Assessment of Automation Awareness

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ABSTRACT

Automation awareness (AA) can be defined as user's conception of the utilized automation system's state in such a manner that enables the user to observe, control, and anticipate the process events mediated by automation. In this paper, we report a study where we utilized a customized simulation system to assess AA. The simulator included a process and automation model with emulated user interface displays for an emergency diesel generator system in a nuclear power plant. The results suggest that in addition to user-related factors, such as the users' automation-specific education, experience, and provided training, the quality of the automation system's user interface is a significant contributor to the development of AA; especially the digital presentation of the measurement values, graphical format of the values' status and their automation-related limits as well as illustrative trend displays seem to improve AA considerably.

1 INTRODUCTION

The concept of automation awareness (AA) has been introduced by VTT Technical Research Centre of Finland Ltd in the SAFIR2014 (The Finnish Research Programme on Nuclear Power Plant Safety 2011–2014) research programme's HACAS (Human-Automation Collaboration in Incident and Accident Situations) project. In this paper, AA is seen as part of the 'situation awareness' (SA), which is already an established human factors research concept and which we also briefly discuss. Firstly, we present the background of the concepts of SA and AA. Secondly, we report a study where we utilized a customized simulation system to investigate and assess AA. Finally, we discuss our findings on a general level and draw conclusions.

2 SITUATION AND AUTOMATION AWARENESS

In previous literature, there are a lot of different definitions of SA. The most cited definition is the one by Endsley /3/, who stated that SA is 'the perception of 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'. AA, on the other hand, has been defined to be a user's conception of the utilized automation system's state in such a manner that enables the user to observe, control, and anticipate the process events mediated by automation /5/. In line with Endsley's /3/ definition of SA, we see that the development and maintenance of AA is a continuous process that comprises of perceiving the current status of the automation, comprehending this status and its meaning to the system behaviour, as well as projecting its future status and meaning. If this conception is at an appropriate level (i.e., matches with reality accurately enough), it means that the user understands sufficiently the automation's role in the on-going process control events, enabling the user to operate the automated system in an appropriate way by taking into account the demands of the situation at hand. Therefore, good AA presumes the user to have the ability to pay attention to the cues indicating the automation's state, interpret these cues correctly, make correct conclusions based on them, and act accordingly. The level of a user's AA becomes especially evident in the activity of the user in such interaction situations with the automated system, which deviate from normal ones. In general, we see that AA is a phenomenon, which should be taken into account, for example, in the design of user interfaces (UIs), user training, and operating procedures of modern automation solutions.

Currently, there are a number of SA assessment methods, such as SAGAT, SPAM, SART, and SA-SWORD (for details, see e.g., /8/), which have elements that can be utilized also in the assessment of AA. However, instead of going through the methods here in detail, we present a brief overview on how we assessed AA in a study with Loviisa nuclear power plant workers. More information on automation awareness and its assessment methodology can be found from our previous publication (see e.g., /1/, /5/, /6/ and /7/)

3 METHODS

3.1 Development of the Simulator to Study Automation Awareness

In order to study AA, we have developed a simulation system. The scope of the simulator is the operation of the emergency diesel generator (EDG) system of Loviisa NPP, and focusing specifically on the periodic testing functionality. The simulator features a new, digital design for the Loviisa's EY01 EDG's operator user interface, in contrast to the analogue system used currently at the plant.

Technically, the simulator environment consists of the Apros (www.apros.fi) simulator and ProcSee (www.ife.no/procsee) user interface software, which communicate via OPC. The simulator uses the Apros model of Fortum's Loviisa Engineering and Development Simulator, but is restricted to include only the EDG system. The design of the simulator UI was based on three guidelines derived from the literature: good observability of automation, minimized workload, and transparent failure management (for details, see e.g., /7/). The displays were highly unfamiliar for the test participants, as the current EDG system uses purely analogue technology.

3.2 User test participants and procedure

In the studies, we had six test sessions with two participants in each session. Therefore, we had 12 participants in total, out of which five were turbine field operators, one a main control room turbine operator, and six automation mechanics from the turbine side. We utilized a pair testing approach (see, e.g., /4/) in the studies.

The participants' work experience in the Loviisa NPP varied between two and 37 years. Some of the participants had previous work experience, for example, from the paper industry. The field operators had conducted a periodic testing of an EDG within the last month, so they remembered the actual testing procedure quite well.

The user study test sessions took place during three consecutive days in May 2014 in the meeting rooms of the gate building of the Loviisa NPP. The researchers, who conducted the tests, sat in front of a meeting room table with a laptop, which was running the EDG system's Apros model and ProcSee software to provide the UI for the test participants. One of the researchers managed the command interface, from which he could do required field actions in the simulator and introduce fault situations in appropriate points during the tests.

The participants sat on the other side of the meeting room table in front of a 24 inch LCD, which showed the UI of the simulator, and operated the system with a regular PC mouse. The test setup included also a duplicated version of the participants' UI view in order for the researchers to observe better what the participants were doing with the UI and to video record discussions and everything what the participants are doing in the UI.

Our research approach in the study was exploratory /9/. In the spirit of exploratory research, we mostly utilized qualitative methods. First, before starting the actual test tasks, a pre-test interview was conducted. In this interview, the participants were asked, for example, about their backgrounds and EDG and automation-related experience. Second, the test instructor did a short walkthrough of the UI for the participants by showing and explaining each display. Third, the participants could briefly practice navigating with the UI by themselves. The walkthrough and navigation without any specific task were performed in order to familiarize the participants with the digital control displays, which were totally new for them.

After these phases, the actual test tasks with the simulator were started. In the first part of the test, the participants were instructed to do a periodic testing with the system according to the periodic testing procedures, the same they normally use in the testing. The participants were also instructed to think aloud /2/ while using the system, so that the researchers could hear how they understood the UI and how their mental model about its behaviour developed. After the first fault-free periodic testing, in the latter part of the test, a second round with different (fault) scenarios was performed. These scenarios ranged from minor departures from standard practice to distinct faults in the system.

After each fault including scenario, the test instructor asked questions to find out more about, for example, what the participants understood about the automation while using the UI. After all the test tasks, a semi-structured post-test interview was conducted, which included questions about the UI and the participants' AA during the test. Finally, an automation awareness questionnaire, which we had developed, was filled in by the participants.

4 RESULTS AND DISCUSSION

The simulator UI and the data it provided were considered realistic by the participants. Most of the participants managed to conduct the given test tasks successfully and the designed UI displays were generally well accepted, although the displays also received many suggestions for improvements from the participants. If the test participant had experience of other NPP systems or similar systems in other process industries, it seemed to affect positively their visions about how the UI could improve the user's automation awareness.

The automation awareness questionnaire results indicate that the participants had fairly good automation awareness with the simulator. When asked how well (1–10 scale, 1 being not at all and 10 being entirely) the participants understood the state and functioning of the automation in different situations during the tests, the average score was 7.4. In addition, when asked about the extent of the UI in helping to understand the state of the automation (1–10 scale, 1 being not at all and 10 being extensively), the average score was 7.7. The participants also felt that the simulator UI presented the automation's state and functioning in a simple rather than in a complex way.

When interviewed about their conception of the role of the automation in the EDG system, most of the participants answered that automation is primarily utilized in the synchronization of the generator to the grid. This is to say that the user does not have to do the synchronization manually, but only wait until the synchronization is done automatically by the system. One of the participants also mentioned that during the start-up of the EDG, several automated sequences take place. Furthermore, the protection signals that caused the diesel system to trip were seen to involve automation.

The educational background of the participants seemed to have an effect on how the concept of automation was understood. For example, participants with background in electrical engineering seemed to understand automation in the EDG system to be very low level technical operations, such as the physical functioning of the relays. If the understanding was on a high level, as was the case with higher education, the participants understood automation to be the whole system, consisting of automatic information processing, logic, and control features of the system.

In summary, to support AA better the participants emphasized especially the importance of 1) the presentation of digital and exact measurement values, 2) graphical presentation styles of the values' status and their minimum and maximum limits, 3) illustrative trend displays in understanding the state of the automation, and 4) presenting clear alarm indications. It can be inferred from the results that particularly the trend displays work as a powerful tool in interpreting the previous, current, and future state of the automation (besides showing the state of the process).

The study results showed that UI is the main contributor to the development of AA. Therefore, we see that different UI means to support the users in understanding the automation more deeply need to be investigated and utilized in design. However, the current technological limitations in the field of nuclear power regarding automation platforms often constrain the possible UI solutions as well.

In addition to UI features and solutions, AA and the understanding of the functioning of automation in the test sessions was affected considerably by the amount of previous work experience and received training. For example, if the participant had only a few years of experience with EDG systems, it seemed (according to the thinking aloud comments) that he was not able to keep track what automation was doing in different phases of the scenarios. Furthermore, if the participant had experience of logic displays, or bar and trend graphs, from other systems, he could easily understand their meaning in our simulator, which resulted in a good level of AA.

Some of the automation mechanics with good AA in the studies emphasized the connection between solving automation-related faults and understanding the actual process (i.e., EDG's functioning). Understanding of the process is very important in the troubleshooting of automation-related issues too. That is why in practice, the automation mechanic and the field operator are, and also should be, working together in case of a fault in the system. Therefore, it can be concluded that good AA requires also deep understanding of the actual process.

5 CONCLUSIONS

We see that user's understanding about automation is an essential part of situation awareness in any modern industrial environment. We call this understanding as automation awareness and state that it creates the prerequisites for appropriate user activity in monitoring and controlling highly automated processes. It is no longer enough for the user to understand only the process and its states, but he/she also needs to understand and follow the progress of the automated functions in order to operate the plant properly. Without sufficient AA, the user has no ability to observe the functioning of the system as a whole. This leads to a situation where the user is 'out-of-the-loop' and therefore loses the hands-on touch both to the automation and to the process control. Consequently, the user's ability to act in demanding situations is also remarkably diminished.

Automation awareness is a phenomenon, which is developed especially in the interaction between the user and automation. The quality of this interaction is dependent from the system's part most importantly on the ability of the automation system's user interface to provide the user the needed information about the functioning of the automation, factors affecting its current state, the system's general structure (i.e., architecture), and the system's functioning principles. This also affects, e.g., the development of user's trust in the automated system, the lack of which we see to be an important determinant of, for example, misuse of automation or whether the user uses it at all (if optional). In addition, automation awareness is built upon the basic knowledge regarding the automation, which is learned during training and with experience gained by operating the system in hands-on work.

In the work presented in this paper, we studied AA by analysing the way field operators and mechanics talked about automation and how they actually conducted tasks in simulator user study sessions. Therefore, for example, the terms participants used and their conceptions about the state of the automation and how they actually operated the system were regarded as indicators of the participants' AA during the tests. Another way of studying AA could have been, for instance, to stop the test (and freeze the simulation) at certain points in time, and ask the participants about the state of the automation, as is done in some other methods of situation awareness (see e.g., /8/). However, we see that our approach is a more subtle way of studying AA as it does not intervene with the participants' task performance and also takes more deeply into account the interpretation of actual activity of the participants. Guidelines by us for AA method development can be found in detail in /5/.

The results of our studies can also be useful for other domains than NPPs. For example, in the maritime context, similar EDGs are utilized for power production in ships. Furthermore, the results related to automation awareness in general are not only NPP specific, so they can be applied to any other process industry, provided its systems include moderate or high levels of automation.

We conclude that it is not reasonable to try to develop a fully generalizable method for the measurement of automation awareness. The measurement of AA needs always to be customized to take into account the system that the users are using and also the specific situation where the method is utilized. Therefore, neither the HACAS project nor this paper end up with a finalized fit-for-all method for the measurement of AA. Instead, we presented our approach of automation awareness and the ways we studied it in the context, which we had.

Finally, it can be said that both the short and long-term implications of digitalization and increasing level of NPP automation need to be carefully considered. According to our experience, potential problems can be largely avoided by increasing the workers' understanding of automation, skills to interact with it and willingness to cooperate with it. This can be done, for example, by involving the users early-on in the design and implementation of the user interfaces and in decisions regarding the level of automation and automation itself.

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