Tool-supported Comparative Visualizations to Reveal the Difference Between ‘What Has Been Designed’ and ‘How It is Perceived’ for Monitoring Interface Design

Bertram Wortelen and Sebastian Feuerstack

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Tool-supported Comparative Visualizations to Reveal the Difference Between 'What Has Been Designed' and 'How It is Perceived' for Monitoring Interface Design

Bertram Wortelen
Cognitive Psychology
C.v.O. University Oldenburg
Oldenburg, Germany
bertram.wortelen1@uni-oldenburg.de

Sebastian Feuerstack
Human Centered Design
OFFIS – Institute for Information Technology
Oldenburg, Germany
feuerstack@offis.de

***Abstract*—Monitoring is one of the most important tasks for an operator of a complex safety-critical system like a ship bridge or air traffic control. It is a prerequisite for good situation awareness. Designing an interface for such environments requires optimizing what is presented to the most limited resource: the operator's visual attention. But the real operator's attention distribution is hard to anticipate for a designer. We apply cognitive attention prediction methods to predict attention based on information gained on the one hand by the HMI designer and on the other hand the future user of an HMI. This contribution proposes and evaluates a set of comparative visualizations that support elaborating the differences between what has been designed and how it is perceived. An initial study indicated that a visually supported comparative analysis supports a designer in identifying differences and also seems to stimulate the designer to reason about the design.**

Keywords—interface design; rapid prototyping; attention allocation; virtual test user

Submission type: Oral presentation paper

I. Introduction

For operators of safety-critical systems (such as a ship bridge or air traffic control) the most important activity is to ensure that the system is under control [1] Therefore the operators spend a substantial amount of their time in monitoring the human machine interface (HMI). To reduce their monitoring effort, user-centered design processes put the operators in focus and involve them throughout the HMI design to carefully analyze their monitoring behavior.

But the access to these experts and environments for performing empirical studies with a reasonable amount of subjects is often limited: These highly specialized operators are physically distributed around the world and efforts are involved to cover travel costs to a lab and to substitute their work absence. Their high degree of specialization further limits the total amount of theoretical available operators. Additionally, performing tests in a realistic environment requires an - at least partially - functional HMI prototype.

Therefore, we propose a tool-supported process that enables highly specialized operators to participate in a user-centered design process remotely in a fast and structured way. Instead of measuring attention distribution directly via eye tracking equipment, our approach relies on a simplified cognitive modeling process that predicts attention distribution on an HMI prototype.

Many aspects influence operator's visual attention distribution [2]: the saliency of information, the distribution of the information sources over the HMI, the operators' tasks, the frequency of relevant updates of information, and the information value. These factors are hard to anticipate during the design process. Therefore, the operators' monitoring behavior is often analyzed by eye-tracking studies, with all the mentioned requirements listed above.

Model-based attention prediction models can support the design process by predicting attention distributions already in an early phase. Wolfe [3] is a good example of a stimulus-driven and saliency-based model for visual search tasks. In contrast, the SEEV (salience, effort, expectancy, value) model [4] is a model for monitoring behavior, which has been applied and validated in different real-world applications [5-7]. They use algorithms to calculate the attention distribution based on several inputs from an operator. This includes the frequency with which the operator expects new information (expectancy coefficient) and a definition of how valuable the information is (value coefficient) for each information source of a monitoring display.

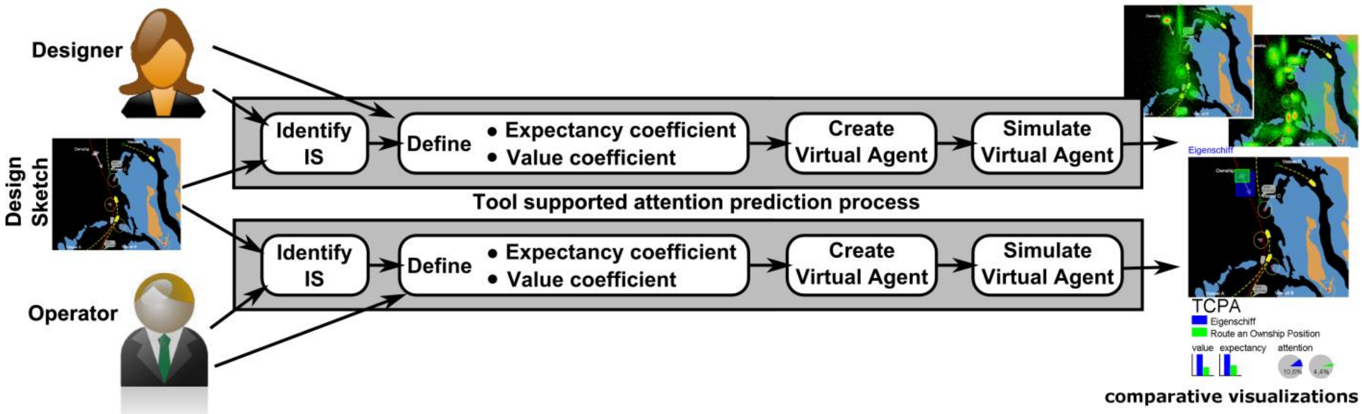

Fig. 1. Tool-supported process to predict operator's attention allocation. In [12] this process was executed by the HMI designer and the operator. Algorithms were developed to automatically create visualizations that help comparing the two attention allocation predictions.

A virtual operator simulation based on a computational cognitive model can also consider probabilistic aspects of behavior such as distributions of reaction times to external events or simulation of gaze sequences [8]. For monitoring tasks the SEEV model was integrated and used in different computational frameworks, like the attention – situation awareness (A-SA) model [9] and the cognitive architectures CASCaS (Cognitive architecture for safety critical task simulation) [10] and MIDAS (man-machine integration design and analysis system)[11]. In [12] a tool-supported process has been proposed to predict operator attention based on basic sketches of the HMI designs. In an experiment different types of experts used the tool to generate attention predictions. Their results varied, but seemed to reflect their respective perspective.

In this paper we extend this tool-driven process for visualizations that can be used to graphically compare attention predictions from two perspectives: The remotely generated operators' one and the designer's one. We explore, which visualizations are reasonable to communicate the operator's perspective to the HMI designer.

In the following section we briefly explain the process of creating and using predictive cognitive models from [12]. In Section 3 we describe the procedure of this study and the different approaches for communicating the operator's perspective to the HMI-designer. In Section 4 we describe our observations and the findings we made, while presenting the different communication approaches to an HMI designer. Finally in Section 5, we conclude by outlining future work that needs to be done to test our findings in controlled environments.

II. Tool-based Attention Prediction Process

Fig. 1 depicts the activities that one has to perform to generate and compare the prediction of attention distribution from the perspective of an HMI designer with the predictions from the perspective of the actual operator. The generation of the two individual predictions is identical to the process described in [12]: Based on design sketches or images all information sources of an HMI are identified and graphically marked with their corresponding size and position. An information source (IS) is a physical space or area in an environment that communicates a certain kind of information to the user. The speed indicator in a car, for example, communicates the current speed of the vehicle. The user gives a name to each IS to describe the information that is provided. Afterwards, the expectancy and value coefficients of the SEEV model (see Section I) are defined for each IS. This is done by using the lowest ordinal algorithm [4]. The tool provides support by guiding the user step-by-step through this algorithm.

After the SEEV model coefficients have been defined for all ISs, a cognitive model is automatically generated based on the cognitive architecture CASCaS, which uses the SEEV model for simulation of attention distribution [13]. The model describes a virtual operator who continuously monitors all ISs in a psychological and physiological plausible way. Simulation of the model results in a sequence of eye movements and fixations. Instead of showing the time trace of these fixations, the simulated monitoring behavior is aggregated and visualized with charts and heat maps similar to visualizations used in eye tracking studies.

We experimented with several visualizations to present the resulting predicted attention allocation. [12] gave indications that presenting a heat map stimulates the reasoning about a design, while at the same time subjects tend to over-interpret what is depicted. These observations lead us to the idea to test, if we can support a HMI designer by offering a visualization that compares the attention predictions gained by an operator with the attention distribution assumed by the HMI designer. For the current study we created algorithms that automatically create such comparative visualizations. These visualizations also show the data that has been used to generate the predictions (i.e. the created visual attention model). We intend to support a designer in the systematic discovery of the operator's perspective and in learning about the impacts of design decisions for the predicted operator attention.

III. Explorative Study

In the maritime domain Electronic Chart Display and Information Systems (ECDIS) are one of the main sources of information that are monitored to support vessel navigation. In a first study [12] four subject matter experts (SMEs) of different areas (HMI designer, operator, expert for cognitive modelling, expert for situation awareness) have applied the tool supported attention prediction and analysis process to compare three different ECDIS designs. The results indicated that each role had a different perspective on the design, presumably by their different background knowledge. Thus, we performed this subsequent study to explore if generated comparative visualizations are applicable to reveal differences between the SMEs. Specifically, we tested whether the perspective of one SME (operator) can be communicated to another SME (HMI designer). If so, it could serve as a fast and well-structured approach for gaining feedback from remote expert users in early design phases. In order to get indications, which of the visualizations had the greatest potential for revealing differences between SME perspectives, our approach was to:

1. Identify the information that was very important for the operator SME
2. Present the different visualizations to the HMI designer SME and instruct him to think aloud while exploring the visualizations.
3. Analyze the recordings of the HMI designer, to identify
   (a) whether the designer could identify what was most important for the operator
   (b) which visualization was most helpful for the HMI designer for reflecting on the operator's perspective of the HMI, and
   (c) whether the designer could get insights that are helping to improve the interface design.

A. *Important Information for the Operator SME*

The subjects' process to predict the attention allocation was recorded and the subjects were asked to think aloud during the process. We analyzed the 4.5 hours long recording of the operator SME, a shipmaster who participated in the first study. For each of the three ECDIS designs we were specifically interested in capturing all information that the shipmaster mentioned to have a high value for performing the overall navigation tasks. We ended up with a list of seven information elements:

1. Course and speed vector of the own ship.
2. Time to closest point of approach to another vessel.
3. Navigation gates of planned routes for other vessels.
4. Course and speed vector of other vessels.
5. Position predictions of vessels.
6. Geographic location and cross traffic to port.
7. Lighthouses.

B. *Visualizations presented to the HMI designer*

The SMEs had to label each IS with a suitable name that describes the information provided by the IS. However, visualizations that show IS properties and statistics by referring to the name of the IS seemed inappropriate, e.g., tabular representations, graphs or pie charts. Different SMEs marked the same information in different ways and especially used very different names for the same information source. Thus the combination of the IS name and physical area defined by the SME is of interest. Therefore, all visualizations we created are overlays of the HMI design sketches. We decided for graphical visualizations that were partially interactive. We elaborated six different comparative visualizations (see Fig. 2-5) that were automatically generated based on the inputs of the operator and designer: the marked ISs and their corresponding ratings of the two SEEV coefficients for *expectancy* (the expected update frequency for new information) and *value*(see Section I).

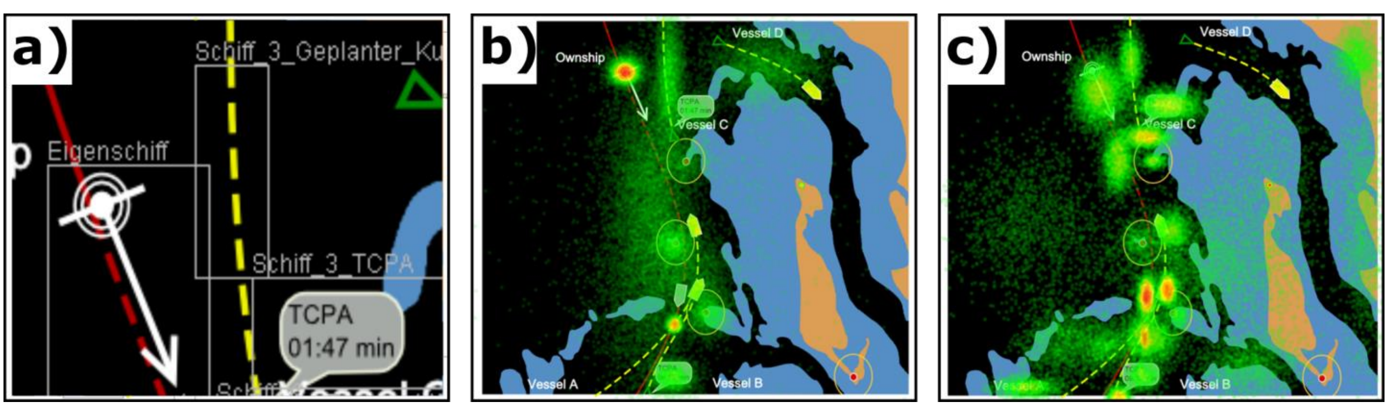

Fig. 2. Heat map visualization. a) The boundaries of the operator's ISs (thin gray lines) used as reference for the interpretation of the operator's heatmap. Shown is only a small, zoomed-in part of the entire sea chart for better readability. IS names are in German, because the operator and HMI designer were German. b) The heat map resulting from the simulation of the cognitive model defined by the HMI designer. C) The heat map resulting from the simulation of the cognitive model defined by the operator.

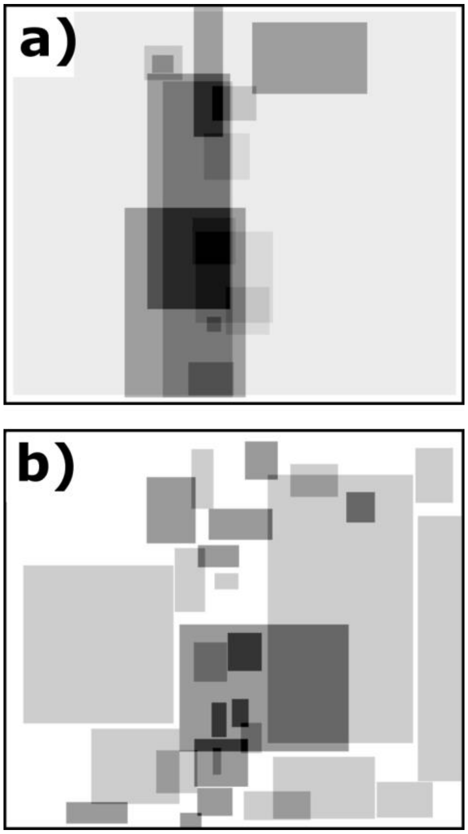

Fig. 3. Colorization of IS based on expectancy coefficients defined by (a) the HMI designer and (b) the operator.

1. Comparison of HMI designer's and operator's attention allocation heat map. For each design, the heat map of the designer (Fig. 2b) and the heat map of the operator (Fig. 2c) were presented at the same time. This enabled the HMI designer to easily identify and compare hotspots of attention predicted by the operator's model with hotspots predicted by his/her own model. To enable reasoning about the differences in the heat maps, an additional overlay was presented to the HMI designer. It showed the boundaries and names of all IS defined by the operator (Fig. 2a). The HMI designer could use this to relate hotspots in the heat map to ISs defined by the operator.

2. Comparison of the designer's and operator's expectancy respectively value rating (Fig. 3a and 3b). Marked IS areas are colorized from light grey to dark grey based on either their expectancy coefficients or their value coefficients. Higher rated and overlaid IS area segments were visualized darker than lower rated ones. This enabled the HMI designer SME to identify areas were the operator SME obtains information with high frequency or highly valuable information and compare it to his/her own expectations. Identically to the previous visualization all IS markups of the operator SME were shown at the same time to provide this information to the HMI designer (Fig. 2a).

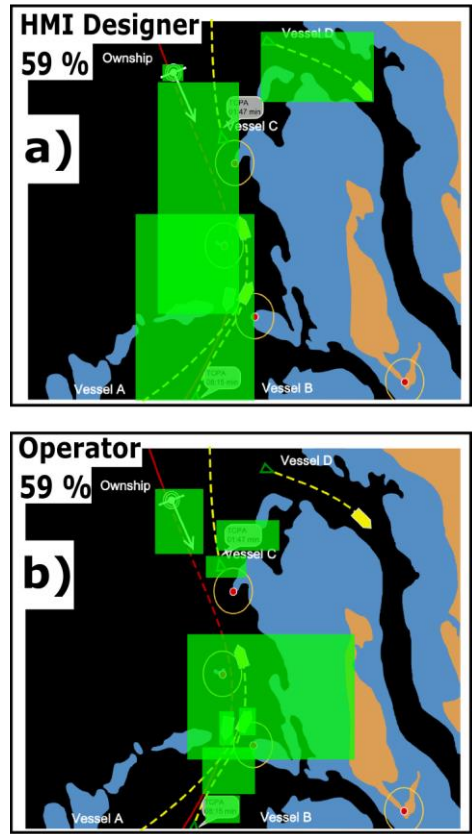

Fig. 4. IS that attract 59% of the attention as predicted by (a) the designer and (b) the operator.

3. A sequence of 100 images. Each, with the IS areas of the designer (Fig. 4a).and the operator (Fig. 4b) subsequently appearing based on the percentage of attention they capture. Those that capture most appeared first. This should enable the HMI designer to identify to which ISs the operator pays attention most of the time. It also allowed the HMI designer to compare it with the ISs that he expected to capture most of the attention.

4. A sequence of figures like the one in Fig. 5. Each figure highlighted one IS of the operator (blue) and one of the designer (green). The sequence of figures was generated for those ISs for which the operator predicted the most amount of attention. An automatic mapping between IS defined by the operator and IS defined by the HMI designer was created based on the geometrical similarity between IS. The geometrically most similar IS of the designer was highlighted in green. The HMI designer could then analyze whether s/he marked the same information and whether s/he rated it as high as the operator. The respective expectancy and value ratings were shown below the figure. The geometrical similarity was calculated by the root integrated squared distance, which is sensitive to differences in size and position of two rectangles.

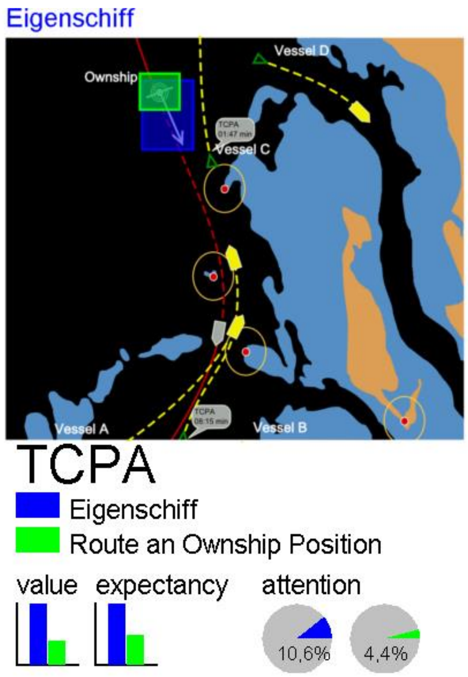

Fig. 5. Direct comparison of two IS. The IS “Eigenschiff” (engl.: own ship) defined by the operator is marked in blue. The closest geometrical match of an IS defined by the HMI designer is shown in green. The IS names, their expectancy and value coefficients and the simulated percentage of attention distributed to these IS.

5. Again a sequence of figures like the one in Fig. 5. But this time the sequence of figures started with the ISs for which only very bad geometrical matches were found, since these most likely indicate IS that have been marked by the operator, but not by the designer. This enables the HMI designer SME to identify ISs which the operator SME uses but which the HMI designer SME did not consider.

6. Finally, by applying the same geometrical matching algorithms, a sequence of figures like the one in Fig. 5 was created. These figures identify ISs that were marked by the designer, but most probably not by the operator.

C. *Analysis of the HMI-designers recordings*

We presented and explained the different visualizations to the designer in the order as listed above. The first four visualizations were presented to the designer for all three alternative interface designs. The last two visualizations only considered the interface design preferred by the designer (we limited the session to two hours). The HMI designer was asked to freely explore the visualizations and to “think aloud”. Afterwards we asked him, which visualizations he preferred and why. The entire session was video recorded. The audio track was transcribed to a textual document. Finally, the transcription was analyzed. However, the designer often commented on multiple ISs at once or pointed on regions rather than on single IS. This often led to an ambiguous text analysis. Thus the analysis was made independently by two persons:

1. It was rated whether the designer commented on the seven information elements that were previously identified important to the operator (see Section III.A)

2. For each visualization a list was created containing all ISs defined by the operator. The list also contains the comments of the HMI designer about each IS while he explored the visualization. For each list entry it was rated, whether the HMI designer gave indications that the operator’s definition of IS itself or the amount of attention predicted by the operator was unexpected (see Table I).

3. Comments in the transcription were identified, which indicate that the designer obtained insights that could help him to improve the interface design.

IV. Observations and Findings

The designer commented on all ISs that were identified as important for the operator already while exploring the first visualization (heat maps). Thus the visualizations were able to communicate all important ISs to the designer.

Table I lists on how many IS the designer commented. In each cell the first number shows the rating of the first analyst and the second number the rating of the second analyst. Designer’s comments were classified, based on whether the predicted attention to the IS was expected or unexpected by the designer. The last column lists the number of ISs, which could not be rated based on designer’s comments. The ratings from the two analysts differed especially for the heat map visualization. One reason might be the invisible boundaries of the ISs on the heat map visualization (see Figure 2a and 2b). Thus it was often ambiguous to identify the IS that the designer was referring to and whether he was referring to one or multiple ISs.

The HMI designer mostly commented on ISs for which he discovered an unexpected difference to his own expectations. We observed a high amount of comments of the designer that used the words “surprising”, “very interesting”, and “unexpected”. We categorized all these comments as “unexpected” in Table I. Furthermore, for nearly all unexpected differences the designer started reasoning about, why the predictions of the operator differ from his own predictions. It seems that it was very easy for him to interpret the intentions of the operator. In only one occasion the designer

TABLE I. Number of commented IS per visualization.

Visualization	No. of IS	Expected	Unex-pected	Not classified
1. Heat maps	14 / 32	4 / 8	6 / 16	4 / 8
2. Expectancy & value ratings	22 / 16	2 / 2	9 / 8	11 / 6
3. Percentage Attention	27 / 25	4 / 3	13 / 10	10 / 12
4. Important for operator	11 / 13	1 / 2	8 / 9	2 / 2
5. Important for designer.	8 / 7	0 / 1	1 / 5	7 / 1
6. Worst IS matches	9 / 7	0 / 2	6 / 4	3 / 1

a. Designer’s comments to ISs were classified as expected or unexpected. Some IS could not be classified based on designer’s comments. Shown are ratings of 1st analyst / 2nd analyst.

explicitly stated that he disagrees with the operator’s view. He seemed to be aware that his interpretation was speculative, because at two occasions he mentioned that he would need to talk to the operator to confirm his interpretation. In a few cases (8) he even started to think about whether the gained insights might affect the final interface design, although he never mentioned what these changes to the interface could be.

The different visualizations had a different effect on how the designer explored the predictions of the operator. The designer made comments for all visualizations. However, the presentation order of the visualizations might have a strong effect on the number of comments.

The heat maps seem to be the most intuitive visualization. They provided a good overview. This was also mentioned by the designer after the study. The designer made a lot of comments to the visualization 2 and 3. They presented overviews of the entire monitoring interface. However, at the end of the study the designer explicitly mentioned that visualization 1 (heat maps) was more helpful than the other visualizations. Visualizations 4-6 provided a detailed insight into the differences between operator’s and designer’s perspective, but did not provide an overview about the entire interface since they focused on just a single IS.

In one case the visualization revealed completely new information to the HMI designer: The operator marked an area of the sea and labeled it “potential crossing traffic”. Even though no port was displayed on the screen, the operator concluded from the displayed geographic information that there most likely was a nearby port, from which he expected future traffic. The designer was very interested in this aspect and mentioned that he was not aware that operators interpret the geographic information in this way.

V. CONCLUSION

Visualizing the differences of a model of attention distribution to an HMI prototype from the perspective of the HMI designer and the perspective of an actual user helps the HMI designer to deliberate about the design. We were surprised by the amount of comments the HMI designer made based on the visualizations. It was obvious that the designer had no problem in deriving the operator’s perspective from the visualizations. Thus, we think that the presented approach is a good way to support the communication of knowledge from operators to HMI designers via a tool supported process. However, the current study was explorative in nature with only a single participant. In a subsequent step of our research we want to conduct a study with a sufficiently large number of HMI designers and test, whether they are able to derive design improvements from the predictions of operators.

Based on the result of this study, we will use the heat maps together with one of the visualizations from 4-6 to enable a more detailed analysis. They provoked a lot of comments and the heat maps were the preferred visualization of the HMI designer. The designer commented so easily on the visualizations that we also intend to improve our tool to record these comments to support documentation and decision making processes during the HMI prototyping phase.

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REFERENCES

[1] N. Moray, “Monitoring behavior and supervisory control,” in *Handbook of Perception and Human Performance. Volume 2. Cognitive Processes and Performance*, K. R. Boff, L. Kaufman, and J. P. Thomas, Eds. Wiley-Interscience, November 1986, ch. 40, pp. 40–1 – 40–51

[2] C. D. Wickens and J. S. McCarley, Applied attention theory. CRC press, Boca Raton, 2008.

[3] J. M. Wolfe, “Guided search 4.0: Current progress with a model of visual search,” in *Integrated Models of Cognitive Systems*, 1st ed., W. D. Gray, Ed. New York: Oxford: Oxford University Press, April 2007, ch. 8, pp. 99–119.

[4] C. D. Wickens, J. Helleberg, J. Goh, X. Xu, and W. J. Horrey, “Pilot task management: Testing an attentional expected value model of visual scanning,” NASA Ames Research Center Moffett Field, CA, Tech. Rep., 2001.

[5] 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, pp. 278–294, 2013.

[6] W. J. Horrey, C. D. Wickens, and K. P. Consalus, “Modeling drivers’ visual attention allocation while interacting with in-vehicle technologies*.” Journal of Experimental Psychology: Applied*, vol. 12, no. 2, p. 67, 2006.

[7] C. D. Wickens, J. Goh, J. Helleberg, W. J. Horrey, and D. A. Talleur, “Attentional models of multitask pilot performance using advanced display technology,” *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 45, no. 3, pp. 360–380, 2003.

[8] B. Wortelen, “Das Adaptive-Information-Expectancy-Modell zur Aufmerksamkeitssimulation eines kognitiven Fahrermodells,” Ph.D. Dissertation, Universität Oldenburg, Fakultät II Informatik, Wirtschafts- und Rechtswissenschaften, Department für Informatik, 2014.

[9] C. D. Wickens, J. S. McCarley, A. L. Alexander, L. C. Thomas, M. Ambinder, and S. Zheng, “Attention-situation awareness (A-SA) model of pilot error,” in *Human Performance Modeling in Aviation*, D. C. Foyle and B. L. Hooey, Eds. New York: CRC Press/Taylor & Francis Group, 2008, pp. 213–239.

[10] A. Lüdtke, J.-P. Osterloh, L. Weber, and B. Wortelen, “Modeling pilot and driver behavior for human error simulation,” in *Digital Human Modeling*, ser. Lecture Notes in Computer Science, V. G. Duffy, Ed. Springer, Berlin, 2009, vol. 5620/2009, pp. 403–412.

[11] B. F. Gore, B. L. Hooey, C. D. Wickens, and S. Scott-Nash, “A computational implementation of a human attention guiding mechanism in MIDAS v5,” in *Digital Human Modeling*. Springer, 2009, pp. 237–246.

[12] S. Feuerstack and B. Wortelen, “Revealing differences in designers and users perspectives: A tool-supported process for visual attention prediction for designing HMIs for maritime monitoring tasks,” in *15th IFIP TC.13 International Conference on Human-Computer Interaction - INTERACT,* LNCS 9299, Springer, 2015, pp. 105–122.

[13] B. Wortelen and A. Lüdtke. Adaptive simulation of monitoring behavior: The adaptive information expectancy model. In *Proceedings of the Sixth International Conferences on Advances in Computer-Human Interactions*, pp. 413–419, Februar 2013.