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Using Driving Simulator Environment to Determine Interactions Between User Behavior and Infrastructure Design Under Autonomous Vehicles

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16. Abstract

Autonomous vehicles have a huge potential to improve transportation systems by increasing roadway capacity, safety, accessibility and reducing pollution, congestion. This emerging technology promises safer, efficient roadways and can help reduce pollution. For the various levels of autonomy to be deployed into the real world safely and efficiently, roadway design modifications such as roadway markings, signage, and channeling devices have been suggested. However, the question still remains as to how human drivers would adapt to such roadway design changes and the presence of AVs. This report addresses these research gaps using a driving simulator experiment that investigates the effect of roadway design modifications and presence of autonomous vehicles on human driving behavior. The experiment analyzed three roadway design modifications: incorporation of a dedicated AV-only lane separated from human driven lanes by road barriers; a mixed-lane design where human driven vehicles and AVs share the lane, and a mixed-lane design with a separate lane for bikes and scooters. The results suggest that the roadway delineation devices can help enhance safety during the initial phase of deployment of autonomous vehicles by minimizing the interactions between autonomous vehicles and human-driven vehicles. The results of experimental and survey data analyses suggest that human drivers are comfortable with sharing the lane with AVs and as indicated by a slight increase in speeds.

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1. INTRODUCTION

Autonomous Vehicles (AVs) have the potential to significantly change the current transportation system by improving safety, accessibility and sustainability while reducing pollution and congestion (Montgomery, 2018), (Pettigrew et al., 2018) and (Fagnant & Kockelman, 2015). Research and development of AVs have primarily focused on improving the hardware and software that support autonomous driving, such as sensing technologies and algorithms that eliminate safety concerns (Faisal et al., 2020a). SAE Level 3 and higher vehicles have been deployed and tested on selected roads in the United States to help researchers and manufacturers improve the hardware and software of AVs (NHTSA, n.d.). While these aspects of AVs have made considerable progress over the past years, there are still many barriers to the deployment of AVs.

The first barrier is the lack of digital and physical infrastructure preparedness, as the transportation system is barely updated (Y. Liu et al., 2019). Digitally, most roads are not able to communicate with AVs and provide information to assist in AV operation. Physically, the roads are not equipped with precise, consistent, and comprehensive pavement markings and signs that can be easily detected by AVs' sensor suite. There is lack of discussions of necessary roadway design modifications that can ensure safety of all the road users.

Secondly, it is still unclear as to how the public acceptance, trust in AVs and the driving behavior will change in the presence of AVs. At the initial stage of AV operations, there will be mixed traffic where AV would be required to travel alongside Human Driven Vehicles (HDVs). The interactions between AVs and HDVs will be impacted not only by the presence of AVs but also the roadway they are driving on. The impacts of AVs on different roadway designs have not been systematically investigated from road user perspective, except through stated preference surveys. The effects of roadway design modifications and the presence of autonomous vehicles on human driving must be addressed to aid the safe deployment of AVs into our current roadway design.

To facilitate the deployment of AVs, this study utilized a highly immersive setting through a motion-based driving simulator to investigate the roadway modifications that can accommodate both AVs and human-driven vehicles and the driver behavior change in presence of AVs. While most AV deployments and tests are shuttles deployed on specified, controlled test tracks Michigan M-city (Mcity, n.d.) and South Korea K-City (K-City, n.d.), by collaborating with Curiosity Lab at Peachtree Corners, this project focused on urban arterial roadways where pedestrians, AVs, and HDVs interact every day.

The objectives of this study are as follows. First, capture the interactions between human driver and physical infrastructure modified to enable AV adoption. Second, capture the effects of the presence of AVs on human driving.

The structure of this report is as follow. Section 2 shows the literature review of the various roadway design changes. Section 3 describes the driving simulator experiment design. Sections 4 and 5 describe the results and concluding comments respectively.

2. LITERATURE REVIEW

2.1. AV Deployment and Field Test

Many states in the U.S. have implemented DMV regulations to allow public tests of AVs and many companies, such as Google, GM, and Ford, began testing AVs on roads as early as 2016 (NHTSA, n.d.). However, many states require a human safety driver to oversee the AV operation. For example, although the California DMV allowed AV testing with a safety driver back in 2014, the deployment of driverless testing hasn't started until December 2020. In December 2020, NURO Inc. received permits to deploy driverless cars in California (California DMV, n.d.). Georgia was one of the first states to approve SAE Level 4 and higher vehicle deployment and testing in select locations across the state back in 2017 (The Eno Center for Transportation, n.d.). One of the locations approved for AV deployment and testing is the Curiosity Lab test track (Curiosity Lab at Peachtree Corners, n.d.) at Peachtree Corners, GA.

Although AVs were deployment at various SAE levels of automation (i.e., driver or driverless) at different places across the U.S, most projects were conducted on controlled AV test environment, such as Michigan M-City (Mcity, n.d.) and South Korea's K-City (K-City, n.d.). The interactions between AVs and HDVs were limited to avoid any safety risks to the public. By collaborating with Curiosity Lab, this report examined the current roadway design of the autonomous and connected vehicle test track (Figure 3), one of the world's real-world testing environments where people, autonomous vehicles, and smart city technology can interact every day.

2.2. Roadway Modifications for AVs

The concept of roadway designs for AVs adoption and deployment have begun to emerge in recent years. Schlossberg et al. 2018 (Schlossberg et al., 2018) re-imagined roadway design and urban form in the presence of AVs by transferring the focus from vehicular throughput to passenger throughput. Since AVs have the ability to drive precisely, future roadway designs can include narrower lanes, freeing up space. Garcia et al.(García & Camacho-Torregrosa, 2020) showed that current automated vehicle systems have the ability to consistently operate on lanes as narrow as 9 feet. But such modifications have an effect on human driving. Machiani et al. 2020 (Machiani et al., 2020) showed that 9 ft dedicated AV lane resulted in poor lane centering for human drivers on the adjacent lane. AVs are often imagined to be operated as shared mobility vehicles and have the luxury to park outside the city. In such a scenario, the curb design would shift from roadside parking to pick-up and drop off zones.

Additionally, the traffic control devices on the road also need to be updated for AVs to reach their potential in improving traffic congestion and enhancing safety. AVs would require accurate sensing of the pavement markings such as edge/centerline markings, right-of-way symbols and roadway signage (de la Escalera et al., 2003) in order to plan their trajectory. In addition, the pavement markings need to be detectable to various sensor suites and must be weatherproof (RetroTek, n.d.). For example, the Ray, GA (The Ray, n.d.) (an 18-mile section of road on I-85) has implemented pavement markings that are suitable for AV deployment. This also applies to the regulatory and warning signs at intersections which need to be accurately sensed by AVs. In addition to providing AVs appropriate right-of-way instructions, pavement markings and roadway signage play an important role in providing right-of-way instructions to the human drivers. These instructions are particularly important during the initial stages of AV deployment, as human drivers are faced with novel road conditions and users. Initial stages of AV deployment would focus on the safety of all users and try to minimize the interactions between HDVs and AVs. To this effect, dedicated AV lanes are one of the most suggested roadway design modifications for AV testing. Razmi Rad et al. 2020 (Razmi Rad et al., 2020) developed a conceptual framework for the design of dedicated lanes that factor in the safety of all the road users. Liu et al. 2019 (Z. Liu & Song, 2019) demonstrated that strategic planning of dedicated AV lanes would improve the overall network performance under mixed traffic conditions. A few AV testing sites such as the Curiosity Lab test track (Curiosity Lab, n.d.) has implemented delineation devices such as plastic barriers to restrict the interactions between HDVs and AVs. Schoenmakers et al. 2021 (Schoenmakers et al., 2021) showed that the humans felt safe driving in the presence of guardrail separation between HDVs and AVs.

Although the findings of previous research showed the importance of roadway modifications, Faisal et al. 2020 (Faisal et al., 2020b) point out that evidence-based research in the social and urban contexts of AVs is still in its early stages. The initial deployment of AVs onto the transportation system will need to interact with humans and human-driven vehicles (HDVs) on the road. There are gaps in existing literature that address and analyze the effects of roadway modifications on human driving. In this study, these gaps are addressed by designing a driving simulator study. The study also uses an urban arterial for analyzing the roadway design modifications as they have lower driving speeds and higher interactions between vehicles.

3. METHODOLOGY

A driving simulator-based experiment was designed to evaluate the impacts of roadway design modifications and the presence of AVs on human driving behavior. The structure of this section is as follow. Section 3.1 introduces the apparatus used in the experiment. Sections 3.2 and 3.3 describe the overall experimental design and procedure. Section 3.4 and 3.5 discuss measures of effectiveness and the post-experiment survey design.

3.1. Apparatus

The experiments were conducted on the high-fidelity RTI full cab driving simulator in the Georgia Tech Autonomous and Connected Transportation (ACT) Lab (Figure 1). The simulator system provides participants with a near 360-degree field of view and a 6 degrees of freedom motion base to experience different roadway designs. In order to simulate the mixed traffic conditions with AVs, the driving simulator is integrated in real-time with a microscopic traffic flow simulator (SUMO) to manage the operations of AVs and other surrounding traffic. The simulator is equipped with a data collection system to track all vehicles' information in the road network during the experiments.

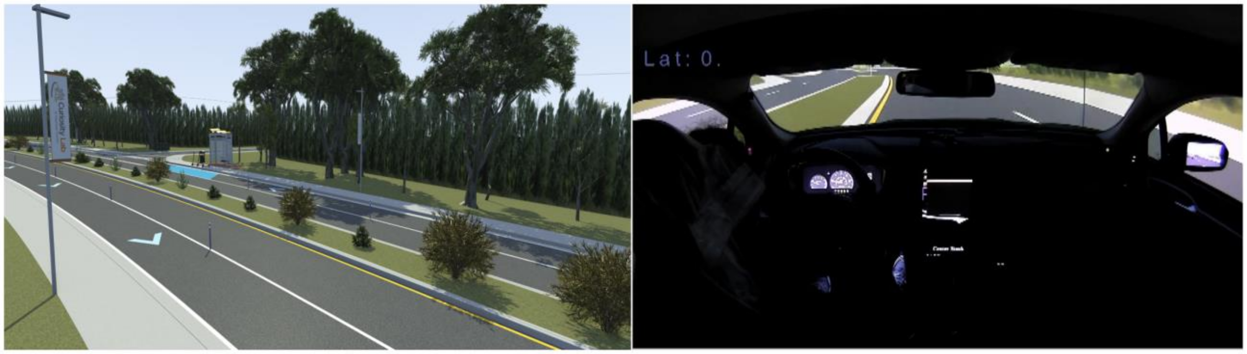


Figure 1: Virtual Test Track and View Inside the Driving Simulator

3.2. Experiment Design

Curiosity Lab test track at City of Peachtree Corners, GA served as the basis for this experiment. Curiosity Lab manages the 1.5 mile 5G enabled autonomous and connected vehicle test track. Currently, it is a four-lane road for bi-directional traffic, with plastic posts that separate a dedicated AV lane from the non-AV lane in each direction (Figure 2). This roadway design aims to limit interactions between AVs and HDVs and avoids potential negative impacts of autonomous test vehicles as AVs are in their initial technological phase. This track was used to study the various effects of AVs and infrastructure modifications. The current roadway design at curiosity lab AV test track is used as one of the scenarios in the experiment.

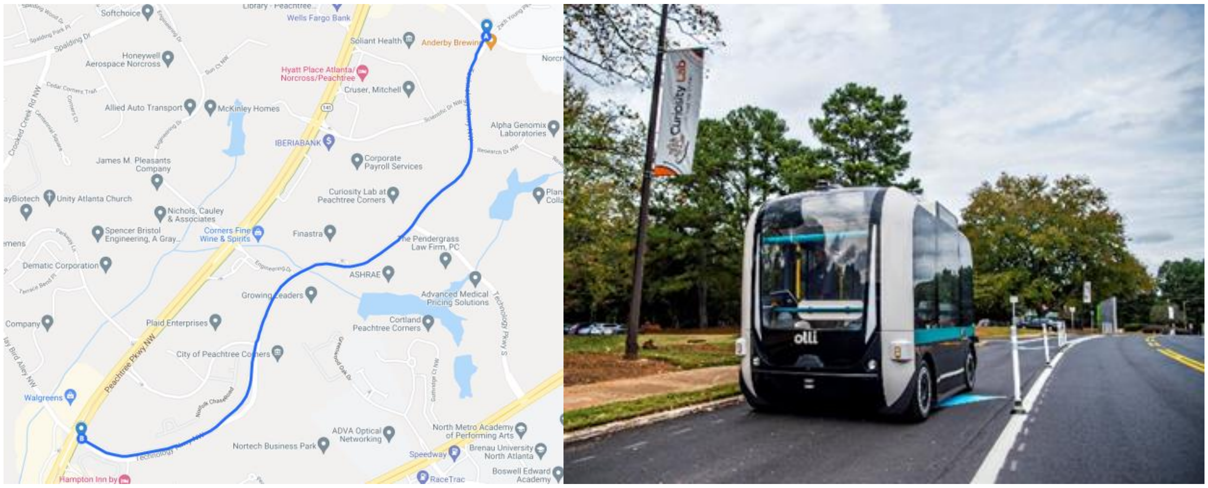
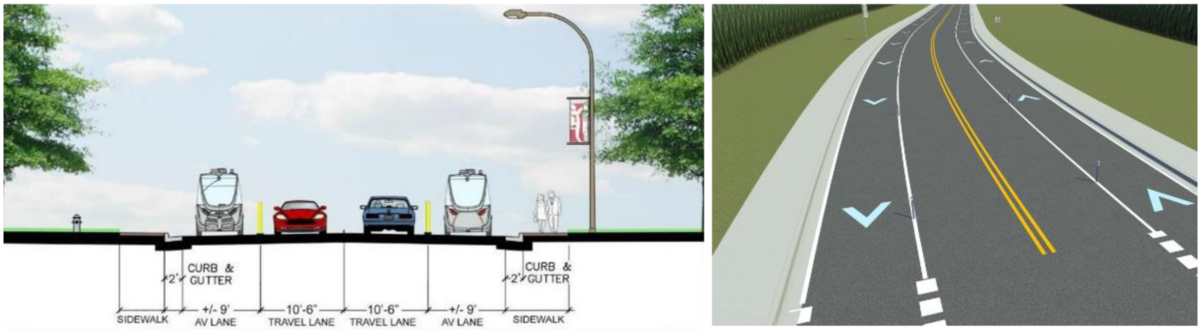


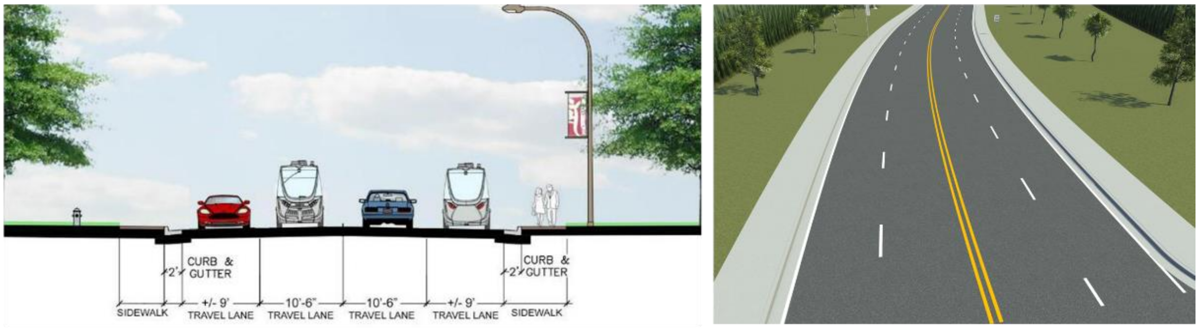
Figure 2: Map of the Curiosity Lab AV Test Track

In addition to the current design, two alternative roadway designs were selected after the discussion with the Curiosity Lab, which are potential modifications to the current roadway design (Figure 3(a)) in the future. The first alternative design (Figure 3, II) is a modified version of the current design, in which the plastic posts are removed to allow AVs and HDVs to operate on all lanes. This design corresponds to the scenario when AV technologies are fully mature, and AVs are well-accepted by the public. The second alternative design (Figure 3(b)) converts one out of the four travel lanes into a bidirectional bike/scooter lane to promote sustainable travel modes. The rest becomes a three-lane road with mixed traffic, with the lane next to the bike/scooter lane having traffic in one direction and the other two lanes in the other direction. Plastic posts are set up between the bike/scooter lane and the vehicular lane to enhance the safety of cyclists and scooter riders. The differences among the three roadway designs are summarized in Table 1. The virtual roadways were modeled using GIS and GPS data from the real world.

(I) Current/dedicated AV lanes design



(II) Mixed traffic lanes design



(III) Multimodal lanes design

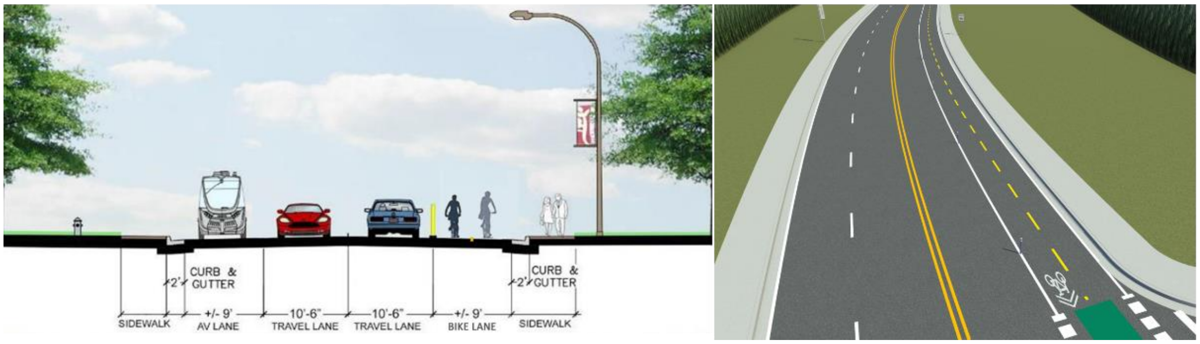


Figure 3: Roadway Design Modifications

Table 1. Roadway Designs Selected for Evaluation

	Current/Dedicated AV lanes design (I)	**Alternative 1 - Mixed flow (Avs and HDVs) lanes**	**Alternative 2 - Mixed flow and dedicated bike/scooter lanes**
Number of lanes	Two vehicular lanes (northbound) Two vehicular lanes (southbound)	Two vehicular lanes (northbound) Two vehicular lanes (southbound)	One vehicular lane + one bike/scooter lane (northbound) Two vehicular lane (southbound)
AV exclusive	AVs only use the outer vehicular lanes HDVs only use the inner vehicular lanes	AVs and HDVs share all vehicular lanes.	AVs and HDVs cannot enter the bike/scooter lane. AV and HDVs share all three vehicular lanes.
Lane separation	Plastic posts Pavement marking (solid white line)	None	Plastic posts Pavement marking (solid white line)
Description	Current design • One travel lane in each direction • One AV dedicated lane in each direction • Unequal lane widths with narrow dedicated AV lane • Plastic post barriers	Higher levels of AV penetration • Two travel lanes in each direction • Unequal lane widths • Avs share the road with human-driven vehicles (HDVs) • No plastic post barriers	Multimodal traffic • Three travel lanes and one bike/scooter lane for bi-directional traffic • Avs share the road with HDVs • Plastic post barrier between travel lane and bike/scooter lane

3.3. Procedures

The study was approved by the Georgia Tech Institutional Review Board (IRB) and followed the COVID-19 safety policies. The experimental procedures were as follows: first, the participant's informed consent was obtained after he/she was introduced to the driving simulator and the objectives of the experiments. Then, the participant performed a practice run in the simulator to get familiarized with the driving environment. If the participant did not report any motion sickness symptoms, the formal experiment runs were initiated. During the experiment, the participant was asked to drive a round trip in three scenarios corresponding to the three roadway designs. Each scenario was around 8-10 minutes long and the participant was asked to drive on the road in both directions in low traffic volume (around 400 AADT). The test order of the three roadway designs was counterbalanced to minimize sequence bias effects. Vehicle trajectory was collected to capture the impacts of roadway design modifications on drivers. A post-experiment survey was administered to obtain the participant's preferences and qualitative feedback. Each participant was de-briefed at the end of the experiment.

3.4. Measures

The following measures were used to analyze the driver behavior from the driving simulator-based experiments:

- MOE 1 – Travel time (s): Lapsed time between the start of the road segment and end of the road segment (both northbound and southbound). The time spent completing the U-turn was excluded.
- MOE 2 – Speed (mph): The average speed at which the participant traveled between the start and end of the road (northbound and southbound) excluding the U-turn. In both real world and virtual environment, the posted speed limit is 30 mph. This is derived from travel time.
- MOE 3 – Number of lane changes: Number of times the participant changed lanes in each roadway design.
- MOE 4 – Improper Lane use: Number of times the participant drove into the wrong lanes (i.e., lane not available to HDVs).

3.5. Post-Experiment Survey Design

The post-experiment survey was designed to gather the participants' prior knowledge and opinions about AVs and their experience with the different roadway designs. The survey was divided into two parts. The first part inquired about the participants' knowledge regarding AVs, their opinions about the adoption of AVs, and their opinions on the various roadway design modifications in the experiment. Part Two of the survey focused on the experience of the participants as they experienced the different roadway designs. The questionnaire focused on their understanding of the roadway design, their comfort, popularity in adoption, and perceived safety. A 5-point Likert scale, 1 being strongly disagree to 5 being strongly agree, was used to rate the different roadway designs.

4. RESULTS AND DISCUSSION

4.1. Participants

56 participants were recruited for the simulator-based experiments through flyers, emails, word-of-mouth, and the ACT Lab’s website. The research was conducted in May 2021 and June 2021. In order to protect the elderly during the COVID-19 pandemic, the age distribution was skewed towards younger drivers: 55 percent of the participants were in the 18-25 age group, 38 percent in the 26-40 age group, 5 percent in the 41-50 age group, and the remaining 2 percent in the over 56 age group. About 43 percent of the participants were female.

4.2. Simulator Results

The results of the simulator-based experiment are shown in Table 2. The Alternative 1 (mixed flow lanes) (II) had the lowest travel time and the highest speeds among all three roadway designs. Meanwhile, Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III) experienced the lowest speeds among all the three designs where the vehicular traffic was restricted to three travel lanes. This indicates that the participants adopted lower speeds in the presence of roadway delineation devices (i.e., plastic posts) on Current Design (dedicated AV lanes) (I) and less space for vehicles on the Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III).

The participants made 3+ lane changes on an average in the absence of channeling devices. The participants while employing higher speeds also performed lane changes in Alternative 1 (mixed flow lanes) (II), leading to unstable trajectories. The participants did not change lanes in the other two designs (I and III) and were driving on the lanes specified for HDVs. The mixed traffic lane also had slightly unstable trajectory i.e., lane changes in the presence of AVs.

Across all three designs, there were no improper lane uses. All participants drove on human driven lanes or mixed traffic lanes, as guided by the pavement marking and signs. This study showed that, with the current use of pavement marking, signs, and channeling devices, the roadway space can be clearly separated for different road users.

Table 2: Trajectory Data Analysis

MOE	Statistics	Current Design – Dedicated AV Lanes (I)	Alternative 1 - Mixed flow (AVs and HDVs) lanes (II)	Alternative 2 – Mixed flow and dedicated bike/scooter lanes (III)
Travel Time (s)	Mean	345.85	341.31	352.11
	SD	48.79	42.22	52.89
	Difference	Baseline	-4.54	6.26
Speed (mph)	Mean	30.75	31.44	30.41
	SD	3.79	5.51	4.44
	Difference	Baseline	0.69	-0.34
Number of lane changes	Mean	-	3.21	-
	SD	-	1.06	-
	Difference	Baseline	-	-
Improper lane use	Mean	0	-	0
	SD	0	-	0
	Difference	Baseline	-	0

Note: SD = Standard Deviation

4.3. Survey Results

The post experiment survey showed that 93.75% of the participants have heard of autonomous vehicles before and 83.3% are interested in using them in some form in the future. Two thirds of the participants agree that AVs will improve their overall travel experience in the future. Compared with previous studies (Nair & Bhat, 2021) it shows that among young people, the trust and acceptance of AVs is relatively high. The evaluation results of the three roadway designs on their understanding, safety, comfort, and popularity are shown in Table 3. Participants reported that they were able to understand the pavement markings and signs on all the three roadway designs, which is consistent with the results we observed in the simulator-based experiment.

Participants felt most safe in the Current Design (dedicated AV lanes) (I) where the AV lane and HDV lane are separated by roadway channeling devices. Both the Alternative 1 (mixed flow lanes) (II) and Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III) received lower scores. However, the results were due to different reason. For the Alternative 1 (mixed flow lanes) (II), participant indicated that they felt that AVs were not at the stage where they can confidently drive alongside them and hence the mixed lane design received a lower score. On the other hand, the Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III) received a significantly lower score as the participants reported that the lanes were relative narrow when the traffic was unchanged, and the right-of-way were allotted to cyclists and scooter rides.

Out of the similar consideration on space usage, the Alternative 1 (mixed flow lanes) (II) was the most comfortable to drive. This comfort level is also reflected by its highest travel speed among the three designs. The Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III) and the Current Design (dedicated AV lanes) (I) received lower scores indicating that the users are less comfortable driving with roadway channeling devices. In terms of AV adoption, the participants felt that the Current Design (dedicated AV lanes) (I) is the most suitable as it limits the interaction with the AVs at the early stages of AV adoption. The Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III) had the lowest score for AV adoption as the design focuses on promoting the sustainable transportation modes at the cost of HDV and AV operations. Participants did not give high rating to the third roadway design, but the popularity of the design was not significantly different than other road designs.

Table 3: Post Experiment Results

MOE	Statistics	Current Design – Dedicated AV Lanes (I)	Alternative 1 - Mixed flow (AVs and HDVs) lanes (II)	Alternative 2 – Mixed flow and dedicated bike/scooter lanes (III)
Understanding	Mean	4.42	4.38	4.44
	SD	1.10	1.05	0.97
	Difference	Baseline	-0.11	0.02
Safety	Mean	4.23	3.98	3.81
	SD	0.87	0.86	1.14
	Difference	Baseline	-0.25	-0.42*
Comfort	Mean	4.02	4.04	3.79
	SD	1.01	0.97	1.11
	Difference	Baseline	0.02	-0.23
AV Adoption	Mean	3.91	3.57	3.51
	SD	1.19	1.05	1.20
	Difference	Baseline	-0.34*	-0.40*
Popularity	Mean	4.21	3.67	3.54
	SD	0.91	0.88	1.05
	Difference	Baseline	-0.55	-0.67

Note: SD = Standard Deviation
* indicates statistically significant difference at 95% confidence level

4.4. Findings

This study illustrated clear tradeoffs between the three roadway designs considered. The post experiment survey and experiment data showed that the Current Design (dedicated AV lanes) (I) with the use of plastic post is most suitable for AV adoption in the near future as it limits the interaction between AVs and HDVs at a time when AV technologies are still in their nascent stages. Drivers also adopted slightly lower speeds in the presence of channeling devices as indicated by the simulator results for both roadway design I and III.

In the Alternative 1 (mixed flow lanes) (II) scenario, participants were observed to travel at higher speeds in comparison the Current Design scenario. This scenario featured two mixed flow lanes in each direction without the presence of roadway delineation devices leading to higher travel speeds. This scenario was rated high on the level of comfort. As the drivers were able to drive on both lanes with a narrow right lane, this scenario also observed less stable vehicle trajectories. In the post experiment survey comments, the participants indicated that they treated AVs as HDVs.

In the Alternative 2 (mixed flow and dedicated bike/scooter lanes) (III) scenario, there is less road space available for motorist as one of the lanes is dedicated to bikes. Hence, this scenario was rated low on comfort and raises safety concerns. This scenario did not outperform the other two designs on any of survey metrics from the perspective of the participants. However, the overall design was at par with the other scenarios on popularity as participants wanted to see more roads adopt this scenario.

Over the three scenarios, participants were observed to slow down at intersections and observe the behavior of other vehicles even when they had the clear right of way. In their post-experiment survey comments, they indicated that they weren’t clear which lane the vehicle would move into at the intersection and hence slowed down naturally. To ensure the safe and effective deployment of AVs in the real-world, it is important for AVs to convey their intent particularly at unsignalized intersections.

5. CONCLUDING COMMENTS

This research focused on evaluating the effects of AVs and related infrastructure modifications on human drivers. Human driving behavior and survey was used to identify the effect of infrastructure changes and AVs in a driving simulator environment with the Curiosity Lab's Test Track roadmap. Three scenarios' designs were designed to simulate various combinations of AVs and infrastructure changes, which are: Current Design featuring dedicated AV lanes, Alternative 1 featuring mixed flows (AVs and HDVs) lanes and Alternative 2 featuring dedicated bike/scooter lanes. The participants that indicated interest in using AVs in the future in the survey also felt more comfortable and safer driving alongside AVs in the Alternative 1 (mixed flow lanes) scenario.

Overall, the findings from this study illustrate that the introduction of AVs into the current roadway system would require modest infrastructural changes and emphasize the importance of clearly demarcating the right-of-way for HDVs and AVs in the initial stages. The study also illustrated the tradeoffs between different roadway designs and discussed their effectiveness in various stages of AV adoption. While there are other factors that affect driver behavior in mixed flow conditions including AV speeds and their identifiability in the traffic stream. The study findings provide insights for roadway designers and operators related to the safe introduction of AVs in operational traffic networks.

Additionally, although the traffic volume was not examined in this study, its importance cannot be ignored in determining road design. As the simulator experiment incorporated relatively low traffic volumes for both AVs and HDVs, the number of lanes did not lead to significant changes in travel time and speed. The findings of this experiment are applicable when the traffic volume is low. When the traffic volume is high and close to the roadway capacity, the driver's behavior and preference may change significantly. The impacts of the traffic volume and the proportion of AVs in the traffic will be investigated in future research.

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7. OUTCOMES AND IMPACTS

7.1. Outputs

Conference publications

- Peeta, S. (2021). Driving Simulator Based Study Of The Impacts Of Various Roadway Design Modifications On The Curiosity Lab Test Track, SMARTer-Together Webinar, November 19, 2021, Georgia Institute of Technology, Atlanta, GA.

- Peeta, S., Qing, Z., Wang, C., Anne, V.R.S. (2021). Driving Simulator Based Study Of The Impacts Of Various Roadway Design Modifications On The Curiosity Lab Test Track, Peachtree Meeting, May 12, 2021, Atlanta, GA.

7.2. Outcomes

This research investigated the effect of autonomous vehicles and related infrastructure changes on human drivers. These findings shed light on the tradeoffs between various roadway modifications and their effectiveness in various stages of AV adoption. These findings from this study can enable roadway designers and traffic operators to introduce autonomous vehicles into their traffic stream safely. Further work should investigate the impacts of autonomous vehicles and infrastructure changes on human drivers at higher traffic volumes.

7.3. Impacts

AVs are expected to be part of the road infrastructure in the near- to medium-term future. Research on AVs in the past decade has primarily focused on building the technological capabilities to navigate on transportation networks. Initial deployment of AVs on the transportation network is through pilot studies and often accompanied by modest infrastructure changes. This study investigates the impacts and tradeoffs of various infrastructure changes in the presence of AVs on human driving. Impacts include understanding the effect of dedicated AV only lanes, mixed flow lanes, reduced lane widths, and roadway delineation devices as well as highlighting future research directions to investigate the impacts of AVs at higher traffic volumes.

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