International Journal of Occupational and Environmental Safety

Driving simulator for evaluating the effects of road geometric design on driver behavior: protocol of a systematic review

Mariane Paula Bobermin[a], Melissa Mariana Silva[b], Sara Ferreira[c], J. C. Guedes[d], J. Santos Baptista[e]

[a]Faculty of Engineering of University of Porto, Porto, PT (mariane.bobermin@fe.up.pt), [b]Faculty of Engineering of University of Porto, Porto, PT (up201202647@fe.up.pt), [c]Faculty of Engineering of University of Porto, Porto, PT (sara@fe.up.pt), ORCID: 0000-0002-8524-5503, [d]Associated Laboratory for Energy, Transports and Aeronautics (PROA/LAETA), Faculty of Engineering of University of Porto, Porto, PT (jccg@fe.up.pt), ORCID: 0000-0003-2367-2187, [e]Associated Laboratory for Energy, Transports and Aeronautics (PROA/LAETA), Faculty of Engineering of University of Porto, Porto, PT (jsbap@fe.up.pt) ORCID: 0000-0002-8524-5503

Article History

Received 31 May 2019
Accepted 25 May 2019
Published 30 June 2019

Keywords

Driving simulator
Road geometry
Road safety

DOI:
10.2480/2184-0954_003.002_0007

ISSN:
2184-0954

Type:
Protocol

Open Access
Peer Reviewed

Abstract

The traditional approach adopted towards road safety is the analysis of risk factors that contribute to frequency or severity of traffic crashes. Many distinct elements play a role, simultaneously, in a crash occurrence, and, undoubtedly, geometric design of highways and its effect on human behavior are part of that equation. A valuable tool to investigate this interaction is the driving simulator. Nevertheless, experiment design, participants' features, and data acquisition are detrimental factors for the effective use of this tool. This systematic review protocol is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) Statement and presents a method to find evidence on driving simulator studies of road geometry effects on drivers´ behavior.

1. INTRODUCTION

1.1. Rationale

A traditional approach in road safety is to identify risk factors that contribute to the frequency or severity of crashes (De Oña, López, Mujalli, & Calvo, 2013; Dingus et al., 2016; Gibson, Heaton, & Tass, 2018; Papadimitriou et al., 2019; Papadimitriou & Theofilatos, 2017; Zhang, Yau, & Chen, 2013). Many distinct agents play a role in crash occurrence and crash outcome, simultaneously. Commonly, they are divided into three main aspects: human, road environment and vehicle related causes.

Among the road environment causes, road geometric design deficiencies represent a risk for crash occurrence. In the analysis made within the Safety Cube Project there were identified 59 specific risk factors related to road environment that potentially play a role in accidents frequency and severity (Papadimitriou et al., 2019). Between them, low curve radius was considered the riskiest deficiency related to road alignment. Aspects of road design are also taken into account in the Infrastructure Risk Rating Manual for Australian Roads (Zia, Harris, Smith, & Anderson, 2019), specifically, lane and shoulder width and horizontal alignment (degrees of turn per km) increase road risk rate.

Understanding driver-roadway interaction can enhance road design strategies to create a safer environment for their users. With this purpose, a powerful tool to assess those two components is a driving simulator. This technique has the advantage of testing and comparing different existing or even new road configurations and how drivers perceive and react to them. It allows to manipulate confounding variables, reproduce repetitively identical situations for each participant, simulate hazards that rarely occur or risky situations, without engaging drivers in dangerous activities. Furthermore, since their early application in the 1960s, they have proved to be capable of addressing a wide range of research questions (Fisher, Rizzo, Caird, & Lee, 2011).

Nevertheless, despite driving is an ordinary daily task for many people, it is also the most complex one, involving perceptual, psychomotor and cognitive skills (Fisher et al., 2011). Experiment design, participants' enrolment, sample size, undertaking of the driving activity and data acquisition are detrimental factors for the effective use of this tool. Problems of inconsistency and inaccuracy can prevent that scientific literature meet all the needs of road safety research for evidence-base findings. In a research regarding driving simulator experiments on the effects of driver distraction, it was reported that the experiments vary considerably in terms of sample characteristics, design and analysis methods, exposing a lack of uniformity in the way they are conceived, conducted and exploited (Papantoniou, Papadimitriou, & Yannis, 2015).

Furthermore, Wynne, Beanland, & Salmon (2019) when analyzing driving simulator validity studies in a systematic review found no straightforward relationship between simulator fidelity and validity, which can raise the doubt if other elements, such as experiment procedure, could be influencing studies outcomes. They also highlighted the lack of detailing when studies reported the simulated driving environment, and the outcomes of statistical analyses.

Therefore, a systematic search of the literature will be undertaken to outline how studies are implementing this interdisciplinary research method regarding road geometry and driver behavior and what are the evidences related to road design effects and driver behavior in simulated environments.

1.2. Objectives

The objective of this research is the critical review of driving simulator studies on driver behavior affected by road geometry. A comparative and quality evaluation of the design and implementation of driving simulator experiments will be carried out for primary components – covering drivers´ characteristics and sample variability, experimental procedure protocols, studied road features and drivers´ behavior data. Furthermore, if the included studies are sufficiently homogenous, a quantitative synthesis will be performed to examine evidence regarding the relationship between a specific road geometry feature (radius of horizontal curves, lane width, shoulder width, among others) and driver performance measures (average speed, lane position variability, among others).

2. METHODS

2.1. Eligibility criteria

Studies that used a driving simulator to test driver's behavior that considered the influence of the road geometry characteristics will be contemplated.

Only studies available online and published in English will be included. Articles and Conference Papers will be admitted, allowing this review to access the most recent and relevant papers in this field.

Since driving simulation technology being used nowadays and the current process of carrying on this type of experience is also a relevant factor in this review, it will be included, in the initial search strategy, studies from 2014 to 2019, once the aim is to access how the recent studies have been performing these experiments. Nevertheless, it will be considerate a backward snowballing approach (Wohlin, 2014) when identified relevant studies for the objective of this review, so the period can be extended in this case.

Papers that do not have the influence of a geometric road element and its effects on human behavior as a main topic of the study will be excluded. Since road geometry is a broad subject, in this review studies that only focused on specific situations as intersections/junctions/roundabouts, u-turns, acceleration lanes, and auxiliary lanes will be excluded. Studies that only considered an urban environment will also be excluded, because traffic volume, presence of pedestrian, road environment (buildings/houses), road signage and density of intersections are too diverse from the studies that considered a rural environment, where, due to fewer variables, road geometry tend to have a more significant effect on driver´s behavior.

In addition, specific physical health conditions will be excluded such as drug usage, diseases or physical and cognitive conditions. However, fatigue a priori, will not be excluded, since it is a state that can be caused by driving activity itself.

2.2. Information sources

The main multidisciplinary and engineer-focused databases will be contemplated during the planned period of January 2019. Databases will be: ASCE Library, INSPEC, Safety Lit, Sage Journals, Science Direct, Scopus, Springer, Taylor & Francis, TRID - Transportation Research Board, Web of Science, and Wiley Online Library.

2.3. Search strategy

The search strategy will include the study population using terms and keywords derived from expertise of the reviewers in the subject field. Study population terms will include always “drive” or “driving” and “simulator” or “simulation”. Most of the articles will be filtered by the reviewers not by the keywords, since the aim is not to exclude papers that had studied geometric road features, but also considered other variables as well (for example, studies that included scenarios with and without guardrail barriers). Since road geometry is a broad subject, in the search strategy, studies that contained subjects as autonomous driving, in-vehicle or on-board devices, and medical perspective of drug usage, diseases, physical and cognitive conditions will be excluded. Search strategy for all databases with detailed search terms, linkage with logical operators and combined queries are described on Appendix A.

To complete the catalogue of studies, a snowballing process (Wohlin, 2014) will be undertaken to find relevant articles examining studies references exclusively related to the identified topic (geometric parameter) for a potential meta-analysis. Moreover, studies catalogue will be updated until conclusion of the systematic review considering the three identified databases with more studies elected.

2.4. Study records

Records will be managed through Mendeley, a specific software for managing bibliographies.

All the results from the search strategy will be reviewed and selected based on their title and abstract and duplicates will be removed. After that, studies will have their full text analyzed and will be selected for the data synthesis stage. This process will be guided by the eligibility criteria. The selection process will be carried out by two reviewers (MB/MS) independently, and a third reviewer (SF) will resolve in the case of disagreement.

The process of data extraction will be performed by two reviewers (MB/MS) searching for information sources independently. Each of the two review authors (MB/MS) will extract data on half of the studies, and check for accuracy on the other half. A third reviewer (SF) will independently check data for consistency and clarity.

The initial records identified for the first and second reviewer will be shared to confirm coding decisions for the worksheet created based on the review objectives. Once there is an agreement on the coding and variables to be searched from the initial studies, the rest of the studies will be coded without sharing between reviewers, unless it is identified a new situation, so the process will be restarted for that specific issue.

If the included studies are sufficiently homogenous regarding variables analyzed and outcomes measures and also were at least classified as “moderate” or “good” by the quality assessment tool, a quantitative analysis will be performed independently by one reviewer (MB) and a second reviewer (MS) will check for accuracy.

2.5. Data items

Beyond data related to the identification of the study (title, authors, year), data extracted will include information from the following summary: leading institution and country, description of the driving simulator, type of the road scenario (number of lanes, directions), number of scenarios, route length, number of drives per participant, ordering of scenarios/studied elements, presence or absence of a practice trial before the principal test, trial duration, break duration, final number of participants in the sample and their characteristics (sex; age mean, range, and standard deviation; social background), sampling method, requirements and justification for the sample, if participants were excluded and the motives and methods of exclusion, objective of the study, measures of outcomes, analyzed road geometry feature, main methods and results, limitations/biases stated and remarks for interesting information that the study might provide.

2.6. Outcomes and prioritisation

For the purpose of this review, the initial focus will be how driving simulator experiments about road geometry effects on driver behavior are being performed and their main findings. Characteristics of the equipment, protocols for experiments, participant´s enrollment process and their features, how the exclusion of participants was undertaken, etc. Furthermore, studies will be classified based on the experiment procedures quality mainly, however, aspects of the simulation equipment and statistical treatment of data will be considered as well (see 2.7).

Secondly, for each road geometry feature a summary of the main findings will be conveyed. Finally, the most frequently evaluated road geometry and parameter of driving behavior will be identified and if possible, a comparison of outcomes from different studies will be performed.

2.7. Risk of bias in individual studies

The quality of the studies will be independently assessed by one reviewer (MB) and a second reviewer (MS) will check for accuracy.

Quality assessment were based on NIH quality assessment tools (National Heart Lung and Blood Institute, 2019) for different types of studies. However, considering the expertise of the research group, a particularized tool (Table 1) to assess quality of the experiments will be applied.

Table 1. Quality assessment questions and possible answers

Simulation	1.1	Was driving simulator apparatus suitable for the research intent?	(Y/N/NR)
	1.2	Was a method of randomization or counterbalance of scenarios performed?	(Y/N/NR/NA)
	1.3	Was a method of randomization or counterbalance of geometries performed?	(Y/N/NR/NA)
Sample	2.1	Does the sample represent target population?	(Y/N)
Procedure	3.1	Was a practical trial performed?	(Y/NR)
	3.2	Was a method to assess driver´s familiarization with the simulator specified?	(Y/N/NR/NA)
	3.3	Was motion sickness assessed?	(Y/NR)
	3.4	Was there a clear description of the method to assess motion sickness?	(Y/N/NR/NA)
	3.5	Was the existence of outliers assessed?	(Y/NR)
	3.6	Was there a clear description of the method to assess outliers?	(Y/N/NR/NA)
Data analysis	4.1	Was a statistical method of analysis applied?	(Y/N)

Driving simulator apparatus will be considerate suitable for the research intent if the interest variables in the study match with the minimum simulator requirements considering the Degrees of Freedom (DOF) of the simulator motion system and the horizontal projected Field of View (hpFOV) (Table 2). Complex geometry is considerate analysis of the influence of transition curves in horizontal curves, vertical alignment (grade), super-elevation, among others. No consideration regarding the suitability of simulators for comparison of different scenarios will be made. Furthermore, since results will be presented exclusively regarding drivers´ performance (see 2.8) the high-level simulator requirement will be applied only if the study did not analysed performance aspects as well.

Table 2. Study´s analyzed variables and simulator minimum characteristics

Study evaluation	Minimum hpFOV	Minimum DOF
Physiological and Subjective (only)	180°	6
Performance and basic geometry	40°	0
Performance and complex geometry	120°	6

If more than one scenario is presented to drivers, and order effects could influence the result of the study, studies will be classified regarding order of scenarios. If order of geometry parameters in a scenario could affect results, they will also be classified accordingly.

Next stage contemplates participants' sample. Studies will be positively classified in this category if they state a target population and provide sample characteristics clear enough to be possible to confirm this.

Final stage assesses typical experimental procedures of driving simulator: if a practical trial was performed, if studies used a method to assure driver´s familiarization with the simulator, if motion sickness and presence of outliers was examined and the methods to do so. For sickness assessment, studies that reported cases of participant drop out will be positively classified in question 3.3, but negatively classified in question 3.4. If studies did not provide information about the existence of practical trial, motion sickness and outliers assessment (questions 3.1, 3.1 and 3.4) they will be marked as neutral (Not applicable) in questions 3.2, 3.4 and 3.6.

Possible answers to the questions are: Yes (Y), No (N), Not reported (NR) and Not applicable (NA). Studies will be classified as weak, moderate or strong based on their scores (Formula 1 and Table 3).

$$Score = \frac{\sum Y}{total\ number\ of\ questions - \sum NA} \quad (1)$$

Table 3. Classification of studies based on their scores

Classification	Score
weak	0|---0.4
moderate	0.4|---0.7
strong	0.7|---|1

2.8. Data synthesis

Data synthesis will be presented as a narrative assessment of the evidence of the effects of road geometry on driver´s behavior divided by type of geometric feature analyzed. If there is not a clear division of each geometric feature influence, results will be combined in a more general division, such as horizontal alignment or vertical alignment.

Outcomes will be reported only regarding driving performance (actions). Hence, outcome from studies that focused only on physiological or subjective measures will not be synthesized, since the interest is to assess how road geometry conditions drivers´ actions. High rated studies, based on the quality assessment tool, will be presented first.

In the possible identification of sufficient homogeneous studies evaluating the same specific road geometry (for example, curve radius, lane width, shoulder width, grade, among others) and outcome (for instance, average speed or average lateral position, among others), a meta-analysis will be performed. We anticipate that the heterogeneity of outcome measures will allow only an exploratory analysis with a possible comparison between studies results.

3. REGISTRATION

Important protocol amendments post registration will be recorded and included in dissemination.

4. CONTRIBUTIONS

Mariane Bobermin (MB) is the research leading protocol development and analyses. Mariane Bobermin and Melissa Silva (MS) are first and second reviewers. Sara Ferreira (SF) is third reviewer. All three authors will contribute to data interpretation and article drafts. Joana Cardoso Guedes (JCG) and João Santos Baptista (JSB) will support the systematic review methodology application.

Acknowledgements

The authors would like to thank laboratory colleagues from the research center of the Faculty of Engineering of the University of Porto that helped with their expertise throughout the process.

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