HUD-SUMO: Simulacra of In-Vehicle Head-Up Displays Using SUMO To Study Large-Scale Effects

Pascal Jansen*
Ulm University, Germany
0000-0002-9335-5462

Mark Colley*
Ulm University, Germany
UCL Interaction Centre, UK
0000-0001-5207-5029

Elisabeth Wimmer
Ulm University, Germany
0009-0007-9711-1717

Jan Maresch
Ulm University, Germany
0009-0004-8330-6861

Enrico Rukzio
Ulm University, Germany
0000-0002-4213-2226

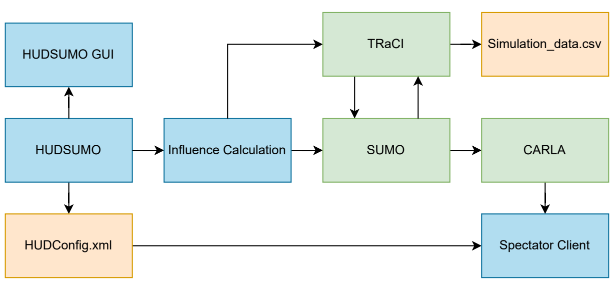

Fig. 1: High-level architecture of *HUD-SUMO*.

***Abstract*—Large-scale effects of head-up displays (HUDs) are currently unknown, as experiments focus primarily on empirical data from one participant. Therefore, we simulate the impact of augmented reality (AR) windshield HUDs on driving performance. Using the open-source simulators SUMO and CARLA, we model various AR HUD settings, such as fatigue, and assess their effects on key driving factors such as reaction time, speed adherence, lane-changing behavior, and acceleration. The HUD settings include brightness, information frequency, field of view, and relevance of displayed information. The simulation provides insight into how different HUD configurations may influence driving behavior, contributing to future vehicle design and safety guidelines for AR HUDs.**

***Index Terms*—automated driving; SUMO; CARLA; open source; head-up-display; driving behavior**

I. Background and Summary

According to the *Global status report on road safety 2018* [1], there are more than 1 million fatalities in traffic per year. Head-up displays (HUDs) are one possibility to improve driving safety by reducing the necessity to glance at displays outside the line of sight. In particular, Augmented Reality Head-up displays (AR-HUDs) gain significance because they offer far greater potential than traditional HUDs by providing drivers with enhanced support through relevant information [2, 3, 4]. AR-HUDs can improve drivers' awareness of their surroundings and reduce reaction times to critical events.

*These authors contributed equally to this work.

Moreover, AR-HUDs are also relevant in the context of automated driving. Passengers need to understand the behavior of the automated vehicle, such as its navigation decisions and its detection of other road users, to feel safe and trust the vehicle [5]. AR-HUDs can visualize the vehicle's intended route [6], highlight road users [5], and display information about surrounding traffic [7], helping passengers build trust in the automated system and maintain situational awareness (see [5, 6, 7, 8]).

The impact of an AR-HUD largely depends on its ability to minimize distractions while effectively conveying essential data. Therefore, this technology represents a crucial advancement toward safer and more efficient driving environments in manual and automated vehicles. However, studying all these factors in an empirical study on AR HUDs is nearly impossible; thus, simulations are necessary.

HUD-SUMO allows studying the effect that AR-HUDs have on the driving performance of drivers in an urban environment. Using SUMO, an open source, multi-modal traffic simulation package [9], it is possible to simulate how driving behavior changes in response to different AR-HUDs, for example by influencing the awareness of the surrounding vehicles or reaction times to events happening nearby. If an AR-HUD has a high distraction level, it negatively influences the driver's reaction time. In contrast, an AR-HUD with a low distraction level but high relevance of information can improve the reaction time. Those changes can be observed in a 3D environment using CARLA, a simulator for autonomous driving research based on Unreal Engine [10], making it easier to observe and evaluate situations. Where possible, we made factors (calculations, values, etc.) impacting the driving performance as reasonable and factual as possible, grounded in scientific resources. Our open source code is available at: https://github.com/Pascal-Jansen/HUD-SUMO.

II. Purpose

HUD-SUMO is a simulation framework designed to assess the large-scale effects of AR windshield HUDs on driving performance in urban environments. Utilizing the microscopic traffic simulation tool SUMO [9] and the CARLA simulator [10], we model various AR-HUD settings and their impact on key driving factors such as reaction time, speed adherence, lane-changing behavior, and acceleration. Microscopic traffic flow models focus on individual road users, capturing dynamic variables like the position and velocity of each vehicle. By varying HUD parameters—including brightness, information frequency, field of view (FoV), and information relevance—*HUD-SUMO* seeks to measure macroscopic changes in traffic flow and driver behavior resulting from different AR-HUD configurations. This approach allows us to explore how various HUD designs can influence driving safety and efficiency, contributing valuable insights for future vehicle design and safety guidelines for AR-HUDs.

III. Characteristics

After repository cloning, install the requirements detailed in the `requirements.txt`. If other cities than those provided are to be used, these must be downloaded and saved in the appropriate directory. We strongly encourage community input, either as comments, issues, or additional code in the GitHub repository. We plan to upgrade these requirements to improve performance and capabilities.

IV. Code/Software

A. Algorithms

TABLE I: HUD factors affecting driving performance.

Factor	Range	Source	Description
Brightness	0–0.9	[11, 12]	Level of HUD visibility. Lower values make the HUD more opaque, whereas higher values (e.g., 0.9) make it almost see-through.
Frequency	*minimum, average, maximum*	[13, 14, 15]	When information is displayed; *minimum*: only when needed, *maximum*: means all info is always displayed.
Field of View	30–100	[13, 16]	FoV in degrees. A higher FoV (e.g., 100°) projects AR elements over most of the windshield; a lower FoV (e.g., 30°) confines elements above the steering wheel.
Relevance	*unimportant, neutral, important*	[15, 17, 18]	Importance of the displayed info; *important*: only essential info (speed, navigation), *unimportant*: includes non-critical info (music track, weather).

The main idea of *HUD-SUMO* is to simulate how different AR HUD design configurations (see Table I) affect driving performance by adjusting driver behavior parameters within the SUMO simulation at each step. This involves modifying the driving factors such as reaction time, speed adherence, acceleration, maximum speed, and minimum following gap based on the specific HUD settings assigned to each vehicle (see Table II). The value ranges of brightness and FoV are continuous to increase design granularity.

TABLE II: Factors defining driving performance.

Factor	Value	Range	Source	Description
Reaction time	1.1	0.5 - 2	[19, 20, 21, 22]	Reaction time in seconds.
Speed adherence	1.0	$x > 0.00$	[13, 19, 23]	Factor how precisely the driver adheres to the speed limit. 1.0 means the driver is driving exactly at the, and 1.2 means driving up to 20% faster than the speed limit.
Acceleration	3.5	$x > 0.00$	[14, 19]	Maximum acceleration in m/s²
MaxSpeed	150	$x > 0$	[14, 23]	Maximum speed driven in km/h.
MinGap	$\frac{\text{speed}}{2}$	$x > 0$	[13]	Minimal gap to the followed car in m.

To optimize performance during the simulation, we precompute mappings between HUD factors (brightness, information frequency, FoV, and information relevance) and their effects on driver states (awareness, distraction, and fatigue). The Appendix details and visualizes these mappings derived from empirical studies and established relationships in the literature (see Table I, Table II, and Table III).

At the beginning of the simulation, we initialize the driver state for each vehicle, setting base values for awareness, distraction, and fatigue levels as specified in Table III. Vehicles are then assigned HUD configurations based on predefined probabilities, allowing us to simulate a variety of HUD settings within the same traffic environment.

The Appendix shows that HUD factors do not always influence the driving performance directly but influence the driver states: awareness, distraction, and fatigue level, affecting the driving performance (see Table III).

TABLE III: Human factors affecting driving performance.

Factor	Value	Range	Source	Description
Awareness level	5	1-10	[17, 22, 24, 25]	The awareness level describes the driver's awareness of their surroundings while driving, where 10 is the highest awareness. A highly aware driver might catch a pedestrian crossing earlier or hold a higher gap to the car before them.
Distraction level	6	1-10	[4, 15, 26]	The distraction level shows how distracted a driver is where 10 is the highest distraction. A distracted driver might take much longer to react to a braking car in front of them or a traffic light turning green.
Fatigue level	5	1-10	[21, 27]	The fatigue level shows how tired a driver is, where 10 is the highest fatigue. A tired driver might react and drive much slower than an awake driver.

The main simulation loop operates as follows:

Driver State Update: At each simulation step, we update the driver states for all vehicles based on their assigned HUD configurations. This involves calculating the new awareness, distraction, and fatigue levels using the formulae provided in the Appendix. For example, the awareness level is adjusted by considering the information relevance, frequency of updates, FoV, and the driver's current distraction and fatigue levels.

Driving Performance Adjustment: With the updated driver states (see Table III), we recalculate the driving performance factors for each vehicle. This includes determining reaction time, speed adherence factor, acceleration, maximum speed, and minimum gap. These calculations use the formulae outlined in the implementation section, incorporating the weighted effects of the driver states and HUD factors.

Vehicle Behavior Simulation: The adjusted driving performance parameters are then applied to each vehicle within the SUMO simulation. For instance, a higher reaction time may result in delayed responses to traffic signals or sudden stops, while changes in speed adherence affect how closely a driver follows speed limits.

Logging and Data Collection: Throughout the simulation, we log relevant data points for each vehicle, such as current speed, acceleration, position, and driver state variables. This data is stored in CSV files for post-simulation analysis, enabling us to assess the impact of HUD configurations on traffic flow and safety metrics.

By iteratively updating driver states and performance factors at each simulation step, *HUD-SUMO* captures the dynamic interactions between AR HUD settings and driver behavior. This allows us to evaluate how various HUD designs influence driving performance on a large scale, providing valuable insights for vehicle designers and policymakers aiming to enhance road safety and efficiency.

B. Co-Simulation with CARLA

Fig. 2: First Person View. Setting: *unimportant* information.

While the effects of AR HUDs can be studied without a visualization, we added support for CARLA for debugging and experiment purposes.

Using CARLA combined with SUMO, the user (i.e., professional user) can spectate the simulation in a real-life setting in a top-down view and "sit" in a simulated car (see Figure 2). The user can see a mockup of the simulated AR HUD from this passenger's perspective. The *information_relevance* variable determines how many elements appear in CARLA: when set to *unimportant*, multiple icons (e.g., calendar, music player, etc.) that are non-critical to the driving are shown, while *important* restricts the HUD to only critical driving information (e.g., speedometer or navigation arrows). An element's content does not alter its assigned relevance; for example, a calendar element provides generally unimportant information in driving contexts regardless of its date content.

The basic requirements for the co-simulation are Python 3.10, SUMO 1.20 or greater, and CARLA 0.9.15 or greater. All three components must be downloaded from their respective distribution pages and installed according to their instructions. Afterward, follow the setup instructions:

1) Clone this repository to a location of your choice
2) Install python packages (`pip install -r .\requirements.txt`)
3) Open "config.py" and set your CARLA base path up to the folder "\WindowsNoEditor"
4) Copy content of setup_files into the CARLA folder (copy the WindowsNoEditor folder over the one from CARLA, merge or overwrite if prompted)

The co-simulation can be initiated by starting the configuration client via *py main.py*. Selecting whether to run the CARLA client within the configuration client is possible. If the CARLA client is not selected but the spectator client option is enabled, CARLA will run silently in the background.

C. Measurements and Logging

In addition to SUMO's standard output (see [28]), we log further parameters in a `CSV` file listed in the Appendix.

V. Usage Notes

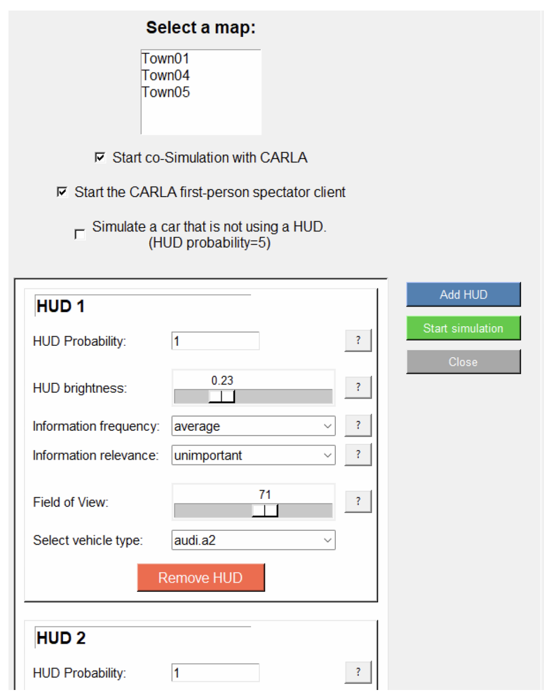

Fig. 3: Overview of the GUI to alter HUDs.

While the implementation is based on the scientific literature, we highlight that the simulation cannot necessarily be seen as an accurate representation of the influence of AR HUDs on drivers. However, in line with Park et al. [29], the simulacra of human behavior with *HUD-SUMO* can generate insights that plausibly define future behavior. This is currently the most appropriate avenue to study the large-scale effects of eHMI and AVs on traffic flow.

Users must run the `main.py` to access the GUI (see Figure 3). After creating custom HUDs in the GUI and running *HUD-SUMO*, it automatically generates the necessary SUMO configuration files, spawns vehicles, and (optionally) launches CARLA for a first-person view. Our repository's `sample_data` folder includes a dataset with five sample HUDs to facilitate users' exploration of *HUD-SUMO*. An R-script in the `analysis` folder demonstrates how to load, process, and perform basic descriptive and inferential analysis of the simulated data, helping users assess the effects of different HUD configurations before expanding to larger-scale studies. Additionally, users can replay the *floating car data* (FCD) logs [30] using SUMO's `fcdReplay.py` to visualize the simulation. FCD logs store each vehicle's metrics, such as position and speed, for every timestep; by default, *HUD-SUMO* exports FCD logs to the `Simulation_data` folder.

VI. Limitations and Future Work

There are several limitations to *HUD-SUMO*:

- Options used to simulate the AR HUDs are very limited. For a more accurate simulation, it would be necessary to differentiate more, maybe even allow customizing the different HUD elements.
- The created formulae, base values, and weights used to simulate the driving performance using AR HUDs are based on data from the linked research. However, the accuracy of the simulation results can be decreased if the data is imprecise or scarce regarding certain factors.
- The number of HUDs simulated simultaneously is limited to the number of available vehicle types (*vTypes*) in CARLA as the HUDs are being mapped to the *vTypes*. Currently, we enable the simultaneous simulation of 11 HUDs.
- CARLA has rather large requirements for self-compiling that made it not feasible for us to modify CARLA directly. Therefore, we used a pre-compiled version of CARLA that works well but imposes restrictions on the overall project.
- The SUMO integration into CARLA can show the state of vehicles in a 3D environment, but using the plethora of sensors and tools that CARLA can provide is impossible. The vehicle data is transferred so that SUMO provides the location of every vehicle at every given time to CARLA, meaning the sensors only see the vehicle projection with no access to the simulation data itself.
- The spectator client is limited in the information it receives because the CARLA sensors are non-functional. Therefore, the visualization is much less dynamic than it could have been. The spectator client is limited to the vehicle speed as a dynamic item in the HUD.
- While SUMO and CARLA synchronize the vehicles pretty well, there are world inconsistencies and synchronization errors between SUMO and CARLA. For example, traffic lights are not in sync, and roadsigns do not match.
- There is no proper way to export maps from SUMO to CARLA, as CARLA requires 3D modeling of the complete map. This limited us to the CARLA-provided maps.

Currently, the simulation focuses on purely simulating the effects of AR HUDs without considering different drivers. Further plans could be to simulate the impact of AR windshields HUDs with drivers of different ages and genders with different driving experiences [31, 32] and other personal factors. Also, there are multiple factors we did not take into account when simulating the AR HUDs. One is the virtual image distance (VID), which influences cognitive tunneling [33, 34]. Another aspect that might be interesting to simulate is the color of the HUD elements, which can affect the visibility of the HUD elements [35]. In general, there are numerous studies about AR HUDs and their influence on driving behaviour [36] and the driver's mental load [37], which might be integrated into this project later on. While the passenger perspective view in CARLA is intended for debugging and simulation visualization, a future version could show *actual* HUD element functionality (e.g., navigation) for end-users, for example, in the context of a user study.

VII. Discussion

In this work, we presented an implementation of *HUD-SUMO* to study the effect of AR HUDs on a large scale. While our simulation implementation is grounded in empirical data, we acknowledge that scientific data regarding certain factors can be scarce. This scarcity highlights a potential limitation in how scientific results are often reported—emphasizing observed differences without providing quantitative measures. Consequently, some of the numerical values in our simulation are based on educated estimations rather than direct extraction from studies and statistics. Despite this, we argue that using these estimations is the most appropriate way to study the large-scale effects we are investigating. The extensive, resulting datasets suggest that spatiotemporal automotive user interface analysis [38] could facilitate future simulation analysis.

VIII. License & Maintenance

The code is available on GitHub under the MIT license, facilitating open use, modification, and collaborative input from the community. Our maintenance plan involves regular checks and timely updates to stay aligned with SUMO's latest versions while preserving compatibility with the last major release. We welcome community contributions such as bug fixes and feature improvements, which the core team will review to ensure consistency and quality.

Acknowledgment

We thank the SUMO developers for their support.

References

[1] H. E. Rosen, I. Bari, N. Paichadze, M. Peden, M. Khayesi, J. Monclús, and A. A. Hyder, "Global road safety 2010–18: an analysis of global status reports," *Injury*, 2022.

[2] C. Chauvin, F. Said, and S. Langlois, "Augmented reality hud vs. conventional hud to perform a navigation task in a complex driving situation," *Cognition, Technology & Work*, vol. 25, pp. 217–232, 2023. [Online]. Available: https://link.springer.com/article/10.1007/s10111-023-00725-7

[3] K. Bauerfeind, J. Drüke, L. Bendewald, and M. Baumann, "How does navigating with augmented reality information affect drivers' glance behaviour in terms of attention allocation?" *Frontiers in Virtual Reality*, vol. 3, 2022. [Online]. Available: https://www.frontiersin.org/journals/virtual-reality/articles/10.3389/frvir.2022.930117

[4] A. Feierle, D. Beller, and K. Bengler, "Head-up displays in urban partially automated driving: Effects of using augmented reality," *2019 IEEE Intelligent Transportation Systems Conference (ITSC)*, pp. 1877–1882, 2019. [Online]. Available: https://ieeexplore.ieee.org/document/8917472

[5] M. Colley, B. Eder, J. O. Rixen, and E. Rukzio, "Effects of semantic segmentation visualization on trust, situation awareness, and cognitive load in highly automated vehicles," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, ser. CHI '21. New York, NY, USA: Association for Computing Machinery, 2021. [Online]. Available: https://doi.org/10.1145/3411764.3445351

[6] R. Currano, S. Y. Park, D. J. Moore, K. Lyons, and D. Sirkin, "Little road driving hud: Heads-up display complexity influences drivers' perceptions of automated vehicles," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. New York, NY, USA: Association for Computing Machinery, 2021. [Online]. Available: https://doi.org/10.1145/3411764.3445575

[7] P. Jansen, M. Colley, T. Pfeifer, and E. Rukzio, "Visualizing imperfect situation detection and prediction in automated vehicles: Understanding users' perceptions via user-chosen scenarios," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 104, pp. 88–108, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1369847824001141

[8] N. Martelaro, D. Sirkin, and W. Ju, "Daze: a real-time situation awareness measurement tool for driving," in *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, ser. AutomotiveUI '15. New York, NY, USA: Association for Computing Machinery, 2015, p. 158–163. [Online]. Available: https://doi.org/10.1145/2809730.2809753

[9] SUMO, "SUMO: Simulation of Urban MObility," https://www.eclipse.org/sumo/, accessed: 2024-12-25.

[10] CARLA, "CARLA, autonomous driving simulator," https://carla.org/, accessed: 2024-12-25.

[11] T. Hosokawa, H. Hashimoto, T. Tsui, K. Saito, T. Igarashi, and A. Hirao, "Effect of luminance of head-up displays on recognition of visual objects on roads," *IATSS Research*, vol. 48, pp. 417–426, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0386111224000414

[12] Y. Zhang, T. Yang, X. Zhang, Y. Zhang, and Y. Sun, "Effects of full windshield head-up display on visual attention allocation," *Ergonomics*, vol. 64, pp. 1310–1321, 2021. [Online]. Available: https://doi.org/10.1080/00140139.2021.1912398

[13] K. S. Pečečnik, S. Tomažič, and J. Sodnik, "Design of head-up display interfaces for automated vehicles," *International Journal of Human-Computer Studies*, vol. 177, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1071581923000691

[14] X. Ma, M. Jia, Z. Hong, A. P. K. Kwok, and M. Yan, "Does augmented-reality head-up display help? a preliminary study on driving performance through a vr-simulated eye movement analysis," *IEEE Access*, vol. 9, pp. 129 951–129 964, 2021. [Online]. Available: https://ieeexplore.ieee.org/document/9536587

[15] R. Eyraud, E. Zibetti, and T. Baccino, "Allocation of visual attention while driving with simulated augmented reality," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 32, pp. 46–55, 2015. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1369847815000741

[16] D. Ren, T. Goldschwendt, Y. Chang, and T. Höllerer, "Evaluating wide-field-of-view augmented reality with mixed reality simulation," *2016 IEEE Virtual Reality (VR)*, pp. 93–102, 2016. [Online]. Available: https://ieeexplore.ieee.org/document/7504692

[17] M. Yu, C. Li, J. Wu, and H. Wang, "Exploring the attention level of ar-hud interface elements based on driving scenarios," *14th International Conference on Mechanical and Intelligent Manufacturing Technologies*, pp. 117–121, 2023. [Online]. Available: https://ieeexplore.ieee.org/document/10199531

[18] R. Lagoo, V. Charissis, and D. K. Harrison, "Mitigating driver's distraction: Automotive head-up display and gesture recognition system," *IEEE Consumer Electronics Magazine*, vol. 8, pp. 79–85, 2019. [Online]. Available: https://ieeexplore.ieee.org/document/8822522

[19] Y.-C. Liu and M.-H. Wen, "Comparison of head-up display (hud) vs. head-down display (hdd): driving performance of commercial vehicle operators in taiwan," *International Journal of Human-Computer Studies*, vol. 61, pp. 679–697, 2004. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1071581904000497

[20] Y.-C. Liu, "Effects of using head-up display in

automobile context on attention demand and driving performance," *Displays*, vol. 24, pp. 157–165, 2003. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0141938204000022

[21] P. Philip, P. Sagaspe, N. Moore, J. Taillard, A. Charles, C. Guilleminault, and B. Bioulac, "Fatigue, sleep restriction and driving performance," *Accident Analysis & Prevention*, vol. 37, pp. 473–478, 2005. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0001457505000114

[22] Y. Hwang, B.-J. Park, and K.-H. Kim, "Effects of augmented-reality head-up display system use on risk perception and psychological changes of drivers," *ETRI Journal*, vol. 38, pp. 757–766, 2016. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.4218/etrij.16.0115.0770

[23] J. Goldsworthy, C. N. Watling, C. Rose, and G. Larue, "The effects of distraction on younger drivers: A neurophysiological perspective," *Applied Ergonomics*, vol. 114, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0003687023001850

[24] H. Kim and J. L. Gabbard, "Assessing distraction potential of augmented reality head-up displays for vehicle drivers," *Human Factors and Ergonomics Society*, vol. 64, pp. 852–865, 2022. [Online]. Available: https://journals.sagepub.com/doi/epub/10.1177/0018720819844845

[25] C. Merenda, C. Suga, J. L. Gabbard, and T. Misu, "Effects of "real-world" visual fidelity on ar interface assessment: A case study using ar head-up display graphics in driving," *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 145–156, 2019. [Online]. Available: https://ieeexplore.ieee.org/document/8943689

[26] C. Maag, N. Schömig, F. Naujoks, I. Karl, A. Keinath, and A. Neukum, "Measuring workload effects of augmented reality head-up displays using detection response task," *Transportation Reasearch Part F: Traffic Psychology and Behaviour*, vol. 92, pp. 201–219, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1369847822002765

[27] M. Gastaldi, R. Rossi, and G. Gecchele, "Effects of driver task-related fatigue on driving performance," *Procedia - Social and Behavioral Sciences*, vol. 111, pp. 955–964, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877042814001311

[28] DLR, "Output," 2024. [Online]. Available: https://sumo.dlr.de/docs/Simulation/Output/index.html

[29] J. S. Park, J. C. O'Brien, C. J. Cai, M. R. Morris, P. Liang, and M. S. Bernstein, "Generative agents: Interactive simulacra of human behavior," in *In the 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23)*, ser. UIST '23. New York, NY, USA: Association for Computing Machinery, 2023.

[30] "SUMO FCD Output Documentation," https://sumo.dlr.de/docs/Simulation/Output/FCDOutput.html, accessed: 2024-12-25.

[31] E. Mouloua, Mustapha abd Rinalducci, J. Smither, and J. C. Brill, "Effect of aging on driving performance," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 48, 2004. [Online]. Available: https://journals.sagepub.com/doi/abs/10.1177/154193120404800206

[32] H. Muslim, M. Itoh, C. K. Liang, J. Antona-Makoshi, and N. Uchida, "Effects of gender, age, experience, and practice on driver reaction and acceptance of traffic jam chauffeur systems," *Scientific Reports*, vol. 11, 2021. [Online]. Available: https://www.nature.com/articles/s41598-021-97374-5

[33] J. Pullukat, S. Tanaka, and J. Jiang, "Effects of image distance on cognitive tunneling with augmented reality head up displays," *Automotive/Vehicular Displays and HMI Technologies*, vol. 51, pp. 1427–1430, 2020. [Online]. Available: https://sid.onlinelibrary.wiley.com/doi/10.1002/sdtp.14155

[34] T. Instruments, "The importance of a longer vid for ar huds," 2021. [Online]. Available: https://www.ti.com/lit/wp/dlpa117a/dlpa117a.pdf

[35] X. Zhong, Y. Cheng, and L. Tian, "Color visibility evaluation of in-vehicle ar-hud under different illuminance," *Proceedings of the International Conference on Information Economy, Data Modeling and Cloud Computing*, 2022. [Online]. Available: https://eudl.eu/doi/10.4108/eai.17-6-2022.2322686

[36] P. A. Yamin, J. Park, and H. K. Kim, "In-vehicle human–machine interface guidelines for augmented reality head-up displays: A review, guideline formulation, and future research directions," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 104, pp. 266–285, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1369847824001268

[37] K. Bauerfeind, J. Drüke, J. Schneider, A. Haar, L. Bendewald, and M. Baumann, "Navigating with augmented reality – how does it affect drivers' mental load?" *Applied Ergonomics*, vol. 94, p. 103398, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0003687021000454

[38] P. Jansen, J. Britten, A. Häusele, T. Segschneider, M. Colley, and E. Rukzio, "Autovis: Enabling mixed-immersive analysis of automotive user interface interaction studies," in *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, ser. CHI '23. New York, NY, USA: Association for Computing Machinery, 2023. [Online]. Available: https://doi.org/10.1145/3544548.3580760