research examining work zone behavior in Italy revealed that drivers are more likely to travel closer to the posted speed limit when the travelling lane was narrowed (Bella 2005). It appears that the drivers were less likely to abide by the posted reduced speed limit if the work zone did not appear to require it. Other studies have similarly shown that drivers will self-select a travel speed, regardless of the posted speed, and will reject artificially low speed limits Cones and barriers are sufficient to show clear direction in a work zone, such as in a lane closure. Drivers responded to this question that 2% Strongly Disagree, 30% Disagree, 24% Neither Agree nor Disagree, 39% Agree, and 5% Strongly Agree (Morris, Cooper et al. 2016, Craig, Achtemeier et al. 2017).

Studies (Wilde 1982), (Näätänen and Summala 1976), (Antonson, Ahlström et al. 2013) showed that, driving speeds increased slightly on wider roads and on roads with a crash barrier. The lateral driving position was nearer to the road center on the narrower road as well as on the road with a crash barrier. The heart rate variability (HRV) data did not indicate that participants experienced greater stress due to road width or due to the presence of a crash barrier. Participant experience captured in the oral questionnaires suggested that road width did not affect driver stress or driving patterns; however, the written questionnaire results supported the driving simulator data, indicating that a wider road led to increased speed. None of the participants felt that crash barriers made them feel calmer. In terms of stress, feelings, and driving patterns and whether subjective experience concurs with the actual driving patterns captured by the quantitative data. The study participants drove faster on roads with crash barriers than on those without. This might indicate that they felt more secure when a barrier was present, encouraging them to compensate for the reduced risk of leaving the carriageway by increasing their speed.

A recent on-road study (Berntman, Jonsson et al. 2012) showed that drivers adopted a higher speed on narrow roads with crash barriers than on a similar road without barriers. Though the authors found these results hard to explain, it is believed that there is a possibility that the increased speed on roads with crash barriers may be explained by drivers' sense of increased security (Antonson, Ahlström et al. 2013).

Research needs to be carried out first before implementing work zone interventions. Driving simulators have been used in a number of researches to study driver behavior (Jeihani and Ardeshiri 2013, Hamdar, Khoury et al. 2016, Jeihani, NarooieNezhad et al. 2017, Banerjee, Jeihani et al. 2018, Jeihani and Banerjee 2018, Jeihani, Banerjee et al. 2018). The objective of this study is to investigate the impact of three different kinds of work zone barriers, namely a concrete jersey barrier, cone pylons, and metal barriers on driver behavior using a driving simulator on a freeway.

METHODOLOGY

A medium-fidelity full-scale driving simulator (Figure 2) at the Safety and Behavioral Analysis (SABA) Center, Morgan State University was used in this study to explore the influence of concrete jersey barriers, cone pylons and metal barriers on driver behavior in work zones.

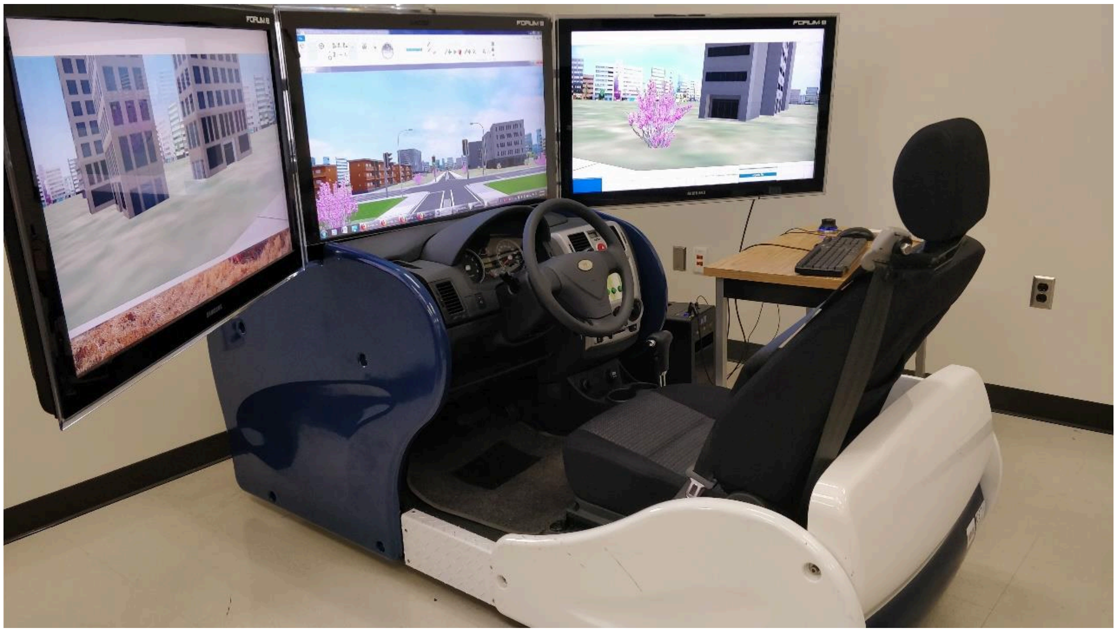

Figure 2. Driving Simulator at SABA

The study arterial is a 1-mile stretch on MD-295 in Baltimore, Maryland, as shown in Figure 2. The section of the road used in this study has three lanes with the two right lanes blocked for construction and not available to the traffic stream. The speed limit in the study area is 55 mph. The dimensions of the barriers are presented in Table 1.

A simulated work zone environment was created which included roadside objects, 3D trees and buildings, vehicles, etc. as seen in Figure 3. The driving simulator output involved steering control, acceleration, braking, speed and lane deviation, among others. The freeway lanes were 12 feet wide. Compliant with the Manual on Uniform Traffic Control Devices (MUTCD) standards, 500-foot transition zones were created at the start and end of the work zones. A screenshot of the simulation environment is shown in Figure 4.

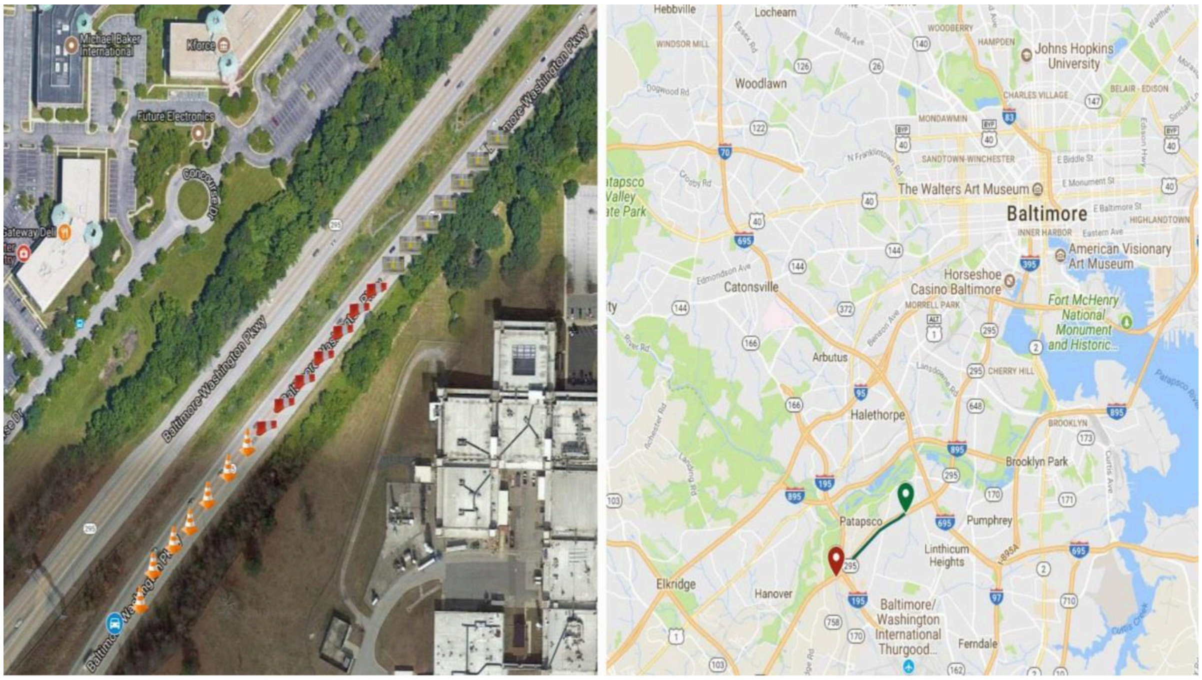

Figure 3. The Study Corridor

Table 1. Work Zone barrier dimensions[1]

Barrier Type	Length (meters)	Width (meters)	Height (meters)
Cone pylons	0.44	0.44	0.75
Concrete jersey barriers	1.24	0.6	1
Metal barriers	1.6	0.2	1

Surveys

A sociodemographic survey was filled out by all participants prior driving the simulator. Age, gender, level of education, employment and annual household income related demographics were extracted through the sociodemographic survey which were used post simulation to explore the likelihood of a correlation between driving behavior and sociodemographic characteristics in a work zone.

A post simulation survey was filled out by the participants in which they were questioned about the type and level of discomfort, if any, experienced during the simulation session. The participants were also asked about the realistic nature of the work zone environment.

[1]FORUM 8. UC-win/Road

Driver Data

Before participants were recruited for the study, Institutional Review Board (IRB) approval was granted. Participants were paid a fixed rate of $15 per hour for their contribution to the study. A total of 68 participants were enlisted but data related to only 65 participants was utilized for this study as data related to 3 participants was incomplete. We had a diverse mix of participants with a balanced gender ratio as compared to prior studies. Table 2 presents the socio-demographic characteristics of the participants.

Figure 4. Work Zone Simulated Driving Environment

Table 2. Socio-demographic characteristics of the Participants

Variables	Description	Percentage
Gender	Male	55%
	Female	45%
Age Groups	<18	0%
	18-25	33%
	26-35	39%
	36-45	11%
	46-55	10%
	>55	07%
Education Level	High School or less	19%
	College degree	62%
	Post-graduate	19%
Household Income Range	<$20,000	39%
	$20.000 - $30,000	14%
	$30,000 - $50,000	20%
	$50,000 - $75,000	12%
	$75,000 - $100,000	08%
	>$100,000	07%

The participants were given an opportunity to familiarize themselves with the driving simulator and were instructed to drive as they would drive in real life. They were informed that they had to drive from Point A to Point B and they were warned about being monetarily penalized for causing crashes deliberately or not adhering to traffic rules. The penalty was described as random and could be anywhere from $0 to the entire payment amount to ensure realism without biasing the data.

ANALYSIS AND DISCUSSION

A single factor analysis of variance (ANOVA) analysis was performed to determine the significance of observed lane offset variations across barriers, and its descriptive statistics are shown in Table 3(a).

Table 3(a). Lane Offset related descriptive analysis

Barrier Type	N	Mean	Std. Deviation
Cone Pylons	65	-0.466	0.229
Concrete Jersey Barriers	65	-0.606	0.239
Metal Barriers	65	-0.560	0.299
Total	195	-0.544	0.263

Table 3(b). Tukey's Post Hoc Analysis – Lane offset

Barrier Type(I)	Barrier Comparison(J)	Mean Difference (I-J)	Sig.
Cone Pylons	Concrete Jersey Barriers	0.140*	0.006
	Metal Barriers	0.095	0.094
Concrete Jersey Barriers	Cone Pylons	-0.140*	0.006
	Metal Barriers	-0.045	0.574
Metal Barriers	Cone Pylons	-0.095	0.094
	Concrete Jersey Barriers	0.045	0.574

*. The mean difference is significant at the 0.05 level.

The ANOVA output, P-value = 0.008 which is significant at the 95% confidence interval, indicates that there is a statistically significant relationship between the lateral movement of the vehicles across the three barriers. Tukey's Post Hoc analysis is conducted to determine which barriers resulted in lateral driving change by way of a one on one comparison as shown in Table 3(b). It shows that the statistical significance in lateral driving behavior lies only between cone pylons and concrete jersey barriers.

Figure 5 shows the average lane center deviation of the participants across the barriers where 00 is the center of the lane. The average lane center deviation is significantly more towards concrete jersey barriers compared to cone pylons.

Speeding across the three barriers was found to be insignificant. Speeding by age group was tested across all the barriers and the descriptive statistics are shown in Table 4(a).

The ANOVA output, P-value = 0.003 which is significant at the 95% confidence interval, indicates that there is a statistically significant relationship between the speeding behavior among the age groups across the three barriers. Tukey's Post Hoc analysis in Table 4(b) shows that the