Proceedings of the 6th International Conference on Civil Engineering for Sustainable Development (ICCESD 2022), 10~12 February 2022, KUET, Khulna, Bangladesh (ISBN-978-984-35-1972-6)

DRIVING BEHAVIOR AND SAFETY RESEARCH USING DRIVING SIMULATOR IN BANGLADESH: PRELIMINARY LEARNING AND OBSERVATIONS

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ABSTRACT

Using driving simulators in the traffic engineering domain for multi-disciplinary investigations and analyses including drivers' performance, driving behavior, impact of perceptual countermeasures, safety assessment is a common practice, particularly in high-income countries. Recent advancement of computer technology has made high-fidelity driving simulators increasingly affordable with added advantages in conducting driving behavior and road safety research over real-world, on-road studies. However, in the context of low-income countries like Bangladesh, where traffic composition, road and roadside environment, and driving behavior is significantly different from high-income settings, the use of driving simulators in road safety research is very limited. Recently, the Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) has led the establishment of a high fidelity driving simulator under a multi-national collaborative project titled "Socio-Technical Approach to Road Safety (STARS)", funded by the National Institute for Health Research (NIHR), to perform advanced driving behavior and safety research in Bangladesh as well as to identify effective safety countermeasures for different roadway sections. As it is a newly established simulator with software developed in a high-income country, therefore based on traffic scenarios derived from those settings, there are lots of technical and operational challenges involved in adapting to the Bangladeshi context, particularly in the development of road and roadway environments to replicate real-world, Bangladeshi scenarios. This paper has drawn attention to those challenges as well as to the opportunities to use driving simulation for driving behavior and safety research in Bangladesh. The study has identified some major challenges primarily related to the development of local roadway and traffic environments, validating the simulator for the selected roadway environments in consideration of local traffic behavior and characteristics etc. An example experimental design to evaluate proposed treatment options for a hazardous road intersection has also been discussed. The major steps include in the experimental design are: selection of study area, selection of probable countermeasures, scenario development and organization, selection of driver, preliminary training and pilot study, driving simulator and data extraction, data cleaning and primary analysis, conflict evaluation and performance evaluation. The study has made a long-term plan to perform a diversified stream of research considering our local problems since the driving simulator provides an inherently safe environment with the facility of changing roadway configurations whilst expending minimum resources. Finally, the paper highlighted future directions of research as a way forward including targeted research plans such as driving behavior study, impact of roadway design and features, roadside treatment/features effect, efficacy of safety interventions etc.

Key Words: *Driving Simulator, Safety, Driving Behavior, Research*

1. BACKGROUND

Using driving simulators in training and research has a long history. In the early 19th century, the US flight training school "Antoinette" first introduced flight simulators for training purpose. The application of driving simulators in transportation research started in the early 1960's as an alternative data source to evaluate complex driving behaviors and their interaction with diverse road environments (Blana, 1996; Lu et al., 2019; Underwood, Crundall, & Chapman, 2011).

With the advancement of computer technology, simulators have become more realistic in terms of vehicle dynamics and driving environment (Boyle & Lee, 2010). Even the portable desktop simulator has gained the capability to model specific vehicle dynamics (Salaani, Schwarz, Heydinger, & Grygier, 2007). On the other hand, driving and safety has been facing a shift due to sharp improvements of in-vehicle and navigational technology, and the changing of the driving environment. In addition, drivers' characteristics are also in constant change due to the overall change of demographic characteristics and lifestyles, e.g., with more females in driving professions, more older drivers, etc. Evaluation of the impact of those changes, and the suggesting of compatible measures for those in different scenarios/conditions in real-world, on-road settings is very challenging, resource intensive, and time consuming. Use of driving simulators has therefore become common as they provide an inherently safe environment which can easily be configured. Hence their popularity among transport researchers, academicians, and professionals.

Nowadays driving simulation is being used in diversified fields of transport research and applications such as the analysis of driver and user behavior, including the impact of individual driver attitudes, perceptions and psychological differences, impaired or distracted driving behavior (Linkov, Zaoral, Řezáč, & Pai, 2019; Saad, Abdel-Aty, & Lee, 2019; Wang, Cheng, Li, André, & Jiang, 2019) including the influence of alcohol, drugs, and fatigue on driving performance (Du, Zhao, Zhang, & Rong, 2016; Price, Lewis, Boissoneault, Frazier, & Nixon, 2018); the testing of in-vehicle technology including in-vehicle eco-driving devices (e.g. driving assistance), vehicle dynamics and layout (e.g. ABS testing, vehicle interior design), intelligent transport systems (e.g. in-vehicle navigation systems, active pedals) (Kummetha, Kondyli, & Schrock, 2020; McIlroy, Stanton, & Godwin, 2017); the investigation of innovative roadway design elements including new road system design (e.g. innovative highway, tunnel design, road and road side features, pavement marking effect, traffic signs), road side features, e.g.. billboards, trees (Calvi, 2015; Daniels, Vanrie, Dreesen, & Brijs, 2010; Mollu, Cornu, Brijs, Pirdavani, & Brijs, 2018); evaluating safety concepts and performance (e.g., the testing of different safety measures, safety performance of perpetual countermeasures, gap acceptance behavior, passing maneuver, crash avoidance study, surrogate safety measures) (Chen, Sze, & Bai, 2019; Hussain, Pirdavani, Ariën, Brijs, & Alhajyaseen, 2018; Kummetha, Kondyli, Chrysikou, & Schrock, 2020) .

Due to their many potential benefits and possible areas of application, many simulator labs have been developed in different renowned research institutes around the world; some prominent are: The U.S. National Advanced Driving Simulator (NADS), the University of Iowa's, USA; Southampton University Driving Simulator (SUDS), UK; Monash University Accident Research Centre (MUARC) driving simulator, Australia; VTI driving simulator, Sweden; Driving Simulator of the Flemish Automobile Association (VAB), Antwerp, Belgium; TNO driving simulator, Delft, Netherland; CRISS driving simulator, Roma Tre University, Italy; Fixed-driving simulator at the University of Central Florida (UCF), USA; University of Leeds Driving Simulator, UK; Qatar Transportation and Traffic Safety Center driving simulator, Qatar University, Qatar; The VERA dynamic driving simulator, TEST Road Safety Laboratory located, Naples, Italy; Advanced Driving Simulator at the Centre for Accident Research and Road Safety–Queensland (CARRS-Q), Queensland University of Technology (QUT), Australia; Tongji University driving simulator, Shanghai, China (250 degrees horizontal view, an eight degree-of- freedom motion system) etc.

The vast majority are in high-income countries. Consequently, almost all existing studies are based on those countries' driving and roadway environments. Roadway environments, diving behaviors, and traffic characteristics are completely different in low-income countries (Mahmud, Ferreira, Shamsul Hoque, & Tavassoli, 2020), a road crashes and injuries are also disproportionately higher in low-income countries despite having lower motorization rates (WHO, 2018). Therefore, it is imperative to develop driving simulator facilities in low-income countries in order to address and investigate diversified problems considering local roadway environments and driving characteristics in order to develop and evaluate suitable countermeasures applicable to those settings.

Recently, the Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) has established a high-fidelity driving simulator as part of a collaborative project entitled "Socio-Technical Approach to Road Safety (STARS)". The STARS project is a multi-national collaborative project funded by the UK's National Institute for Health Research that aims to improve road safety in the collaborative countries including Bangladesh. Out of many objectives set out for this project, one is to identify safety problems in some priority roadway sections or black spots, select countermeasures, and implement those treatment options in a simulated environment in order to evaluate their effectiveness. In this regard, two hazardous locations were identified considering two different traffic scenarios. One is a rural highway section including a hazardous intersection and other is in an urban traffic setting. The main thrust behind choosing these two intersections is that striking crashes have occurred at locations in the past. The following research question and hypotheses will be tested through a proposed experiment:

Research Question: How can safety best be improved through intervention at the selected locations?

Research Hypothesis:

- Design interventions will improve drivers' operational performance and make drivers more aware of other road users.
- Design intervention will reduce the probability of conflicts and improve safety.

This paper mainly deals with the experimental design, and the challenges therein. There are some major challenges primarily related to the development of local roadway and traffic environments, validating the simulator for the selected roadway environments in consideration of local traffic behavior and characteristics etc. This paper also draws attention to those challenges and opportunities in use of driving simulation for driving behavior and safety research in Bangladesh. It is expected that, in the long run it will open a new avenue to perform diversified stream of research and investigation considering our local problems since driving simulator provides an inherently safe environment with the facilities of changing roadway configuration by expending minimum resources.

2. EXPERIMENTAL DESIGN

2.1 Driving Simulator Setup

A fixed based, compact driving simulator has been installed in the traffic laboratory of Department of Civil Engineering at Bangladesh University of Engineering and Technology (BUET) (see Figure 1). This high-fidelity simulator consists of a locally fabricated personal computer based complete car driving station equipped with a Logitech Driving Force G29 Racing Wheel with responsive floor pedal unit, Logitech Driving Force Shifter providing transmission option of both automatic and manual (six speeds with push-down reverse gear), a surround-sound system for engine and environmental noise, three 31.5 inch IPS Technology monitors with WQHD (2560x1440) resolution, and 178° wide viewing angle (see Figure 1), and an adjustable real car seat. This simulator is integrated with steering wheels capable of 900° lock-to-lock rotation for realistic turn on the track, hall-effect steering sensor, dual-motor force feedback, and overheat safeguard; non-linear self-calibrating floor pedals with integrated throttle, brake, and clutch pedals; and gear shifter made of steel and leather components providing comfort and durability.

The simulation platform used in this driving simulator is the SCANeR™ studio software developed by A.V. Simulation. SCANeR™ studio is a comprehensive driving simulation software package used for vehicle ergonomics, advanced engineering studies, human factor studies, driver training, validate embedded road systems, and research related to road safety. SCANeR™ studio has an ergonomic interface used for either light or heavy vehicle simulation. This simulation software can be used to create road network terrains, build 3D vehicle models, develop traffic scenarios, simulate real-life driving environments, and analyze driving behavior based on various parameters with graphical representations.

Figure 1: a) The driving simulator platform at BUET (left);
b) The Experimental driving simulator with a predefined driving environment (right).

2.2 Selection of Study Area

As described earlier, two roadway sections were selected. One is a rural highway section including a hazardous intersection and other is an urban traffic setting. The rural highway section is the Uthali intersection and its approach roads in Dhaka-Aricha Highway, one of the major highway sections (National Highway 5) in Bangladesh. For the urban setting, Banani Overpass in Tongi Diversion Road, a section of a major primary road in Dhaka city, has been selected. Previous crash history, importance of the road in terms of traffic demand, socio-economic contribution and probable safety risks were considered for the selection of these two roadway locations.

2.3 Selection of Probable Countermeasures

Potential countermeasures were selected using Design with Intent (DwI) approach (Parnell et al., 2020). Several separate workshops were organized on the application of this method in designing countermeasures. A number of participants from various disciplines including road safety researchers, road safety practitioners, and university professors participated in each workshop. Some low-cost treatment options were selected on a priority basis considering resource and other limitations.

2.4 Scenario Development and Organization:

Two simulation environments (herein labeled ‘scenarios’) for each location will be created, one reflecting the existing condition and one with the incorporation of proposed improvement measures. For creating the natural environment in the simulator, still pictures and videos of the surroundings will be captured from the real field. These pictures will be rendered on 3D objects to be used while creating the scenario in SCANeR driving simulation software. Native vehicle models will also be developed to make the simulated environment as close to the reality as possible. In order to simulate the traffic settings of the selected spot, a observational study will be conducted at the real-world locations to gather traffic volume, speed and density. These data will be used to incorporate traffic settings in the simulated traffic scenario.

For the simulator experiment, four driving scenarios will be experienced by the participants; two of the existing, on-road reality (one each for urban and rural) and two with design changes incorporated (again, one each for urban and rural). Each participant will drive each scenario twice. Different participants will experience the scenarios in different orders, as shown Table 1. All participants will experience both urban and rural scenarios, with half of the participants driving in the urban settings first, the other half driving in the rural settings first. This arrangement is necessary in order to overcome practice and order effects (whereby participants simply become better at using the simulator with experience, regardless of the environment in which they are driving).

Table 1. Summary of order of presentation of the different driving scenarios.

	Order of scenario presentation				Proportion of participants experiencing this order
Urban setting	Existing	New	Existing	New	25%
	Existing	Existing	New	New	25%
	New	Existing	New	Existing	25%
	New	New	Existing	Existing	25%
Rural settings	Existing	New	Existing	New	25%
	Existing	Existing	New	New	25%
	New	Existing	New	Existing	25%
	New	New	Existing	Existing	25%

2.5 Selection of Driver

For driving in the simulated environment in order to evaluate the effectiveness of countermeasures, 40 drivers will be selected. To balance with the real drivers' characteristics driving on the existing roadway section, drivers will be selected from different age groups with different experience levels. Each driver will undertake two sessions of simulated driving: one for urban, one for rural. Drivers will be selected randomly. However, preference will be given to those drivers who have experienced driving in the selected roadway sections. Status of the driving license, experience and education level will also be considered in selection criteria.

2.6 Preliminary Training and Pilot Study

To acquaint participants with driving in the simulated environment as well as to inform them about the background of the study, a day long training session will be organized. This training session will also be helpful for the drivers to behave responsibly during driving for actual data collection. Overall procedure including data capture, export and analysis will be applied as a pilot study prior to the actual study involving different group of participants. Necessary adjustment and modification (if needed) will be made based on the experience of the training and pilot study. Participants will be fully informed. written consent will be taken. They will also complete a demographics questionnaire at the very outset.

2.7 Driving simulator and data extraction

In the study a driver will make four round trips in total. The first two round trips will be made in the rural settings while the other two trips will occur under the urban settings. Necessary data attributed in the form of different file types will be recorded and extracted for every single trip. On-road driving video file will also be recorded and extracted for those trips. To ensure normal driving behavior, drivers will be encouraged and advised to drive normally. Moreover, continuous motivation before and in-between trips will be given to drive in usual manner from the inception to completion of trips to ensure normal driving and the quality of data.

Normal physical and mental condition of the driver will be tested before entering simulator room through discussion and social interaction. A short interview will also be taken on some subjective questions prior and after the experiment to gather information particularly related to their experience, mental condition, workload etc. A list of potential dependent and independent variables is shown in Table 2.

Table 2: Potential dependent and independent variables

Dependent Variables (DV)	Independent Variables (IV)
• Average Speed • Speed standard deviation • Steering wheel position standard deviation • Lane position / Lateral displacement • Headway • Crashes / Conflicts • Speed limit exceedances • Workload	Primary: • Scenario experienced (urban, rural, existing, new) Secondary: • Driving experience • Education • Age • Gender • Income

2.8 Data Cleaning and Primary Analysis

Extracted data files will be transferred into conventional structured data format. Necessary data cleaning and data pre-processing will be made. Preliminary analysis will be made using basic statistics including descriptive statistics, significance test e.g., t-test, z-test, ANOVA to get some fundamental driving parameters such as average speed, lateral position, travel time, delay etc.

2.9 Conflict evaluation

Different type of conflicts and conflict severity will be defined using standard surrogate safety indicators e.g., Time to collision (TTC), Deceleration Rate to avoid conflict (DRAC), Headway (H) etc. Detailed conflict observation techniques can be seen in Johnsson, Laureshyn, and De Ceunynck (2018); (2018); Mahmud, Ferreira, Hoque, and Tavassoli (2017); Zheng, Ismail, and Meng (2014).

2.10 Performance Evaluation

Finally, the effectiveness of the treatments will be evaluated using comparative statistical analyses of the data arising from the existing-reality and new-design scenarios. Statistical significance of the differences in performance will be tested using tests such as ANOVA. Attempt will also be made to develop econometric model including regression model, i.e., linear regression model for speed behavior, count data model for crash or conflict probability to evaluate the factors affecting safety performance.

A summary of the entire experimental design process, from simulator development to data analysis; is illustrated in the Figure 2.

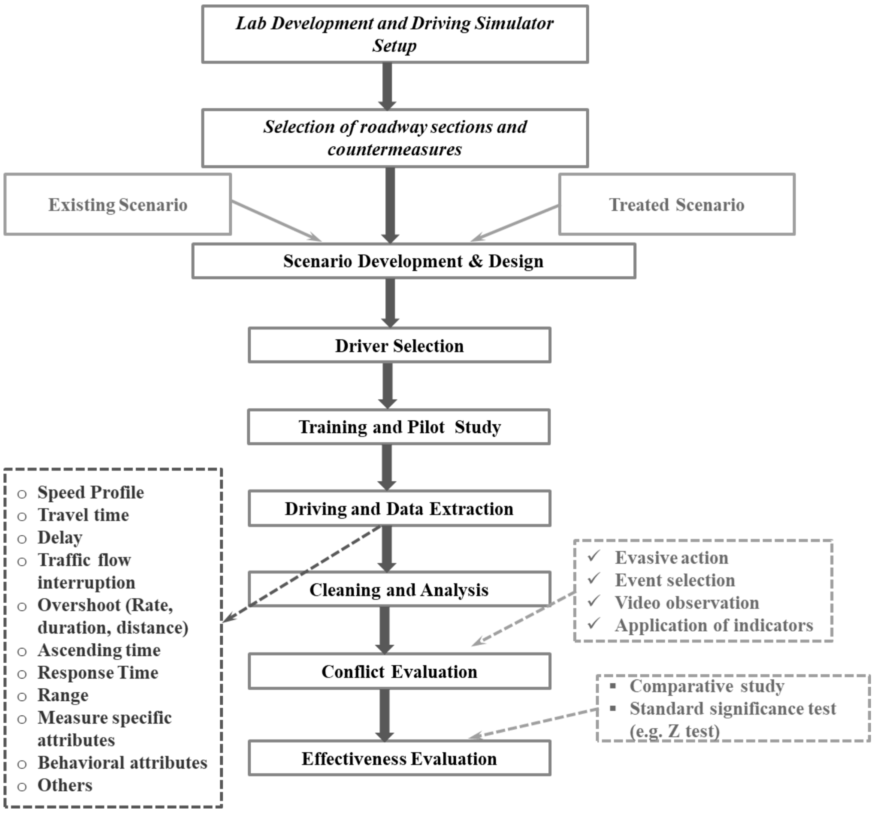

Figure 2: Overview of the experimental design process

3. CHALLENGES AND THE WAY FORWARD

3.1 Development of Driving Environment

To perform extended cutting-edge research using the newly established driving simulator at BUET, an extensive number of simulated driving environments incorporating local scenarios and peculiarities need to be developed. It is a challenging job particularly in low-income countries like Bangladesh as the roadway environment and traffic characteristics are significantly different to those of high-income countries. The level of difficulty associated with using the driving simulation software is high as it has been developed primarily based on the traffic environment of the high-income country in which the software was developed.

For carrying out diversified research works during and after the STARS project period, a representative number of roadway scenarios need to be developed for different types of roads including single lane, two-lane and multi-lane roads/streets under both urban and rural settings. Topographical, environmental, and geometric characteristics of roadways along with local vehicle types are needed to be simulated using customized tools for representing near to reality scenarios in virtual environment. Although challenging, development of a representative number of local scenarios for different roadway environments is highly important for effective research from different perspectives as well as for continued use of this facility after the end of the current project.

In the long term, the BUET simulation research team is planning to develop a 20km long roadway environment encompassing at least 15 scenarios under rural highway and urban arterial settings in Bangladesh. We believe that the development of this roadway environment will work as the foundation of our simulator-based research endeavor. We aim to create 3D models of existing elements along the road and roadside of the selected road segments; as well as to texture those 3D elements to incorporate in the driving simulator so that all the 3D elements along the road and its surroundings match with the existing, real-world condition.

3.2 Validation of Simulator

Without proper validation, the simulator cannot become a useful research and road design tool as without it, simulator experimental results cannot be compared with the real-world situations (Wynne, Beanland, & Salmon, 2019). Hence, validating the driving simulator in order to verify its usefulness is essential. In the future, the BUET simulation research team have the vision to convert the current simulator into an advanced driving simulator consisting of a fully instrumented vehicle (a typical car) with automatic transmission, a surround-sound system for the engine and environmental noise, and an eight degree-of-freedom motion platform system that can move and twist in three dimensions, and a high-fidelity visual system. The visual system will consist of five simulation projectors; the projectors will produce a view of horizontal 250 degrees and vertical 40 degrees. Wing mirrors and the rear-view mirror will be replaced by LCD monitors to simulate the side and rear-view high-frequency images.

Currently, the study will consider mainly behavioral validity i.e., relative and absolute validity in terms of the behaviour exhibited by drivers. For validation, the study will compare the real-world data and the simulated data under the selected roadway environment, and different performance measures will be tested. As it is always not necessary that all variable available in the driving simulator need to be identical with the real field observations, we do not need all variables to be validated to perform a particular task. Therefore, in some cases, task-specific validation will be conducted to check whether the simulator is sufficiently valid to complete this task or can be investigated using this simulator.

3.3 Research and Analysis:

Two research programs are planned within a year, one is complete validation of the developed environment as outlined in the previous section and other is the proposed treatment evaluation for two hazardous locations considering two different traffic scenarios i.e., urban and rural. However, it remains a big challenge to do in-house studies with human participants due to different unavoidable circumstances surrounding the COVID-19 pandemic. Nevertheless, the study has made a long-term plan to perform a diversified stream of research considering our local problems since the driving simulator provides an inherently safe environment with the facility of changing roadway configurations whilst expending minimum resources. Some of the targeted research plans are:

1. Driving behavior
   - ✓ Impact of individual driver attitudes, perceptions, gender, and psychological differences.
   - ✓ Influence of drugs, education and training, socio-economic status, and fatigue on driving performance.
   - ✓ Effect of mixed traffic under different percent and compositions, destruction due to sudden weather situations, use of mobile phones.
   - ✓ Impact of haphazard pedestrian movements, group walking and crossing.
2. Impact of roadway design and features
   - ✓ Evaluation of road and roadside features, pavement marking, traffic signs.
   - ✓ Impact of differences in the vehicle and on-road devices/features.
   - ✓ Performance of different types of speed-reducing devices.
3. Roadside treatment/features effect
   - ✓ Impact of roadside hazard, direct access and induced traffic impact.
   - ✓ Impact of different types of billboards, advertisement.
   - ✓ Impact of roadside features (e.g., trees, guardrails, barriers).
4. Efficacy of safety interventions
   - ✓ Evaluation of perceptual safety measures.
   - ✓ Safety impact of geometric configuration and features.

Finally, the proposed research is planning to develop and configure newly established driving simulator in Bangladesh with local roadway environment encompassing rural highway and urban arterial settings in Bangladesh, which will be compatible to our local non-lane based heterogeneous traffic operating condition. In the long run it will open a new avenue to perform diversified stream of research and investigation considering our local problems since driving simulator provides an inherently safe environment with the facilities of changing roadway configuration by expending minimum resources. Ultimately that will assist to achieve academic mote i.e., foster and promote world-class research and encourage innovations.

The future research directions also anticipate a snowball impact of the project, as the findings from the research reach out beyond the individual or host organization involved to influence research, policy and practice in the connected organizations, institutions, professionals and policy maker, thereby positively affecting road safety in Bangladesh and will contribute to achieve target proclaimed in the UN global road safety targets including SDG 3.6 and SDG 11.2 for Sustainable Development. The impacts are also expected to be longer-lasting (academic output) and widespread, as the findings will be relevant to other countries particularly in Low- and Middle-Income Countries (LMICs), too.

ACKNOWLEDGMENTS

This research was funded by the National Institute for Health Research (NIHR; 16/137/122) using UK aid from the UK Government to support global health research. The views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the UK Department of Health and Social Care.

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