REAL VS. SIMULATED SURROUNDING TRAFFIC – DOES IT MATTER?

Dominik Muehlbacher [1], Lena Rittger [2] & Christian Maag [3]

(1) : Center for Traffic Sciences
University of Wuerzburg
Roentgenring 11
97070 Wuerzburg
Germany
+49-931-3819051
muehlbacher@psychologie.uni-wuerzburg.de

(2) : Adam Opel AG
65422 Ruesselsheim
Germany
+49-6142-7-69912
lena.rittger@de.opel.com

(3): WIVW GmbH
Robert-Bosch-Straße 4
97072 Veitshoechheim
Germany
+49-931-78009114
maag@wivw.de

Abstract – Multi-driver simulators include several human participants who are able to interact in the same situation at the same time. The present study demonstrates the benefit of this simulation via a comparison to single-driver simulations, which contain one participant and simulated surrounded traffic.

In total, N=20 drivers participated. Each participant completed a run in both driving simulations. Half of the drivers were assisted by a traffic light assistant. This system informs the driver about economic driving behaviour when approaching traffic lights. In some cases the system recommends to drive slowly or to brake at large distances in front of the traffic light.

In the multi-driver simulation, the participants follow the system's recommendations to a lesser extent compared to driving in the single-driver simulation. Additionally, driving in the multi-driver simulation is rated as more realistic compared to the single-driver simulation.

These results show the importance and the benefit of the multi-driver simulation. The multi-driver simulation is an appropriate tool for questions regarding interactions between several drivers.

Key words: connected driving simulation, methodology, driver assistance systems.

1. Introduction

For a long time, driving simulators have been used successfully for research in traffic sciences. By means of this method, a participant steers a virtual vehicle in a simulated environment. The surrounding traffic is realized via simulated driver models. Recently, advancements in driver simulators have allowed for a multi-driver simulation, which is an enhancement of the traditional single driving simulator [Han1; Hee1; Maa1; Mue1; Mue2]. Using this linked driving simulation, several human participants can drive in the same situation at the same time under controlled conditions.

The use of several human drivers contributes to a higher external validity: Driving behaviour of human participants is more realistic compared to the behaviour of the simulated traffic generated by the driver models. Additionally, the participants know that the surrounding traffic consists of real drivers with human behaviour and cognitions and not of simulated computer models. [Fri1] showed that the presence of human-controlled surrounding traffic in driving simulators is important for participants' behaviour: Participants who thought that another vehicle was controlled by another participant behaved more cooperatively than participants who thought it was controlled by a computer (e.g. allowed another vehicle to merge into their lane).

Human-controlled and computer-controlled agents were also compared in other kinds of virtual environments. Several studies on human behaviour in video games demonstrate higher presence (i.e. the illusion to be physically in a mediated environment [Min1]) when participants are playing against human-controlled opponents compared to playing against computer-controlled opponents [e.g. Wei1; Rav1].

However, the participation of several human drivers at the same time has a disadvantage: Compared to a single-driver simulation with standardized surrounding traffic, several human drivers reduce the controllability of the experimental situation. Hence, it is important to examine for which research purposes each driving simulation is more applicable.

One application of driving simulators is the evaluation of driver assistant systems. A system which has been the focus of much research in driving simulators in recent years is the traffic light assistant [Dui1; Kra1]. This system informs the driver about economic driving behaviour when approaching traffic lights. In some cases the system recommends to drive slowly or to brake at large distances in front of the traffic light. A previous study by [Mue2] showed that following drivers without traffic light assistant could be annoyed by this driving behaviour. Therefore, assisted drivers might worry about hindering the drivers following behind them. This could result in a weak compliance to the system recommendations. In the present study it was analysed if compliance to the recommendations of the traffic light assistant depends on the presence of surrounding traffic. This was investigated by means of a multi- and a single-driver simulation. It was expected that compliance was independent of surrounding traffic in the single-driver simulation setting, because here the driver is surrounded by simulated driver models which cannot be annoyed. If the effect does not occur in the single-driver simulation but does occur in multi-driver simulation, a benefit of the latter is demonstrated.

2. Methods

2.1. Driving simulation laboratory

The driving simulation laboratory consists of four driving stations with one subject at each driving station (see Figure1).

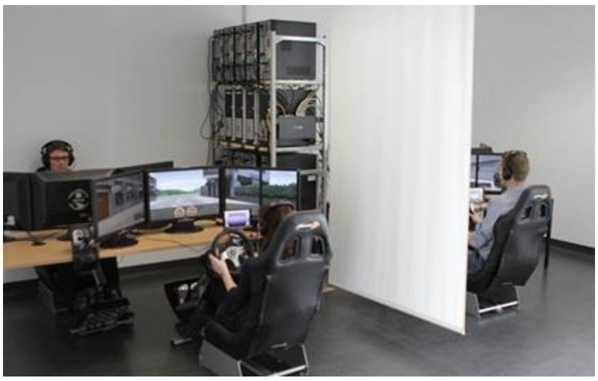

Figure 1: driving stations of the driving simulation laboratory.

The driving simulation laboratory can be used either as a single-driver simulation or as a multi-driver simulation: (1) In the single-driver simulation each participant drives through a separate but identical virtual environment. Only simulated driver models generate the surrounding traffic. (2) In the multi-driver simulation the four participants drive through the same virtual environment. In this virtual environment, the drivers are able to see the vehicles of the other study participants and can react to their behaviour. Only the vehicles of the study participants make up the surrounding traffic.

The visual system of each driving station provides a horizontal field of view of 150 degrees which is shown on three 22″ size LCD-displays with a pixel resolution of 1680x1050. The left, right and rear mirrors are shown in the front view. The drivers control their vehicle via a high-quality PC-game steering wheel with force feedback and accelerate and brake with pedals on the ground. In addition, a 10″ LCD-display with a pixel resolution of 800x480 can be used for visual secondary tasks, HMI-studies or touchpad-based questionnaires. The drivers wear a headset that enables them to hear the sounds of the simulated vehicle and its environment. Furthermore, the operator is able to communicate to the driver(s) in two possible modes: (1) The operator can communicate with one driver or with all drivers simultaneously. (2) The drivers can communicate with the operator. The simulator is run by the software SILAB developed by the Wuerzburg Institute for Traffic Sciences (WIVW GmbH).

2.2. Traffic light assistant

The traffic light assistant aims at increasing traffic efficiency and enhancing traffic flow. While approaching a traffic light, this system informs the driver via a HMI about the optimal driving behaviour (e.g. "drive 20 km/h", "slow down to 30 km/h"; see Figure 2) to reach a green traffic light. To generate these recommendations, the algorithm of the traffic light assistant considered the current and next traffic light phase, participants' driving speed and distance to traffic light. In the HMI, the driving recommendations contained a combination of action and speed recommendations, which were presented as text with distinctive colors. The minimum speed recommendation for approaching the traffic light was 20 km/h. The HMI was presented on the 10″ LCD-display.

The participants were instructed that following the system recommendations is voluntary and not obligatory.

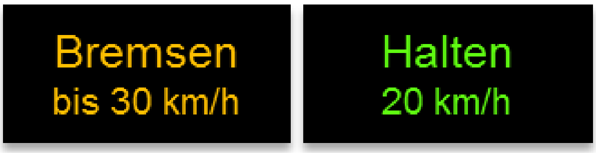

Figure 2: examples for recommendations of the traffic light assistant in the HMI (on the left: slow down to 30 km/h ; on the right: drive 20 km/h).

2.3. Penetration rate

In the multi-driver simulation condition, the penetration rate of the traffic light assistant was 50%. While two drivers were assisted by the system, the other two drivers had no assistance.

In the single-driver simulation, the platoon consisted of one participant and three driver models. While two driver models followed the recommendations of the traffic light assistant, the third driver model was unequipped. It had target velocity of 55 km/h while approaching the traffic light. Therefore, the penetration rate was either 50% or 75%, depending on the equipment of the individual driver.

In both runs, the participants were not informed if the other drivers/models were equipped with the traffic light assistant or not.

2.4. Test scenario

The course was a one-lane urban road. It consisted of eight identical segments: At the beginning of each segment the four vehicles approached an intersection with a traffic light in platoon formation (i.e. in line). The traffic light was timed so that if the drivers travelled at the recommended speed they arrived at the intersection when the light turned green and avoided a stop. If the participant drove faster than recommended they arrived at a red light and had to stop. After crossing the intersection the drivers had to stop at a 'positioning sign' (see Figure 3).

The positioning sign pictured all four vehicles of the platoon (with their different colours). Below each displayed vehicle was a parking space on the road. Each driver had to stop at the designated parking space. After all four drivers had stopped, the driver on the left parking space started to drive towards the next traffic light. The other drivers followed him/her in the prescribed sequence from left to right. In each element, the vehicle order on the positioning sign was different. By means of this method the order within the platoon was controlled and balanced such that each driver experienced each position for an equal number of times.

Figure 3: positioning sign.

2.5. Study design

The main independent variable was the type of driving simulation: single-driver or multi-driver simulation. Each participant completed a session in both driving simulations (within-subjects factor). In the single-driver simulation, each platoon consisted of one human driver and three driver models. In the multi-driver simulation, each platoon consisted of four human drivers. Before each run, the experimenter informed the participants whether they would be using the single-driver or the multi-driver simulation, respectively.

In both runs, the drivers were either assisted by the traffic light assistant or not assisted (between-subjects-factor).

Each run consisted of eight elements - each element included one traffic light at an intersection. The drivers had to approach the traffic light in platoon formation. After each element, the drivers changed positions within the platoon and approached to the next traffic light in another sequence of drivers. By means of this method, each driver was in 2 of 8 approaches each on first, second, third or fourth position in the platoon (within-subjects factors).

2.6. Dependent variables

After each run, the drivers rated different aspects of the run (e.g. "In the virtual world, I felt surrounded by real drivers") on a 7-point scale from 1="disagree" to 7="agree". In a final inquiry at the end of the session, the drivers had to compare both runs in an open-question format.

To assess compliance to the traffic light assistant, the percentage of stops at intersections was calculated. A stop was defined as reaching a driving speed of <1 km/h. Only if the assisted drivers followed the system recommendations, they could avoid a stop at the traffic light. Therefore, the percentage of segments without a stop at the traffic light is an indicator for the system compliance (so-called compliance rate).

2.7. Sample

Four test drivers participated in each session. In total, there were N=20 participants (10 women and 10 men) between 20 and 65 years of age (M= 36.8; SD= 15.6). The participants were recruited via the test driver panel of the WIVW. Prior to the study, all participants were trained with the multi-driver simulation (the training based on [Hof1]) in order to introduce them to the simulator and reduce the probability of simulator sickness. The participants were paid for taking part in the study.

3. Results

3.1. Drivers' judgments

After each run, all drivers rated different aspects of the run in a questionnaire. Several differences between driving in a single-driver simulation and a multi-driver simulation are noticed both from drivers with and without system: According to the participants, the virtual world of the multi-driver simulation is more realistic compared to the single-driver simulation ($t(19)=2.27$; $p=.035$; see Figure 4). Additionally, the driving behaviour of the surrounding traffic is rated as more realistic in the multi-driver simulation ($t(19)=4.24$; $p<.001$). Furthermore, the participants state that they feel observed by the other drivers in a higher degree in the multi-driver simulation ($t(19)=4.53$; $p<.001$).

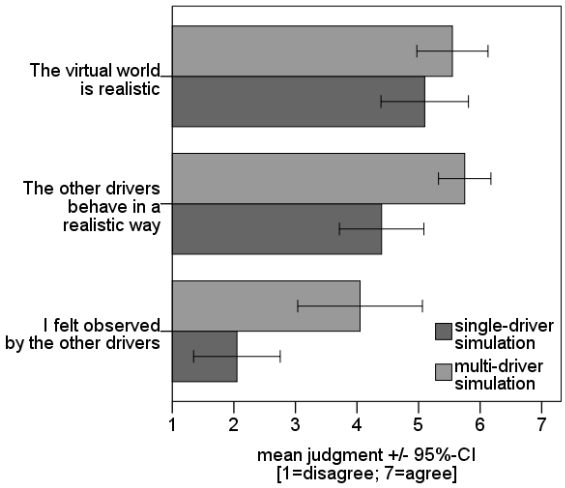

Figure 4: mean subjective judgments for various items in the questionnaire for multi-driver and single-driver simulation.

3.2. System compliance

In the single-driver simulation the compliance rate lies between 80% and 90% on average and is independent from the position ($F(3, 27)=1.00$; $p=.864$; see Figure 5). However, the position has an effect ($F(3, 27)=5.21$; $p=.006$) in the multi-driver simulation: While the compliance rate is approx. 20% on position 1, it increases gradually to 80% at position 4.

In the direct comparison between single-driver simulation and multi-driver simulation drivers in the multi-driver simulation have a lower compliance rate on position 1 ($t(9)=3.97$; $p=.003$) and position 2 ($t(9)=2.86$; $p=.019$). In position 3 ($t(9)=1.50$; $p=.168$) and position 4 ($t(9)=1.00$; $p=.343$) are no significant differences.

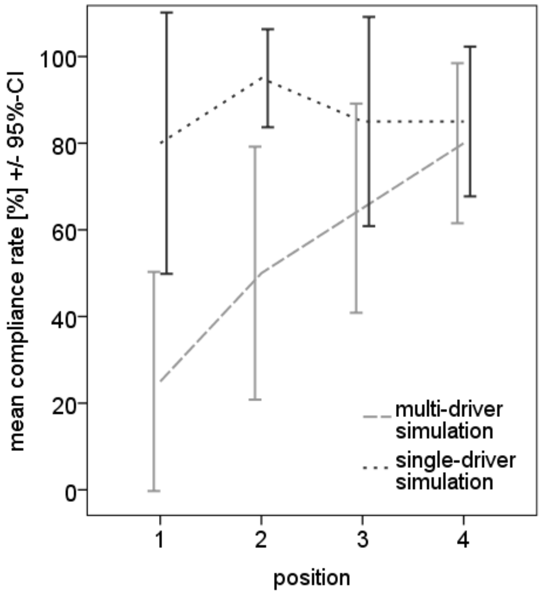

Figure 5: mean compliance rate for each position in the platoon in multi-driver and single-driver simulation.

4. Discussion

The present study analyses if compliance to the recommendations of a traffic light assistant depends on the presence and type (real vs. simulated) of surrounding traffic. For this purpose, drivers performed one run in the multi-driver simulation and one run in the single-driver simulation. The runs occurred in platoon formation, four vehicles drive in line.

First, the participants notice several differences between both runs. In total, the run in the multi-driver simulation with human surrounding traffic is rated as more realistic compared to the run in the single-driver simulation with simulated surrounding traffic. This result underlines the external validity of the multi-driver simulation.

Additionally, the type of surrounding traffic effects the participants' compliance to the traffic light assistant. When driving in front of two or three human drivers, the participants do follow the system's recommendations to a lesser extent compared to driving in front of one or no human drivers. In contrast, when driving in front of simulated drivers there is no effect of the number of vehicles driving behind. The reason for this behaviour could be that assisted drivers might worry about hindering the drivers following behind them.

These results show the importance and the benefit of the multi-driver simulation. Compared to a single-driver simulation, the external validity is enhanced and driving is more realistic. In particular, the multi-driver simulation is an appropriate tool for research questions regarding interactions between several drivers.

5. Acknowledgements

This study was performed in the scope of the German project UR:BAN (Urban Space: User oriented assistance systems and network management), funded by the Federal Ministry of Economics and Energy, due to a decision of the German Bundestag.

6. References

[Dui1] Duivenvoorden K. Roadside versus in-car speed support for a green wave: a driving simulator study, Master's Thesis, University of Twente. 2007.

[Fri1] Friedrich M., Nause D., Heesen M., Keich A., Kelsch J., Baumann M., Vollrath M. Evaluation und Validierung des MoSAIC-Fahrsimulators. Presentation at the 55. Tagung experimentell arbeitender Psychologen, Vienna. 2013.

[Han1] Hancock P. A., De Ridder S. N. Behavioural accident avoidance science: understanding response in collision incipient conditions. In Ergonomics. 46(12): 1111-1135, 2003.

[Hee1] Heesen M., Baumann M., Kelsch J., Nause D., Friedrich, M. Investigation of Cooperative Driving Behaviour during Lane Change in a Multi-Driver Simulation Environment. In D. De Waard, K. A. Brookhuis, F. Dehais, C. Weikert, S. Röttger, D. Manzey, S. Biede, F. Reuzeau, P. Terrier (Eds.), Human Factors of Systems and Technology. Toulouse. Available under http://hfes-europe.org. 2012.

[Hof1] Hoffmann S., Buld S. Darstellung und Evaluation eines Trainings zum Fahren in der Fahrsimulation. In VDI-Gesellschaft Fahrzeug- und Verkehrstechnik (Ed.), Integrierte Sicherheit und Fahrerassistenzsysteme (pp. 113-132). Düsseldorf: VDI Verlag. 2006.

[Kra1] Krause M., Bengler K. Traffic Light Assistant – Driven in a Simulator. In R. Toledo-Moreo, L. M. Bergasa, M. Á. Sotelo (Eds.), Proceedings of the 2012 International IEEE Intelligent Vehicles Symposium Workshops. 2012.

[Min1] Minsky M. Telepresence. In Omni. 2(9): 45-51, 1980.

[Maa1] Maag C. Emerging Phenomena During Driving Interactions. In E. Mitleton-Kelly (Ed.), Co-evolution of Intelligent Socio-technical Systems (pp. 185-217). Berlin: Springer. 2012.

[Mue1] Muehlbacher D., Zimmer J., Fischer F., Krueger H.-P. The multi-driver simulator – a new concept of driving simulation for the analysis of interactions between several drivers. In D. de Waard, N. Gérard, L. Onnasch, R. Wiczorek, D. Manzey (Eds.), Human Centred Automation (pp. 147-158). Maastricht, the Netherlands: Shaker Publishing. 2011.

[Mue2] Muehlbacher D., Fischer F. The multi-driver simulation as a new method for researching driver behavior and traffic. Presentation at the Driving Simulation Conference, Paris. 2012.

[Mue3] Muehlbacher D., Fischer F., Buld S., Totzke I., Krueger H.-P. The multi-driver simulation as a tool for the evaluation of traffic efficiency-orientated driver-assistance systems. Presentation at the 5th International Conference on Traffic and Transport Psychology, Groningen. 2012.

[Rav1] Ravaja N., Saari T., Turpeinen M., Laarni J., Salminen M., Kivikangas M. Spatial Presence and Emotions during Video Game Playing: Does It Matter with Whom You Play? In Presence: Teleoperators and Virtual Environments. 15(4): 381-392, 2006.

[Wei1] Weibel D., Wissmath B., Habegger S., Steiner Y., Groner R. Playing online games against computer- vs. human-controlled opponents: Effects on presence, flow, and enjoyment. In Computers in Human Behavior. 24(5): 2274-2291, 2008.