Influence Analysis of Median Type and Infrastructure on Driving Behavior: A Driving Simulator Experiment

Hezheng Bi¹, Shengdi Chen²*, Jian Lu³

¹School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
²College of Transport and Communications, Shanghai Maritime University, Shanghai 201306, China
³School of Transportation Engineering, Tongji University, Shanghai 200092, China

* Corresponding author

Abstract — This paper describes the results of a driving simulator study that focuses on the influence of median type and infrastructure on attention, speed choice and lateral placement of car drivers. The driving simulator experiment serves as a means to include human factors principles into median infrastructure guidelines. Studied median features include median type, median width and infrastructure such as barrier. It is found that the concerns and related degree of driver’s attention is different under 15 kinds of median conditions. In marking medians, the driving workload is the heaviest and the principal concern of drivers is the opposing traffic. When entering marking medians from physical medians, drivers tend to laterally move away from the road centerline, and they slow down. For physical medians, the lateral wave goes down with the increase of median widths. But there is no influence on lateral wave if the widths are more than 5m. The fact that barriers along the median are not considered to be a risk, with drivers not adjusting their behavior, makes the installation of barriers need more careful consideration.

Keywords - driving simulation; median type; speed control; lateral offset

I. INTRODUCTION

A median is the portion of a highway separating opposing directions of the traveled way. The principle function of a median is to separate opposing traffic, provide a recovery area for out-of-control vehicles, and provide a stopping area in case of emergencies [1]. Median crossover accidents are generally severe and result in a high cost to society. Such accidents also have a greater potential for creating liability, both because of their severity and because of their inherent link with design deficiencies. In some regions, the median widths of new highways are being minimized to control the amount of right-of-way required, and in others, existing highway medians are being reduced so that additional travel lanes can be built to improve capacity. Such actions tradeoff safety to reduce costs or increase efficiency.

It was hypothesized that roadways separated by a median of some sort would reduce the head-on type of accident. Medians can be found which are raised, depressed, traversable, non-traversable, earth, concrete, with and without barriers, with and without plants, and so on. The research findings about the impact of median on traffic and safety were obtained based on statistical analysis of data from accidents that occurred in the field roads. American Federal Highway Administration studied the association of median width and highway accident rate in 1993, and the general findings indicated that accident rates do decrease with increasing median width for unprotected medians [2]. However, the data set could not be used to determine the median width at which a positive barrier should be used. The study of Glad recommends that the 50-foot width requirement for median barriering is optimal from a benefit/cost analysis of observed crash histories on Washington State highways. This finding is based on the comparison of societal costs of median crossovers on sections with and without cable median barrier treatments [3].

At present, a sense of the impact of the median was not clear or unified. The current version of the Roadside Design Guide (AASHTO 2002) suggests the use of a simple bivariate analysis of average daily traffic (ADT) and median width as a guide in determining median barrier requirements. The relationship is a simple decision rule chart: if ADT is above a certain value and median width below a certain value, the chart shows the recommended type of median barrier [4]. In China, the Design Specification for Highway Alignment state: when the design speed of highways is 100km/h, the width of the median should be 3.5m, which includes the width of left shoulders [5]. Chinese design standards of lane width and median width are developed based on foreign standards. However, foreign standards are mainly traditional road alignment design theory supported by the driving theory. Along with the high speed development of traffic, old theories are facing increasingly serious challenges.

The current road design is people-oriented. It focuses on riding comfort, physiological and psychological reactions, and the driver’s driving behavior. This idea finally develops into a new road-designing concept. Making use of driving
behavior to evaluate the impact of road alignment or facilities can help us develop a new concept for road design. As part of the European project RISER (Roadside Infrastructure for Safer European Roads), TNO conducted a driving simulator experiment to gain more insight in the influence of continuous roadside furniture elements such as guardrails and barriers. An extensive summary of literature findings on driver behavior and driver interactions with roadside infrastructure is given in the project report [6]. American experts Tamar Ben-Bassat and David Shinar researched the impact of shoulder width, guardrails and road geometry elements on the driver’s perception and driving behavior. Data analysis shows that road geometry impacts both subjective and objective information, and shoulder width has a great influence on driving speed, vehicle location and the driver’s perception of safe driving [7].

Limited safety analysis techniques have been researched and used in the area of median effect on driving behavior. In this paper, we will concentrate on speed and lateral position adaptation as a result of the different conditions as an indication of guidance or risk perception. And relevant questions in this experiment are:

- What’s drivers’ speed choice under different median conditions?
- How do drivers deal with lateral guidance as well as with risks involved in the driving task?

Therefore, according to the indicators trends, and combined with a subjective questionnaire, the impacts of different median were evaluated comprehensively. It could provide a theoretical foundation for advancing a reasonable highway median.

II. Method

A. Participants

Thirty-two healthy drivers including 18 men (mean age ± SD =32±6.6 years, age range from 24 to 49 years) and 16 women (mean age ± SD =31±4.9 years, age range from 24 to 39 years) took part in the driving simulator experiment. All participants had at least two years of driving experience (mean driving experience± SD =5.6 ± 3.3 years, range 2-12 years).

B. Task

All participants completed a total of 15 drives in randomized order. In all highway conditions, the maximum speed limit was 100km/h. Participants started the simulation at a speed of 60km/h and were able to adjust their speed as they normally do in a real vehicle. To make sure they were immersed in the environment right away and aware of the change in scenario, each condition started with 1km of diving before the specific treatment (if any) started. Participants were asked to drive as they normally would with their own preferred speed, to refrain from overtaking and to remain in the left lane in order to measure a continuous influence of the median on the left side on speed or lane position.

C. The UC-win/Road driving simulator

The medium-fidelity driving simulator (UC-win/Road, FORUM 8 Technology Incorporated, Fig. 1) at Transportation Lab for Comprehensive Performance Surveillance and Simulation, Shanghai Jiao Tong University mainly includes a cockpit, computers, video and audio equipment. The road scenario is projected onto three big screens providing a 130 degree field of view. The simulator records the actions of the driver on vehicles (e.g. braking, accelerating and turning the steering wheel) 20 times per second (i.e. 20Hz). Additionally, the simulator provides numerous other parameters that describe travelling conditions, such as the longitudinal position of vehicle’s center of gravity, the relative lateral position or displacement of vehicle with respect to center line of the road, the speed and acceleration.

D. Simulated scenarios

1) Base conditions for highways: We determined a basic set of road conditions before we established the simulated scenarios in order to guarantee the pertinence and rationality of experiment. These conditions include good weather, good visibility, and no incidents or accidents. Other traffic was present and responded to the participant in such a way that effects on the participant’s speed were kept to a minimum. They kept such a distance to the participant’s vehicle that the participant never had to pass another vehicle because of speed differences.

- Road alignment: straight four-lane two-directional road, with a length of 2km; lane width of 3.75m; left shoulder width of 0.50m; right shoulder width of 3.75m (hard shoulder width of 3m, earth shoulder width of 0.75m); cross slope of 2%.
- Landscape design: a row of polar trees and cypress trees were set on each side of the road. The polar spacing is about 10m, while the cypress spacing is 15m; this design could ensure that the roadside landscape went through the drivers’ vision at a certain rate.
- Access: there is no direct access points along the roadway.

2) Experiment condition for highways: Each experiment roadway is 2km long (K0-K2000), and consists of 3
sections: reference section, transition section and experimental section (Fig. 2).

The first 900m (K0-K900) is the base median type (condition 6) for all conditions, giving the driver a possibility to get comfortable in the ride and also to measure the effect of introducing other conditions. The second 200m (K900-K1100) is the transition section of the median, the configuration of median changes smoothly. The third 900m (K1100-K2000) is the experimental section with specific median condition. During the 900m of the drives, the median and infrastructure type were varied as well as the median width or the presence of a guardrail.

In order to reflect the real traffic environment, we set a fixed flow (800pcu/h/lane, 15% heavy vehicles) on lane 1, lane 3 and lane 4. And the experiment will be held on lane 2.

On the four-lane two-directional highways participants drove a total of 15 sections, differing in median type (marking, facilities or physical type), median elements (with or without barrier), material of barrier (concrete, metal or wire rope) and median width. For details, see Table 1 and Figure 3. The lane was 3.75m and the vehicle width was 1.47m. On the right side a standard roadside was present in all conditions. The straight highway sections were not completely straight but had a very slight curvature in order to stimulate participants to steer actively.

<table>
<thead>
<tr>
<th>NO.</th>
<th>Median Type</th>
<th>Median Width</th>
<th>Barrier/guardrail</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>marking median</td>
<td>central line</td>
<td>—</td>
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<tr>
<td>2</td>
<td>wide central line</td>
<td>—</td>
<td>—</td>
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<td>3</td>
<td>concrete barrier</td>
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<td>4</td>
<td>metal barrier</td>
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<td>5</td>
<td>wire rope barrier</td>
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<td>6</td>
<td>grass and bush 1m without</td>
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<td>8</td>
<td>grass and bush 3m without</td>
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<td>grass and bush 5m without</td>
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<td>10</td>
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<td>15</td>
<td>grass and bush 10m with</td>
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</table>

It was expected that drivers choose a speed and lateral position corresponding to their perception of risk from the different configurations of median type and infrastructure. If a driver perceives a condition as a risk, he is expected to move away from that risk and possibly decrease his speed. If the median condition is not perceived as a risk one would expect no change in behavior or even an increase in speed in case of visual guidance.

E. Experiment designs and procedures

The experiment includes four parts: (1) General instructions for all participants; (2) Before-drive questionnaire; (3) Driving through 15 scenarios with different type of medians; (4) Post-drive questionnaire.

All participants were given the following instructions for driving the simulator: “You are about to participate in a driving simulator experiment. The experiment will include three parts: a before-drive questionnaire, 15 independent driving segments, and a post-drive questionnaire. During driving in the simulator, please drive habitually but obey the traffic laws, and exit when you see the stop sign on the right side of the road.”

Figure 2. Diagram of the experimental roadway and changes in median.

Figure 3. Simulated scenarios (1) to (15).
After the instructions, participants were asked to fill out a before-drive questionnaire. This questionnaire collected participants’ demographic and physical information. The first part included participant’s age, gender, height, weight, profession and other information. The second part was designed to check participants’ fatigue level and whether they were under the influence of drugs or stimulating food.

For the driving experiment, participants were asked to complete driving tasks in 15 scenarios. To avoid ordering effects, the sequence of simulations was counterbalanced across drives. Each driver was given a 3-minute-drive between consecutive simulations to reduce any fatigue effects and re-establish psychophysical conditions similar to those at the beginning of the test.

After driving the simulator, participants were asked to fill out post-drive questionnaire that consisted of two parts. The first focused on participants’ physical conditions after driving. The second evaluated the driving simulator’s ability to mimic real-life conditions, including scenarios, operating and feelings [8].

F. Data collection and process

The data recording system collected the desired parameters at a frequency of 20Hz. They include position, speed and lateral offset from the lane center. The raw data were first averaged over a distance of 10 meters along the test segment and matched with the road mileage.

III. ANALYSIS AND RESULTS

For each condition, segments from K1400 to K2000 of experimental section were analyzed. When diver comes into the experimental section from the transition section, he will adjust his driving behavior based on the judgment of the risk in new condition. And that will lead to high volatility in experimental data at the first beginning.

Segments from K1400-K2000 were selected further on in the drive where the treatment had been present for a while (300m) to see what effects would last. For all groups of segments, effects of different median condition on the dependent variables speed and lateral position were analyzed with an analysis of average value and variance. The number of observations within each segment varies with speed and sample rate.

A. Driver’s attention

A study showed that, 40% of road traffic accidents are related with driver’s attention. However, a driver's attention is restricted to a certain extent, which is limited. When driving on different-difficulty roads, the drivers will attach different amount of attention. Generally, the allocation of drivers’ attention is proportional to the difficulty of the roads. Thus, the traffic information received by drivers or their focused objects directly impact drivers’ analytical judgment or their driving behaviors [9]. Therefore, we conduct a subjective questionnaire on the driver, after the driving simulation on each scenario. The main contents of the questionnaire include the main concern of the driver on road and environment, and related degree of attention in the driving simulation. The processed results are shown in Table 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Opposite direction traffic</th>
<th>Median</th>
<th>Road markings</th>
<th>Same direction traffic</th>
<th>Driving workload</th>
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</table>

According to the results of questionnaire we know that:

(1) The factors that affect drivers’ attentions in the driving process are divided into two categories. One is road-related: road markings and medians. Another is related to traffic participants: opposite-direction traffic on the left side and same-direction traffic on the right side.

(2) With the same road alignment and traffic flow conditions, for different medians, drivers’ attention for various factors will differ from one another. That is, medians will affect drivers’ focused objects and the related extent.

(3) We assume that driving workloads from different degree of drivers’ attention are as follows: driving workload under special concern is 3, driving workload under normal concern is 2, and driving workload under little concern is 1. Then we can initially obtain the total workloads for various medians, which are shown on the right column of Table 2. From big to small, the sequence is marking medians > facility medians > physical medians. In marking medians, drivers have to pay attention to more information, and the treatment is relatively complex. While in physical medians, drivers are required less attention on traffic information, due to the well guidance effect of the median.

B. Operating speed

Speed plays a significant role in crossover accidents. In many instances drivers lose control over their vehicles because the speed chosen is not appropriate in a given situation. In general, one can say that, if a driver can increase speed without increasing perceived task difficulty (or perceived risk), he or she will do so [10]. Figure 4 shows the average speed in the section from K1400 to K2000 of 15 experimental conditions.
According to Figure 4, the average speeds are different when drivers enter different simulation scenarios, and the average speeds under different median scenarios are compared from big to small: physical medians > facility medians > marking medians. When drivers enter the marking medians or facility medians, they reduce the speed, indicating the increase of driving workloads. The width of medians has no effect on average speed. With the increasing median width, the speed varies little. With or without the barrier has no effect on average speed. For physical medians, the appearance of a barrier doesn’t make drivers increase or decrease the speed obviously.

C. Lateral offset

Lateral position is another important indicator in the driving task [11][12]. It is a position choice made by drivers after they balance the potential risk on both sides of the car, which can also reflect what object or conditions they will perceive as an obstacle. So it’s easy to cause an accident if drivers choose an unreasonable lateral position when they are not sensitive to the potential risk. The raw lateral offset data was obtained as the relative lateral distance to the centerline of roadway.

1) Lateral position: The lateral position (LP) was computed as in

\[ LP = \frac{\sum_i y_i}{N} \]

where \( N \) is the total number of observed samples of one driver during the specific configuration, \( y_i \) is the \( i \)th observed lateral position. Figure 5 shows the 85% percentile of average lateral position across the 32 drivers, where a positive value indicates the vehicle was on the right side of the centerline, and a negative value indicates it was on the left side.

According to the questionnaire we know that the main road and environmental factors which drivers have to focus on in the driving process include: opposite-direction traffic on the left side, same-direction traffic on the right side, median and road markings. Therefore, combined with statistical data of vehicles’ lateral positions, we can analyze to obtain these results:

(1) When the driver is driving on the road with marking medians, the lateral position of driving trajectory is generally at the right side of the central line (average= +0.560), i.e., the driver judged that the comprehensive risk on the left side is higher than that of the right. Therefore, for marking medians, the driver will choose to keep away from it. That is, marking medians play a limited role in isolation, and bring serious interferences to drivers from the opposite-direction traffic flow.

(2) When the driver is driving on the road with facility medians, the lateral position of driving trajectory is slightly at the right side of the central line (average= +0.205), i.e., the driver judged that the comprehensive risk on the left side is slightly higher than that of the right. Therefore, facility medians can release the impact of the opposing traffic to drivers. While the wire rope barrier and metal barrier have limited protective effect; on the other hand, concrete barrier itself is deemed to be a dangerous object, so the medians also have some effect on the lateral position of the vehicle.

(3) When the driver is driving on the road with physical medians, the lateral position of driving trajectory is generally at the left side of the central line (average= -0.245), i.e., the driver judged that the comprehensive risk on the left side is smaller than that of the right. Therefore, physical medians can greatly release the impact to drivers from the opposite-direction traffic, and are considered to be protective facilities to isolate the opposing traffic.
vehicle will be more close to the medians. However, if the median width is greater than 5m, the lateral position of the vehicle varies little. What’s more, with or without a barrier has no significant impact on drivers’ lateral positions (Paired Sample Test, sig.=0.116>0.05). Therefore, we can know that drivers haven’t generally considered barriers as hazardous objects, which were attached less attention.

2) Lateral wave: In order to quantify the “lateral wave” along the test highway segment, the standard deviation (from its average vehicle trajectory) of lateral offset was computed for each configuration. The standard deviation of lateral offset (LOSD) was computed as in [13]:

\[
LOSD = \sqrt{\frac{\sum_{i=1}^{N} (y_i - LP)^2}{N}}
\]

where \( N \) is the total number of observed samples during the specific configuration, \( y_i \) is the \( i \)th observed lateral offset and \( LP \) is the average value for the sample. Figure 7 shows the evaluation results from the 85% percentile of standard deviation of lateral offset across the 32 drivers. The results showed that the LOSD was averaged to be 0.360m for marking medians, 0.377m for facility medians and 0.280m for physical medians. The lateral waves of physical medians are generally less than those of marking medians and facility medians. But the difference within the physical medians ranges from 0.158m to 0.397m.

Figure 8 indicates the relationship between the 85th \( LOSD \) and median width of physical medians. For physical medians, with the increase of median width, the lateral wave of the vehicle will decrease. However, if the median width is greater than 5m, the standard deviation of lateral offset descends very slowly. As with lateral position, barrier treatments also have no significant impact on drivers’ lateral waves (Paired Sample Test, sig.=0.714>0.05).

IV. CONCLUSIONS AND DISCUSSIONS

Given the limited data of the median accidents, a driving simulation study was conducted to investigate some of the main factors leading to single vehicle crashes: attention, speed and lateral offset. In this study we utilized the driving simulator to simulate a four-lane highway and develop a practical approach for evaluating the effects of 15 different medians. Driving behavior and vehicle dynamics data were collected for the median utility evaluation in terms of attention allocation, speed control, lateral offset and vehicle stability.

Road elements, traffic flow and environment do have an influence on driver’s attention which is an important factor of driving behavior and quite related with driving safety. According to the questionnaire, for different types of medians, the factors that drivers concern about and the related extent on them will change. It suggests that roads with physical median require less attention on traffic information than those with marking medians or facility medians. And drivers will feel more comfortable and less workload on physical median conditions.

On the highway drivers adjusted their speed when various median scenarios were introduced. When the marking median was introduced, the speed went down. But they tend to keep a high speed when entering the physical medians. In other words, drivers generally consider the perceived task difficulty (or perceived risk) in physical median conditions low to that in marking or facility conditions.

When under the marking medians or physical medians, drivers tended to choose a position on the road that is further away from the left-side marking (or road centerline). While they chose a position on the road that is close to the left-side marking under the physical median conditions. How close this was depended on the width of the median. The vehicle will be more close to the median with the increase of median width until it was greater than 5 meters. Another similar conclusion was found in the relationship between the lateral wave and median width. The vehicles seemed to be more stable in the road with physical medians.

Median barriers physically separate opposing traffic streams. For the conditions on the physical median roadway with the barrier introduced, the presence of barrier had no significant effect on speed or on lateral position. Therefore, the question arises whether drivers understand the risks of barrier alongside the median and whether this overconfidence in the protective effect of barrier might be an underlying risk of some incidents and accidents with barrier. It is important to understand that safety barriers also
constitute a hazard to the occupants of errant vehicles. And this is in line with studies reported in Australia[14], where recommend that a median barrier should only be installed if the consequences of striking the barrier are expected to be less severe than a resulting collision should no barrier be provided.

Several possible developments were considered for the future study. Firstly, the results for this study were determined only based on the conditions of straight non-access highways. A broader sample size from different radius or traversable roads will be helpful to identify the general effects of medians. Secondly, it may be valuable to consider how to combine the lateral position and stability measures to provide more practical median evaluation approach.

REFERENCES