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Information Theory-based Approach for Modeling the Cognitive Behavior of NPP operators

Jong Hyun Kim and Poong Hyun Seong

Korea Advanced Institute of Science and Technology
Department of Nuclear Engineering
373-1 Kusong-dong, Yusong-gu
Taejon, Korea 305-701

Abstract

An NPP system consists of three important components: the machine system, operators, and MMI. Through the MMI, operators monitor and control the plant system. The cognitive model of NPP operators has become a target of modeling by cognitive engineers due to their work environment: complex, uncertain, and safe critical. We suggested the contextual model for the cognitive behavior of NPP operator and the mathematical fundamentals based on information theory which can quantify the model. The demerit of the methodology using the information theory is that it cannot evaluate the correctness and quality of information. Therefore, the validation through the experiment is needed.

1. Introduction

An NPP system consists of three important components: the machine system, operators, and MMI. Through the MMI, operators monitor and control the plant system. Consequently, all of the components have their contributions to the safety and reliability of the total system as a whole. The safety and reliability of the machine system have been paid much attention to and enhanced along the technology advancement. Along with the automation and computerization of the machine system, it becomes necessary to identify the interaction between humans and computers or machines in the new viewpoint. The advancements of information technology have changed not only the nature of controlled systems but also the role of operators in NPP. Operators have changed their role in the total system from the manual controllers to the supervisor of automated system that consists of multiple computer-controlled subsystems [1]. In such systems, operators merely monitor the operation of the systems. When a malfunction occurs, operators diagnose the fault and find the root of cause.

The ultimate objective of modeling the cognitive behavior of operators of nuclear power plant (NPP) is to improve the system design. In order to achieve this duty, it is important to develop a very detailed operator model in which particular emphasis will be given to the modeling of operator error [2]. The operator model, especially contextual approach, suggests several aspects which are important in designing to support human beings in complex tasks [3]. Another objective is to improve the training of operator. Different training methods are suited to different types of cognitive process. Systems which involve control automation or cognitive automation (decision support systems) need to be designed so that operators can develop and maintain the perceptual-motor and cognitive skills they may need during manual take-over.

The cognitive model of NPP operators has become a target of modeling by cognitive engineers due to their work environment: complex, uncertain, and safe critical. Meister described cognitive behavior of NPP reactor operators as a task oriented model which divides operator's behavior into fault diagnosis and restoration of stability [4]. In the IDA cognitive model, the problem solving and decision making model under accident conditions was proposed concentrated on the goal and strategy selection [5]. In addition, some models for simulation of operator behavior have been developed [6], [7].

The first goal of NPP operators is to stabilize the plant. The first concern of NPP operators faced with an abnormal system will, very likely, be a compensation of the immediate influence on some vital performance parameter of the observed abnormal state [8]. The task is to protect the system and immediately to bring it into a safe state before maintenance is considered. NPP operators are responsible for stabilizing the plant to prevent it from losing power and/or decaying to the point that an accident, such as LOCA and core melt down, will occur.

Bainbridge pointed out some drawbacks of sequential model the chief characteristics of which are [3]: There is a one-directional sequence of processing, from stimulus reception to response execution; the output of a stage is a simple mapping of its input; there is a set of sequence of processing stages, though some of the stage may be omitted; and other knowledge is referred to, if at all, only at later stages in the processing. As the author said, the sequential model does not represent the dynamic behavior and is not adequate to model the operator's behavior such as continuous monitoring and information acquisition during performing other process. Therefore, we suggested a contextual model of the cognitive behavior of NPP operator. The terms "sequential" and "contextual" emphasize the comparison between a set sequence of processing stages and the choice of processing topic as a function of context. Then, we used information theory as a methodology to quantify the model. Kang and Seong have attempted to evaluate the complexity of interface and alarm system, based on information theory [9], [10],

[11]. And they have found that information theory is a good tool for evaluating the MMI quantitatively.

II. Modeling the cognitive behavior of NPP operators

After the analysis of MCR operator's behavior, we developed the cognitive behavior model of NPP operators focused on senior reactor operator (SRO) as shown in Figure 1.

We categorize the information processed in the plant and in operator's cognitive activities as follows;

–Plant data

•Raw data detected on instruments, ex)15.2, 12.3,...,67.8

–Signal

•The data presented on MMI, ex) indicator #1:15.2, indicator #2: 12.3

–Sign

•The first processed data in human, ex) the data related to SG #1, its value 15.2…..

–Symptom

•Ex) Temp. of SG #1 is low and decreasing

–Cause

•Ex) The cause of this symptom is U tube rupture.–Goal or procedure

–Action

The information takes the role of the input and output in the operator model. The suggested model is a combined one where the information flow is added to the cognitive process of NPP operator. The explanation of each process is as follows

1) Information Acquisition

This process is the stage which relates raw data to the different physical and logical variables of plant. In this stage, operators acquire actively or inactively the information about the plant through five senses of them, mainly, sight, hearing and touch. The input information is signal-typed and open to all the environments, but varies according to the next process connected. The output information is sign-typed.

2) Event Acknowledgement

In this process which is the starting point of the cognitive activity, operators detect and acknowledge the normal or abnormal change of the situation in the system and equipment of the plant. The input is the sign-type information from alarm and the other operators and the output is the alert which informs the occurrence of some event. After acknowledgement, immediate responses operators may take are to push the buttons of "acknowledgement" in alarm annunciator panel and to notify the occurrence of the event to the other operators.

3) Identification

In this stage, operators interpret the input information and identify the state of system and equipment. If the operators judge that the stabilization of the plant is more urgent than diagnosis and can not find the cause of the anomaly, they can skip the diagnosis and perform the planning process. The input is the sigh-type information from alarm, indicator, status window, diagram, the other operators, alarm processing system (APS), etc. and the output information is the symptom of the plant. The immediate responses are to ask local operators to identify the state of system or equipment by phone call and to notify the symptom to the other operators

4) Diagnosis

Operators generate the hypotheses concerning the meaning of the status information they receive, i.e., the hypotheses concerning the cause and location of the anomaly and test the hypotheses. The input is the symptoms from the prior stage or the other operators and the cause and location of the anomaly from the other operators or fault diagnostic system (FDS). The output information is the cause and location of the anomaly.

5) Planning

After operators understand the state of the system, in this stage they predict the situation which the system or equipment may result in. Then decide the goal which the system or equipment should attain and the procedures to follow in order to attain the goal. The input information is the cause or symptom from prior stages and the other operator and the goal and procedure from the other operators. The output is the goal and procedure.

6) Procedure following

In this process, operators follow the procedure to respond to the situation, to solve pre-defined categories of problems, and achieve specific goals. The procedures may be written, memorized through experience and training, and given as oral instructions by the other operators. The input information is procedures from the prior stage and the other operators, actions to execute from the other operators, and symptoms from the prior stage. The output information is actions to execute.

III. Mathematical Fundamentals based on Information Theory

During operation, operators gather information through MMI, process the information, and decide the response adequate to the current situation. For this reason, we can assume that NPP operators are a kind of information channel. Information theory was created for the purpose of studying the communication of messages from one point to another. There are attempts to evaluate the MMI using information theory as mentioned above. They showed the relation between operator's performance and entropy of MMI. The idea of using information theory to gain a better understanding of systems was used by Conant [12]. He derived an expression, called Partition Law of Information Rates, for the total information rate F (in bits/s) as a measure of the total processing activity.

$$F = F_t + F_b + F_c + F_n \tag{1}$$

Total rate of “information flow”= thruput rate + blockage rate + coordination rate +

$$\sum_{j=1}^{n} \bar{H}(X_j) = \bar{T}(E : S_O) + \bar{T}_{S_O}(E : S_{int}) + \bar{T}(X_1 : X_2 : \cdots : X_n) + \bar{H}_E(S) \tag{2}$$

The term F_t is the thruput rate is a measure of the relatedness between input and output; it is the term that transmission engineers wish to optimize in the case where system is a transmission channel. The second term is the blockage rate and represents the effort needed by system in order to block nonrelevant information (e.g., If the system is a system that from a sequence of natural numbers only presents the prime numbers at its output, then the system internally blocks all non prime numbers). The coordination rate F_c represents the amount of information processing needed to obtain a coordinated action among the system variables (i.e., subsystems) of the system. For example, the previous prime numbers could be obtained using a microprocessor, memory and bus structure. In that case, the commands on the bus given by the microprocessor (like read, write, enable, etc.) are needed for the internal coordination. Hence, part of the processing power is used for this coordination. The noise rate F_n reflects the amount of information in S that is not reflected in (i.e., dependent on) the input to the system. For instance, in a transmission channel, the noise rate reflects the amount of thermal noise produced in that channel.

Conant admitted that there are obvious dangers in applying information theory, designed for use under the severe mathematical constraints of stationarity and ergodicity, to real world systems not thus constrained. However, we could assume that the activities of the human operator is stationary in the suggested model, since the behaviors which operators can take in the MCR are restricted within some limits and run to pattern. If all the information processed in human cognitive behavior is observable, it is thought that the Conant’s model can describe the cognitive behavior of NPP operator.

Since we can assume that as the rate of information flow, viz., the entropy of operators, increases, the performance of the operators is of lower efficiency, the following considerations for the system design, especially MCR, can be recommended.

–Produce the minimum allowable output

•Let operators not do anything unnecessary

•Reduce the number of the information presented as adequately as possible

–Perform as little blockage as possible

•Try to take in a minimum of irrelevant input

•Reduce the number of information which operators do not accept and handle

–Reduce internal coordination to the minimum consistent with other requirements

•Maximize freedom of the components

–As far as possible, match components to tasks so that each component is operated at capacity

•Let each component do what it does best, and work it as hard as you can

IV. Conclusion

We suggested the contextual model for the cognitive behavior of NPP operator and the mathematical fundamentals which can quantify the model. It may be inappropriate to quantitatively model the cognitive behavior of NPP operator due to its dynamic and complex feature. However, considering the purpose of modeling, the quantitative measure is indispensable for development of the MMI familiar and usable. The demerit of the methodology using the information theory is that it cannot evaluate the correctness and quality of information. Therefore, the validation through the experiment should be accompanied.

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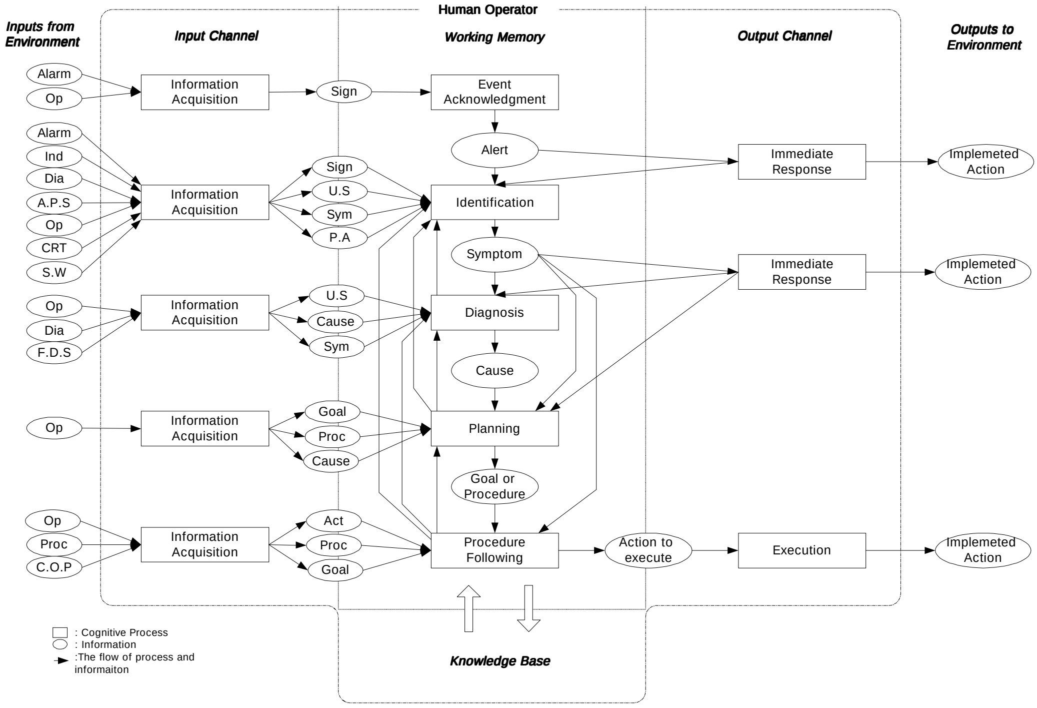

Figure 1. The cognitive behavior model of NPP operator