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Computational Representation of Situation Awareness with Graphical Expressions

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1. Introduction

Systems are modified and fortified with new features due to competitive business environment and safety issues, and thus more tasks are being assigned to nuclear power plant (NPP) operators to run plants safely and efficiently. Thus the chief concern of NPP management has been to enhance operators' performance of those activities in recent decades. Situation awareness (SA) evaluation has been one of those endeavors. Training is also frequently listed in general applications of SA evaluation. Unfortunately, almost of all methods are either subjective or qualitative, and often time consuming. Since the problems indicate, the core matter of using SA in training is the lack of well-developed or robust measurement tools. Therefore, an intuitive and easy handling SA measurement tool for NPP operators was developed based on the Petri-net and Bayesian inference. Measuring SA using Bayesian theory has been controversy, so sets of simulation training conducted by real NPP operators were video recorded for validation of the tool.

2. A Proposed Method

In this paper, we consider SA in one operator. The concern of this method is twofold. First, we want to provide quantitative and solid evidence of operator's behaviors. Second, we want to visualize a stream of information flow that an operator used so that trainers can catch clues of operator's reactions and decisions.

2.1 Modeling of Human Operator's SA

Two theories were considered to give more realism to a quantitative model of the human operator: one is limitation of human ability in information processing. The other is a general way of problem solving. The operator's reasoning process is simplified by rule based behaviors of the operator for effective calculation of information processing. Firstly, Cognitive Load Theory (CLT), as presented by Sweller, offers explanation on how learning can be difficult because of the limited nature of our working memory [1]. Secondly, a production system model, the foundation of the modern rule-based expert system, is well-known and used in computer science, but it was first introduced by Newell and Simon (1972) in their psychological study of human problem solving. Production system consists of a collection of if-then rules that together form an information-processing model of some cognitive tasks. Production systems have special properties that make them highly suited to modeling cognition, the independence of their rules, and their flexible control [3].

2.2 Representation of SA building process

Bayesian inference was used to quantitatively represent the status of operator's SA. Bayes' theorem (by Thomas Bayes) is origin and fundament of the 'Bayesian Philosophy' which opines that probability is the only tool for representing belief with adequate strength in view of ignorance and uncertainty [4]. There has been an attempt to use it for SA representation in the nuclear domain [5]. Bayesian inference derives the posterior probability as a consequence of two antecedents, a prior probability and a "likelihood function" derived from a probability model for the data to be observed. Bayesian inference computes the posterior probability according to a Bayes' rule. The Bayes' rule provides an expression for the conditional probability, for any probability distribution P, of A given B, which equals to

$$P(A|B) = \frac{P(B|A) \times P(A)}{P(B)}$$

where,
$P(A)$: a priori belief in A
$P(A|B)$: a posteriori belief in A given evidence B
$P(B|A)$: a likelihood of A. a belief in B if A is assumed

The PN was used to model real-time fault tolerant and safety critical systems. One of the most successful application of the PN is modeling and analysis of dynamic systems, such as communication protocol [6]. The PN also has lent its power of graphical expression to a business field and become a fundamental framework of Workflow Management. For all these reasons, the expression power of the PN was borrowed to model SA of the NPP operator.

2.3 Tool development

To graphically express operator's SA, a SA measurement tool named Computational Representation of Situation Awareness with Graphical Expressions (CoRSAGE) was developed. To make graphical expression simpler, three components were newly developed: A Bayesian inference transition, a volatile memory token, and non-volatile memory token. Brief explanations are;

A Bayesian inference transition

The cognitive loop of information processing using Bayesian inference constantly appears while dealing with tasks. So, the loop can be represented by a sub-net concept of the PN.

A volatile memory token

This token carries information from an environment. Information is captured in the sensory memory and pushed to the working memory. In any case, it is vanished shortly to make a room for the upcoming information. Therefore, information in the volatile memory token is instant.

A non-volatile memory token

This token carries probability of events at a certain moment and the sequence. So, the non-volatile memory token acts like a part of operator's working memory. The number in a square box represents the number of updates.

3. Case Study.

Training data of emergency conditions were video recorded in a training center of Korea Hydro & Nuclear Power Co., Ltd. (KHNP) by KHNP personnel. The main purpose of training was V/V of HSI in an advanced main control room. The Loss of Coolant Accident (LOCA) scenario was conducted by selected operators from NPPs for HSI V/V. Performance scores were checked for a comparison using the Operator Performance Assessment System developed by the Halden Reactor Project [7].

3.1 Results and Discussion

In this scenario, operators knew the LOCA had happened, so there was no diagnostic process. Operators had to follow 1 to 34 steps in a LOCA emergency operating procedure (EOP) to complete given missions. Thus, probabilities in this case study could be interpreted as both operator's exertion of assigning cognitive resources and confidence level. The referential information process starts from a recognition of the LOCA. Then the operator checks whether safety injection (SI) system is working properly. The operator needs to find out the location of the LOCA while maintaining heat removal of a reactor coolant system (RCS). Finally, the operator has to decide whether a shutdown cooling process is enough or a long term cooling process is necessary. Task analysis was conducted, and 30 pieces of critical information were selected to appropriately handle a given LOCA situation. At the initial condition, the probability of the normal condition was 1. But, when the operator acknowledged the LOCA and saw pressurizer (PRZ) pressure was decreasing he/she started to consider three possible events, namely normal, LOCA, and pressure control system malfunction, with almost even possibilities. With some more piece of information, the operator figured out the LOCA had happened within the containment building, and the location of local was not isolated. Probabilities in the 20^{th} step (RCS temperature) could be interpreted that he/she thought heat removal was not sufficient (0.1702) because of unsatisfied SI flow (0.4149), but RCS heat removal was being maintained (0.4150). Then, the operator confirmed that the RCS could remove heat by natural circulation, so the SI system was no longer required. Finally, the operator decided simultaneous injection to both hot and cold legs with a certain level of confidence of shutdown cooling operation was secured.

4. Conclusions

There have been many attempts to understand cognitive processes in operators. Describing operator's SA is considered as one of the most plausible ways of such endeavors. Operator's cognitive activities in training can be a barometer of operator's unknown behavior in real situations. Knowing what the operator is thinking is important for better results of upcoming training. To give trainers an intuition that how well operators cope with dynamic situations, the quantitative tool to estimate SA named CoRSAGE was proposed. CoRSAGE gives reasonable clues why the operator behaves in a certain way by showing possible changes in a quantitative and graphical manner. Especially, a graphical comparison between referential information processing flow and operator's real information processing flow can offer trainers a detailed insight. In short, despite the incredulous opinion on measuring human cognition with probability, the result showed a positive view of applicability of Bayesian inference to SA measurement. The next step of the research will be improvement in responsiveness to 'rare but important' information.

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