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Human Factors and Usability Analysis of a Virtual Reality-Based Driving Simulation Application

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Abstract
Virtual Reality (VR) technology enables a 3D, computer-generated simulation of real-world environments and situations. Applying VR-based simulation is important for minimizing real-world driving incidents before they occur. This study investigated the influence of human factors on completion time and error rate during a VR driving simulation, and evaluated the usability of the simulation using the System Usability Scale (SUS). Sixteen participants (eight male, eight female; eight experienced and eight novice drivers) completed eight scenarios combining weather (clear/rainy), time of day (morning/night), and traffic condition (light/heavy) using the City Car Driving simulator. Data were analyzed using multivariate analysis of variance (MANOVA) in SPSS 23. The results showed that driving experience had a statistically significant effect on accumulated error ($p = 0.000$), while gender showed a significant effect on completion time ($p = 0.006$) but not on error rate. Weather, time of day, and traffic condition did not significantly affect completion time or error rate ($p > 0.05$). The optimal scenario was clear weather, night, and light traffic (Scenario 3), yielding a completion time of 9,360 seconds and a total of 106 errors, whereas the scenario with the highest total errors (137) was rainy weather, night, and heavy traffic (Scenario 5). The SUS evaluation yielded a mean score of 82 out of 100, corresponding to Grade A, indicating that the simulation was highly usable. These findings suggest that driving experience is the dominant human factor influencing performance in VR driving simulation, and that the simulator provides an acceptable and usable training platform for improving driver safety awareness.
Keywords: *Virtual Reality; Driving Simulation; Human Factors; Usability; System Usability Scale; MANOVA*

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I. Introduction

Vehicles are an essential component of daily human activity, and passenger cars remain one of the most widely used modes of transportation (Kadir, 2006). Data from the Indonesian Central Bureau of Statistics (Badan Pusat Statistik, 2018–2022) show that the number of passenger cars in Indonesia rose steadily from 14,830,698 units in 2018 to 17,168,862 units in 2022. While transportation growth supports economic, social, and political development, it is also associated with an increase in traffic accidents caused by higher road density, inadequate infrastructure, and insufficiently skilled drivers (Kadir, 2006). Between 2018 and 2022, Indonesian traffic accident statistics recorded between 23,529 and 29,472 fatalities annually, alongside tens of thousands of serious and minor injuries.

According to Flin, O'Connor, and Crichton (2008), traffic accidents are attributable to both technical and non-technical driving factors. Technical skills involve vehicle maneuvering and operation (e.g., acceleration, braking, steering), whereas non-technical skills comprise cognitive, interpersonal, and intrapersonal competencies such as situational awareness, decision-making, communication, and stress or fatigue management. Because non-technical skills are difficult and potentially hazardous to train in real traffic conditions, simulation-based training has become an increasingly important alternative for preparing drivers to handle diverse road situations safely (Setiawan, 2020).

Virtual Reality (VR) is a technology that renders real-world environments and situations as computer-generated 3D simulations, allowing safe and repeatable practice of hazardous or rare scenarios (Sudiarno & Wahyuni P., 2020). However, a gap remains between VR hardware capability and the human body's physiological response to virtual stimuli, which can affect user performance and comfort. This study builds on prior work by

Wahyuni, Zidane, Padhil, and Pawennari (2024), conducted using the same City Car Driving simulator and MANOVA approach, which found that driving experience significantly affected accumulated error ($p = 0.000$) and identified cybersickness symptoms — most prominently dizziness, reported by 87% of participants — as a notable side effect of VR exposure, but which did not address usability. The present study therefore analyzes (1) the influence of human factors on completion time and error rate in a VR driving simulation, and (2) the usability level of the simulation, measured with the System Usability Scale (SUS), with the aim of identifying the optimal driving scenario and the technical and non-technical factors that most affect driver performance.

II. Literature Review

2.1 Driving Skills and Safety Driving

Driving competence comprises technical skills — vehicle operation such as starting the engine, adjusting mirrors, and controlling the accelerator and brake — and non-technical skills, grouped by Flin, O'Connor and Crichton (2008) into cognitive (situational awareness, decision-making), interpersonal (communication, cooperation), and intrapersonal (stress and fatigue management) categories. Safety driving training builds on these foundations by cultivating four attributes — alertness, awareness, attitude, and anticipation (the "4A" principle) — that help drivers recognize and respond to hazards (Pinayungan, 2019). Safety driving performance is influenced by human factors such as age and experience, vehicle factors, and environmental factors including road condition and weather (Puteri & Nisa, 2020).

2.2 Virtual Reality and Driving Simulation

Virtual reality enables users to interact with and feel immersed in a simulated environment (Musril et al., 2020). Sherman and Craig (2003) identify four defining elements of VR experience: the virtual world, immersion, sensory feedback, and interactivity. This study used City Car Driving, a commercially available simulator (Forward Development Ltd., released 2007) featuring a first-person perspective and configurable scenario parameters including area, vehicle transport type, season/weather/time of day, and traffic density (Franssugar & Sarvia, 2023). The simulator's traffic module allows independent control of vehicular traffic density, traffic behavior, and pedestrian density, enabling the construction of realistic and repeatable scenarios.

2.3 Human–Computer Interaction and Usability

Human–Computer Interaction (HCI) is concerned with the design of computer systems and their interaction with users, encompassing cognitive and attitudinal aspects of human–system engagement (Said, 2016). Preece and Benyon (1994) identify environment, comfort, health and safety, user characteristics, organization, task, system function, productivity, and constraints as key considerations in HCI design. Usability — the core objective of HCI — refers to the extent to which a product can be used by specified users to achieve specified goals effectively, efficiently, and with satisfaction (ISO 9241-11, 2018). The System Usability Scale (SUS), introduced by John Brooke in 1986, is a widely used ten-item, five-point Likert questionnaire providing a reliable, low-cost usability metric even with small samples (Murdin et al., 2011; Thomas, 2015). Raw SUS scores are converted to a 0–100 scale, with a score of 68 representing the average and scores above 80.3 corresponding to Grade A (Sauro, 2011).

2.4 Multivariate Analysis of Variance (MANOVA)

Multivariate analysis of variance (MANOVA) is a statistical technique used to test whether one or more categorical independent variables produce a significant effect on two or more continuous dependent variables simultaneously (Hasanah et al., 2022). MANOVA requires multivariate normality, homogeneity of covariance matrices across groups, and the absence of significant outliers, since the method is sensitive to outlying observations.

2.5 Related Studies

Prior studies provide relevant context for this research. Ernawati, Anwariningsih, and Musslifah (2023) applied SUS to evaluate a psychology-term dictionary application and found an "acceptable" and "good" usability rating, with recommendations for improved technical assistance. Sudiarno and Wahyuni P. (2020) analyzed human factors and workload in a VR-based earthquake evacuation simulation, reporting significant effects of mental demand, physical demand, and task control on performance. Pramono, Az-Zahra, and Rokhmawati (2019) evaluated the MyTelkomsel application using usability testing across five criteria and obtained an SUS score of 69, above the average threshold. Dewi and Masfuri (2023) reported that VR-based distraction techniques were effective and safe for pain and anxiety management, reinforcing the broader value of VR as an immersive, low-risk simulation medium across domains. Most directly related to the present work, Wahyuni, Zidane, Padhil, and Pawennari (2024) used the same City Car Driving simulator and a Multi-Variate ANOVA approach to analyze cybersickness across driving scenarios combining weather, time of day, and traffic density; they likewise found a significant effect of driving experience on accumulated error ($p = 0.000$), no significant effect of weather, time of day, traffic condition, or gender, and identified the rainy–night–crowded scenario as producing the highest cybersickness score, with dizziness as the most frequently reported symptom (87% of participants). Their study did not, however, evaluate system usability, a gap the present study addresses through the System Usability Scale.

III. Materials and Methods

3.1 Research Framework

This study used an experimental design in which participants completed a series of VR driving scenarios while completion time and error count were recorded, followed by a post-simulation usability questionnaire. Data were processed using MANOVA (for the quantitative dependent variables) and the SUS scoring procedure (for the qualitative usability data) to determine the optimal scenario and the technical/non-technical human factors affecting performance.

3.2 Variables

The independent variables were gender (male/female), weather (clear/rainy), time of day (morning/night), traffic condition (light/heavy), and driving experience (expert/novice, based on driving hours). The dependent variables were completion time (total time, in seconds, to finish a scenario) and number of errors (traffic violations or incidents recorded per scenario, e.g., speeding, lane violations, collisions).

3.3 Participants

Sixteen participants were recruited, all holders of a valid driving license (SIM A) and habitual users of automatic-transmission vehicles, none of whom had prior experience with the Oculus Rift VR headset used in this study. Participants were balanced by gender (eight male, eight female) and by experience level (eight expert, eight novice/moderate), aged 19–24 years, allowing each of the eight scenarios to be repeated twice.

3.4 Scenarios

Eight scenarios were constructed from three binary factors — weather (clear, rainy), time of day (morning, night), and traffic condition (light, heavy) — selected to reflect conditions realistically encountered in Indonesia. The eight combinations were: (1) clear–morning–light, (2) clear–morning–heavy, (3) clear–night–light, (4) clear–night–heavy, (5) rainy–morning–light, (6) rainy–morning–heavy, (7) rainy–night–light, (8) rainy–night–heavy.

3.5 Data Collection and Analysis

Data were collected at the Ergonomics and Work System Design Laboratory, Faculty of Industrial Technology, over approximately one month, through direct observation during simulation (completion time, error count) and a post-task questionnaire (SUS). Quantitative data were analyzed with multivariate ANOVA in SPSS 23, using a significance threshold of $\alpha = 0.05$, with pairwise comparisons (Bonferroni-adjusted) conducted for each independent variable. Usability data were scored following the standard SUS procedure: odd-numbered item scores were adjusted by subtracting 1, even-numbered item scores were adjusted by subtracting the raw score from 5, the ten adjusted scores were summed, and the sum was multiplied by 2.5 to yield a 0–100 usability score per participant, subsequently averaged across the sample.

IV. Results and Discussion

4.1 Overview of Collected Data

Across the sixteen participants and eight scenarios (two repetitions each, 128 trials total), total completion time per scenario ranged from 9,360 to 11,774 seconds, and total error counts per scenario ranged from 106 to 137. Scenario 3 (clear, night, light traffic) produced the shortest total completion time (9,360 s) and the lowest total error count (106), representing the most favorable driving condition observed. Scenario 5 (rainy, night, heavy traffic) produced the highest total error count (137).

4.2 Effect of Driving Experience

MANOVA results indicated a statistically significant effect of driving experience on accumulated error ($p = 0.000$), while its effect on completion time was not significant ($p > 0.05$ in the omnibus test, though descriptively substantial). Novice drivers recorded a mean of 66.5 errors compared with 42.75 for experienced drivers. This finding indicates that greater driving experience — reflected in higher cumulative driving hours — improves adaptation to the simulated environment and reduces error frequency, consistent with the expectation that experienced drivers approach the simulation with pre-established technical routines and situational awareness, whereas novice drivers require more adjustment time.

4.3 Effect of Gender

Descriptively, male participants completed scenarios faster on average (668 s) than female participants (712 s), while female participants recorded a higher mean error count (69) than male participants (58.3). Pairwise comparison confirmed a statistically significant effect of gender on completion time ($p = 0.006$) but not on error rate ($p = 0.915$), indicating that gender differentiated driving speed but not driving accuracy in this sample.

4.4 Effect of Weather, Time of Day, and Traffic Condition

Weather (clear vs. rainy), time of day (morning vs. night), and traffic condition (light vs. heavy) did not produce statistically significant effects on completion time or error rate (all $p > 0.05$ in pairwise comparisons). Descriptively, rainy weather was associated with longer completion time (781 s vs. 652 s for clear weather) and higher error counts (54 vs. 48), and night scenarios showed a lower mean error rate (58) than daytime scenarios were expected to, which participants attributed to reduced glare and a more relaxed driving posture at night. Although these differences were not statistically significant at the sample size tested, the directional trends are consistent with real-world expectations regarding visibility and hazard exposure.

Independent Variable	Completion Time (Sig.)	Number of Errors (Sig.)
Gender	0.006 *	0.915
Weather	0.383	0.288
Time of Day	0.651	0.650
Traffic Condition	0.673	0.482
Driving Experience	0.182	0.000 *

*Table 1. Summary of pairwise-comparison significance values (α = 0.05; * indicates a statistically significant effect).*

4.5 Usability Evaluation

The SUS evaluation, completed by all sixteen participants, yielded a mean score of 82 out of 100 — well above the 68-point average benchmark and the 80.3-point threshold for Grade A (Sauro, 2011). This result indicates that the City Car Driving VR simulation was perceived as highly usable, easy to learn, and well-integrated in its functions, supporting its viability as a driver-training and driving-behavior research platform.

4.6 Discussion

Overall, these findings position driving experience as the dominant human factor shaping performance in VR driving simulation, while environmental scenario factors (weather, time of day, traffic density) exerted comparatively limited statistical influence within the tested sample. This is consistent with the view that non-technical driving competencies — situational awareness, decision-making, and stress management — are cultivated primarily through accumulated practice rather than through exposure to any single environmental condition (Flin, O'Connor & Crichton, 2008; Burkhardt et al., 2016). The significant effect of gender on completion time, without a corresponding effect on error rate, suggests a speed–accuracy trade-off difference between male and female participants rather than a difference in overall driving competence. The high SUS score corroborates the simulator's suitability for controlled human-factors research and supports its use as a safe, low-cost alternative to on-road testing for training novice drivers and evaluating driver behavior under varied conditions.

V. Conclusion

This study demonstrated that driving experience significantly affects error accumulation in a VR-based driving simulation ($p = 0.000$), with experienced drivers committing substantially fewer errors than novices, while gender significantly affected completion time but not error rate. Weather, time of day, and traffic condition did not produce statistically significant effects on either dependent variable, although rainy, heavy-traffic conditions were descriptively associated with longer completion times and higher error counts. The optimal driving scenario was clear weather, night-time, and light traffic, while rainy, night-time, heavy-traffic conditions produced the highest error accumulation. The System Usability Scale evaluation returned a mean score of 82 (Grade A), confirming that the VR driving simulation is highly usable and immersive. These results support the use of VR driving simulation as an effective, safe tool for assessing human factors and training driver competency. Future work should incorporate higher-fidelity graphics to enhance immersion and satisfaction, and add automated performance-logging features at the end of each simulation session to streamline data collection.

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References

[1]. Badan Pusat Statistik. (2024). Banyaknya jumlah kecelakaan 2018–2022 [Statistical report]. Makassar: Badan Pusat Statistik.
[2]. Burkhardt, J-M., Corneloup, V., Garbay, Y., Bourrier, F., Jambon, V., Luengo, A., Job, P., Cabon, A., Bennabbon, D., & Lourdeaux, D. (2016). Simulation and virtual reality-based learning of non-technical skills in driving: Critical situations, diagnostics, and adaptation. IFAC-PapersOnLine, 49(19), 66–71.
[3]. Dewi, E. S., & Masfuri. (2023). Manajemen nyeri distraksi berbasis virtual reality. Jurnal Keperawatan Silampari, 6(2).
[4]. Ernawati, S., Anwariningsih, S. H., & Musslifah, A. R. (2023). Analisis tingkat usabilitas aplikasi kamus istilah psikologi menggunakan metode System Usability Scale. TEKINFO: Jurnal Ilmiah Teknik Industri dan Informasi, 11(2).
[5]. Flin, R., O'Connor, P., & Crichton, M. (2008). Safety at the sharp end: A guide to non-technical skills. Ashgate Publishing.
[6]. Franssugar, Y., & Sarvia, E. (2023). Matrik analisis pengaruh temperatur dan aroma kopi terhadap jumlah pelanggaran, denyut jantung dan kelelahan saat menggunakan driving simulator. Jurnal Manajemen dan Teknik Industri-Produksi, 24(1).
[7]. International Organization for Standardization. (2018). ISO 9241-11:2018 — Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts.
[8]. Kadir, A. (2006). Transportasi: Peran dan dampaknya dalam pertumbuhan ekonomi nasional. Jurnal Perencanaan dan Pengembangan Wilayah Wahana Hijau, 1(3).
[9]. Madan, A., & Dubey, S. K. (2012). Usability evaluation methods: A literature review. International Journal of Engineering Science and Technology, 4(2), 590–599.
[10]. Murdin, L., Golding, J., & Bronstein, A. (2011). Managing motion sickness. BMJ, 343, d7430.
[11]. Panuntun, M. B., Bolet Atmojo, T., & Hastuti, H. (2022). Hubungan pengetahuan mengemudi aman dan masa kerja dengan perilaku mengemudi aman pada sopir bus PO. X Kutoarjo. Jurnal Kesehatan Lingkungan, 19(1).
[12]. Pinayungan. (2019). Pengertian mengemudi. Gastronomía Ecuatoriana y Turismo Local, 1(69), 5–24.
[13]. Pramono, W. A., Az-Zahra, H. M., & Rokhmawati, R. I. (2019). Evaluasi usability pada aplikasi MyTelkomsel dengan menggunakan metode usability testing. Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer, 3(3).
[14]. Pudjoatmodjo, B., & Wijaya, R. (2016). Tes kegunaan (usability testing) pada aplikasi kepegawaian dengan menggunakan System Usability Scale. Seminar Nasional Teknologi Informasi dan Multimedia, 37–42.
[15]. Puteri, A. D., & Nisa, A. M. (2020). Faktor-faktor yang berhubungan dengan perilaku safety driving pada supir travel di PT. Libra Wisata Transport. PREPOTIF: Jurnal Kesehatan.
[16]. Said, S. A. (2016). Analisis usabilitas sistem informasi administrasi sekolah terpadu (SIASAT) menggunakan model Human Computer Interaction (HCI) pada SMK Nasional Makassar [Thesis].
[17]. Sauro, J. (2011). Measuring usability with the System Usability Scale (SUS). MeasuringU. https://measuringu.com/sus/
[18]. Saurik, H. T. T., Purwanto, D. D., & Hadikusuma, J. I. (2019). Teknologi virtual reality untuk media informasi kampus. Jurnal Teknologi Informasi dan Ilmu Komputer, 6(1), 71.
[19]. Sherman, W. R., & Craig, A. B. (2003). Understanding virtual reality: Interface, application, and design. Morgan Kaufmann.
[20]. Sudiarno, A., & Wahyuni P., A. D. (2020). Analysis of human factors and workloads in earthquake disaster evacuation simulations using virtual reality technology. IOP Conference Series: Materials Science and Engineering, 1003(1), 012082.
[21]. Theresia, C., Angela, D., & Theopilus, Y. (2023). Analisis kinerja berdasarkan perbedaan realitas dan tingkat kesulitan tugas: Studi kasus pada perakitan repetitif. Jati Undip: Jurnal Teknik Industri, 18(2), 109–119.
[22]. Thomas, N. (2015). How to use the System Usability Scale (SUS) to evaluate the usability of your website. Usability Geek.
[23]. Wahyuni, A. D., Zidane, M. Z., Padhil, A., & Pawennari, A. (2024). Factor analysis of cybersickness in driving simulation using virtual reality technology. International Journal of Computational Engineering Research (IJCER), 14(5), 71–75.
[24]. Xu, J., et al. (2018). Human performance measures for the evaluation of process control human-system interfaces in high-fidelity simulations. Applied Ergonomics, 73, 151–165.