An Accident Diagnosis Methodology Using System Dynamics

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1. Introduction

For nuclear power plants, EOPs (Emergency Operating Procedures) help operators to diagnose and analyze accidents. But it is very difficult that operators diagnose and analyze similar accidents with EOPs in a given short time. There are also possibilities to follow wrong procedures due to complex and extensive procedures.

Therefore, it is important to develop a methodology for time – dependent diagnosing accidents in a short time and reduction of human errors that made by complex signals and indicators.

2. Methods and Results

In this study, system dynamics and bayesian operation have been applied for construction of accident diagnosis model. And parameters in the model have been collected from EOPs.[1]

2.1 Dynamic reliability

The failure probabilities of the systems are, then, evaluated on the basis of failure parameters characteristic of the elementary components combined according to the laws of probability theory. Evidently, the methodology is not intended to directly simulate the integrated, dynamic response of the plant during an accident. Therefore, the model consists of a set of logic statements deterministically associating sets of success and failure top events with plant damage states.

From a qualitative modelling point of view, the event tree/fault tree methodology does not treat the time-dependent interactions occurring during the accident evolution between plant physical processes, hardware states and human operators action. From a quantitative perspective, the lack of treatment of these dynamic interactions is such that potentially significant dependencies between failure events modelled in current risk assessments may not be identified or properly quantified. These are the main reasons for the inability of classical methodologies to deal with scenarios for which the plant dynamic behaviour is a significant factor.[2]

2. Bayesian Operation for Accident Diagnosis

System dynamics methodology useful for complex systems such as a nuclear power plant has been applied for representing the time-dependent behavior (feedback and dependency, etc) and uncertain behavior of complex physical system. And Bayesian Theorem has been applied for quantification of this model. The employment of Bayesian operation for quantification offers an appropriate method to model the human decision process.[2-5]

Bayesian operation in Influence Diagrams model is,

$$\begin{aligned} P(AE) &= P(A)P(E|A) \\ &= P(E)P(A|E) \end{aligned} \tag{1}$$

$$P(A|E) = P(A)\frac{P(E|A)}{P(E)}$$

where, $p(A|E)$: Posterior

$p(A)$: Prior

$\frac{p(E|A)}{p(E)}$: Likelihood of Evidence

$$P(A_j \mid E) = \frac{P(A_j)\times L(E \mid A_j)}{\int_{j-1}^{N} L(E \mid A_j)P(A_j)} \tag{2}$$

2.3 Accident Diagnosis Model using System Dynamics

The purpose of this study is development of accident diagnosis model and application of given accident such as SLOCA (Small Loss Of Coolant Accident) and SGTR (Steam Generator Tube Rupture). It is difficult that diagnosis of this accidents because of similar symptoms. Therefore, in this study, diagnosis model has been constructed with parameters of these accidents.

This model contains 1 diagnosis variable, 18 symptom variables. These nodes are connected with arc. Initiating event frequency and component unavailability have been used for data of diagnosis node and measurement nodes. For symptom nodes, “increase, decrease, no change” condition has been applied according to given symptoms of accidents. When evidences are given by symptoms, quantification of this model is performed by Bayesian calculation procedures mentioned above.

In EOPs, each accident has their symptoms. From these symptoms and EOPs, data have been chosen. Also, probabilities of symptom variables are know, because it is

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clearly shown that the types of accidents have significant symptoms. Simplified model is presented in Fig. 1 and is the one that has been applied system dynamics

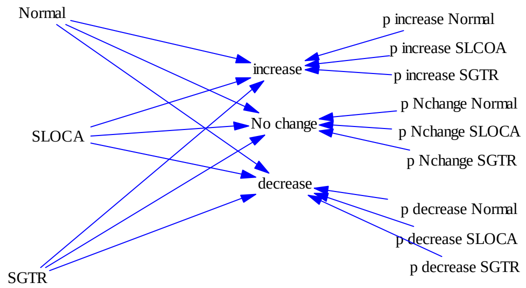

Figure 1. Accident Diagnosis Model using System dynamics

2.4 Results

From the developed model, changes of probability of each accident caused by evidences (symptoms) are observed. As a result, probabilities of each accident have been changed by applied evidence (PRZ_PR decrease and SG_LEV increase) in Fig. 2.

Before application of given evidence, the probability of each accidents are: “Normal Operation”: 94%, “SLOCA”: 2.4% and “SGTR”: 3.6% (case (a)). As an example, some of symptoms have been applied. Then the results are shown below.

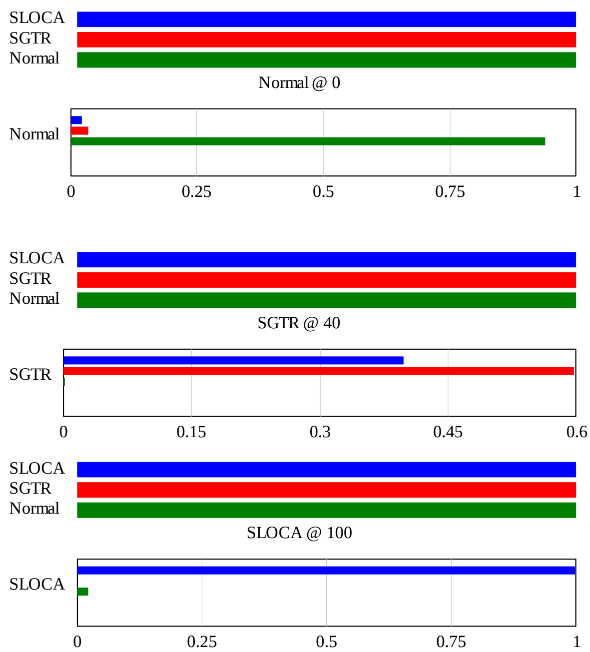

Figure 2. Probabilities of accidents with evidence (case (a,b,c))

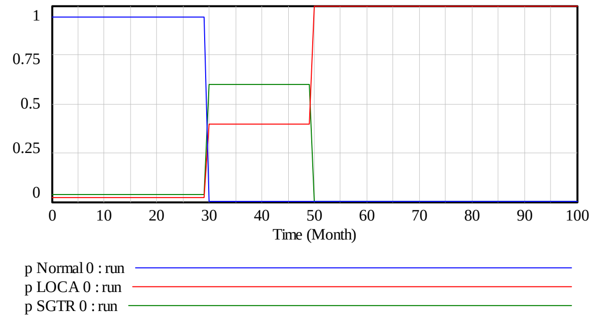

Figure 3. Time-dependent accident diagnosis with evidences

In case (b), situation which has pressurizer pressure decrease has been applied and quantified by this model. For this case, operators could diagnose this accident occurred currently “Normal Operation”: 0.0028%, “SLOCA”: 39.88% and “SGTR”: 59.84% (case (b)).

In this (c), situation which has pressurizer pressure decrease, and steam generator level increase has been applied and quantified by this model. Operators could diagnose this accident occurred currently as SLOCA(case (c)). As results, this model could help operators to diagnose accidents that have similar symptoms.(Figure 3.)

3. Conclusion

Using system dynamics, a quantitative methodology that could diagnose accidents has been introduced in this study. It is shown that the diagnosis results might help operators have enough reaction time and select the appropriate procedure to prevent or mitigate accidents that may occur during normal operation. Some accidents such as SLOCA and SGTR applied in this study have similar symptoms and it is very important to diagnose them correctly.

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