Journal of Traffic and Logistics Engineering Vol. 6, No. 2, December 2018

Impact of Mobile Work Zone Barriers on Driving Behavior on Arterial Roads

Snehanshu Banerjee
Department of Transportation & Infrastructure Studies, Morgan State University, Baltimore, MD, USA
Email: snban1@morgan.edu

Mansoureh Jeihani and Zohreh Rashidi Moghaddam
Department of Transportation & Infrastructure Studies, Morgan State University, Baltimore, MD, USA
Email: {mansoureh.jeihani, zoras1}@morgan.edu

***Abstract*—In the year 2015, in the United States, a work zone crash occurred once every 5.4 minutes, according to the Federal Highway Administration (FHWA). Work zone barriers can help reduce the risk to the work crew as well as drivers by containing and redirecting vehicles, thereby minimizing the risk of vehicles entering work zones. In a first of a kind study on an arterial road, this study investigated the impact of work zone barriers (cone pylons, concrete jersey barriers, and metal barriers) on driver behavior; speeding and lateral movement, using a high fidelity driving simulator. Traffic volumes were based on Level of Service (LOS) C in which 53 individuals participated in the study. Analysis of variance (ANOVA) test indicated that there was a statistically significant difference between mean vehicle speeds and mean vehicle deviation from the lane center while driving beside cone pylons, concrete jersey barriers, and metal barriers. An additional Tukey's Post Hoc analysis disclosed that the difference in means is statistically significant only between cone pylons and concrete jersey barriers. The study results indicated that drivers tend to increase speed alongside concrete jersey barriers, which corresponds with prior research. An interesting observation was that drivers tend to deviate from the center of the lane, away from the barrier, while driving alongside concrete jersey barriers.**

***Index Terms*—driver behavior; driving simulator; work zone; work zone barriers; ANOVA**

I. INTRODUCTION

Road safety depends on driving behavior as well as vehicle characteristics and road conditions. Several researchers have conducted research to determine driver behavior on freeways. There were 96,626 work zone crashes in the United States in 2015 [1]. That is a 7.8% increase in work zone crashes since 2014 and an alarming 42% increase since 2013 Despite this increase, there have been very few studies related to work zone driving behavior [2], [3] Work zones can cause a change in driving behavior that may result in crashes and cause excessive delays. One of the primary causes of work zone crashes slow moving and stopped vehicles [4]. Findings from a study in New Zealand suggest that, excessive speed of passing traffic is another crucial factor contributing to work zone crashes [4].

Driving behavior in a work zone is important to study both for the safety of the driver and work zone crews. Between 2003 and 2010, 92 work zone crew members died while directing traffic and 16 workers were run over by intoxicated drivers [5]. Factors such as driver behavior road and traffic conditions, vehicle attributes and environment play a key role in crashes in work zones. A study by Zhe and Song [4] show that time of the day, vehicle involvement and presence of vulnerable road users contribute to crash severity in work zones. Studies also show that crashes in work zones involving heavy trucks results in higher injury severities [6]-[9]. One of the major causes is the difference in speed changes between trucks and passenger cars. Other factors influencing crashes in work zones involve reduction in number of traffic lanes, road geometry, road lighting, absence of traffic control devices, bad weather and poor driver maneuvering skills among others [6]-[11]. Researchers have stated the need to come up with a comprehensive model on how drivers deal with roadside hazards or obstacles while driving. It is seen from studies that drivers tend to move away from anything they perceive as a hindrance [10].

Work zone barriers are deployed to separate work zone crews from moving traffic while maintaining traffic mobility [12]. If a barrier is placed on the right side of the road, the driver moves closer to the neighboring left lane. If barriers are placed on both sides of the road, the vehicles will move closer to each other. To understand driver behavior toward hazards and obstacles, a comprehensive model or a driving simulator may be an appropriate medium. Driving behavior, road conditions, and vehicle characteristics are all related to road safety.

There are several studies that use a driving simulator to understand driving behavior and other performance aspects in work zones. Bham *et al*. [3] validated their driving simulator (DS) outcome using field data. Their study results showed that, mean speeds from the DS data were a good match with the field data. Their evaluation also indicated that the participants had a realistic driving experience using a DS that could reproduce close-to-real-world scenarios. In another study, a driving simulator was used to test different variables such as the length of the work zone, duration of activity and barrier type [13]. The researchers observed that average speed was higher

---

Manuscript received July 19, 2018; revised November 5, 2018.

doi: 10.18178/jtle.6.2.37-42

for longer work zones compared to the short ones. This could be attributed to the driver's growing impatience over time or growing comfort and familiarity with the work zone. Average speed was higher beside concrete jersey barriers compared to drums which was consistent with the results obtained by Reyes and Khan [14]. Reyes and Khan [14] showed that the participants in the study drove the fastest and with less variability in work zones with concrete jersey barriers. Shakouri *et al*. [2] used a high fidelity full sized driving simulator to model Conventional Lane Merge (CLM) and Joint Lane Merge (JLM). Their objective was to observe the effect of changing traffic density on driver's performance in a work zone. Their results show that, changes in the JLM offer more favorable merge configuration in both high and low traffic density. Researchers have also investigated the behavioral responses of road users to different mobile barriers. A study carried out in Netherlands showed that existing H4 safety barriers could not prevent vehicles from crossing the median and causing crashes on the other carriageway [15]. Hence, there was a need to improve the containment level of safety barriers and determine which barriers were suitable. Step barriers have been used in the Netherlands to reduce vehicle damage in case of minor collisions. Steel and concrete step-barriers were tested and found to meet the containment requirements. Oregon State University used a DS with 36 participants to examine the influence of mobile work zone barriers on vehicle trajectory, lateral position and glance patterns on a 4-lane, 2-way divided highway [16]. It was observed that driving speeds were slower while driving next to the barriers as opposed to a work zone without barriers.

The safety of motorists and work zones on roadways is a priority. Positive protection in the form of barriers reduces the risks to travelers and workers by redirecting and containing vehicles, reducing the risk of vehicles entering the work zones. Work zones have posed a significant threat to both drivers and work zone crew members, causing numerous deaths and injuries. Research needs to be carried out first before implementing work zone interventions. A driving simulator is an appropriate environment to test and validate work zone interventions to enhance safety. Very few studies have focused on the impact of mobile work zone barriers on driver behavior. The authors did not find any study examining the impact of different mobile work zone barriers on driver behavior especially on an arterial road where the speeds are comparatively lesser than a highway. The objective of this study is to investigate the impact of three distinct kinds of work zone barriers – namely concrete jersey barriers, cone pylons, and metal barriers – on driver behavior using a driving simulator.

II. METHODS

A high-fidelity driving simulator (Fig. 1) at the Safety and Behavioral Analysis (SABA) Center, Morgan State University was used to investigate the effect of concrete jersey barriers, cone pylons and metal barriers on driving speed (throttle/braking control behavior) and lateral movement (steering handling behavior) in work zones.

Figure 1. Driving simulator at SABA.

The study arterial is a 1-mile stretch on Hillen Road in Baltimore, Maryland, as shown in Fig. 2. Hillen Road is selected as the study area as there has been a lot of ongoing roadwork in the area, and it is frequented by Morgan State University students. The section of the road used in this study has three lanes with the extreme right lane blocked for construction and not available to the traffic stream. The speed limit in the study area is 50 mph. The dimensions of the barriers are presented in Table I. The barriers were arranged in the following order: cone pylons, followed by concrete jersey barriers and lastly metal barriers. LOS C was chosen as it is stable and is mostly the target LOS for most urban roads. With the software, VR-Design Studio developed by FORUM8 Co. [17], the authors simulated a real-world arterial in Baltimore, MD.

TABLE I. 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

The simulated work zone environment included 3D trees and buildings, roadside objects, vehicles, etc. as seen in Fig. 3. Data obtained from the driving simulator software involved acceleration, braking, steering control, speed and lane deviation among others, recorded in real time. The lanes are 12 feet wide and there are 500-foot transition zones at the start and end of the work zones compliant with the Manual on Uniform Traffic Control Devices (MUTCD) standards. The transition distance is sufficient for participants to reach the speed limit.

A. *Surveys*

All the participants filled out a sociodemographic survey prior to their driving simulation session. The survey was designed to extract demographics related to gender, age, level of education, employment and annual household income. The demographics were used post simulation to investigate the possibility of a correlation

---

[1] FORUM 8. UC-win/Road

between sociodemographic characteristics and driving behavior in a work zone.

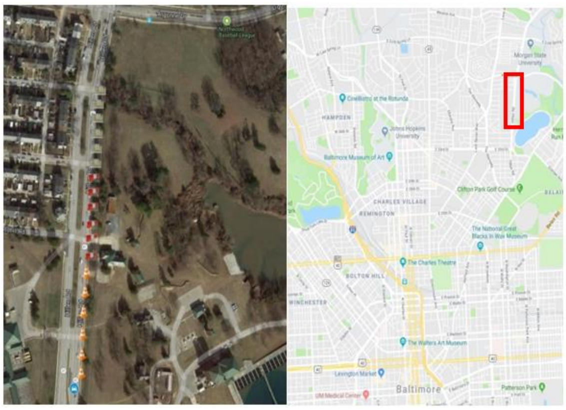

Figure 2. The study corridor.

Figure 3. Work zone simulated driving environment.

After the simulation session, participants filled out a post simulation survey in which they were questioned about the level and type of discomfort, if any, experienced during the simulation session as well as the realistic nature of the work zone environment.

B. Driver Data

Institutional Review Board (IRB) approval was granted before participants were recruited for the study. Participants were monetarily compensated at $15 per hour for their contribution to the study. A total of 53 participants were enlisted but data related to only 45 participants was utilized for this study. The remaining 8 participants chose not to drive beside the barriers in the work zone and instead they switched lanes. The participants were not pre-informed about driving beside the barriers as that would have biased the results. Despite our attempt to have an unbiased age group of participants, with the location being a university, younger male participants were the majority of volunteers. As a result, there were fewer female participants compared to male participants. This is not a serious limitation because, as it will be seen, age and gender are not statistically significant descriptors of changes in driving behavior in the presence of barriers in this study. Table II presents the socio-demographic characteristics of the participants.

The participants were briefed about the scenario in which they were told that they had to go from Point A to Point B. They were given an opportunity to get familiar with the driving simulator and instructed to drive as they would drive in real life. They were warned about being monetarily penalized for causing crashes or not adhering to traffic rules.

TABLE II. SOCIO-DEMOGRAPHIC CHARACTERISTICS OF THE PARTICIPANTS

Variables	Description	Percentage
Gender	Male	72%
	Female	28%
Age Groups	<18	0%
	18-25	38%
	26-35	41%
	36-45	9%
	46-55	6%
	>55	6%
Education Level	High School or less	32%
	College degree	47%
	Post-graduate	21%
Household Income Range	< $20,000	32%
	$20.000 - $30,000	15%
	$30,000 - $50,000	24%
	$50,000 - $75,000	17%
	$75,000 - $100,000	7%
	> $100,000	5%

III. DATA ANALYSIS

Vehicle speeds alongside the barriers were averaged and considered for analysis. To evaluate the statistical significance of mean vehicle speeds and mean vehicle offset from lane center across the different barrier types, an ANOVA test was performed. The interaction of gender and age groups with mean speed and mean vehicle offset from lane center were also tested for statistical significance. The null hypotheses ($H_{0,00}$) were:

a) *Mean vehicle speeds across different types of barriers were equal*

H_0: $\mu_1 = \mu_2 = \mu_3$

H_A: Mean speed $\mu_{1/2/3}$ differed near at least one barrier

b) *Vehicle offset from lane center across the different types of barriers were equal*

H_{00}: $\mu_1 = \mu_2 = \mu_3$

H_A: Vehicle offset $\mu_{1/2/3}$ differed near at least one barrier

where,

μ_1 = mean speed/vehicle offset across cone pylons

μ_2 = mean speed/vehicle offset across concrete jersey barriers

μ_3 = mean speed/vehicle offset across metal barriers

H_A = Alternate hypothesis

The null hypotheses were rejected if the P value was found to be less than or equal to the level of significance ($p \leq 0.05$). If the P value was significant, Tukey's

Honestly Significant Difference (HSD) Test was conducted post-ANOVA to determine which groups differ from each other through pairwise comparison of means. The HSD value was compared to the difference between the mean value of barriers to evaluate the difference between the two means. As the barriers were the primary variable of interest, age and gender significance was tested only on barriers with significant interactions.

Results for each hypothesis are explained using a box plot. A horizontal line inside the box in a box plot indicates the median; the top of the box and bottom indicate the 75th and the 25th percentiles which is the interquartile range. The values which are 1.5 times greater than and less than the interquartile range were considered as outliers and hence not shown in the box plots. The top and bottom of the whiskers on a box in a box plot present the maximum and minimum values as observed in the data.

IV. RESULTS

An ANOVA analysis was performed to determine the significance of observed speed variations across barriers, and the descriptive statistics are shown in Table III.

TABLE III. SPEEDING RELATED DESCRIPTIVE ANALYSIS

Barrier type	N	Mean	Std. Dev
Cone pylons	45	52.366	9.597
Concrete jersey barriers	45	59.682	11.145
Metal barriers	45	56.373	8.639
Total	135	56.140	10.225

The result of ANOVA, P-value = 0.003 which is significant at the 95% confidence interval, indicates that there is a statistically significant relationship between the speeding behavior of participants across the three barriers. The ANOVA analysis does not indicate where the significance lies in a three-way comparison. In this case, Tukey's Post Hoc analysis is conducted to determine which barriers resulted in significantly more speeding by way of a one on one comparison as shown in Table IV.

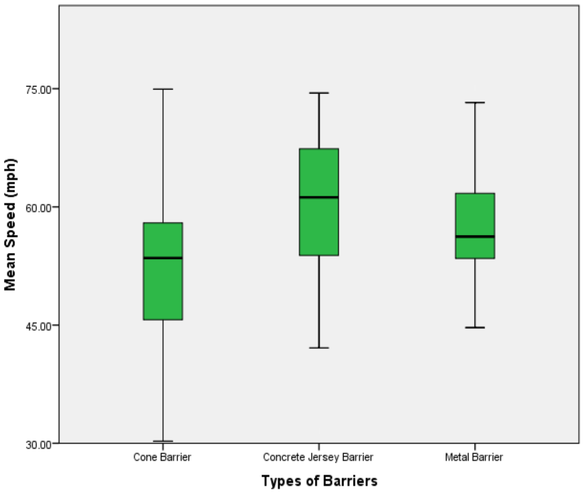

Figure 4. Speed box plot.

Tukey's Post Hoc analysis in Table IV shows that the statistical significance in speeding behavior lies only while driving beside cone pylons and concrete jersey barriers, but not metal barriers. Fig. 4 shows the average speeding behavior of the participants across the barriers. The average speeds are significantly higher for concrete jersey barriers compared to cone pylons. Another ANOVA analysis was performed to determine the significance of observed lane offset variations across barriers, and its descriptive statistics are shown in Table V.

TABLE IV. TUKEY'S POST HOC ANALYSIS - SPEEDING

Barrier type	Barrier comparison	Mean Difference (I-J)	Sig. (P)
Cone pylons	Concrete jersey barriers	-7.315*	0.002
	Metal barriers	-4.006	0.134
Concrete jersey barriers	Cone pylons	7.315*	0.002
	Metal barriers	3.308	0.252
Metal barriers	Cone pylons	4.006	0.134
	Concrete jersey barriers	-3.308	0.252

* Mean difference is significant at 95% CI.

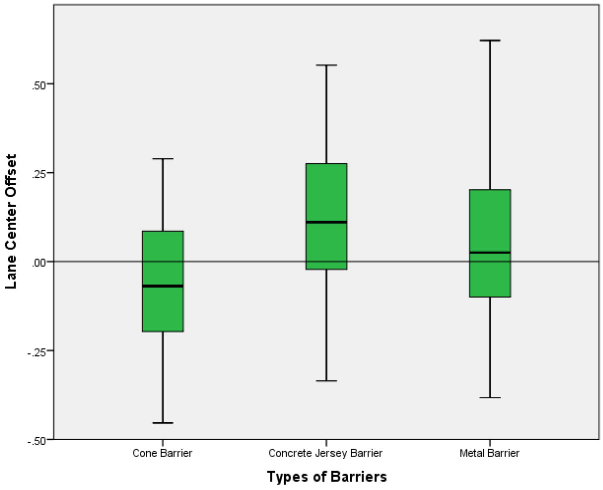

Figure 5. Lane center deviation box plot.

The result of ANOVA, P-value = 0.001 which is significant at the 95% confidence interval, indicates that there is a statistically significant relationship between the lateral behavior of participants across the three barriers. Tukey's Post Hoc analysis (Table VI) shows that the statistical significance in lateral driving behavior lies only between cone pylons and concrete jersey barriers. Fig. 5 shows the average lane center deviation of the participants across the barriers where 00 is the center of the lane. It can be seen that participants tend to deviate away from the lane center while driving beside concrete jersey barriers, and to a lesser extent while driving beside metal barriers, whereas participants tend to drive toward the cone pylons.

The average deviation from the center of the lane by the 45 participants while driving alongside the respective barriers is shown in Fig. 6.

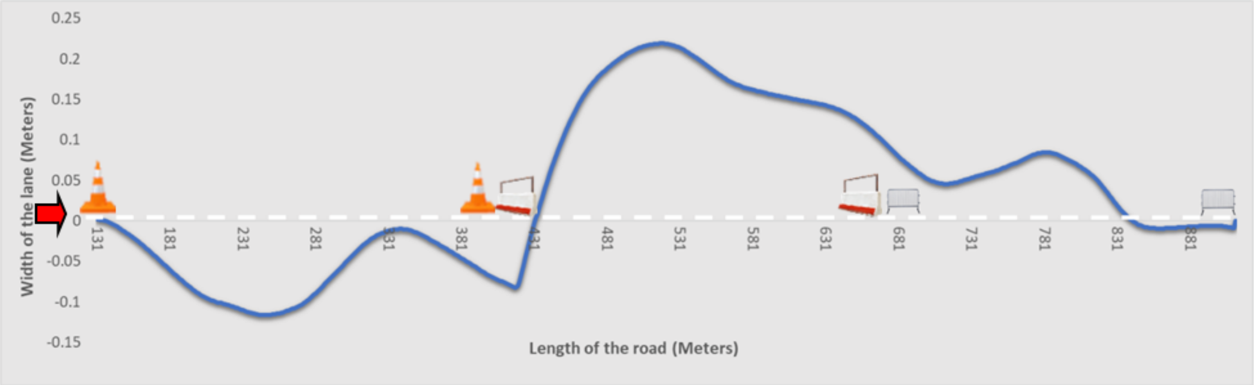

Figure 6. Lane center deviation box plot

TABLE V. LANE OFFSET RELATED DESCRIPTIVE ANALYSIS

Barrier type	N	Mean	Std. Dev
Cone pylons	45	-0.057	0.189
Concrete jersey barriers	45	0.123	0.245
Metal barriers	45	0.046	0.217
Total	135	0.037	0.229

TABLE VI. TUKEY'S POST HOC ANALYSIS – LATERAL MOVEMENT

Barrier type	Barrier comparison	Mean Difference (I-J)	Sig. (P)
Cone pylons	Concrete jersey barriers	-0.181*	0.000
	Metal barriers	-0.104	0.065
Concrete jersey barriers	Cone pylons	0.181*	0.000
	Metal barriers	0.077	0.218
Metal barriers	Cone pylons	0.104	0.065
	Concrete jersey barriers	-0.077	0.218

* Mean difference is significant at 95% CI.

The barriers shown Fig. 6[2] are just a representation of its location to understand the deviation. It also shows an abrupt shift in average deviation in the transition phase from cone pylons to concrete jersey barriers. Independent t-tests were carried out to investigate the significance of gender and age on speeding and lane deviation behavior while driving in a work zone. Since the outcomes of the t-test analysis were statistically insignificant, the results have not been added to this paper.

V. CONCLUSION AND DISCUSSION

This study investigated the effects of three mobile work zone barriers on drivers' throttle/brake control behavior (speeding behavior) and steering handling behavior (vehicle's lateral movement) on an arterial road using a driving simulator. When compared to cone pylons, the mean vehicle speeds were higher while driving beside concrete barriers, which corresponds with prior research [13], [14]. In this study, participants' age and gender did not have any effect on driving behavior while driving beside mobile work zone barriers. An interesting observation was that participants tend to move away from concrete jersey barriers in the work zone. Even though prior studies [10] suggest that drivers tend to move away from any obstacle they view as a hindrance, this study shows that drivers drove towards the cone pylons thereby suggesting that they perceive them as less of a hindrance than the concrete jersey barriers. Another reason could be that drivers perceive that cone pylons would not cause severe damage to the vehicle in case of a collision as compared to concrete jersey barriers.

When compared to cone pylons and metal barriers, concrete jersey barriers might be more effective to protect work zone crews. They could be used for mid to long-term projects on high speed roadways where work zone crews are more vulnerable to oncoming traffic and in situations such as in tunnels, bridges and lane expansion work. Cone pylons, on the other hand, have high visibility even at night due to the highly reflective surfaces and are easy to deploy. They should be used with caution on roads with work zone crews but could be used as temporary traffic diversions in case of crashes. Arterial roads have lower speed limits when compared to highways. Based on the findings of this study, concrete jersey barriers would be appropriate on arterial roads as drivers would maintain or slightly increase their speed as they drive through the work zone. Presence of other types of barriers may possibly lead drivers to slow down thereby causing backups and thus creating congestion in the work zone. A work zone pilot study would be beneficial to corroborate the findings of this study. A characteristic of the study was the order of barriers in the work zone, starting with cone pylons, followed by concrete jersey barriers and metal barriers. Future studies would involve participants driving in multiple scenarios, with interchanging order of work zone barriers and the presence of reduced work zone speed limit signage.

ACKNOWLEDGEMENT

The authors would like to thank Morgan State University's National Transportation Center and National

---

[2] The barriers are located 1.8 meters below the lane center. Even though lane deviation ranges from -0.15 to 0.25, which is low in comparison to the lane width of 3.6 meter or 12 feet, the values are still statistically significant considering the average width of a car is 2 meters or 6.67 feet.

Transportation Center – the University of Maryland for their funding support.

REFERENCES

[1] FHWA. (2017). *Work Zone Facts and Statistics*. [Online]. Available: ops.fhwa.dot.gov/wz/resources/facts_stats/safety.htm

[2] M. Shakouri, L. H. Ikuma, F. Aghazadeh, K. Punniaraj, and S. Ishak, "Effects of work zone configurations and traffic density on performance variables and subjective workload," *Accident Analysis & Prevention*, vol. 71, pp. 166-176, 2014.

[3] G. H. Bham, M. C. Leu, M. Vallati, and D. R. Mathur, "Driving simulator validation of driver behavior with limited safe vantage points for data collection in work zones," *Journal of Safety Research*, vol. 49, no. 53, pp. e1-60, 2014.

[4] N. Sze and Z. Song, "Factors contributing to injury severity in work zone related crashes in New Zealand," *International Journal of Sustainable Transportation*, pp. 1-7, 2018.

[5] S. M. Pegula, "An analysis of fatal occupational injuries at road construction sites, 2003-2010," *Monthly Lab. Rev.*, vol. 136, p. 1, 2013.

[6] Y. Li, Y. Bai, S. D. Schrock, and T. E. Mulinazzi, "Modeling Truck Speed in the Upstream of One-lane Two-way Highway Work Zones: Implications on Reducing Truck-Related Crashes in Work Zones," University of Kansas Center for Research, Inc.2011.

[7] Y. Bai, "Determining major causes of highway work zone accidents in Kansas," University of Kansas Center for Research, Inc.2006.

[8] R. W. Hill, "Statistical analysis of fatal traffic accident data," Texas Tech University, 2003.

[9] G. P. Jerry and R. A. Kenneth, "Highway accidents in construction and maintenance work zones," *Transportation Research Record*, vol. 1227, 1986.

[10] R. V. Der Horst and S. D. Ridder, "Influence of roadside infrastructure on driving behavior: driving simulator study," *Transportation Research Record*, vol. 2018, no. 1, pp. 36-44, 2007.

[11] J. Weng and Q. Meng, "Effects of environment, vehicle and driver characteristics on risky driving behavior at work zones," *Safety Science*, vol. 50, no. 4, pp. 1034-1042, 2012.

[12] G. C. Price. Cost-Benefit Analysis & Justification Mobile Barriers MBT-1. (2017) [Online]. Available: http://www.mobilebarriers.com/images/docs/Cost%20Benefit%20Analysis%20w%20FEMADHS%20Justification%20re%20Mobile%20Barriers%20MBT-1%20rev%20170605.pdf.

[13] S. H. Hamdar, H. Khoury, and S. Zehtabi, "A simulator-based approach for modeling longitudinal driving behavior in construction work zones: Exploration and assessment," *Simulation*, vol. 92, no. 6, pp. 579-594, 2016.

[14] M. L. Reyes, S. A. Khan, and S. Initiative, "Examining driver behavior in response to work zone interventions: A driving simulator study," Iowa City, IA, University of Iowa, 2008.

[15] C. A. Verweij, "Developing H4-safety barriers for Dutch motorways," in *Road Safety Three Continents in Pretoria, South Africa, 20-22 September 2000*: Statens väg-och Transportforskningsinstitut, 2001, pp. 81-91.

[16] J. Swake, D. S. Hurwitz, J. Neill, and J. Gambatese, Influence of Mobile Work Zone Barriers in Maintenance Work Zones on Driver Behavior: A Driving Simulator Study, 2014.

[17] FORUM8. *3D VR & Visual Interactive Simulation*. [Online]. Available: http://www.forum8.com/

Snehanshu Banerjee is a Ph.D. student at Morgan State University. He is the lead researcher at the Safety and Behavioral Analysis lab in the Department of Transportation and Infrastructure Studies. He received a Master's in Construction Management from Marquette University and a Master's in Transportation Engineering from Virginia Tech. He has over 5 years of transportation research experience. His main research interests include data analytics, human factors, intelligent transportation systems and traffic safety.

Mansoureh Jeihani, Ph.D, PTP, is a Professor in the Department of Transportation and Urban Infrastructure Studies at Morgan State University. Proficient in transportation modeling and planning, travelers' behavior, ITS, and traffic safety, Dr. Jeihani has over 15 years of experience in applied research. She has published a book on Transportation Network Modeling and 64 papers in journals and conference proceedings. She has also been PI/Co-PI for over 20 research grants funded by federal or state agencies. Dr. Jeihani serves on the transportation network modeling committee for the Transportation Research Board (TRB).

Zohreh Rashidi Moghaddam obtained Masters degrees in artificial intelligence and transportation engineering from Sharif University of Technology and Morgan State University, respectively. Her main research interest is applying artificial intelligence in transportation systems, i.e. intelligent transportation systems, and data analytics in transportation systems. She is currently working at the Office Performance Management in the Maryland Transit Administration, Baltimore.