Modeling Situation Awareness: The Impact of Ecological Interface Design on Driver's Response Times

Thomas Friedrichs, Andreas Lüdtke
R&D Division Transportation – Human Centered Design
OFFIS – Institute for Information Technology
{friedrichs, luedtke}@offis.de

***Abstract*— Endsley's Situation Awareness (SA) theory and a variety of SA-measurement methods like SAGAT and SPAM aim to explain how humans make errors and assess the SA of operators in dynamic workspaces. However, in order to evaluate the impact of future assistance systems on the SA of operators at design time, predictions about operator performance are needed. In this work, existing SA measurement methods are used to construct a cognitive model which predicts driver reaction times on the basis of SA to road and system events. Ecological Interface Design variants will be used as a test case to show how information presentation influences driver performance.**

Keywords-situation awareness; cogntivie systems; evaluation; ecological interface design; response time; dynamic systems.

I. Introduction

Truck platooning is defined as a series of trucks that drive with close distances and automatic longitudinal control. In our case, all trucks are equipped with a cooperative cruise control system which communicates with other trucks in order to cooperatively control the distances and the speed of each truck. Braking maneuvers are executed automatically. All drivers maintain lateral control all the time. The driver of the lead truck uses a conventional cruise control system (with optional sensor based braking assistance) and observes the driving scene. The lead truck driver is also responsible for emergency braking actions. The benefits of driving in a platoon include reduced fuel consumption, better use of the infrastructure and improved safety. Bergenheim et al. provide an overview of platooning systems [1].

However, drivers in a platoon are not in a fully automated setting where no manual actions are needed. They are required to constantly steer the truck. Furthermore, they have to regain full control over the vehicle very quickly if necessary. This can happen if the system reaches its functional limits or a road hazard requires immediate intervention of the driver. Drivers also have to remember when platooning maneuvers like splitting, merging or expanding will happen and need to receive sufficient support with these tasks [2]. Another aspect is that if the system makes actions (e.g., adapts the speed automatically), the driver should not be surprised [2], which is an issue known as "Automation Surprises" [3].

Figure 1. Close-following scene in a platoon.

It is therefore important that the driver maintains a sufficient level of Situation Awareness (SA) which is defined as "*[…] the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*" [4]. SA incorporates three levels: Level 1 is the perception of information, Level 2 is information integration and Level 3 is the projection of the future status. In platooning, the short inter-vehicle distances lead to problems with the visual perception (SA Level 1) of the environment because of the back of the trailer directly in front of the driver (see Figure 1). Thus, drivers miss crucial visual information. Another aspect is that the lateral control is with the driver, while longitudinal control is a system function. Drivers might get bored and uninformed about the driving situation because they are by default not required to drive fully manual (SA Level 2 and 3). Both factors can contribute to human-out-of-the-loop problems because the SA of the driver is impaired. If an operator gets removed from the control loop, the responses get slower and breakdowns or malfunctions might occur [2][5]. Short response times are a crucial factor in driving, because even fractions of a second can make the difference between an accident and avoidance. For example, a truck which moves with a velocity of 80 km/h covers a distance of 22,22 m in one second.

It is assumed that if the driver is in the loop and therefore has a sufficient SA, response times are minimal. Response time is here defined as the time interval from where a certain stimulus is perceived to where a possible action can be executed. It does not include the time from onset until perception, time for motor movement or task completion. It is therefore a "cognitive" response time.

It becomes evident that drivers in a platoon need to receive support in order to maintain a good SA because of the occlusion they are not able to do this themselves. An approach is to offer platooning support in the form of an information system which serves as a "third eye". It supports the drivers so that they can maintain a sufficient level of SA. Such a system will be referred to as a Platooning Support System (PSS). It consists of a HMI that displays information about the system state and the driving context. This information can include:

- Sensor readings
  - Distance readings
  - Vehicle velocity
- Environmental information
  - Weather information
  - Topographic information
  - Road status
- Platooning / navigation information
  - Merge / split maneuvers
  - Accordion maneuvers
  - Route information
  - System status, future actions

It is not sufficient to only display this information; drivers have to understand the variables and the interplay between them in an easy way. A promising way to do this, is to display continuous information about the changes and linkages of relevant information from the environment [6]. This approach is grounded in the margins of the Ecological Interface Design framework, which proved to increase operator knowledge in complex and dynamic environments [7]. For example in electric cars, often the flow of energy is visualized. If the car runs in electric power mode, energy flows from the battery to the engine and when the car brakes, energy flows from the brakes back to the battery. This information presentation offers a good way of informing the driver about a variety of parameters and the status of a complex system in an easy to understand and efficient way.

Continuous information presentation can give drivers the ability to track the changes in an evolving situation, which in turn can lead to a better understanding of the dynamics of the situation. This approach uses functional information of the situation, which is relevant to the driver's goals. In terms of SA, continuous information supports on Level 2 and 3 because the comprehension (Level 2) and projection (Level 3) are supported. This is important because if drivers can anticipate what either the system does in the future or how the road status changes, it is assumed that the response times of the driver to these events decrease. Results from other domains show that such a support can increase SA even in unanticipated situations [8]. PSS therefore should use the continuous information approach for information relevant for safe driving. Relevant variables can include relative distances to the surrounding cars, relative speeds, system status and changes, future system actions and so on.

In contrast to continuous information support, there are situations where immediate actions and warnings are needed. For example, if there is a pressure decrease in one of the trucks tires, the driver needs to get informed immediately. Here, continuous information would be inappropriate. This is because tire pressure rarely gets into a dangerous state and therefore the effort to keep track of continuous information would be too high. This approach is referred to as event-based information presentation. Here, drivers are only informed about a certain status change by a warning sound, message or other indication in the cockpit when an immediate action is necessary. For a close-following scenario in the platooning context, certain information can be visualized using this approach, for example blind spot warnings or changes of the speed limit. A balanced combination of continuous and event-based information presentation is a promising approach to support drivers' SA in close-following and at the same time it reduces the complexity of HMIs.

However, when designing such a system it is not clear if information is better presented in a continuous or event-based way. The traditional way of testing such a system would involve experts, focus groups and most importantly, human testers. The latter are not only the most valuable source of feedback, from a legal perspective, human testing is a requirement for the homologation of a new product like a PSS. The evaluation effort for a PSS is very high, because it is much effort to plan, conduct and analyze tests with human testers. Moreover, dynamic situations are very complex and a variety of scenarios have to be covered, what makes this approach even more complex.

Therefore, the objective of this work is to create a cognitive model of driver SA which predicts response times of a cognitive agent under the influence of visual interface design variants. For this, a traffic simulation is used, which includes a platooning scenario. Experiments with real drivers will be performed to calculate the model fit. Two different HMI designs, which will be developed in the scope of the COMPANION project [9], will serve as test cases. One design will show functional information in a continuous way, the other design will use event-based warnings.

In Section 2, the current state of the art of cognitive modeling in dynamic contexts is described. Section 3 presents related work in Situation Awareness modeling. Section 4 describes the approach. In Section 5, the proposed methodology is explained. The paper concludes with Sections 6 and 7, which cover open issues and a final summary.

II. COGNITIVE MODELS OF HUMAN BEHAVIOR

To be able to profit from user data and at the same time avoid high costs and time consuming test procedures, cognitive architectures like ACT-R have shown to be an alternative way to the classic user testing methods. These models are able to simulate and predict human behavior, even in dynamic and complex environments. Initially such models replicated experiments conducted with humans in order to expand the knowledge about human cognition.

Today, cognitive models are able to produce valid predictions of human behavior even in complex and dynamic use cases like aviation and driving. For example, pilot [10] and driver models [11][12] gained a lot of attention in cognitive modeling. It was shown that the effects of devices like telephones and visual displays on the performance of the driving task can be simulated with a cognitive driver model and a traffic simulation [13][14].

The SA theory involves several cognitive processes. The theory builds upon these cognitive processes to describe how information directs operator performance. SA can help to explain when and why errors occur. However, the SA theory is not able to make predictions about operator performance. It is however possible to measure SA. State of the art methods include SAGAT (Situation Awareness Global Assessment Technique) [15], SPAM (Situation Present Assessment Method) [16] or SART (Situation Awareness Rating Technique) [17]. The SA measurement is often performed within a task simulation. These include driving simulations, flying simulations or air-traffic control simulations. SAGAT was introduced by Endsley to measure the SA of pilots. It is an offline measure where the simulation is stopped and questions about the situation are asked.

In contrast, the SPAM method is an online measure. The simulation does not have to be stopped to query operator SA. While the simulation is running, the operator is presented with a stimulus that indicates that they have to answer a situation related question. The operator decides when he will answer the question after the presentation of the stimulus. When the operator is able to listen and answer the query, he indicates that. Then, the question is asked while the simulation is running permanently. The time from the presentation of the question until the answer is here referred to as response time. Durso et al. state, that if the operator has "*in consciousness the information needed to answer a query*", response time is shorter [16]. Operators would still be able to answer correctly if they are able to search the display or environment for it. In that case, response time would be longer. It could be shown that the SPAM measures response time and accuracy have predictive power and are able to add to the incremental validity of a larger battery of cognitive tests [16].

For this work, the SPAM method itself, and results from existing studies where SPAM was applied, will contribute to the development of the model. Due to the following reasons this approach was chosen: First, SPAM offers performance measures for dynamic contexts. With latencies, such as response times, an important aspect of operator performance is evaluated because it guides how fast operators act. This is especially important for safety critical environments like driving. Second, SPAM is built to attribute to the dynamic characteristics of situations. SPAM does not interrupt the simulation, which underlines the dynamic aspect. Third, it can assess SA of the operators when "*it is successful, rather than only when SA fails*" [16]. These factors attribute to the applicability of SA measurements inside a cognitive architecture.

III. RELATED WORK

The SA theory gained a lot of attention and measurements of operator SA were developed and widely applied in various domains. SAGAT consists of a closed-loop simulation where (in that case) pilots fly a given scenario. At a random point in time, the simulation gets paused and the screen goes black. The pilot has to answer several questions (randomly selected from a larger set) concerning the situation to measure his knowledge. The answers of the pilot are compared to the aspects of the real situation to find out where the differences between the real and the perceived situation are. This method makes it possible to identify the SA elements pilots perceive and process depending on prior identified goals and tasks. Thus, it is possible to assess relevant knowledge of operators in a dynamic context. The development of SA evaluation methods also resulted in a use of this method in the industry where it is used to design new systems, train operators and measure the performance of operators to ensure optimal performance. SAGAT also got transferred to the driving domain where it was used in a variety of studies [18]. There has been work on driver reaction times to unexpected and expected road events, which revealed shorter brake response times for expected events [19].

Baumann and Krems propose that SA construction is comparable to language and text comprehension and state that "In both cases an integrated mental representation of the perceived and processed pieces of information is constructed." [20]. Their algorithmic approach to model SA aims to understand SA as a whole in order to extend the knowledge about the cognitive processes, which attribute to Endsley's initial theory [20]–[22]. Matthews [23] integrated driver's awareness of spatial, temporal, goal and system into a model of SA which is goal oriented and includes strategic, tactical and operational driving. The model aims to understand how modern intelligent transportation systems impact driver performance. Gugerty [24] used direct and indirect measures to assess driver's knowledge of the locations of other cars. This work provides implications about how people maintain SA in dynamic tasks like driving. In another work, Gugerty [25] reviews models and theories of attention, SA, comprehension and multitasking. Measures of SA are also presented. A collection of SA measurements is provided by Gawron where different techniques are presented [26].

IV. PROPOSED APPROACH

To be able to meet the objective of this work, it is planned to complete the following tasks:

1. Analysis of the fundamental cognitive processes which lead to variation in response and retrieval time of operators

2. Development of a theory of how these cognitive processes lead to variances in response times under consideration of continuous and event-based information techniques
3. Implementation of the theory from Step 2 in a cognitive architecture
4. Test of two design variants with the model and a driving simulation and predict response times to road and system events
5. Verification and model fit by an empirical evaluation of the model

It is planned to conduct the work in step 1-3 in two iterations. Starting from a first version, the model will be evaluated along the building process with human data. The question this work should answer is: How can the influence of continuous and event-based information on driver's reaction time to road / system events under partly automated driving be modeled with a cognitive architecture?

A. Significance and Innovation

Although SA helped to get insights about operator performance, to the knowledge of the author, no cognitive model incorporates SA as a foundation for the measurement of specific performance values like response times. Thus, this work extends the state of the art by proposing a method for the computational evaluation of assistance systems under the aspect of operator response time. To date, evaluations of SA are performed manually in complex settings with test personnel. Although the information gain with the existing methods is large, the applicability of these methods in the design process of assistant systems is limited. With cognitive models, design variants can be evaluated before actual user testing to identify presentation techniques, which are suitable for tests with users. Thus, the effort to evaluate such systems would decrease with the evaluation approach, this work offers.

To the knowledge of the author there are no models which allow an evaluation of driver reaction to external events under the consideration of information support from an assistance system. While the idea of system evaluation with cognitive models itself is not new, the approach of practically applying knowledge from existing SA rating techniques is novel and adds a valid contribution to the field. This is because models, which try to model SA in a cognitive architecture, assemble complex relationships between perception, memory and decision making in order to model a large amount of cognitive processes. The approach presented here is based on observations of existing test procedures and aims at the prediction of one specific performance measure (response time) as a resulting measure of SA. Thus, the complexity of the SA theory is limited to one factor, which makes the model building process less complex and manageable.

V. METHODOLOGY

The existing work introduced in the related work part of this proposal will be evaluated. The fundamental cognitive processes will be analyzed and based on this, a theory of how the response time under the influence of continuous and event-based information presentation are constructed, will be developed. This theory will be included in an existing driver model which will be the foundation for the development of the SA model. The driver model was built within the cognitive architecture CASCaS [10][27]. The CASCaS driver model consists of top-down visual attention mechanisms [27], bottom-up visual attention mechanisms are currently under development and will be integrated in the future. The symbolic representations of objects from the environment are transferred into the memory of the driver model. Concerning the Level 1 SA mechanisms, there is considered to be sufficient state of the art cognitive processes already implemented in the CASCaS architecture, so the perceptual part of the model will not be considered. The driver model will serve as a starting point for the exploration of how to include the cognitive processes, which will be developed in the model building process. Furthermore, a driving simulation is used where the cognitive driver model will be placed in. In such a closed-loop simulation, the model will be tailored to the use case in the platooning field. It will be supported by a symbolic representation of the two design variants which include continuous and event-based information presentation. In such a scenario, data will be generated from the model. In another step, the same scenario will be applied with human testers in a driving simulator. From the empirically gained data in this experiment, the model data will be compared to and the model fit will be calculated.

VI. QUESTIONS AND ISSUES

There are some issues which have to be considered. First, having response time as a dependent variable, it is important to examine and control the independent variables which lead to response time as a predictor of SA. Second, factors like experience, motivation and general cognitive capabilities attribute to driver performance. It is not clear at the moment how the interaction between these factors and the impact on performance measures like response time will add to the complexity of the model. Thus, for now it is assumed that these factors can be controlled by the study design.

VII. CONCLUSION

The presented dissertation project proposes a method to assess the impact of Ecological Interface Design variants on response times to road and system events of truck drivers. The foundation for this research includes current Situation Awareness measurements in dynamic contexts. The project extends the state of the art by using a specific performance measure (response time) as an indicator of SA inside a cognitive architecture. Thus, the evaluation of driver assistance systems will be supported at design time.

ACKNOWLEDGMENTS

The research received funding from the European Commission Seventh Framework Program (FP7-ICT–2013-10) under Grant Agreement No. 610990, Project COMPANION. The authors thank Sebastian Feuerstack, Bertram Wortelen, Jan-Patrick Osterloh, Christian van Göns and Christian Denker for their helpful comments on earlier versions of this paper.

REFERENCES

[1] C. Bergenheim, S. Shladover, E. Coelingh, C. Englund, and S. Tsugawa, "Overview of platooning systems," Proceedings of the 19th ITS World Congress, 2012.
[2] M. Saffarian, J. C. F. de Winter, and R. Happee, "Automated Driving: Human-Factors Issues and Design Solutions," Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 56, no. 1, Oct. 2012, pp. 2296–2300.
[3] N. Sarter, D. Woods, and C. Billings, "Automation surprises," Handbook of human factors and ergonomics, vol. 2, 1997, pp. 1926–1943.
[4] M. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 37, no. 1, Mar. 1995, pp. 32–64.
[5] D. Kaber and M. Endsley, "Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety," Process Safety Progress, vol. 16, no. 3, 1997, pp. 126–131.
[6] G. H. Walker, N. a. Stanton, T. a Kazi, P. M. Salmon, and D. P. Jenkins, "Does advanced driver training improve situational awareness?," Applied ergonomics, vol. 40, no. 4, Jul. 2009, pp. 678–87.
[7] K. J. Vicente and J. Rasmussen, "Ecological interface design: Theoretical foundations," IEEE Transactions on Systems, Man and Cybernetics, vol. 22, no. 4, 1992, pp. 589–606.
[8] C. M. Burns, G. Skraaning, G. a. Jamieson, N. Lau, J. Kwok, R. Welch, and G. Andresen, "Evaluation of Ecological Interface Design for Nuclear Process Control: Situation Awareness Effects," Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 50, no. 4, Aug. 2008, pp. 663–679.
[9] "COMPANION Project." [Online]. Available: http://www.companion-project.eu/.
[10] A. Lüdtke and J. Osterloh, "Simulating perceptive processes of pilots to support system design," Human-Computer Interaction–INTERACT, 2009, pp. 471–484.
[11] D. D. Salvucci, "Modeling Driver Behavior in a Cognitive Architecture," Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 48, no. 2, Jun. 2006, pp. 362–380.
[12] L. Weber, M. Baumann, A. Lüdtke, and R. Steenken, "Modellierung von Entscheidungen beim Einfädeln auf die Autobahn," 8. Berliner Werkstatt Mensch-Maschine-Systeme, 2009, pp. 86–91.
[13] J. Lee, J. D. Lee, and D. D. Salvucci, "Evaluating the distraction potential of connected vehicles," Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI, 2012, pp. 33–40.
[14] D. D. Salvucci, "Rapid prototyping and evaluation of in-vehicle interfaces," ACM Transactions on Computer-Human Interaction, vol. 16, no. 2, Jun. 2009, pp. 1–33.
[15] M. Endsley, "Situation awareness global assessment technique (SAGAT)," Proceedings of the IEEE 1988 National Aerospace and Electronics Conference, 1988, pp. 789–795.
[16] F. T. Durso, M. K. Bleckley, and A. R. Dattel, "Does Situation Awareness Add to the Validity of Cognitive Tests?," Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 48, no. 4, Dec. 2006, pp. 721–733.
[17] M. A. Vidulich and E. R. Hughes, "Testing a Subjective Metric of Situation Awareness," Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 35, 1991, pp. 1307–1311.
[18] N. Rauch, B. Gradenegger, and H. Krüger, "Die SAGAT-Methode zur Erfassung von Situationsbewusstsein im Fahrkontext," in Fortschritte der Verkehrspsychologie, vol. 1, J. Schade and A. Engeln, Eds. VS Verlag für Sozialwissenschaften, 2008, pp. 197–214.
[19] G. M. Fitch, M. Blanco, J. F. Morgan, and A. E. Wharton, "Driver Braking Performance to Surprise and Expected Events," in Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2010, pp. 2076–2080.
[20] J. Krems and M. Baumann, "Driving and situation awareness: A cognitive model of memory-update processes," Human Centered Design, 2009, pp. 986–994.
[21] M. Baumann and J. Krems, "A comprehension based cognitive model of situation awareness," Digital Human Modeling, 2009, pp. 192–201.
[22] M. Baumann and J. F. Krems, "Situation awareness and driving: A cognitive model," in Modelling driver behaviour in automotive environments, Springer, 2007, pp. 253–265.
[23] M. Matthews and D. Bryant, "Model for situation awareness and driving: Application to analysis and research for intelligent transportation systems," Transportation Research Record: Journal of the Transportation Research Board, vol. 1779, 2001, pp. 26–32.
[24] L. Gugerty, "Situation awareness during driving: Explicit and implicit knowledge in dynamic spatial memory.," Journal of Experimental Psychology: Applied, vol. 3, no. 1, 1997, pp. 42–66.
[25] L. Gugerty, "Situation awareness in driving," in Handbook for driving simulation in engineering, medicine and psychology, 2011, pp. 19/1–19/8.
[26] V. J. Gawron, Human performance, workload, and situational awareness measures handbook. CRC Press, 2008.
[27] B. Wortelen, M. Baumann, and A. Lüdtke, "Dynamic simulation and prediction of drivers' attention distribution," Transportation Research Part F: Traffic Psychology and Behaviour, vol. 21, Nov. 2013, pp. 278–294.