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# An analytic model for situation assessment of nuclear power plant operators based on Bayesian inference

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**Abstract**

Simulation-based human reliability analysis (HRA) methods such as IDAC seem to provide a new direction for the development of advanced HRA methods. In such simulation-based HRA methods, the simulation model for the situation assessment of nuclear power plant (NPP) operators is essential, especially for addressing the issue of errors-of-commission (EOCs). Therefore, we propose an analytic model for the situation assessment of NPP operators based on Bayesian inference. The proposed model is found to be able to address several important features of the situation assessment of NPP operators, and is expected to provide good approximations to some parts of the situation assessment. A comparison with an existing model and identification of several other features of the situation assessment of NPP operators that should be further addressed are also provided.


*Keywords:* Human reliability analysis; Analytic model; Situation assessment; Bayesian inference; Nuclear power plant operators

## 1. Introduction

Recently, many advanced human reliability analysis (HRA) methods have been developed, such as ATHEANA [1], CREAM [2], and AGAPE-ET [3], and more are currently under development. Among them, several simulation-based HRA methods such as IDAC [4,5], the antecedent model of which is IDA [6,7], seem to provide a new direction for the development of advanced HRA methods. To develop such simulation-based HRA methods, we believe that a simulation model for the situation assessment of nuclear power plant (NPP) operators is essential, especially for addressing the issue of errors-of-commission (EOCs).

So far, many qualitative (descriptive) situation awareness models, such as those by Endsley [8], Bendy and Meister [9], and Adams et al. [10], have been developed, and most of these qualitative situation awareness models provide descriptions for the process of situation assessment. These models basically describe basic principles and general features regarding how people process information or interact with the environment to attain their situation awareness. Even though these models are very helpful for understanding the process of situation assessment when analyzing events retrospectively, their descriptive and qualitative nature is limiting in terms of helping us predict what will happen in various situations. For simulating the behavior of NPP operators under abnormal situations, we need quantitative (prescriptive) models that can be used to predict what will happen in various situations. However, only a few quantitative situation assessment models, such as that by Miao et al. [11], have been developed so far.

Therefore, we propose an analytic model for the situation assessment of NPP operators based on Bayesian inference, which can be used as a basis for the development of quantitative models for the situation assessment of NPP operators. Even though there has been some controversy over the use of Bayesian inference to describe how humans process incoming information, the summary of which can be found in Reason [12], we believe that Bayesian inference can be used at least as an approximation for how incoming information is processed. The following quotations support

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our view on the use of Bayesian inference as the basis for developing an analytic model for the situation assessment of NPP operators:

– ‘Man, by and large, follows the correct Bayesian rule [in estimating subjective probabilities], but fails to appreciate the full impact of the evidence, and is therefore conservative’ (Edwards [13]).
– ‘In a situation assessment problem we expect beforehand that if the situation is *S*, then *E* (as set of event cues associated with *S*) should occur. After we detect these events, we then attempt to reassess *S*, based on our understanding of the situation–event relations. In other words, the situation assessment process is a diagnostic process (from effects to possible reasons), instead of a deductive reasoning process’ (Miao et al. [11]).

The basic assumptions and a description of the proposed model are provided in Section 2, and an example of the proposed model is given in Section 3. Discussions on the proposed model are provided in Section 4 and conclusions are drawn in Section 5.

## 2. The proposed model

### 2.1. Description of situation assessment process

When an abnormal situation occurs in an NPP, operators perform a *situation assessment*, which means that they try to understand what is happening in the plant. During this situation assessment process, operators receive information from indicators or from other operators and process the information to establish *situation models* based on their *mental models*. As O’Hara et al. [14] summarized, a *situation model* is an operator’s understanding of the specific situation, and the model is constantly updated as new information is received. *Mental model* refers to the general knowledge governing the performance of highly experienced operators. When the operator’s situation model accurately reflects the plant’s state, the operator can be said to have good *situation awareness*. In other words, as Endsley [8] pointed out, *situation awareness* is a state of knowledge while *situation assessment* is the process of achieving, acquiring, or maintaining situation awareness.

The knowledge and background as field operators and main control room (MCR) operators and their experiences during full-scope simulator training are the major sources of establishing the mental models of NPP operators for the NPPs. These mental models include expectations on how the NPPs will behave in various abnormal situations. Examples of such expectations are: ‘when a LOCA (loss of coolant accident) occurs, the pressurizer pressure and pressurizer level will decrease, and the containment radiation will increase’, and ‘when an SGTR (steam generator tube rupture) accident occurs, the pressurizer pressure and pressurizer level will decrease and the secondary radiation will increase’. These expectations form rules on the dynamics of the NPPs, and those rules become an important part of the mental models of NPP operators.

When an abnormal or accident situation occurs in an NPP, operators usually first recognize it by the onset of alarms. The major role of alarms is to draw the attention of operators to the relevant indicators, which they read after receiving an alarm. After reading the indicators, operators try to establish their situation models. At this point, operators usually also consider the possibility of sensor or indicator failures. If operators receive other alarms, operators will read the relevant indicators. Even if operators do not receive other alarms, operators will probably decide to monitor other indicators to confirm their situation models. Regardless of why they monitor other indicators, the observations they make will alter their situation models accordingly.

### 2.2. Simplification of the situation assessment process

To develop an analytic model for the situation assessment of NPP operators, the scopes of terms used in the model should be defined clearly. However, *situation model* and *mental model*, which are the two most important terms for understanding the process of situation assessment, cover too wide a range of concepts. In fact, the term *situation model* covers all aspects of how NPP operators recognize the situation, and the term *mental model* covers all kinds of general knowledge on various areas related to the operation of NPPs. To develop an analytic model for the situation assessment of NPP operators, we first need to restrict the scopes of these two terms so that they can be clearly defined in the analytic model.

A *situation model* is basically the understanding of NPP operators of the state of the plant. Event though there can be an almost infinite number of different states of the plant, we can define a finite number of representative states of the plant. For example, even though the states of the plant will be different when the breaking locations in a reactor coolant system (RCS) are different, some common symptoms, such as a decrease in pressurizer pressure and pressurizer level and an increase in the containment radiation, can be observed by NPP operators. Therefore, a lot of different states of the plant can be represented by the representative state of the plant termed LOCA. Similarly, a finite number of other representative states of the plant can be defined. Also, it is assumed that the situation model of an NPP operator can be modeled using the representative states of the plant, which means that NPP operators consider only the representative states of the plant.

As mentioned, operators form rules on the dynamics of the plant, and those rules become an important part of the mental models of NPP operators. It also seems that those rules have an important role in the understanding of the state