A Situation Assessment Model of Nuclear Power Plant Operators based on Bayesian Inference

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ABSTRACT

Even though many descriptive and qualitative models for situation awareness and situation assessment have been developed, only few quantitative models have been developed so far. In this paper, we propose a quantitative model for situation assessment, with an application to nuclear power plant operators. Basically, our quantitative model is based on Bayesian inference and information theory, and describes the process of knowledge-driven monitoring and the revision of operators' understanding of the plant status. We believe that the proposed quantitative model can be used as the basis for establishing the quantitative model for the situation assessment of real human operators.

KEYWORDS

situation assessment, situation awareness, Bayesian inference, information theory, nuclear power plant operators

INTRODUCTION

Needless to say, probabilistic safety assessment (PSA) and human reliability analysis (HRA) in the framework of PSA (HRA-cum-PSA) are important, and many literatures mentioned the importance of them. Human operators take important roles in generating appropriate control signals to mitigate accident situations, as a backup of automatic control systems or as the only barrier to unfavorable events. The role of HRA in the framework of PSA is to estimate the failure probabilities of those actions.

Whether operators take appropriate actions in accident situations or not is highly dependent on the situation assessment of human operators. In this sense, the situation assessment of human operators in accident situations is considered to be most important in HRA. But, in most conventional (first generation) HRA methods such as THERP (Swain and Guttman, 1983), ASEP (Swain, 1987),
and HCR (Hannaman et al., 1984), the methods for estimating the failure probabilities of situation assessment do not consider the situations in which operators have to perform the situation assessment, and this becomes one source of a lot of criticisms on the conventional HRA methods. As a result, conventional HRA methods cannot consider the possibility of operators’ unsafe actions due to wrong situation assessment (so called errors-or-commission in many literatures). As Hollnagel (Hollnagel, 1998) mentioned, we believe that the advanced HRA methods should be established on the firm basis of operator models which can explain the operators’ actions and their performance. In this sense, we propose a new model for the situation assessment of nuclear power plant (NPP) operators which can be used to overcome the limitations of conventional HRA methods.

THE PROPOSED MODEL

1. Interdependency of I&C Systems and Human Operators

Many situation awareness models have been developed, and they usually include the process of situation assessment. Generally, those models explain the situation assessment as the process of accumulating the situation awareness (the degree of understanding the situation correctly) based on their knowledge, which is formed from training and experience, and the information that they receive. Because instrumentation and control (I&C) systems are a major source of information to main control room (MCR) operators, it can be said that the situation assessment of human operators are dependant on I&C systems. On the other hand, it can be said that the reliabilities of automatic control signals for mitigating accident situations generated by I&C systems are also dependant on the situation assessment of human operators, since human operators can bypass those signals, appropriately or inappropriately. In this sense, it can be said that I&C systems and human operators are interdependent.

In the viewpoint of PSA, what is important is the probability that necessary control signals for mitigating accident situations can be generated by I&C systems or human operators. Since I&C systems and human operators are interdependent as mentioned above, I&C systems, man-machine interface (MMI) and human operator should be considered as one integrated entity which performs the function of generating necessary control signals.

In this sense, a quantitative model for the integrated entity was developed by Kim and Seong (Kim and Seong, 2004). This model was a pure mathematical model, and described the information flow in various stages from information gathering to the generation of control signals. The sensitivity analysis of the model concluded that the reliabilities of instruments and factors related to human operators are important to the generation of necessary control signals.

The concept of risk concentration on I&C systems by Kang and Jang (Kang and Jang, 2004) also emphasizes the interdependency of I&C systems and human operators. The major point of the concept is that the failure of one safety-critical digital system in an NPP not only leads to the failure of generating the reactor trip signal and necessary control signals for mitigating accident situations, but also possibly deteriorates the generation of manual control signals by human operators because
the digital system possibly also fails to generate necessary alarms for human operators. Even though we agree with the possibility of that kind of situations, we are actually more concerned about the effects of instrument faults to the situation assessment of human operators. As mentioned in ATHEANA handbook, there has been very little consideration on how instrument faults will affect the ability of the operators to understand the conditions within the plant and act appropriately.

2. Effect of instrument faults to the situation assessment of human operators

To demonstrate the possibility that the instrument faults can not only lead to the failures in generating the reactor trip signal and necessary control signals for mitigating accident situations but also deteriorate the situation assessment of human operators, we performed a simulation experiment. The simulation reveals that the common cause failure of pressurizer pressure sensors can simultaneously prohibit the reactor protection system (RPS) from generating the reactor trip signal and the engineered safety features actuation system (ESFAS) from generating the safety injection (SI) signal. In this situation, operators can see several alarms generated by control systems and alarm systems, which inform the operators the occurrence of an abnormal situation. What is important in the viewpoint of PSA is the probability that human operators correctly recognize the occurrence of an accident and generate the manual reactor trip signal and SI actuation signal.

In estimating such probabilities, one thing that should be considered is operators’ reluctance on the manual actuation of reactor trip or safety functions such as SI without clear understanding of the situation. Analysis of incident reports reveals that operators sometimes even bypass safety functions when they cannot clearly understand the situation, with a hope that they can manage the situation. An AEOD report (AEOD, 1995) which identified 14 inappropriate bypasses of engineered safety features (ESFs) over 41 months supports this operators’ tendency. This operators’ tendency also emphasizes the importance of operators’ situation assessment in accident situations.

Therefore, we believe that it is necessary to develop a quantitative model for the situation assessment of human operators in accident situations which include instrument faults.

3. A Quantitative Situation Assessment Model

Many situation awareness models have been developed, and they usually include explanations to the process of situation assessment. But, due to the qualitative and descriptive nature of the existing situation awareness models, we believe that a new quantitative model for the situation assessment needs to be developed. In this sense, we develop a new quantitative model for the situation assessment of human operators, with the following two assumptions:

1. Human operators can do Bayesian inference, even though the result cannot be as accurate as mathematical calculations.

2. In knowledge-driven monitoring, human operators select the most informative indicator as the next indicator to monitor.

Admitting the characteristics and limitations of human operators, we first develop a mathematical model for the situation assessment of ideal operators, which is based on Bayes’s Theorem and the information theory. Explanations for the details of the model are not included in this paper. We believe that there are some consistencies between the mathematical model for the situation assess-
ment of ideal operators and the model for the situation assessment of human operators. A preliminary experiment revealed that the assumptions we made seem to be reasonable. In our opinion, the mathematical model for the situation assessment of ideal operators can be used as the starting point for the development of the quantitative model for the situation assessment of human operators.

CONCLUSIONS AND PERSPECTIVES

To make PSA more realistic, the improvements of HRA are essential. But, current HRA methods have many limitations including the lack of considerations on the interdependency between I&C systems and human operators, and lack of theoretical model for situation assessment. To overcome these limitations, we develop a quantitative model for the situation assessment of NPP operators. The proposed model is developed based on Bayesian inference and the information theory. The proposed model is expected to increase the reality of PSA, by increasing the reality of HRA in the framework of PSA.

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