Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Accelerating Insight: A Thorough Systematic Review on Driving Simulators and Their Transformative Effect on Driver Behaviour

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ARTICLE INFO

Article history:
Received 21 January 2025
Received in revised form 7 March 2025
Accepted 15 July 2025
Available online 28 July 2025

Keywords:
Behaviour; driving simulator; simulator fidelity

ABSTRACT

Driving simulators have emerged as a valuable tool for evaluating driver behaviour and performance in various scenarios, offering a controlled and safe environment for testing and research. In this paper, a systematic review following a Prisma guideline to assess the effectiveness of driving simulators across a range of scenarios and examine their potential applications in enhancing road safety and driver training. The review incorporates studies published between 2019 and 2023 that investigated driving simulator effectiveness. A comprehensive search was conducted across major scientific databases, resulting in a final selection of 39 relevant articles. These studies encompassed diverse scenarios, including urban driving, highway driving, adverse weather conditions, distracted driving and impaired driving, among others. Several studies have reported positive effects on driver skills, knowledge acquisition and hazard perception after simulator-based training interventions. Furthermore, simulator-based assessments and training have the potential to address specific populations, such as older drivers or individuals with certain medical conditions, by tailoring scenarios to their unique needs. However, some limitations were identified within the reviewed studies, including limited sample sizes, variations in simulator fidelity and software and potential discrepancies between simulator and real-world driving experiences.

1. Introduction

Driving simulators nowadays are often used by researchers around the world. Numerous fascinating discoveries and study findings were achieved from driving simulators because of their sophistication and capacity for creating various series of complex scenarios. For instance, circumstances involving lane changing, passing vehicles, crossing streets, braking and many more can be measured by this advanced technology. Hence, there is a big challenge that is proposed to every researcher is the choice of how and when to use driving simulator to maximize education

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https://doi.org/10.37934/ard.140.1.3955

productivity. This choice implies a selection of simulation realism and its trade off with the simulator cost [1].

Simulator studies have proven to be a reliable and valid tool which integrates perceptual input, cognitive processing and behavioural output [2]. This study has determined four situations that are very significant and are always studied using driving simulators. These situations are braking, crossing situations, lane changing and takeover situations. This will focus on which situations are most effectively studied in a driving simulator. However, the fidelity and validity of the simulators are crucial to characterise the simulator quality. There is an observable relationship between these two metrics, seeing as high-fidelity simulators provide a more realistic driving environment and resulted in a higher validity of obtained results when compared to low fidelity driving simulators, which have a lower data validity. The level of realism represented in the simulation is frequently used to define fidelity.

It has been revealed that the greater the fidelity of a simulator, the closer it approximates the real world in terms of control design and layout, the realism of the shown scene and so on. In addition, high fidelity is frequently related to high driving simulator costs; particularly for human factors research, driving simulator costs are commonly very high [3]. Validity typically refers to the degree to which behaviour in a simulator corresponds to behaviour in real-world environments under the same circumstances and it may be directly impacted by the level of fidelity, as previously stated. Therefore, it is very important to undertake a validation study for any new driving simulator to ensure that it measures what it is supposed to measure and does not lead to false conclusions regarding the objectives of the study [2].

The validity of the results is heavily contingent on the fidelity of the simulator. Although this seems intuitive, importantly, the relationship between simulator fidelity and validity is not straightforward, with some low-fidelity simulators demonstrating acceptable validity on some measures and some high-fidelity simulators appearing to be invalid on other measures. Thus, researchers need to carefully select appropriate simulator characteristics for the specific research design and aims [4]. Therefore, a systematic review of the literature was performed to analyse the relationship between driving simulator scenarios and driver behaviour, evaluating the impact of different simulation levels and identifying optimal combinations of scenarios and simulator fidelity that yield the most favourable outcomes.

1.1 Evolution of Driving Simulators

There are countless driving simulators available today and they are constantly evolving. Driving simulators are now used not only in research studies, but also in the various stages of in-vehicle system design, development and validation, as well as in the design of infrastructure elements [44]. The older models have been constantly improved to replicate real-world driving conditions as accurately as possible [5]. These advancements are primarily due to rapid technological improvements and feedback from users, but they are also due to scientific data on the psychology and psychophysiology of perception. Therefore, driving simulators are considered useful to explore driving-related high-level tasks that would pose a high risk of collision to the driver if encountered in a real environment [6].

The virtual driving simulator environment mostly consists of static universe, dynamic objects and interior of the driver vehicle. The static universe can be buildings, trees, roads and others. While dynamic objects can include any moving objects in a virtual scene like cars, people and crowds. With more complex virtual scene will contain many thousands of polygons which need more graphic processing power and more computation cost to render the scene. Physical equipment has also seen significant improvements. Experiment design, participant enrolment, sample size, driving activity and data acquisition are all detrimental to the effective use of this tool in the context of driving simulator studies [7]. Participants in the most basic simulator configurations sit in a single chair and use a limited movement steering wheel or joystick, but simulators that incorporate a full or partial vehicle body and motion platform are becoming more common [4].

In summary, technological advancements have resulted in simulators that more closely resemble real driving in terms of vehicle controls and visual environment. Even though level of realism is thought to be important in validity, there has been little empirical research that directly tests how much it makes a difference.

1.2 Simulator Fidelity

In this study, the simulator fidelity framework proposed by Wynne *et al.,* [4] is adopted to systematically assess the realism of driving simulators across three key dimensions. The first dimension, Visualization System Characteristics, is defined by the configuration of the visual display system, including whether single or multiple monitors or projectors are used. The field of view (FoV) is also considered and categorized into ranges such as less than 180°, between 180° and 270° and greater than 270°, as broader FOVs are generally associated with enhanced immersion. The second dimension, Motion Base Properties, is characterized by the presence and the degrees of freedom (DoF) of the motion platform. Higher DOF configurations allow real-world vehicle dynamics to be more accurately replicated, thereby increasing motion fidelity. The third dimension, Physical Realism, is determined by the extent to which the simulator physically resembles an actual vehicle environment, ranging from a basic desk setup to a fully immersive vehicular cabin. The level of physical realism is considered important, as it can influence user behaviour and perceived immersion. Through these dimensions, a structured and comprehensive evaluation of simulator fidelity is enabled, ensuring the reliability and applicability of simulation-based research findings [4].

1.3 Objectives

The primary objective of this systematic review is to critically evaluate and consolidate empirical findings from individual and group studies that investigate the use of driving simulators in the assessment of driver behaviour. By synthesizing current evidence, this review aims to enhance the accessibility, transparency and validity of research outcomes within this domain. Secondary objectives are structured to support this aim through two focused analyses. First, an inventory of real-world driving scenarios simulated in experimental studies is compiled and categorized. These scenarios encompass a range of driving tasks, including lane changing, overtaking, braking and collision-related events involving pedestrians, oncoming vehicles, or stationary obstacles. Second, the scope and variability of measurement parameters employed across comparative studies are examined. This includes demographic variables such as driver age (e.g., young versus middle-aged), experience level (e.g., novice versus experienced drivers), study publication window (limited to the period between 2019 and 2023), and research themes focused on risk-related driving behaviour. Through these objectives, the review provides a structured and comprehensive understanding of the methodologies and behavioural constructs that characterize simulator-based driving research.

2. Methodology
2.1 Strategy for Reviewing Literature

In this paper, the method of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is considered and implemented in choosing and screening the articles available online regarding the required research topic [8]. The PRISMA is an evidence-based minimum set of reporting articles in systematic reviews and meta-analyses. This method provides a detailed guideline on the conducting process, as well as a set of items for improving quality in systematic reviews and meta-analysis [7]. Transparent and complete reporting is an essential component of “good research”; it allows readers to judge key issues regarding the conduct of research and its trustworthiness and is also critical to establish a study’s replicability [9]. Two electronic databases (Science Direct and Scopus) were searched to identify studies of the last 4 years that examines how driving simulator scenarios and different simulation levels influence driver behaviour.

2.2 Inclusion Criteria and Selection

Some criteria are listed as a guideline for choosing and evaluating a good article. This method ensures that only the corresponding article will be considered. Although there are enormous articles available online in many publications and search engine (i.e., Google Scholar), where most of them might contains the required keyword or criteria, there are some criteria need to be excluded in ensuring that this review will be accurate and consistence with the assigned objective. Hence, the article must contain all the items addressed below:

i. <u>Inclusion Criteria:</u>
- Study based on driving simulator or test track
- Young/middle-aged driver
- Novice driver
- Involves collision with obstacle (pedestrian, incoming vehicle, static subject)
- Road condition (bad-traffic, curve road)
- Article published within 2019 - 2023
- Driver/driving behaviour, driver risk field
- Collision avoidance

ii. <u>Exclusion criteria:</u>
- Naturalistic, on-road/actual road condition study
- Specific population area (German, China, Europe)
- Old-aged driver (>50 years)
- Vehicle other than car (truck, bus, motorcycle, bicycle)
- Taxi or e-hailing driver
- Experiment area range: anything with mention range except Malaysia

After the evaluation of the criteria is made based on the title reading done roughly by the observer, there are still a huge number of remaining articles, thus, it needs to be filtered according to the specific topics as listed below:

Type of filter used to choose article:

i. Accident Analysis & Prevention
ii. Transportation Research Procedia
iii. Transportation Research Part B: Methodological
iv. Transportation Research Part C: Emerging Technologies
v. Transportation Research Part F: Traffic Psychology and Behaviour
vi. IEEE Transactions on Intelligent Transportation System

2.3 Article Source

i. Science Direct
ii. Scopus

2.4 Resources of Information

Two electronic databases, ScienceDirect and Scopus, were systematically searched to identify relevant literature. This approach enabled a comprehensive review of peer-reviewed publications indexed in both databases. The search process was conducted between January 2023 and August 2023, and included studies published up to January 2023.

2.5 Research Approach and Study Selection

Focusing on an initial literature search, Boolean search terms were developed to retrieve all relating derivations of the base term:

i. TITLE-ABS-KEY (driving) AND (simulat* OR behaviour)
ii. TITLE-ABS-KEY (driving) AND (simulat* OR behaviour) AND (road OR test track)

3. Results

3.1 Reviewed Studies

Between 2019 and 2023, a cumulative total of 96,403 study records were initially identified in the database search using the PRISMA methodology, as illustrated in the figure below. All items were originally published in the English language. The database search yielded items that met the inclusion criteria, including articles, papers or reports. The number of articles narrowed down based on relevant topics amounted to 3,290. Among the 2,150 articles reviewed at the title level, 219 redundant articles were eliminated, resulting in 1,726 remaining research articles. These articles underwent further screening for full-text availability, which subsequently reduced the count from 1,541 to relevant articles. The abstracts of these 1,541 articles were carefully examined, leading to the exclusion of 121 research records. Consequently, after a thorough assessment of inclusion and exclusion criteria, a total of 39 full-length research articles were deemed suitable for consideration.

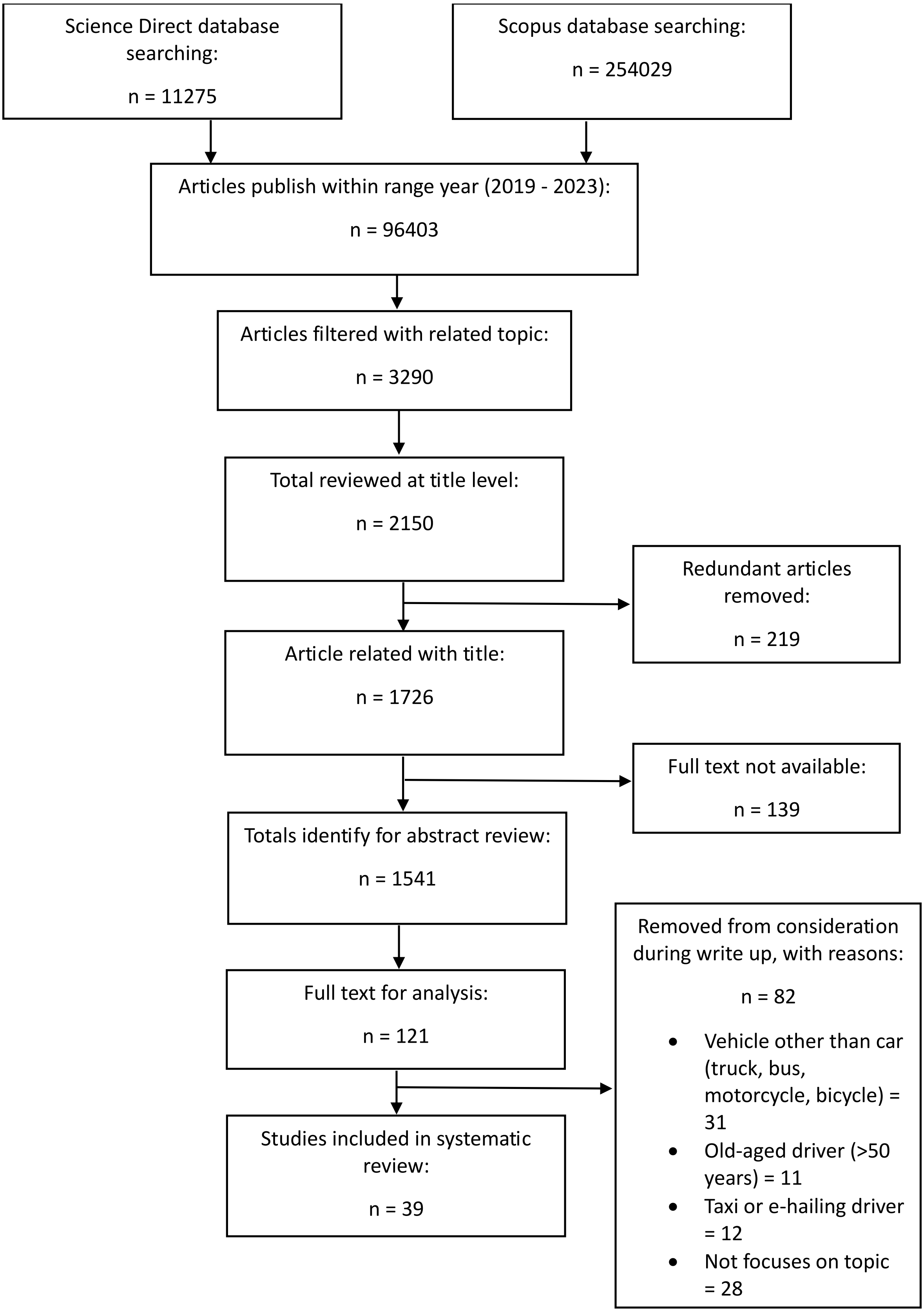

Fig. 1. The systematic review's selection, screening and inclusion procedure for appropriate studies

3.2 Synthesis of Review Articles and Meta-Analysis

3.2.1 Sample size study

Three studies encompassed a sample size ranging from 10 to 20 participants, indicative of a deliberate focus on specific research inquiries that necessitated a relatively smaller sample [10-12]. In contrast, there were five studies with participant counts between 21 and 30, implying an interest in augmenting statistical power and obtaining a more diverse representation of the target population [13-17].

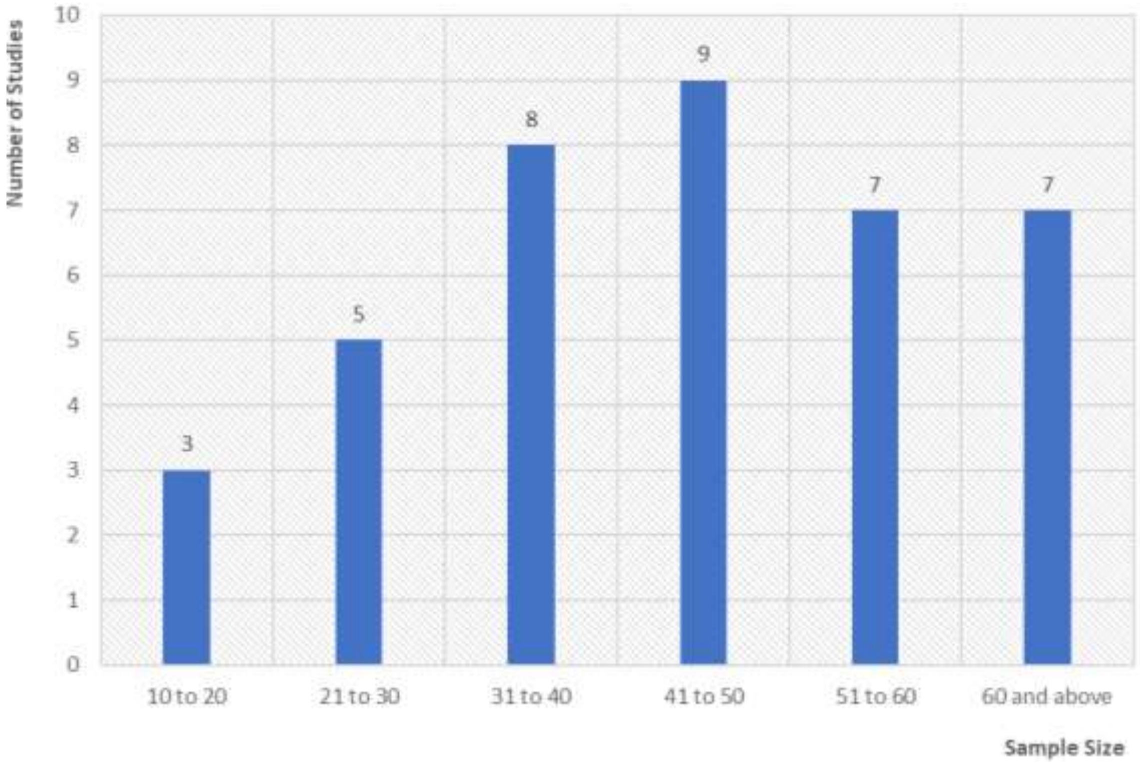

Fig. 2. Sample size distribution of selected 39 studies

Moreover, the inclusion of eight studies with a sample size of 31 to 40 participants signifies a concerted effort to enhance statistical robustness and explore a wider range of variables [18-24]. These studies likely sought to establish more precise relationships between navigation system display size, environmental illumination, gender and driver safety and performance. Moving forward, the sample sizes expanded further, with nine studies incorporating participant counts ranging from 41 to 50 [21,25-31]. This age group often encompasses individuals who have established careers, raised families and accumulated substantial driving experience. Exploring the driving profiles of this demographic can provide valuable insights into how life experiences and responsibilities impact driving behaviours. These larger sample sizes can be able to detect subtler effects and delve into potential interactions or moderating influences.

At the higher end of the participant count spectrum, seven studies encompassed sample sizes between 51 and 60 participants [32-36]. The inclusion of such extensive samples facilitated greater generalizability and elevated the reliability of findings. Researchers could investigate individual differences, considering demographic variables like age and driving experience, while simultaneously maintaining a manageable research scope.

Lastly, seven studies featured a sample size of 60 participants and above [37-41], reflecting a comprehensive data-gathering endeavour involving a substantial number of participants. Older drivers above the age of 60 have garnered attention in several studies, indicating a recognition of the unique challenges and considerations associated with ageing and driving. These studies may aim to explore age-related factors, such as physical changes, cognitive abilities and the impact of medical conditions on driving behaviours and profiles. These studies likely facilitated more intricate analyses and robust statistical conclusions. By accounting for potential confounding variables and covariates, they could elucidate the effects of navigation system display size, environmental illumination and gender on safety and performance with greater precision.

3.2.2 Driver profile/participant

Table 1
Driver profile means age and standard deviation

Mean Age	Standard Deviation Age Range	Number of Journal	Citation
< 20 years old	0.9	1	[29]
20 < Age <25	1.8 to 4.5	4	[11]
25 < Age <30	3.1 to 9.9	10	[12,26,28,33,34,37-39]
30-35	3.1 to 15.1	10	[13,17,20,23,25,27,31,35,36,41]
36-40	8.8 to 13.5	7	[15,19,22,24,32,40,42]
< 40	9.9 to 17	4	[14,16,18,21]

The participant profile based on the provided data reveals interesting insights across different age ranges. Firstly, a group of researchers conducted a study on drivers who were under 20 years old [29]. Research and studies focusing on this age group are limited, with only one journal dedicated to this category. This suggests a potential gap in understanding the characteristics and behaviours of young participants. Moving on to participants aged between 20 and 25, indicating a greater research interest in this transitional period from adolescence to early adulthood [11] The wider age distribution within this range, as indicated by the standard deviation ranging from 1.8 to 4.5, suggests varying levels of participation experience and maturity.

Several studies focused on drivers aged 25 to 30 [12,28,33,34,37-39,43]. The wider standard deviation range of 3.1 to 9.9 suggests a diverse range of factors that researchers are interested in, such as participation experience, risk-taking behaviour and cognitive abilities during this stage of adulthood. Similarly, drivers aged between 30 and 35 were the subject of ten studies, and all reported mean ages within this range, but with a wider standard deviation range of 3.1 to 15.1 [13,17,20,25,27,31,35,36,41,44]. Research in this age range may focus on participant performance, decision-making and changes in cognitive abilities as individuals progress into their thirties.

A narrower age range of 36 to 40 was investigated in seven studies, with a narrower standard deviation range of 8.8 to 13.5, suggesting a more homogeneous group in terms of age [15,19,22,24,32,40]. Research in this category might delve into areas such as participation experience, reaction time changes, and lifestyle factors' impact on participant behaviour. Lastly, drivers below 40 years old were studied in four articles and reported a mean age below 40 with a wider standard deviation range of 9.9 to 17. Despite having four journals dedicated to this age range, research covering participation skills, behaviour and factors influencing participant performance could span various subtopics due to the wider age distribution [14,16,18,21].

3.2.3 Synthesis of driving simulator studies

As evident from the analysis, a notable trend emerged in the selection of driving simulator types for experimentation, with most studies (32 out of 39) opting for fixed-base driving simulators. A more limited number of studies (6 out of 39) employed motion-based driving simulators, while just a single study utilized virtual-reality-based simulators. It's important to recognize that simulator fidelity plays a pivotal role in shaping driver behaviour outcomes.

Table 2
The type of driving simulators used for selected 39 studies

Type of driving simulator	Number of studies	List of studies
Fixed based driving simulator	32	[10,12-14,18-20,24-29,31-35,37,38,45]
Motion based driving simulator	6	[15,17,23,40,41]
Virtual reality-based simulator	1	[39]

Driving simulator fidelity significantly influences how drivers respond within simulated environments. The utilization of low-fidelity driving simulators on fixed-base platforms may restrict the movements drivers can make and they don't provide the same feeling of vibrations that drivers feel while driving in real traffic. Restricted degrees of freedom and the absence of tactile feedback, such as the vibrations that occur during real-world driving, can contribute to this reduced sense of immersion. On the other hand, high-fidelity driving simulators equipped with motion-based platforms offer a heightened level of realism. They better capture the nuances of drivers' responses and mirror real-world scenarios more accurately. The higher level of realism provided by motion-based platforms raises the veracity of the observations of driver behaviour. This emphasises how important simulator fidelity is as a key consideration for analysing and evaluating driver behaviour in virtual environments.

3.2.4 Driving mode

Manual driving has traditionally been the dominant mode of transportation and it continues to be widely used today. The percentage for manual driving mode being the largest at 74% suggests that most of the research or data included in the study focuses on manual driving. Besides, despite advancements in autonomous driving technology, fully autonomous vehicles are not yet widely adopted, so manual driving remains the primary mode in practice.

While the intermediate category of autonomous and manual driving mode at 18% indicates that there is research or data available that focuses on both autonomous and manual driving modes. This suggests an interest in studying the interaction, comparison or combination of these two driving modes. For example, Ko *et al.,* [29], conducted research study that initiated driver take-overs during critical braking manoeuvres in automated driving using the driving simulator. Two driving simulator studies involving a total of 100 participants were conducted to determine whether trust in automation and the criticality of the driving situation predict driver-initiated takeovers during highly dynamic braking manoeuvres.

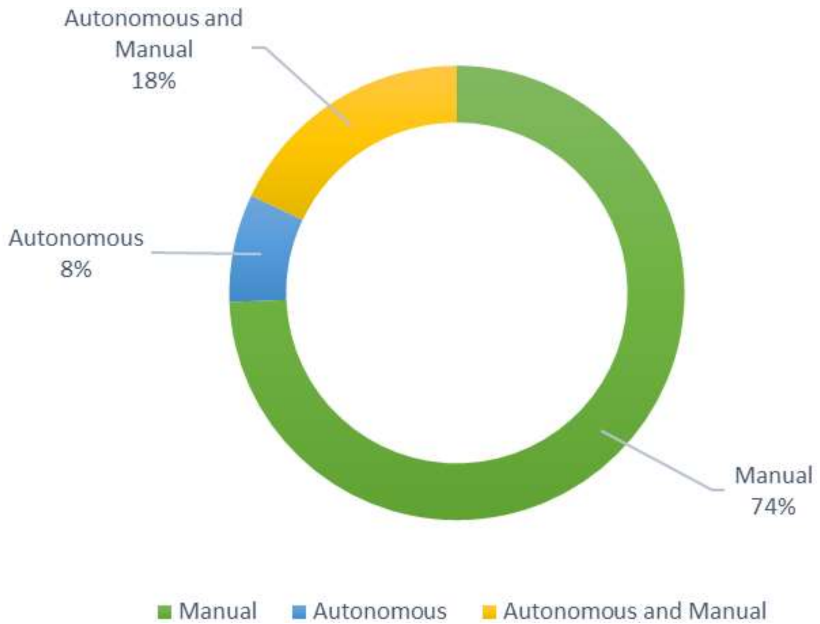

Fig. 3. Driving mode distribution of selected 39 studies

Comparative analysis between autonomous and manual driving may also be conducted to assess performance, safety or user experience in specific contexts or scenarios. Participants in a study must complete a manual drive and then complete 2 of the four automated drives in different environmental contexts, with a short break in between each to investigate how environmental factors and individual differences effect on the subjective evaluation of human-like and conventional automated vehicle controllers. These studies provide insights into the advantages and limitations of each mode, informing decisions related to the development and implementation of autonomous driving technology.

The least representation of studies at 8% for autonomous driving mode suggests that this kind of driving mode is still relatively nascent and emerging. The technology and infrastructure required for fully autonomous vehicles are still being developed and refined. A case study by uses a fully autonomous driving mode to investigate state anxiety, situational awareness, trust and role adaptation. The automated driving style has been confirmed to have a moderating role in the relationship between the direct and indirect effects of state anxiety and role adaptation.

3.2.5 Country wise distribution

A total of 39 studies were conducted across various countries to explore the use of driving simulators. Among these studies, China had the highest number with 9 studies, followed by Germany with 10 studies. The United States also contributed significantly with 6 studies, while Italy had 3 studies, Belgium and the UK had 2 each and Qatar, Israel, France, Japan, Australia and Canada each had 1 study.

The wide distribution of studies across different countries suggests a global interest in utilizing driving simulators as a research tool. It is likely that these countries recognize the potential benefits of simulators in studying driving behaviour, evaluating road safety interventions and developing innovative training programs [46].

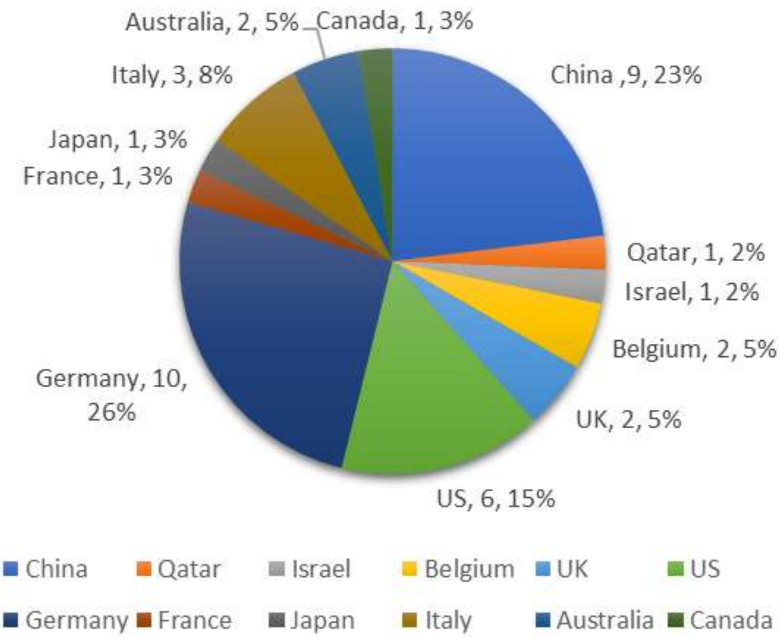

Fig. 4. Country-wise distribution of selected 39 studies

The high number of studies conducted in China and Germany could be attributed to their large populations, advanced research infrastructure and substantial investments in transportation research. These countries may have prioritized the use of simulators to investigate driving patterns, human factors and the effectiveness of driver assistance systems in their respective contexts.

On the other hand, countries like Qatar, Israel, France, Japan, Australia and Canada, which had fewer studies, might have a more focused approach or limited research capacity in this area. Nonetheless, their participation in driving simulator studies indicates an interest in exploring the potential applications of simulators for their unique transportation challenges and goals.

Overall, the collective findings from these studies have likely contributed to our understanding of driving behaviour, road safety measures and driver training techniques. The diverse representation of countries also suggests the potential for cross-cultural insights and the transferability of simulator-based research findings across different driving contexts.

3.2.6 Selected studies: Driving simulators and their impact on driver behaviour

Within the scope of this systematic review, we have identified and selected six studies that present valuable insights into the effectiveness of driving simulators in various scenarios. These studies have been chosen based on their relevance, significance and contribution to the broader understanding of driving simulator training and its implications for real-world driving performance. In this section, we present the findings and analysis of these selected studies, exploring the impact of driving simulator interventions across a range of scenarios, from urban driving challenges to hazardous weather conditions. The synthesis of these studies aims to shed light on the overall efficacy of driving simulators in enhancing driving skills and behaviour.

Table 3
Selected 6 studies

Author	Driving Simulator Type	Scenario Tested	Sample Size	Outcome Measure
Savage *et al.,* [47]	Fixed base	intersections scenario with traffic	29	gaze behaviour, scan frequency and magnitude, head vs. eye movement contributions, fixation tendencies
Calvi *et al.,* [28]	Fixed base	pedestrian crossing, hidden pedestrian crossing	46	speed, Distance, Time to collision, TTZ, deceleration
Xiang *et al.,* [23]	Motion base	a 10-kilometer long six-lane expressway in both directions with three lanes in each direction	40	response time, LC initiation location, average speed, average deceleration, lane-changing longitudinal distance,
Ko *et al.,* [48]	Fixed base	participants played the game, 2048 on a laptop -> take over request -> manual	43	reaction time, takeover time,
Goddard *et al* [38]	Fixed base	driving environment with upcoming bicyclists riding inside the lane	101	steering wheel position, accelerator pedal position, brake pedal position, velocity, time to lane crossing, time headway to an upstream object and lane position
Becker *et al.,* [49]	Fixed base	Trust in automation, THW, TU	41	participants experienced braking manoeuvres with nine different combinations of THW and TU

Several valuable insights have emerged, highlighting the complex nature of driver behaviour in simulated driving environments. One important finding comes from research on augmented reality warnings near pedestrian crossings. Human errors like distraction or mental overload can lead to delayed recognition of the road environment, which plays a major role in many accidents [28]. Interestingly, repeated exposure to risky situations can reduce a driver's sense of uncertainty over time [32], pointing to how experience and familiarity can influence decision-making. This highlights the potential for technology-based interventions to shape behaviour and improve safety, especially for vulnerable road users like pedestrians.

Other studies also shed light on how drivers respond during automated driving, especially when they have to take back control in urgent situations. Factors like trust in the automation system, the time gap between vehicles, and how drivers use the brakes all come into play. Striking the right balance between automated systems and human input is crucial to ensure smooth transitions. Practical examples, such as improving signage at toll plazas, show how well-designed interventions can help guide drivers and encourage safer decisions in real time.

When it comes to intersections, things get even more complicated. Drivers' gaze behaviour is influenced by several factors, including who has the right of way, the type of intersection, and whether the driver is dealing with any distractions. In a simulator study by Savage *et al.,* [47], researchers found that older drivers tend to scan less widely and less frequently compared to younger drivers. This has important implications for designing intersections to support drivers of all ages. Finally, looking at the psychological side of things, studies into overtaking behaviour reveal how drivers' attitudes in both conscious and unconscious situations can influence risky choices, offering useful insights for targeted safety campaigns.

4. Discussion
4.1 Limitations

It's critical to acknowledge the limitations that influence our understanding. These limitations are not intended to decrease the significance of our findings but rather provide us with a clear picture of where our conclusions are relevant. By openly discussing these limitations, we gain a more complete picture of the insights and future research directions.

4.1.1 Methodological diversity and comparability

Looking across these studies, one significant limitation stands out due to the various ways researchers have approached driving simulator studies. Different methods, experiment setups and types of driving simulators have been used, making it tricky to directly compare findings. The range of simulator types, including fixed-base, motion-based and virtual-reality systems, adds to the complexity. This makes it harder to draw clear conclusions when studies have such diverse designs. It's a reminder of the importance of consistent methods for better reliability.

4.1.2 Simulator-to-real world gap

Another important limitation we find when using driving simulators is how well the behaviours, we see in simulations match up with real-world driving. While simulators aim to mimic real driving, there's still a gap. Simulated situations lack the real risks and consequences, which could lead drivers to behave differently. This raises questions about whether what we see in simulators truly reflects how drivers act on actual roads. Recognizing this gap helps us see the limitations of simulator-based results in real-life contexts.

4.1.3 Potential for one-sided reporting

In this collection of studies, an interesting concern arises regarding what gets published and how it's reported. Studies with positive or statistically significant results tend to get more attention, potentially leading to an uneven representation in the review. This could bias our overall understanding of how much driving simulators really affect driver behaviour. Studies showing no significant effects might not get the same spotlight. Being aware of this potential bias reminds us to consider a wider range of study outcomes to form a more balanced conclusion.

5. Conclusion

In conclusion, this systematic review has provided a comprehensive analysis of the impact of driving simulators on driver behaviour. Through the synthesis of diverse studies, this study has gained valuable insights into the complex interactions between simulated scenarios and real-world driving actions. The findings highlight the significance of simulator fidelity, scenario design and participant characteristics in shaping driver responses within simulated environments. While acknowledging the limitations inherent in driving simulator research, such as methodological diversity and potential transferability challenges, this review underscores the potential of driving simulators as powerful tools for studying and influencing driver behaviour.

The integration of insights from various studies has illuminated both the strengths and the areas for improvement within the realm of driving simulator research. Simulators offer a controlled platform for investigating driver responses in a controlled setting, enabling interventions that could lead to safer and more efficient driving practices. Nevertheless, the limitations discussed in this review, including the need for standardized methodologies, concerns about ecological validity and potential publication biases, emphasize the importance of careful interpretation and further exploration. By addressing the limitations and capitalizing on the insights acquired, we can continue to refine the use of driving simulators to positively influence driver behaviour and contribute to safer roads.

Acknowledgement
This research is supported by the Ministry of Education (MoE) through the Fundamental Research Grant Scheme (FRGS/1/2021/TK0/UTEM/02/45) and Universiti Teknikal Malaysia Melaka Short-term Grant (PJP/2020/FTKMP/PP/S01785). The author would like to thank Fakulti Teknologi dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, for providing feasible research facilities for this study.

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