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ORIGINAL ARTICLE

RESEARCH DESIGN FOR INVESTIGATING TRUCK DRIVERS' RISK BEHAVIOR IN A SIMULATED ROAD TRAFFIC ENVIRONMENT: INSIGHTS FROM A CAR DRIVING SIMULATOR STUDY

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Abstract: Considering the statistics of road accidents worldwide, the study of drivers' risk behavior is important from both a road safety and public health perspective. The aim of this paper is to present a research design to investigate truck drivers' risky behavior on the road in a simulated traffic environment, based on our experience with a car driving simulator study.. The proposed research scheme was tested in a pilot study involving 30 professional male truck drivers (aged 30-62 years, M = 41.67; SD = 7.8) recruited using a convenience sampling method from various transport companies. The truck simulator, owned by the Military Institute of Aviation Medicine (WIML), was used in the study. The paper describes the procedure of the study, including the principles of designing driving scenarios, as well as the method of acquiring data from the simulator and preparing it for further statistical analysis and substantive interpretation of the results. The study of risky driving behavior, according to the research design adopted, has revealed the main challenges of using a virtual environment to simulate different driving events and make assessments of drivers' behavior in response to given stimuli. Therefore, the paper discusses the key issues related to conducting studies on drivers' risk behavior using a virtual environment and also includes some suggestions on research design to take into consideration.

Keywords: risky behavior, truck drivers, car simulator, driving scenarios, road traffic, virtual environment

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INTRODUCTION

Road traffic accidents are one of the leading causes of death worldwide in all age groups [13]; hence, it is undeniably important to conduct research on various aspects related to road safety. The importance of carrying out studies in this area is evidenced, though, by accident statistics, which are difficult to argue with. For example, according to estimates by the World Health Organization [13], there were 1,190,000 road fatalities worldwide in 2021. The WHO also reports that 144,090 road traffic deaths occurred in the Americas, and 62,670 in Europe, representing 12% and 5% of the worldwide burden, respectively [13]. Moreover, the report of the General Directorate of National Roads and Motorways on the state of road traffic safety for national roads for the year 2023 [7] indicates that 546 people were killed and 4423 injured in 3396 road accidents in Poland. At the same time, it should be noted that people injured in accidents represent a serious problem for the public health care system.

Considering the above, it should be pointed out that one of the causes of accidents on the roads, and thus loss of health and life and disability of millions of people worldwide, is the risky behavior that drivers engage in while driving [2,4,9]. Therefore, the study of drivers' risk behavior on the road is an issue that is not only of cognitive interest but also vitally important from both a road safety and public health perspective.

Nevertheless, investigating risky behavior that drivers engage in behind the wheel is, for various reasons, not a simple matter. The willingness to assess risky driving behavior is problematic mainly for safety reasons. Standardizing the conditions for the study of risky driving behavior and, at the same time, ensuring the safety of all road users is not really possible in real-life driving situations. Hence, a solution may be to conduct research under simulated traffic conditions using modern driving simulators. And although there are some disadvantages of such devices (e.g., a risk of simulator sickness; a limited level of environmental realism, etc.), it is indisputable that this type of equipment offers the opportunity to conduct research under conditions that are fully safe and controlled by the researchers, and hence the application's field for driving simulators is wide and diversified [12,16].

The use of a driving simulator in driver research provides the opportunity to model, repeat, and analyze various experimental situations on the road, including dangerous situations such as mobile phone distraction [e.g., 6,11] or alcohol-impaired driving [e.g., 14,15], without exposing drivers to any serious risks [1,8,10]. Simulators are often used by researchers in experimental studies, for driver training, and in the automobile design and research industry, because they are environmentally friendly, meaning that they do not generate additional pollution, and they offer a cost-effective method of collecting data in a fully controlled environment [11].

Considering the above, the aim of this paper is to present a research design for investigating drivers' risk behavior in a simulated road traffic environment, based on our own experiences from a car driving simulator study. The results of the study itself devoted to risky behaviors undertaken by truck drivers behind the wheel and their determinants will be presented in separate papers.

GENERAL STUDY DESIGN

A car simulator, owned by the Military Institute of Aviation Medicine (WIML), was used to study driver risk behavior. The simulator is a stationary device that replicates the operation of a truck. It is equipped with a six-degree-of-freedom motion system and systems for simulating different driving situations and driving under varying environmental conditions. A detailed description of the simulator's technical parameters and testing capabilities is presented in a separate paper [3]. A view of the simulator cabin and instructor seat is shown in Fig. 1.

In the study we carried out on a group of 30 professional truck drivers, the pilot investigation was designed to test the proposed research scheme. Participants were recruited individually using a convenience sampling method from various transport companies. The inclusion criteria comprised holding an active category C driving license and daily driving practice. All participants were male volunteers (aged 30-62 years, M = 41.67; SD = 7.8) with an average driving experience of 13.3 years (SD = 8.33). The study followed the Declaration of Helsinki ethical guidelines, and written informed consent was obtained from all participants after they were thoroughly informed about the study's purpose, procedures, and potential risk of simulator sickness symptoms. Drivers were instructed to participate in the study well-rested and healthy and to avoid alcohol and stimulants the day before testing. The study protocol was approved in advance by the relevant Institute's authorities.

The comprehensive research design included, beyond the simulator driving task, a battery of measures: (1) computerized tests from the

Fig. 1. Truck simulator at the Military Institute of Aviation Medicine (WIML).

Vienna Test System (VTS) assessing cognitive and psychomotor performance as well as tendencies toward risky traffic behaviors; (2) self-report questionnaires evaluating selected personality traits, risk-taking tendencies on the road, and risk perception; and (3) a demographic questionnaire collecting basic sociodemographic data and information about traffic violation history (i.e., penalty points, collisions, accidents, traffic tickets, radar detections, license suspensions, and driving under the influence of alcohol). These variables will enable further analyses concerning both the selection of optimal risky driving indicators from the simulator task and the relationships between simulator performance and other measured variables.

Based on experiences from this pilot study, we recommend that future full-scale investigations pay particular attention to sample representativeness, ensuring adequate diversity in terms of age, driving experience, and potentially other demographic characteristics relevant to the research objectives.

Nevertheless, the aim of the study was, among other things, to confront self-descriptive methods regarding driving behavior on the road [5] with the actual behavior and decisions made by drivers in specific traffic situations. For this reason, the research design and procedure using the simulator were intended to allow unsafe behavior to emerge in risk-prone drivers. Therefore, the drivers performed, according to the test scheme with repeated measurements, 2 standardized driving scenarios, i.e., an experimental scenario, a specific one to assess risk behavior and consisting of several events and situations on the road in which the driver could take risks or be cautious, and a control one, identical to the experimental scenario in terms of conditions and the route taken, but without "decision situations" to take risks. The scenarios were carried out in alternating order, i.e., half of the test drivers took the experimental run first and then the control one, while the other half of the drivers did the opposite, with the control scenario first and then the experimental one, in order to minimize the possible influence of the test order on the results obtained. In the instructions for the simulator tests, drivers were asked to imagine that they were participating in real traffic and to try to drive in the way they would drive every day. In addition, prior to the actual tests, the drivers performed a short test run of about 2-3 minutes, which was not subject to evaluation and was only used to familiarize themselves with the use of the truck simulator.

SIMULATED DRIVING SCENARIOS

The development of appropriate experimental scenarios to evaluate specific driver behavior and responses to stimuli that occur in road traffic is crucial in the process of designing research using a virtual environment. Simultaneously, given the complexity of the traffic environment and the heterogeneity of driver behavior, it is challenging to try to replicate real-life traffic situations in scenarios created for experimental purposes. All in all, following the efforts made, the solution that was adopted and that worked well in the truck driver research is presented below.

In our study, the experimental run, i.e., the actual driving scenario, was used to assess risky behavior and consisted of 12 specific road traffic cases in which drivers, depending on their individual characteristics and decisions made, may have reacted and behaved in a manner appropriate to themselves, i.e., by being more adventurous and risky or by adopting a greater dose of caution. The duration of the experimental drive averaged about 15 minutes. Road and weather conditions were good, i.e., drivers drove in conditions without any precipitation and with good visibility. Difficulties in the form of bad weather conditions or terrain-related difficulties were deliberately not introduced into the scenarios, so that the drivers' driving behavior resulted more from their individual decisions and characteristics rather than being forced by independent external circumstances.

There were 12 "decision situations" in the experimental scenario, which involved the following:

- a drunk person moving by the side of the road (2 situations in the scenario),
- a driver's reaction to a "stop" sign placed by the roadside (2 situations in the scenario),
- driving through a railway crossing,
- children moving by the side of the road,
- a person walking towards a pedestrian crossing,
- an attempt by a lorry to join traffic from a sub-road and the potential risk of forcing a priority crossing,
- the movement of a dog and a deer close to the edge of the road (2 separate situations),
- driving past a road accident,
- driving in conditions of reduced visibility due to significant smoke in the area.

The control scenario used in the study was identical in terms of the route taken and road conditions to the experimental one, but was a standard run without "decision situations" to take risks. The duration of the control scenario also averaged about 15 minutes.

Examples of driving scenario views are shown in Fig. 2-4.

(a)

(b)

Fig. 2. Experimental scenario (a) and control one (b) with children moving by the side of the road.

(a)

(b)

Fig. 3. Experimental scenario (a) and control one (b) in a situation of potential risk of forcing priority by a lorry leaving a sub-roadway.

(a)

(b)

Fig. 4. Experimental scenario (a) and control one (b) in a situation of severe roadway smoke.

METHOD FOR ASSESSING DRIVERS' RISK BEHAVIOR IN SIMULATED DRIVING SCENARIOS

Due to the lack of ready-made and universal solutions, a method for assessing driver behavior in the simulated driving scenarios also had to be developed for the study. In order to assess drivers' risk behavior under simulated road traffic conditions, both qualitative and quantitative indicators of driving in the experimental scenario were analyzed.

Regarding the qualitative assessment of drivers' runs in simulated road traffic conditions, the experimental scenario was evaluated on an ongoing basis by the researchers using the "decision situations" evaluation sheet included in the driving scenario, specially constructed for the study. Each of the 12 "decision situations" was evaluated in relation to the following parameters: increasing speed, decreasing speed, stopping, passing, use of the horn, and no reaction. Each of these parameters was rated on a YES or NO scale depending on whether it occurred or not. In the "Other" section of the questionnaire, the researchers had the option of noting other than the above-mentioned reactions of drivers to individual events in the scenario. Furthermore, the qualitative assessment of events in the driving scenario was supported by a quantitative assessment, made possible by an analytical tool developed and described in detail in the following section.

ANALYTICAL TOOL FOR PROCESSING AND AGGREGATING THE TRUCK SIMULATOR'S DATA

A major challenge in designing and conducting research in a simulated traffic environment proved to be the acquisition of data from the simulator and its proper preparation for conducting further analysis. Hence, an analytical tool was developed in the R computing environment for pre-processing and aggregating data from the truck simulator. This tool has the form of a set of R-language scripts.

The aforementioned scripts integrate data from three sources, which are the test identification files, driving parameters, and the environmental object register, extracting key driving parameters and interaction characteristics with objects in the vehicle surroundings. The analysis of the driving parameter files involved searching for measurement ranges to be analyzed in detail, using auxiliary objects placed in the driving scenarios (i.e., markers), and then calculating selected statistical driving parameters within these ranges. What should be noted, however, is that the precise timing of the scenarios, due to different driving speeds and maneuvers, may have varied between drivers. Hence, the placement of markers along the driving route made it possible to overcome these differences regarding the speed of performing the scenarios and, therefore, encountering certain on-road situations. The start and end of the measurement ranges were determined from the time at which the truck was closest (respectively) to the start and end markers.

The measurement ranges included all events planned in the experimental scenario to which drivers were expected to react in their own appropriate way, i.e., the 12 "decision situations". In the control scenario, the measurement ranges determined were the same as those in the experimental one. Figure 5 shows the route taken by the truck along with the measurement ranges determined in the experimental scenario.

The driving parameters determined in the measurement ranges included the following:

- duration of ranges,
- speed at the beginning of the measurement range,
- speed at the end of the measuring range,
- minimum speed in the measuring range,
- maximum speed in the measuring range,
- average speed in the measuring range.

To evaluate risky behaviors of truck drivers undertaken behind the wheel, quantitative indicators of risky driving were compared between the experimental scenario and the control one. In addition, the iteration over successive measurement ranges was combined with an analysis of the file with a record of the parameters of the simulation objects closest to the truck model in order to find the closest object relevant to the test scenario in a given measurement range and determine the parameters of this object, as well as the parameters of the truck model at the time when the distance to the selected object was the smallest. Among the most relevant values determined in the way described above were:

- selected parameter measurement time,
- distance to the selected object,
- angle of the object relative to the cab,
- vehicle speed.

The distance of the driver's truck from key objects in the experimental scenario, such as pedestrians or animals moving along the roadside and close to the edge of the road, was determined as described above. Moreover, the other analytical tool scripts used in the study were those that

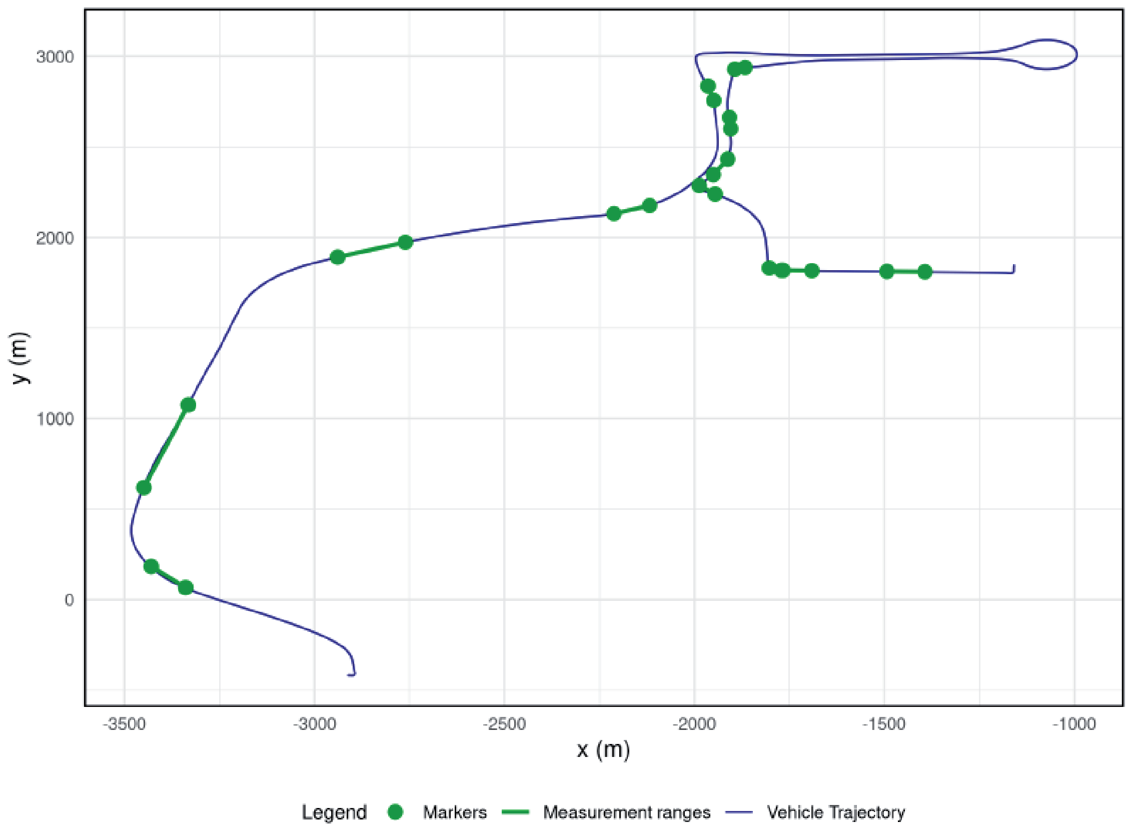

Fig. 5. Truck route with defined measurement ranges related to the 12 "decision situations" in the experimental scenario.

convert the records that the simulator generates into the commonly used .csv (comma-separated values) data sheet format.

All in all, the data obtained and prepared by means of a developed analytical tool formed the basis for further statistical analyses and factual interpretations of drivers' risky behaviors while driving under simulated traffic conditions, according to the purpose of the research conducted. The results of the analyses carried out on those data will be presented in separate papers.

CONCLUSION

The paper presents a research design for investigating truck drivers' risk behavior in road traffic, with regard to the experiences from a car driving simulator study carried out at the Military Institute of Aviation Medicine. The proposed methodology was validated through a pilot study with 30 professional drivers, confirming its feasibility for assessing risky driving behaviors in controlled conditions.

The research conducted has provided, above all, additional insight into the investigation of drivers' risk behavior when driving under simulated traffic conditions. Alongside, the research itself revealed some challenges in designing driver studies using virtual environments. From the other side, naturally, there were certain difficulties that occurred during the research and planning stages of the study that may have been due to the specifics of the car simulator itself used in this particular case, including its software and instrumentation. Nevertheless, there are several issues that would need to be addressed and that would require more scrutiny when designing a study such as the one described in this paper to obtain reliable and standardized measurements of drivers' risky behaviors in simulated road traffic conditions.

Primarily, it seems important to carefully develop and standardize driving scenarios that will effectively capture and reflect specific events in road traffic. For this purpose, firstly, the start and end points of measurement ranges should be precisely defined, which will ensure both a non-delayed estimation of drivers' reactions to different traffic situations and a consistent assessment of all participants, taking into account both quantitative and qualitative risky driving indicators. For the correct estimation of quantitative indicators of risky driving, such as average speed under simulated various road situations, the precise determination of measurement ranges in experimental scenarios is crucial. Moreover, it is important to make sure that risk indicators can be reliably measured within the technical capabilities of the study's simulator. And finally, it is also necessary to verify whether the selected parameters can be standardized across all test runs, taking into account the limitations of the simulator software, particularly in terms of random traffic generation and other vehicles' behavior. As an example, when selecting indicators such as inter-vehicle distance, it is necessary to assess beforehand whether it is possible to reliably standardize them in the context of the simulator's traffic generation patterns.

Furthermore, when planning full-scale studies, careful attention should be paid to sample selection criteria and recruitment strategies to ensure adequate representativeness of the target population, considering factors such as age distribution, driving experience, and exposure to various traffic conditions.

In conclusion, the research design proposed in this particular pilot study proved useful for assessing the risk behavior of truck drivers in road traffic. However, when designing and conducting experiments using virtual environments, it is important to bear in mind both the great research potential of this tool and the challenges that come with using car simulators to assess risky and dangerous driving behavior in a reliable and standardized manner.

AUTHORS' DECLARATION

Study Design: Paulina Baran, Piotr Zieliński, Mariusz Krej, Marcin Piotrowski, Łukasz Dziuda. **Data Collection:** Paulina Baran, Mariusz Krej, Marcin Piotrowski. **Manuscript Preparation:** Paulina Baran, Piotr Zieliński, Mariusz Krej, Marcin Piotrowski, Łukasz Dziuda. The Authors declare that there is no conflict of interest.

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