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From Concept to Action - Measuring General and Applied Mental Models in the Context of Automated Driving

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Abstract: This paper presents a research concept for comparing general and applied mental models in automated driving, with a focus on the transition between automation levels. The research concept measures general and applied mental models, gaze movement, and driving performance within a driving simulator. It aims to correlate different mental models with driving performance, to identify how mental models should be characterized for safe interaction, and to provide insights for developing effective training concepts to improve user interaction with automated systems.

1. Introduction

1.1 Mode Confusion and Out-of-Loop Problem

The ongoing automation of vehicles provides drivers with increasing comfort, but also presents significant challenges (SAE International, 2021). Conditionally Automated Driving (CAD, Level 3) (SAE International, 2021) takes over both longitudinal and lateral control of the vehicle and is capable of recognizing system limitations and prompting the driver to take over driving tasks. While CAD allows the driver to disengage from the driving task and focus on activities, such as reading or texting, it also requires the driver to immediately return attention to the driving task and assume full control of the vehicle in the event of a Takeover Request (TOR). Furthermore, CAD is only available under certain conditions, so that in other cases only partially automated driving (PAD, Level 2) or even no automation can be activated. PAD (SAE International, 2021) also provides longitudinal and lateral control of the vehicle, with the difference that the driver is responsible for monitoring the system and environment. Transitions between these levels not only create out-of-loop problems for the driver, but also mode confusion (Kurpiers et al., 2020). Thus, it is essential for drivers to perceive and comprehend relevant information to ensure safe operation of automated vehicles. Therefore, individuals require a suitable mental model of the autonomous vehicle (Endsley, 2017).

1.2 Mental Models in the Automated Driving Context

Mental models are cognitive representations of an external reality and necessary for real-world orientation (Johnson - Laird, 1980). They enable the categorization of perceived information, and support the comprehension of goals, processes, as well as performance and limitations of systems (Seppelt & Victor, 2020). They evolve with increasing experience and are continuously adjusted (Beggiato & Krems, 2013).

Mental models can be categorized into three types (Fig. 1): conceptual, general, and applied mental models. In the context of automated driving, these can be explained as follows. *Conceptual mental models* are precise and comprehensive representations (Norman, 1983) of vehicles, including the interaction of all sensors and actuators installed. *General mental models* comprise the theoretically and practically acquired knowledge about the goals, processes, structures, and limitations of the vehicles (Seppelt & Victor, 2020) and reflect the driver's understanding of their functions and limitations. The driver's general mental model directs the allocation of attention and thus influences the perception of information, which in turn activates the *applied mental model* (Seppelt & Victor, 2020). The applied mental model is represented by the situation awareness, i.e., the perception, understanding, and projection of a situation, and is reflected in the driver's behavior. However, it is possible that the general mental model and the applied mental model may not align.

1.3 Measurement of Mental Models

Several qualitative and quantitative methods exist for measuring mental models, each with specific advantages and limitations (Beggiato, 2015; Bellet et al., 2009; Kearney & Kaplan, 1997; Richardson et al., 2019; Tergan, 1986). While qualitative methods better represent the development process and individual differences in mental models, quantitative methods provide statistical comparability.

In the field of automated driving, research focuses on investigating the evolution of general mental models with increasing practical experience, depending on the accuracy of the initial vehicle description (Beggiato & Krems, 2013; Beggiato et al., 2015; Blömacher et al., 2018, 2020; Forster et al., 2019; Gaspar et al., 2021). Mental models were usually measured objectively through pre- and post-drive questionnaires that cover some driving functions, limitations, and parts of the interaction concept. However, there has been a lack of comparative analysis between subjectively recorded general mental models and applied mental models, as well as

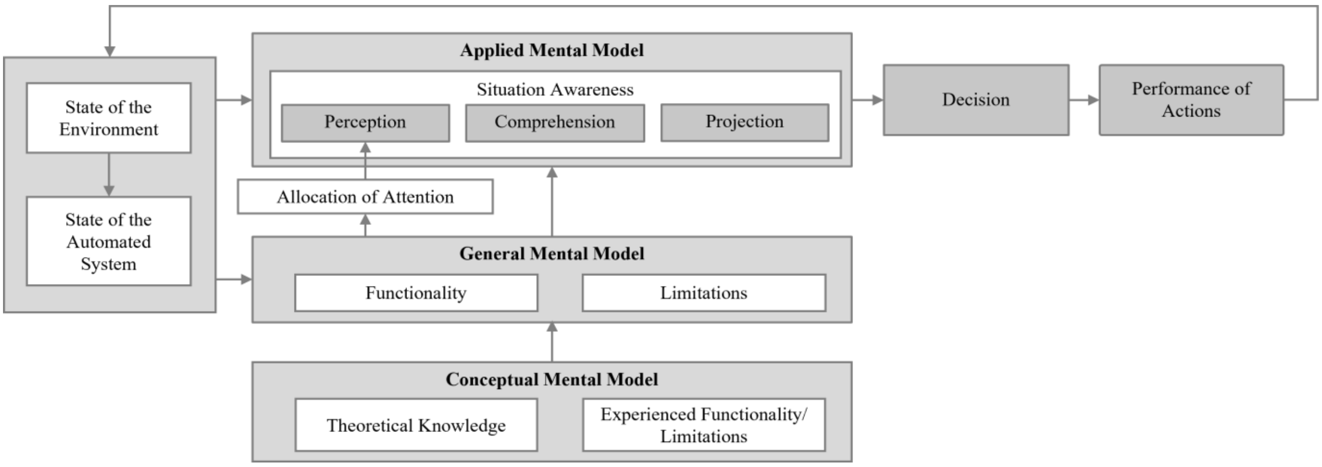

Fig. 1*. Conceptual, general and applied mental models in the context of automated driving (based on: Endsley, 2015, 2017; Norman, 1983; Seppelt & Victor, 2020)*

the resulting driving performance. Additionally, mental models have primarily been described for a single level of automation or driver assistance system, rather than the entire automated driving system.

2. Research Objective

Given the research gap described above, this paper presents a research concept that enables the measurement and comparative evaluation of the general and applied mental model of the automated driving system and the resulting behavior represented by gaze movement and driving performance. In particular, the change between the automation levels is addressed. The resulting data will provide insights on how a mental model should be characterized to ensure safe interaction with the automated driving system. Based on this, the results will enable the development of a training concept for the education of future users.

3. Study design for measuring general and applied mental models

3.1 Dependent, Independent, and Confounding Variables and Measurement Methodologies

The dependent variables to be measured include situation awareness resulting from the applied mental model, as well as the driver's behavior in terms of gaze movement and driving performance (Zhang et al., 2021). Situation awareness is objectively assessed using the Situational Awareness Global Assessment Technique (SAGAT) (Endsley, 1988). The driver's gaze movement is measured using eye tracking (Forster et al., 2019). In order to quantify driving performance, reaction times, time to collision, braking and acceleration behavior, as well as steering behavior are extracted from the driving data (Müller, 2020).

The initial general mental model as measured using the Structural Laying Technique (Scheele & Groeben, 2010) serves as the independent variable between participants. The level of automation activated (Level 0, Level 2, or Level 3) serves as the independent variable that varies within a participant.

Confounding variables include socio-demographic characteristics, driving experience, and experience with automated driving functions, and are collected through questionnaires. Furthermore, reaction time is measured using a stimulus-response test (Matheus & Svegliato, 2013) and motion sickness is assessed pre- and post-driving using the Simulator Sickness Questionnaire (Kennedy et al., 2009).

3.2 Experimental Environment

To create a safe testing environment and capture the applied mental model represented by situation awareness using SAGAT, a fixed-base driving simulator with 360° simulation is selected. The SILAB simulation software is used to conduct a continuous drive with an automated driving system in which the participants experience the transition between automation level 0, 2, and 3 (Fig. 2). Reasons for the level transitions are system limitations such as road section category, roadworks or inappropriate maximum speed limitation.

3.3 Procedure

After informing the participants about the objectives and procedures of the experiment, socio-demographic characteristics, driving experience, experience with automated driving functions, and individual reaction times are recorded. The general mental model is then captured using the Structural Laying Technique. Following this, the participants are given a short introduction on how to operate the vehicle, including the activation and deactivation of the different levels of automation. Simulator sickness is then assessed before participants are equipped with the eye-tracking device and instructed to enter the driving simulator. After a ten-minute familiarization phase, the continuous automated drive begins. During the drive, participants are required to play games on their smartphones whenever it is allowed to engage in a non-driving-related task. Shortly before each level transition, the simulation is paused and the applied mental model, represented by the situation awareness, is assessed using SAGAT. Gaze movement and driving performance are recorded throughout the whole drive. At the end, the participants' simulator sickness status is checked in

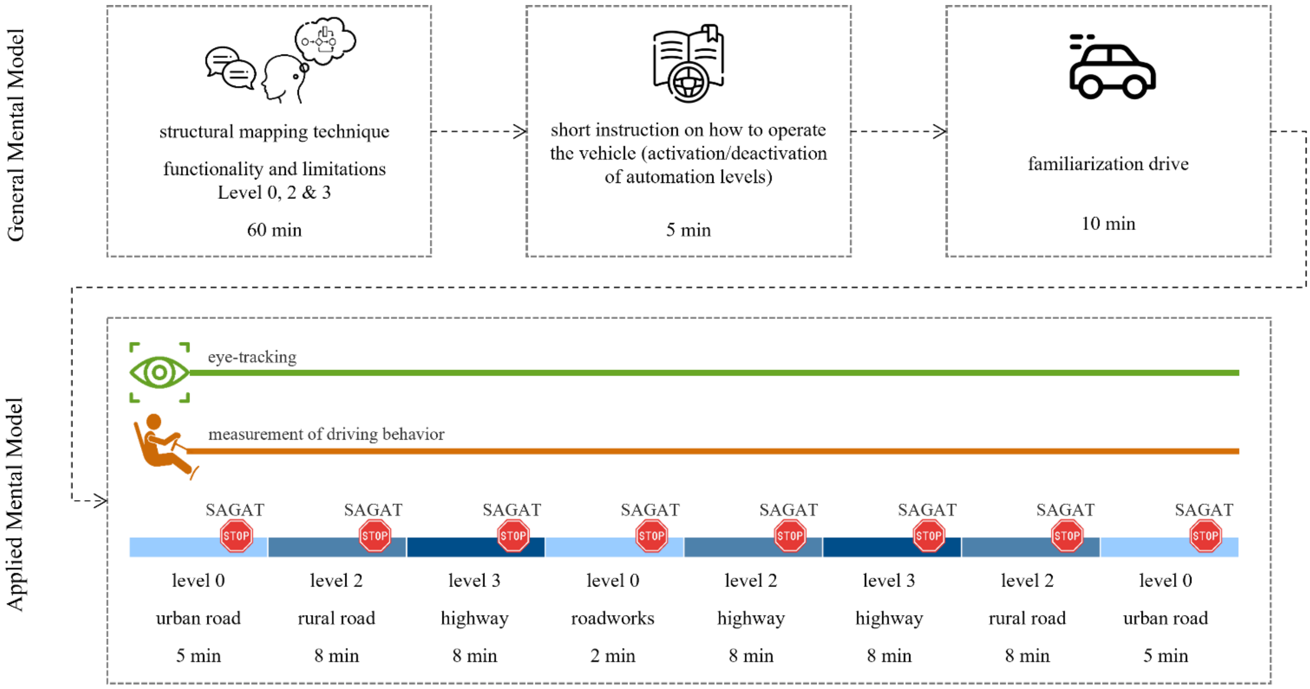

Fig. 2. *Study design for measuring general and applied mental models*

order to exclude participants significantly affected by simulator sickness.

4. Advantages and Limitations

Although the validity of the proposed research concept has not yet been tested, this theoretically sound approach provides a way to collect and compare general and applied mental models for automated driving systems. The results are limited by the reduction in realism due to the implementation within a driving simulator. However, an objective measurement of situational awareness using SAGAT is only feasible within a simulation environment (Endsley, 1988). Furthermore, since the research concept provides a relative comparison of mental models, the results can be used without restrictions.

5. Conclusions and Future Work

This paper presents a research concept for measuring the general mental model, applied mental model, as well as the resulting gaze movement and driving performance while driving with an automated vehicle, with special focus on the transition between the automation levels. The collected data will provide insights on how a general mental model should be characterized in order to ensure safe interaction with automated vehicles. This will serve as a baseline for developing training concepts to support future drivers. The proposed research concept will be validated through user studies in the next step.

References

Beggiato, M. (2015). *Changes in motivational and higher level cognitive processes when interacting with in-vehicle automation* [Dissertation]. TU Chemnitz, Chemnitz.

Beggiato, M., & Krems, J. F. (2013). The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. *Transportation Research. Part F, Traffic Psychology and Behaviour*, *18*, 47–57. https://doi.org/10.1016/j.trf.2012.12.006

Beggiato, M., Pereira, M., Petzoldt, T., & Krems, J. F. (2015). Learning and development of trust, acceptance and the mental model of ACC. A longitudinal on-road study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *35*(1–3), 75–84. https://doi.org/10.1016/j.trf.2015.10.005

Bellet, T., Bailly-Asuni, B., Mayenobe, P., & Banet, A. (2009). A theoretical and methodological framework for studying and modelling drivers' mental representations. *Safety Science*, *47*(9), 1205–1221. https://doi.org/10.1016/j.ssci.2009.03.014

Blömacher, K., Nöcker, G., & Huff, M. (2018). The role of system description for conditionally automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *54*, 159–170. https://doi.org/10.1016/j.trf.2018.01.010

Blömacher, K., Nöcker, G., & Huff, M. (2020). The evolution of mental models in relation to initial information while driving automated. *Transportation Research Part F: Traffic Psychology and Behaviour*, *68*(1), 198–217. https://doi.org/10.1016/j.trf.2019.11.003

Endsley, M. (1988). Situation Awareness Global Assessment Technique (SAGAT). *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference (S. 789–795).*

Endsley, M. (2015). Situation Awareness Misconceptions and Misunderstandings. *JOURNAL of COGNITIVE ENGINEERING and DECISION MAKING*, *9*(1), 4–32. https://doi.org/10.1177/1555343415572631

Endsley, M. (2017). From Here to Autonomy. *HUMAN FACTORS*, *59*(1), 5–27. https://doi.org/10.1177/0018720816681350

Forster, Y., Hergeth, S., Naujoks, F., Beggiato, M., Krems, J. F., & Keinath, A. (2019). Learning and Development of Mental Models during Interactions with Driving Automation: A Simulator Study. In *Proceedings of the 10th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design: driving assessment 2019* (pp. 398–404). University of Iowa. https://doi.org/10.17077/drivingassessment.1724

Gaspar, J. G., Carney, C., Shull, E., & Horrey, W. J [W. J.] (2021). Mapping drivers' mental models of adaptive cruise control to performance. *Transportation Research. Part F, Traffic Psychology and Behaviour*, *81*, 622–638. https://doi.org/10.1016/j.trf.2021.07.012

Johnson-Laird, P. N. (1980). Mental Models in Cognitive Science. *Cognitive Science*, *4*(1), 71–115. https://doi.org/10.1207/s15516709cog0401_4

Kearney, A. R., & Kaplan, S. (1997). Toward a Methodology for the Measurement of Knowledge Structures of Ordinary People. *Environment and Behavior*(Vol. 29 No.5), 579–617.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (2009). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*, *3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

Kurpiers, C., Biebl, B., Mejia Hernandez, J., & Raisch, F. (2020). Mode Awareness and Automated Driving—What Is It and How Can It Be Measured? *INFORMATION*, *11*(5), 277. https://doi.org/10.3390/info11050277

Matheus, C. C., & Svegliato, J. (2013). Stimulus-response tests: An applied demonstration: Demonstration paper. In I. Staff (Ed.), *2013 IEEE Seventh International Conference on Research Challenges in Information Science* (pp. 1–2). IEEE. https://doi.org/10.1109/RCIS.2013.6577740

Müller, A. L. (2020). *Auswirkungen von naturalistischen fahrfremden Tätigkeiten während hochautomatisierter Fahrt* [Dissertation]. TU Darmstadt, Darmstadt. https://doi.org/10.25534/TUPRINTS-00011342

Norman, D. A. (1983). Some Observations on Mental Models. In D. Gentner & A. L. Stevens (Eds.), *Mental Models.* Psychology Press.

Richardson, N. T., Sprung, A., & Michel, B. (2019). Entwicklung und Validierung eines Fragebogens zur Erfassung des mentalen Modells für das hochautomatisierte Fahren. *Zeitschrift Für Arbeitswissenschaft*, *73*(3), 312–323. https://doi.org/10.1007/s41449-019-00157-y

SAE International (2021). *Surface Vehicle Recommended Practice:* Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (J3016_202104).

Scheele, B., & Groeben, N. (2010). Dialog-Konsens-Methoden. In G. Mey & K. Mruck (Eds.), *Handbuch qualitative Forschung in der Psychologie* (1. Auflage, pp. 506–523). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-92052-8_36

Seppelt, B., & Victor, V. W. (2020). Driver's Mental Model of Vehicle Automation. In D. L. Fisher, W. J. Horrey, J. D. Lee, & M. A. Regan (Eds.), *Handbook of human factors for automated, connected, and intelligent vehicles* (pp. 55–66). CRC Press.

Tergan, S. (1986). *Modelle der Wissensrepräsentation als Grundlage Qualitativer Wissensdiagnostik. Beiträge Zur Psychologischen Forschung Ser: v.7*. VS Verlag fur Sozialwissenschaften GmbH.

Zhang, T., Kaber, D., & Zahabi, M. (2021). Using situation awareness measures to characterize mental models in an inductive reasoning task. *Theoretical Issues in Ergonomics Science*, 1–24. https://doi.org/10.1080/1463922X.2021.1885083