A Driving Simulator Evaluation of Cross-Sectional Design Elements and the Resulting Driving Behaviors

SAFETY RESEARCH USING SIMULATION

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A Report on Research Sponsored by

SAFER-SIM

September 2017

Table of Contents

List of Figures

List of Tables

Abstract

This research explores the relationship between the cross-sectional design elements and the impact on selected driver attributes such as speed profiles and lateral positioning. In this experiment a traditional collector-type base roadway of 1.5 miles with a 14 ft travel lane and an 8 ft shoulder was modeled using an advanced driving simulator. The base scenario was subsequently reconfigured with four different cross-sectional designs with various elements within the same physical right-of-way. Specific design elements included narrower lanes, bicycle lanes, raised center median and a curvilinear roadway profile. Twenty participants each drove five developed scenarios, which were presented in a counterbalanced fashion to mitigate any potential order effect. Participants' speed and lateral position were recorded throughout each of the drives. Across the virtual scenarios the same performance measures were analyzed by comparing data at each of five controlled collection points (checkpoints). Experimental results were analyzed using both descriptive and inferential statistical tests.

The obtained results show that the mean participants' speed was higher than the posted speed limit in all scenarios, except for the curvilinear profile scenario. There was no statistically significant difference in speeds between the base (Sc1), narrower lane (Sc2), bicycle lane (Sc3) and raised median (Sc4) scenarios. In the curved roadway profile scenario (Sc5), the difference in speeds was statistically significant. The lateral positioning between the scenarios across the checkpoints was significant. Overall, the results suggest that narrower lanes, bicycle lanes, or a raised median have no significant influence on speed reduction. Nevertheless, narrower lanes result in vehicle lateral position towards the center lane.

1 Introduction

From 2006 to 2010, an average of *37654.4* annual road deaths occurred in the United States each year. While a decline in this statistic was seen from 2011 to 2014, the recent reports from NHTSA [1] showcase a 7.7% increase in motor vehicle traffic deaths in 2015 and an estimated 35,200 deaths in 2015, up from 32,675 in 2014. It also explains that 94% of crashes can be tied back to human choice and error. Road geometry, environmental and vehicle aspects are crucial in influencing dangerous driver behaviors such as speeding and drunk driving that contribute to traffic crashes [2]. Identifying factors affecting crash rates is crucial to transportation planners and engineers in order to detect hazardous locations, or sites that require safety treatments. One such crucial factor is the cross-sectional design of the roadway. According to the American Association of State Highway and Transportation Officials (AASHTO), the cross-section of a roadway is the view obtained looking at the section between the right-of-ways from the perspective of the driver. The design elements include travel way, median area, shoulder, bicycle and pedestrian facilitates, utility and landscape areas, drainage channels and side slopes, and clear zone width [3].

1.1 Design Factors Affecting Crash Rates

In this study, the following geometric elements were specifically considered due to their effects on crash rates: lane width, median area, bicycle facility, clear zone, shoulder width and curved roadway profile.

According to a hierarchical, tree-based regression research study aiming to find the relationship between rural road geometric characteristics, accident rates and their prediction, lane width and serviceability index largely impact crash rates on rural two-lane roadways. The study also showed that on rural multilane roads, median width and access control are major factors [4].

A fundamental feature of the travel lane is the lane width. It is limited by the physical dimensions of automobiles and trucks to a range of 9 ft to 12 ft, but 12 ft wide lanes are desirable on both rural and urban facilities [5]. Though lane width varies from country to country and even city to city, in most cases 12 ft is considered as the maximum lane width for arterials and 12 ft for local roads [6]. In a rural two-lane or multilane road environment, elements of road geometry associated with road width, such as number of lanes and lane width, were substantial and are associated with crash risk [7]. Correspondingly, findings for urban areas seem to have variations with regard to the effect of lane width. Many studies in urban areas show that wider lanes resulted in higher crash rates than narrower lanes [8, 9, 10]. A similar study on urban arterials found that increases in lane width and decreases in shoulder width reduced both roadside and midblock crashes [11].

The median dimension should be in accordance with the roadway cross-section. In general, median width ranges from 4-80 ft in rural areas. AASHTO [5] suggests the use of raised median treatment to alleviate operational and safety deficiencies for arterial streets. There are different types of medians: raised, flush two-way-left-turn-lanes (TWLTL), continuous raised curbs, and barrier. The results of a public opinion survey indicate that the majority of respondents in Knox County, Tennessee, preferred the raised median, while business owners and operators showed an interest in TWLT median lanes [12]. In order to substantially affect driver behavior, raised median islands are strongly recommended in the United States [13]. Raised curb medians provide lower vehicle crash rates and pedestrian crash rates than either TWLTL or undivided cross- sections. In addition, TWLTL medians in central business district (CBD) areas had lower vehicle accident rates (property damage only) than either raised curbs or undivided cross-section medians [14].

Cyclists have become an increasingly important factor in roadway design. A driving simulator study comparing vehicle speeds and lateral positioning at midblock locations with and without bicycle lanes indicated that roadways with bicycle lanes had slightly higher speeds than those without. The presence of bicycle lanes had an impact on lane position because the participants traveled further from the edge line than when bicycle lanes were not present [15]. Separated bicycle lanes with raised medians and buffer zones add more comfort to bicyclists as well as drivers [16]. However, separated bicycle lanes introduce challenges at intersections where motorists and cyclists must interact [17].

AASHTO defines a clear zone as an unobstructed traversable roadside area designed to enable a driver to stop safely or regain control of a vehicle that has accidentally left the roadway [3]. Findings on the effects of clear zone width and roadside vegetation on driver behavior show that clear zone size/vegetation density combinations influence both driver speed and the lane position of the vehicle [5].

According to AASHTO [5], a roadway paved shoulder enables drivers to pull off the road and stop safely; it also serves as a recovery area for driver error [19]. However, an increase in shoulder width has a positive effect on decreasing the crash rate. A field experiment in Greece [20], with three nonconsecutive road sections containing various curves, was used to study risk perception regarding different road geometric elements. The results specified that a curvilinear roadway profile highly affected drivers' safety perceptions. Therefore, a conventional straight road was perceived as less risky than a curved one.

1.2 Research Objectives

At present, there is a notable gap in literature that quantifies the impact that cross-sectional roadway design elements employed to reduce speed have on driver performance. Speed selection is critical to roadway safety because higher speeds result in higher crash risks and more severe crashes [21, 22]. More recently, practices related to complete streets have translated into a revised approach to managing roadway speeds that are necessitated for accommodating multiple modes within a single space. Previous studies have demonstrated the efficacy of various devices that, when implemented individually or in treatment combinations, can effectively decrease roadway-related crashes and fatalities. Nevertheless, there is a gap when it comes to specific roadway design elements and their direct impact on the resulting driver behaviors.

The objective of this research is to explore the relationship between cross-section design elements and driver performance as measured by vehicle speed profiles, lateral positioning, and a perceived sense of safety.

Table 1.1 Research hypotheses

Scenario	Speed	Lateral Position
Narrower Lane	Participants' speed selection will be influenced by lane width	Participants will move along the center line
Bicycle Lane	The presence of a bicycle lane with no cyclists will not influence speed choice	The presence of bicycle lane pavement markings will influence lateral positioning, and drivers will move away from the edge line
Raised Median	Participants will pick higher speeds on 14 ft wide lanes, and curb median may not impact speed selection	Participants will travel closer to the center line when raised medians are present

2 Methods

A within-subjects experimental design was developed based upon existing literature to examine the effect of cross-section design on key driver performance measures that influence roadway safety. The following section outlines the research tasks that were employed to address the objectives of this study.

2.1 Apparatus

2.1.1 Driving Simulator

The driving simulator used for the study comprises a fully equipped, fixed-base 1995 Saturn sedan positioned in front of three screens subtending 135 degrees horizontally. The virtual environment is projected on each screen at a resolution of 1400 × 1050 pixels and at a frequency of 60 Hz. The virtual environment is projected on each screen through a network of four advanced Realtime Technologies (RTI) simulator servers. The participant sits in the car and operates the controls, moving through the virtual world according to his or her inputs to the car. The audio is controlled by a separate system consisting of four high-frequency speakers located on both sides of the car and two sub-woofers located under the hood of the car providing realistic road, wind, and other vehicle noises with appropriate direction, intensity, and Doppler shift.

2.1.2 Scenario Development

The virtual scenarios for the driving simulator were developed using a 3D modeling software called Internet Scene Assembler (ISA). ISA utilizes the Virtual Reality Modeling Language (VRML) file format. Apart from ISA, two other software tools were used: Autodesk Civil3D and Blender. Autodesk Civil 3D was selected because of its ability to export 3D surfaces of proposed roads, which can later be uploaded in Blender for texturing and conversion into the VRML file format. Blender is a robust 3D modeling tool available as an open-source product free of cost. During scenario creation, Blender plays a key role in the manipulation of dxf files, which contain the surface of a project created from a 3D CAD drawing using a design software such as Civil 3D.

Figure 2.1 University of Massachusetts Driving Simulator

2.2 Measures

The independent variables for the current study were lane width, bicycle facility, curb median, clear zone, and shoulder. In order to not inhibit participants' speed choice, there was no traffic in the participant's direction of travel. In the oncoming direction, four vehicles, including a truck, were individually programmed so that traffic could be controlled across all participants for each cross-section configuration.

Data was collected continuously, but five locations were selected for data comparisons. Each participant's vehicle speed and lateral position at these five checkpoints were compared in all scenarios. Data collection checkpoints within the scenarios were (1) Start, (2) Straight, (3) Small Left Curve, (4) Right Curve, and (5) End.

2.3 Participants & Procedure

Participants started by giving informed consent and then completed a pre-study questionnaire that asked for their demographics, driving history, and medical conditions that may influence their driving performance. Participants then completed a simulator sickness questionnaire to ensure they were not at risk for simulator sickness. Before entering the simulator, participants were fitted with the head-mounted eye tracker. After calibration, participants were given a practice drive session to familiarize them with the driving simulator. The practice training drive included a typical roadway with 12 ft lanes and 4 ft shoulder with a posted speed limit of 30 mph. Prior to the driving experiment, participants were instructed to follow the posted speed limit and to drive through all the scenarios as they normally would in their own vehicles.

Finally, a post-study questionnaire was administered to evaluate post-exposure information about the virtual environments and their driving performance. Participants were compensated $20 for their time. All procedures, including informed consent, payment, and participant recruitment followed Protocol ID#: 2016-2903 as approved by the Institutional Review Board (IRB) of the University of Massachusetts.

A total of 20 drivers (nine females, eleven males) participated in the experiment. Their ages ranged from 20-60 years old (mean: 29.35, SD: 10.91), and all had more than one year of driving experience (mean: 11.245, SD: 10.99) and minimal or no prior simulator driving experience.

2.4 Experimental Design

The experiment consisted of approximately 1.5 miles of a simulated real-world scenario, which was typically a collector-type roadway. The base scenario was reconfigured using four different geometrical design cross-sections. The design elements included a narrower travel lane, increased shoulder widths, added bicycle lanes, a continuous center raised curb median, and a curvilinear roadway profile. In addition, roadside vegetation was manipulated. The order of scenario occurrence was varied for each participant using the Latin Square method of counterbalancing. Screenshots of the five scenarios along with specific details on cross-sectional design elements are shown in Figure 2.2.

Existing Burnett Road, Chicopee MA, USA: 14ft travel lane, 8 ft shoulder, no median

Base Scenario (Sc1): 14ft travel lane, 8ft shoulder, no median

Narrower Lane (Sc2): 12ft travel lane, 6ft shoulder, no median

Bicycle Lane (Sc3): 14ft travel lane, 5ft bicycle lane, 1ft bufferzone, no median and no shoulder

Raised Median (Sc4): 14ft travel lane, 2ft shoulder, 6ft median

Curved Profile (Sc5): 14ft travel lane, 2ft shoulder, 6ft median

Figure 2.2 Experimental Scenario Description

3 Results

The research objectives addressed the relationship between cross-sectional design elements and their effect on drivers' behavior pertaining to their vehicle speed and lateral position. The results were consistent with the stated objectives and are detailed further below. As discussed, the main dependent variables were speed and lateral positioning, while the independent measures were various geometric roadway design elements (scenarios). Lateral position is calculated by measuring the difference between the absolute center of the vehicle and the center of the travel lane within the simulated roadway scenario. Negative lateral position values indicate that a participant's vehicle is closer to the centerline, while positive values imply that it is closer to the edge line. A between-subject t-test was used for comparative analysis. The α level was set at 0.05, and p values ≤ 0.05 were considered statistically significant.

3.1 Speed

To evaluate the participants' vehicle speed data to address the objectives of various cross-sectional design scenarios (Sc1, Sc2, Sc3, Sc4, Sc5), we looked at the mean participant speed across the scenarios along all the checkpoints. Table 3.1 shows the mean speeds of participants in each of the five scenarios at the five different checkpoints. For the base scenario (Sc1), with a 14 ft wide travel lane and an 8 ft shoulder, the mean vehicle speed was M = 29.5 and SD = 5.4. As the participants drove into the scenario at Checkpoint 2 (straight), the mean speed increased to M = 35.6 with SD = 8.4. At Checkpoint 3 (small left curve), the mean speed was M = 39.5 with SD = 10.0. At Checkpoint 4 (right curve), the mean speed increased to M = 41.3 with SD = 12.2, while at Checkpoint 5 (end of the roadway), it was M= 41.6 with SD = 13.7.

Table 3.1 Descriptive statistics for speed

Observed Mean Speeds for Scenarios at Checkpoints					
Scenario / Checkpoint	**Base Scenario (Sc1)**	**Narrower Lane (Sc2)**	**Bicycle Lane (Sc3)**	**Raised Median (Sc4)**	**Curved Profile (Sc5)**
	Speed (mph)				
1. Start	**29.5** ± 5.4	**28.7**± 5.8	**30.3** ± 5.0	**28.3** ± 6.0	**23.0** ± 5.4
2. Straight	**35.6** ± 8.4	**36.0** ± 6.9	**37.0** ± 6.5	**35.7** ± 6.9	**25.9** ± 5.5
3. Small Left Curve	**39.5** ± 10.0	**39.5** ± 8.2	**39.8** ± 8.2	**38.7** ± 9.3	**27.2** ± 5.2
4. Right Curve	**41.3** ± 12.2	**39.9** ± 8.7	**41.3** ± 11.8	**41.2** ± 11.9	**27.4** ± 5.2
5. End	**41.6** ± 13.7	**40.9** ± 10.1	**40.7** ± 14.8	**41.2** ± 14.1	**30.6** ± 5.5

Note: All values are Mean ± St. Dev.

Note: Bold indicate increased speed pattern from checkpoint 1 to 5

Table 3.1 clearly demonstrates that the participants' vehicle speed increased as they drove through the scenarios, irrespective of the roadway geometry. This trend seems to be constant across all the scenarios along the checkpoints. The participants' mean vehicle speed was lower for the curved roadway profile (Sc5) (10 mph less than the mean speeds of the base scenario), and participants did not tend to exceed the posted speed limit of 30 mph.

The participants' mean speeds for the narrower lane (Sc2) were comparatively lower than for the wide-lane scenarios, i.e., Sc1, Sc3, and Sc4 along Checkpoints 1, 2, and 4, while the speeds at Checkpoints 3 and 5 were almost equal. The descriptive analysis shows that the participants' mean speed for the bicycle lane scenario (Sc3) was higher at Checkpoints 1, 2, 3, and 4, but not at Checkpoint 5, when compared with the base scenario (Sc1). Interestingly, introducing a 6 ft raised median in Sc4 resulted in a slight change in the speed profile (slight decreased speeds) when compared to the base scenario (Sc1) across all the checkpoints of the roadway.

The paired t-test compared results between scenarios (

Table 3.2) and revealed no significant differences in speed between the base scenario (Sc1) and the narrower lane (Sc2), the bicycle lane (Sc3), or the raised median scenarios (Sc4). This result supported the hypothesis that introducing a narrow lane, bicycle lane, or raised median would not influence the participants' speed at any of the checkpoints along the roadway. However, there seemed to be well established significance between the base scenario (Sc1) and the curved roadway profile (Sc5), where p was much lower than 0.05 at all the checkpoints along the roadway.

Paired t-tests between the narrower lane (Sc2) and the bicycle lane (Sc3) indicated some significance in participants' mean speed at Checkpoint 1; $p = 0.02$. Also, at Checkpoint 1, significant differences existed between the bicycle lane scenario (Sc3) and the raised median scenario (Sc4); $p = 0.04$.

Table 3.2 Inferential difference of mean speed (mph) and paired t-test p values

Scene	Checkpoints	Base Scenario (Sc1)	Narrower Lane (Sc2)	Bicycle Lane (Sc3)	Raised Median (Sc4)	Curved Profile (Sc5)
		Mean (P Value)				
Base Scenario (Sc1)	1. Start		0.8(0.66)	-0.8(0.81)	1.2(0.77)	**6.5(0.00)**
	2. Straight		-0.4(0.70)	-1.5(0.30)	-0.2(0.89)	**9.7(0.00)**
	3. Small Left Curve		0.0(0.99)	-0.3(0.99)	0.8(0.19)	**12.2(0.00)**
	4. Right Curve		1.3(0.23)	0.0(0.81)	0.1(0.90)	**13.9(0.00)**
	5. End		0.6(0.66)	0.9(0.57)	0.4(0.66)	**11.0(0.00)**
Narrower Lane (Sc2)	1. Start			**-1.6(0.02)**	0.4(0.71)	**5.8(0.00)**
	2. Straight			-1.1(0.15)	0.3(0.81)	**10.1(0.00)**
	3. Small Left Curve			-0.3(0.74)	0.8(0.44)	**12.2(0.00)**
	4. Right Curve			-1.4(0.15)	-1.2(0.29)	**12.5(0.00)**
	5. End			0.9(0.85)	-0.3(0.85)	**10.4(0.00)**
Bicycle Lane (Sc3)	1. Start				**2.0(0.04)**	**7.3(0.00)**
	2. Straight				1.3(0.12)	**11.1(0.00)**
	3. Small Left Curve				1.1(0.22)	**12.5(0.00)**
	4. Right Curve				0.2(0.86)	**13.99(0.00)**
	5. End				-0.5(0.72)	**10.1(0.00)**
Raised Median (Sc4)	1. Start					**5.3(0.00)**
	2. Straight					**9.8(0.00)**
	3. Small Left Curve					**11.5(0.00)**
	4. Right Curve					**13.7(0.00)**
	5. End					**10.7(0.00)**

Note: Bold indicates a significant difference based on a Paired t-test

3.2 Lateral Positioning

The participants' mean vehicle lateral positioning is displayed in Table 3.3. Participants drove further from the centerline in the base scenario (Sc1) along Checkpoints 1, 2, 3, and 5 and towards the center line at Checkpoint 4 (right curve), M = -0.9 SD = 0.6. In the narrow lane scenario (Sc2), as expected, participants drove close to the center line along all checkpoints with the exception of Checkpoint 5. Similar patterns were observed in the bicycle lane scenario (Sc3), where participants drove further from the center line irrespective of the checkpoint geometry. For the curved roadway profile scenario (Sc5), participants moved towards the edge line at all checkpoints except for Checkpoint 5, where the participants positioned themselves closer to the center line.

Table 3.3: Descriptive statistics for lateral position

Observed Mean Lane Positions for Scenarios at Checkpoints					
Scenario / Checkpoint	**Base Scenario (Sc1)**	**Narrower Lane (Sc2)**	**Bicycle Lane (Sc3)**	**Raised Median (Sc4)**	**Curved Profile (Sc5)**
	Lateral Position (ft)				
1. Start	1.7 ± 0.9	**(-)** 1.5 ± 0.6	2.0 ± 0.9	7.2 ± 4.3	1.9 ± 2.7
2. Straight	1.9 ± 0.7	**(-)** 1.4 ± 0.7	2.2 ± 0.9	8.3 ± 2.6	1.9 ± 2.5
3. Small Left Curve	2.2 ± 0.6	**(-)** 0.8 ± 0.7	2.1 ± 0.7	4.9 ± 5.0	3.2 ± 1.7
4. Right Curve	**(-)** 0.9 ± 0.6	**(-)** 1.1 ± 0.6	2.3 ± 0.7	4.0 ± 2.9	0.4 ± 1.3
5. End	2.6 ± 1.2	0.3 ± 1.0	4.9 ± 0.1	**(-)** 1.5 ± 4.4	**(-)** 0.03 ± 4.3

Note: Values are Mean ± St. Dev.

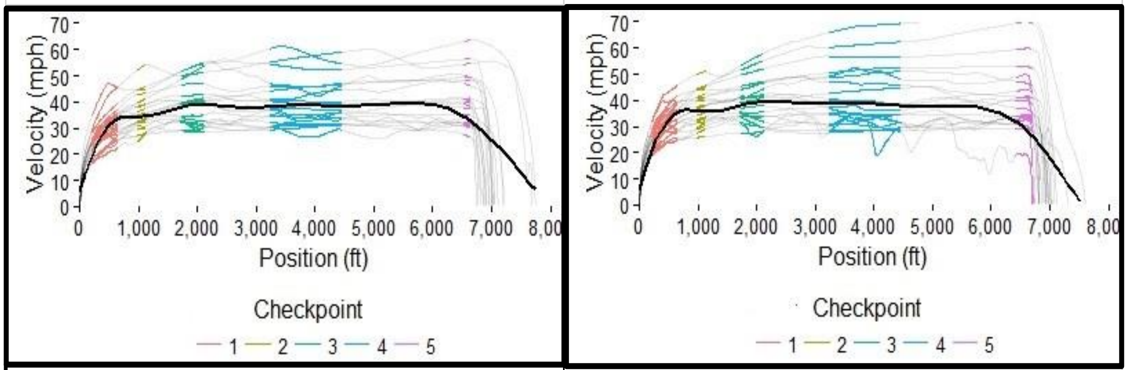
Note: **(-)** indicates vehicle position closer to centerline.

To achieve the research objectives and test the developed hypotheses, paired t-tests were performed between the scenarios at all checkpoints to explore the participants' lateral positions (Table 3.3). Although the participants moved towards the edge line in most of the scenarios, there seemed to be statistical significance in terms of vehicle lateral position between the base scenario (Sc1) and the narrower lane (Sc2) along all the checkpoints where p<0.05, indicated in

Table 3.4. A similar comparison between the base scenario (Sc1) and the bicycle lane scenario (Sc3) revealed little significance at Checkpoints 1, 2, and 3 (p>0.05), while at Checkpoints 4 and 5 the differences were statistically significant. A paired t-test between the base scenario (Sc1) and the raised median scenario (Sc4) revealed that, at all the checkpoints, lateral position mean differences were not significant. For the base (Sc1) and curved roadway profile (Sc5) scenarios, the patterns are quite different. At Checkpoints 1, 2, and 4 the mean difference seemed to be poorly significant, while at Checkpoints 3 and 5 the differences were significant.

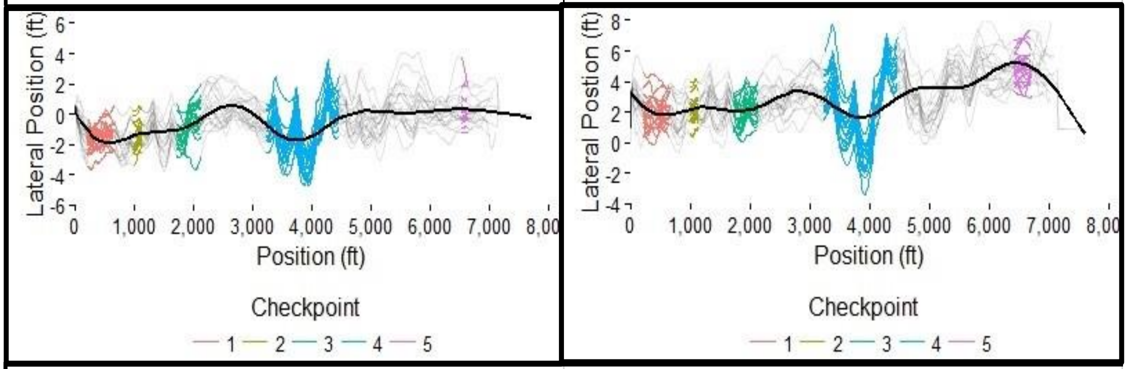
As shown in

Table 3.4, additional paired t-tests were performed to explore the lateral positioning between the the narrower lane (Sc2), bicycle lane (Sc3), raised median (Sc4), and curved roadway profile (Sc5) scenarios. It is evident that there is high significance along Checkpoints 1, 2, 3, and 4 between the narrower lane scenario (Sc2) and the bicycle lane (Sc3), raised median (Sc4), and curved roadway profile (Sc5) scenarios with respect to participants' mean lateral positioning; Checkpoint 5 is the exception. A paired t-test between the bicycle lane (Sc3) and the raised median scenario (Sc4) revealed significant differences at all checkpoints. However, when compared with the curved roadway profile scenario (Sc5), there was no significant difference at Checkpoints 1 and 2, while significant differences were observed at Checkpoints 3, 4, and 5. Figure 3.1 illustrates the individual participants' speed profiles in the narrower lane (Sc2) and bicycle lane (Sc3) scenarios.



Participants Speed Profile Scenario 2

Participants Speed Profile Scenario 3



Participants Lateral Position (-Left, +Right) Scenario 2

Participants Lateral Position (-Left, +Right) Scenario 3

Figure 3.1 Participants' speed and lateral position for Scenarios 2 and 3

Table 3.4 Inferential difference mean lateral position (ft) and paired t-test p values

Scenario	Check-points	Base Scenario (Sc1)	Narrower Lane (Sc2)	Bicycle Lane (Sc3)	Raised Median (Sc4)	Curved Profile (Sc5)
		Mean (P Value)				
Base Scenario (Sc1)	**1.Start**		**3.2(0.00)**	-0.3(0.15)	**-5.4(0.00)**	-0.2(0.78)
	2.Straight		**3.4(0.00)**	-0.2(0.35)	**-6.4(0.00)**	0.0(0.97)
	3.Small Left Curve		**3.0(0.00)**	0.1(0.51)	**-2.7(0.04)**	**-1.0(0.04)**
	4. Right Curve		**1.0(0.00)**	**-2.5(0.00)**	**-4.1(0.00)**	-2.3(0.15)
	5. End		**2.3(0.00)**	**-2.3(0.00)**	**4.1(0.00)**	**2.7(0.03)**
Narrower Lane (Sc2)	**1.Start**			**-3.5(0.00)**	**-8.7(0.00)**	**-3.4(0.00)**
	2.Straight			**-3.6(0.00)**	**-9.8(0.00)**	**-3.4(0.00)**
	3.Small Left Curve			**-3.6(0.00)**	**-9.8(0.00)**	**-3.4(0.00)**
	4.Right Curve			**-3.4(0.00)**	**-5.1(0.00)**	**-1.5(0.00)**
	5.End			**-4.7(0.00)**	1.8(0.10)	0.3(0.76)
Bicycle Lane (Sc3)	**1.Start**				**-5.2(0.00)**	0.1(0.86)
	2.Straight				**-6.2(0.00)**	0.2(0.73)
	3.Small Left Curve				**-2.8(0.03)**	**-1.1(0.04)**
	4.Right Curve				**-1.7(0.03)**	**2.0 (0.00)**
	5.End				**6.5(0.00)**	**5.0(0.00)**
Raised Median (Sc4)	**1.Start**					**5.2(0.00)**
	2.Straight					**6.4(0.00)**
	3.Small Left Curve					1.7(0.13)
	4.Right Curve					**3.6(0.00)**
	5.End					-1.5(0.32)

Note: Bold indicates significant difference based on a Paired t-test

4 DISCUSSION

Results showed that participants' mean speed was higher than the posted speed limit in all the scenarios except the curved roadway profile scenario (Sc5). The speed trends appeared to be increasing along the checkpoints as the drivers progressed through the virtual scenarios. Except at the start (Checkpoint 1), the mean speed in all scenarios was higher than the posted speed limit. As the participants drove through the scenarios, they must have felt comfortable driving the vehicle within the lab environment, and familiarity with the virtual scenarios may have resulted in increased speed patterns.

The speeds shown in Figure 3.1 were not largely affected by the various cross-section designs. Specifically, in the narrower lane scenario (Sc2), only a few participants chose speeds above 40 mph; the rest drove at or below the posted speed limit. This scenario had a 12 ft lane with a 6 ft shoulder. For all checkpoints, an extreme change was seen in participants' lateral position; they drove closer to the center line. In the bicycle lane scenario (Sc3), it appeared that participants did not perceive the risk of bicyclists despite the presence of a bicycle facility adjacent to the travel lane. This finding on speed and lateral position in the presence of a bicycle lane matches the work conducted by Fournier et al. [15].

There were no significant differences in speeds between the base (Sc1), bicycle lane (Sc3), and raised median (Sc4) scenarios. This may be due to the presence of 14 ft wide lanes in all three scenarios, which may have accounted for the lack of influence on participants' speeds. In fact, the wider lanes encouraged participants to select higher speeds, even in the presence of bicycle lanes or raised medians. The low vehicle density in the oncoming lane and the lack of a lead vehicle in the travel direction may have contributed to the higher speed selection. Likewise, the lack of pedestrians and cyclists along the roadway might have encouraged participants to drive at higher speeds. Nevertheless, there was some significance in mean participants' speed along the checkpoints between the base scenario (Sc1) and the curved roadway profile scenario (Sc5) even on the 14 ft wide lane. This might be due to the curved roadway profile, which would have influenced the participants to slow down along all the checkpoints.

Figure 3.1 also demonstrated that at lower speeds participants moved towards the center line, while at higher speeds they moved towards the edge line. Wider lanes had no influence on maintaining the participants' lateral positioning or in binding the vehicle towards the center of the lane. There was significance between the scenarios in terms of lateral positioning along the checkpoints.

4.1 Limitations

This study was undertaken on a fixed-base driving simulator, so the lack of motion may have played a role in the lack of differences in participant speeds as they could not physically sense their movement. However, previous literature has suggested that the absolute differences in speeds in this environment are consistent across scenarios as compared to real-world driving [23]. The roadway was simulated under daylight conditions, and there were few driver distractions. Beyond this, moderate traffic density was used for each scenario, and results may have differed with higher simulated traffic densities. During the experiment, it was evident that a few participants were driving cautiously, as if they knew that their performance was being monitored by the researcher.

4.2 Future Work

Future studies could examine using plant potters instead of a painted 1 ft buffer zone in the bicycle lane scenario, cautioning the driver through the presence of a physical object. Beyond that, it would be interesting to look at drivers' speed and lateral positioning while adding cyclist density as a constant. Also, this study can be elaborated and improved upon by looking at curved roadways without a median. Studying speed and lateral position with the presence of pedestrian movements may yield different findings as well.

5 CONCLUSIONS

The objective of this research was to explore the relationship between the various cross-sectional roadway design elements and their impact on driver performance when subjected to different types of roadway geometry. Results from the study indicated that participants' mean speed was higher than the posted speed limit on wider lanes, irrespective of the presence of a median or a bicycle lane. However, slightly lower mean speeds were observed on the narrower lane, and major speed differences (lower speeds) were visible on the curved profile roadway. The results of the experiment also revealed that there were no differences in driver speed patterns between the base scenario (Sc1), bicycle lane scenario (Sc3) and raised median scenario (Sc4) at different roadway cross-sections, while the curved roadway profile (Sc5) had a significant difference in participants' speed profile. Another noteworthy finding from the present study is that the presence of bicycle lane and median had no influence on the vehicle lateral positioning on wider lanes.

In summary, considering all the factors between the scenarios analyzed above, the current research suggests that the narrower lanes might have greater influence on both controlling driver speed and maintaining the lateral position along the roadway. While curved roads are more influential in lowering speeds and maintaining lateral positioning, curved roadways may not always be possible due to geometric constraints.

6 Acknowledgements

This research was funded in part through a research project awarded by the Safety Research Using Simulation (SAFER SIM) University Transportation Center (UTC) at the University of Iowa. Funding for the UTC Program is provided by the Office of Assistant Secretary for Research and Innovation (OST-R) of the United States Department of Transportation (USDOT).

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