Development of a Situation Assessment Model of a Nuclear Power Plant Operator from Compact Nuclear Simulator Simulations

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1. Introduction

In our previous works, we developed a quantitative model for the situation assessment of nuclear power plant (NPP) operators under accident situations, based on Bayesian inference and the information theory. [1,2] To demonstrate the feasibility of the model, we apply the developed model to the situation assessment of various malfunctions in Compact Nuclear Simulator (CNS) [3], which is a small simulator for Westinghouse 900MWe 3-loop pressurized water reactors (PWRs) such as Kori 3&4 and Younggwang 1&2 NPPs.

2. CNS Simulation

The CNS simulator can simulate the effects of 79 different malfunctions. Among them, 43 malfunctions are selected because they can actually change the plant state. Thus, the simulation experiments are performed for 44 different plant states, including the (100% power) normal operation state. For each simulation experiment, the behavior of 100 selected indicators is logged. Figure 1 shows the trend of a selected indicator (reactor power) for the 44 different plant states. By analyzing the 100 logged indicator trend data, 31 indicators are identified to be useful for assessing the 44 different plant states and they are used to develop the situation assessment model for an NPP operator.

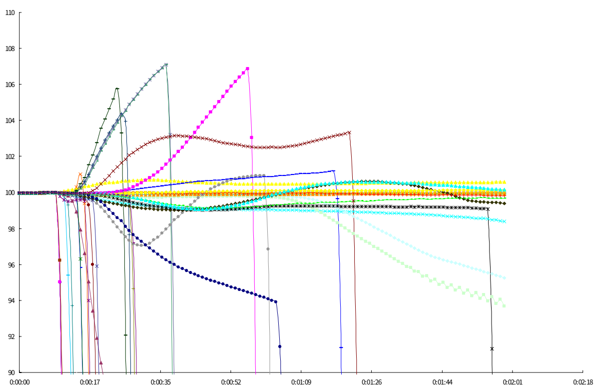

Figure 1. The trend of reactor power for 44 different plant states (Malfunctions are inserted at 10 seconds.) The trends of reactor power are divided into three categories, increase, no change, and decrease. The trends of other plant parameters (indicators) are analyzed in a similar way.

Because there are 44 different plant states and 31 indicators, totally 1,364 trends of different indicators for different plant states are identified and summarized. Those data are used as the basis for the development of the mental model of the NPP operator, with the assumption that the NPP operator is well-trained and highly experienced, i.e. he/she knows exactly how the dynamics of the plant will be observed in different plant states.

Figure 2 shows the Bayesian network model for the situation assessment of the NPP operator. From Figure 2, it can be seen that 31 indicators are considered as information sources, and the NPP operator consider 44 different plant states, the probability distribution of which represents the situation model of the NPP operator. In Figure 2, it is shown that the NPP operator makes the conclusion that the plant state is “Drop of several control rods,” from the observations that the reactor power is decreasing, generator output is decreasing, the full-withdrawal of control bank D, and the onset of the pressureizer backup heater.

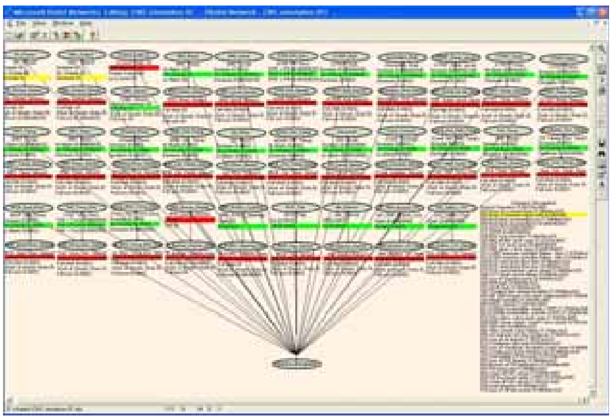

Figure 2. Baysian network model for the situation assessment of the NPP operator

Because the Bayesian network model shown in Figure 2 provides only the calculation results for the situation model of the NPP operator given observations, it cannot provide the change of the situation model of the NPP operator as a function of time or the effects of various context factors to the performance of human operators. To overcome these limitations of the Bayesian network model, we developed a Mathematica® [4] code.

When the number of plant states and indicators are less than 10, calculating the exact probabilities of all possible scenarios is somewhat feasible. But, when the number of plant states and indicators are bigger than 10, calculating the exact probabilities of all possible scenarios takes too much time, and therefore Monte Carlo simulation becomes more beneficial. In this sense, the Mathematica(R) code makes use of Monte Carlo simulations in calculating the probability distributions of the situation model of the NPP operator after observing the behavior of indicators. For example, if the NPP operator observes that the pressuirzer pressure is decreasing, and the pressurizer backup heater is ON, the observations change the situation model of the NPP operator, and the changed situation model guides the knowledge-driven monitoring of the NPP operator. The two references Ref.[1,2] provides mathematical basis to describe the change of the situation model and how the NPP operator performs the knowledge-driven monitoring process. From the probability distributions calculated using the analytic solutions [1,2], the Mathematica® code determines what the NPP operator decides to monitor and what the NPP operator will observe from the indicator. The observation will further change the situation model of the NPP operator and the NPP operator will monitor other indicator. In this way, the simulation is an iterative process.

Figure 3 shows a result of such a simulation. Figure 3 shows the change of the probability that the NPP operator assesses the situation as the occurrence of a small LOCA when the plant state is "Small LOCA," as a function of the number of indicators the NPP operator makes observations. The probabilities are calculated based on 100 simulations.

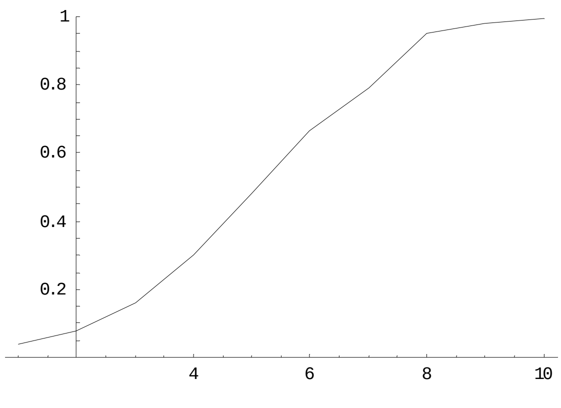

Figure 3. The change of the probability that the NPP operator assesses the situation as the occurrence of a small LOCA when the plant state is "Small LOCA," as a function of the number of indicators the NPP operator makes observations

4. Conclusions

From the simulation results of various malfunctions in CNS, the situation assessment model for the NPP operator can be developed. The situation assessment model provides the change of the situation model of the NPP operator as the NPP operator makes more and more observations. The situation assessment model also includes the effects of context factors such as working condition, crew collaboration quality and so on, and the possibilities of instrument faults.

Even though the situation assessment model of the NPP operator requires some refinements, we think that the developed situation assessment model of the NPP operator can contribute to analyze the effects of context factors and instrument faults on the performance of NPP operators in various situations. We also think that the developed Bayesian network model can be used as the basis for the development of fault diagnosis systems for NPPs.

REFERENCES

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