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A decision support system for identifying abnormal operating procedures in a nuclear power plant

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ABSTRACT

In order to prevent safety hazards that can result from inappropriate decisions made by the operators of a nuclear power plant (NPP), this study was undertaken to develop a decision support system to reduce the complexity of the decision-making process by aiding operators' cognitive activities, integrating unusual symptoms, and identifying the most suitable abnormal operating procedure (AOP) for operators. The study was conducted from the perspective of human factors engineering in order to compare the process that operators originally used to select an AOP with a process that included a support system for AOP identification. The results of the study indicated that the existence of a support system reduces errors by quickly suggesting likely AOPs. With such a support system in place, there were clear improvements in human performance, i.e., decision-making time decreased by about 25%, and the accuracy of the operators' decisions, judged by the successful resolution of specific problems, increased by about 18%. In addition, there were fewer erroneous solutions implemented, and the mental workload was reduced. Hence, the decision support system is proposed as a training tool in identifying AOPs in the main control room (MCR).

1. Introduction

In nuclear power plants (NPPs), operational safety is the top priority because the release of radioactive materials can result in loss of life, environmental pollution, and financial losses. Isaac et al. (2002) indicated that human error is a major contributor (70–90%) to accidents at NPPs. For instance, the Chernobyl disaster in 1986 in the Soviet Union was caused by human errors that dealt with decision making, receiving information, and action selection. In order to maintain safety in NPPs, the human factor issue cannot be ignored.

Alarm systems play an important role in NPPs. They are the main source that operators must depend on for detecting abnormal situations and failures. Alarm systems monitor all important plant systems and alert operators when abnormal situations occur (O'Hara et al., 2000; Noyes and Bransby, 2001), so robust alarm systems are very important. In conventional NPPs, the traditional analog alarm systems use continuous physical phenomena, such as electrical, mechanical, or hydraulic quantities, to assess the status of the operational components of the plant. However, as technology has developed, digital systems gradually have been overcoming the use of analog systems in NPPs. Although digital systems are more precise, too much information and too many alarms may make it difficult for the operator to comprehend what is actually happening in the plant. For this reason, some latent problems associated with the digital main control systems must be solved.

In an NPP, the operators' tasks include information gathering, planning, decision making, and avoiding unforeseen risks through the alarm system (Noyes and Bransby, 2001) if they follow an incorrect operating procedure, for instance. The operators' tasks are to monitor the system continually to ensure that the system is stable and functioning normally (Ma et al., 2006). During abnormal situations, a well-trained operator should comprehend a malfunction in real time by analyzing alarms, assessing values, or recognizing unusual trends of multiple instruments (Hogg et al., 1995; Vicente et al., 1996). In an NPP, many alarms from many different systems often occur at the same time during an incident, making it difficult for the operator to select a correct response efficiently. Too many information imposes a heavy burden on operators in a time-critical situation, and it is very difficult for them to conduct a thorough assessment of each individual symptom in a short period of time. In the absence of operator support systems, the operators must consider an overwhelming amount of information and make decisions very quickly. Unfortunately, this can take too much time. Since the decision-making environment is extremely complicated and data intensive, the use of automated systems or expert systems to aid decision making is likely to become more common. The models

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of these cognitive agents must be accurate and complete if such systems are to be effective in enhancing the speed, accuracy, and efficiency of human decision making (Parasuraman and Mouloua, 1996).

The Lungman NPP in Taiwan uses an advanced boiling water reactor (ABWR) and digital alarm systems. Hence, in this study, the issues at the Lungman NPP were used as a case in order to discuss the design and safety of the fault diagnosis and alarm systems. At the Lungman NPP, three kinds of procedures have been implemented to deal with an abnormal operation status, i.e., Emergency Operating Procedure (EOP), Abnormal Operating Procedure (AOP), and Annunciator Response Procedure (ARP). There are seven EOPs, about 80 AOPs, and over 20,000 ARPs. When the alarms occur, the first thing the operator must do is to confirm whether an EOP should be performed and, if so, which one. If the plant is at risk for radiation leakage, the operator will perform an EOP. If there is no appropriate EOP for the emergency situation at hand, the operator will consider an AOP next. If there is no proper AOP, the operator will operate alarms with ARPs. The entry conditions of EOPs are clearly defined and listed in the EOPs. In addition, each individual alarm has a specific ARP. However, identifying AOPs is more difficult than identifying EOPs or ARPs. There are many abnormal symptoms listed in each AOP. All of the symptoms listed in the AOP might not necessarily be presented. Some symptoms may be related to each other, but some are independent of each other or mutually exclusive. The situation becomes more difficult when many AOPs have the same symptoms. The operators must consider many information sources, organize information, and make a decision. Wickens (1992) indicated that there are four limitations that influence the quality of the operator's decision, i.e., perception, attention, long-term memory, and working memory. It is evident from the above description that the process of decision making that involves the identification of AOPs is very complex. For this reason, this study is focused on the development of a decision support system to improve operators' performance and to lower the chance of human errors. There are many formal and informal symptoms that help plant operators to make their decisions. In the present study, we focus on the symptoms provided by the alarm system for selecting the most likely AOP in time. The objectives of the decision support system are to reduce the amount of information that an operator must consider and integrate during the abnormal situation, to ensure that operators do not overlook important information, and to reduce human errors. In addition, the study was conducted from the perspective of human factors engineering in order to validate the appropriateness and effectiveness of the system.

2. Decision support system applications in NPPs

Kim et al. (2001) used an alarm and diagnosis-integrated operator support (ADIOS) system to prevent too many alarms from influencing the operator's judgment. They indicated that the activation of a large number of alarms imposes too heavy a burden on operators in such a time-critical situation. Multiple alarms interfere with the operator's judgment and ability to diagnose the situation, and they are likely to contribute to human errors. Artificial intelligence techniques have the potential to make a significant contribution to the reliable operation of NPPs, and there were many previous studies concerning the design and implementation of excellent expert systems and operator support systems. Kwon and Kim (1999) applied the Hidden Markov Model (HMM) to identify accidents in NPPs and showed its robustness. The accident identification system accurately identifies the type of accident and also predicts abnormal occurrences in advance. Lee et al. (2007) developed the fault diagnosis advisory system (FDAS), which is based on dynamic neural networks. They indicated that FDAS facilitates the fault diagnosis task and reduces errors by quickly suggesting appropriate courses of action. FDAS provides accurate, reliable advice for operators who must make decisions quickly.

However, according to several papers that assessed the evaluation results provided by decision support systems, such systems do not guarantee improvement in the operator's performance. Some support systems could actually increase the operator's mental workload during these critical times. Therefore, an effective support system must aid, not hinder, the operator's cognitive processes (Yoshikawa, 2005; Kim and Seong, 2006). Time constraints and the volume of information also are crucial issues that support systems must deal with. For any initiating event, there will be a time period beyond which a bad consequence may result. In that time period, the operator has the opportunity to take some action to prevent an adverse radiological event or a reactor accident. The time period might range from fractions of a second to a few minutes. However, if the allowable time period is too short, it is very difficult for the operator to make a decision. In addition, the quantity of information available may impose a heavy burden on operators in a time-critical situation. Thus, a decision support system should be capable of repeating and updating information continually and it should be capable of processing multiple problems simultaneously. Most importantly, the support system should be programmed to provide the best possible answer based on the situation at hand. The combination of a human decision maker and an automated decision aid should result in improved performance (Bernard, 1999).

3. Method and experiment

After visiting the operation training in the Lungman nuclear power plant for several times and interviewing with operators, operators proposed the difficulty of selecting an appropriate AOP under time pressure. Therefore, this study focused on constructing a decision support system to resolve the current problem.

3.1. Decision support system

A decision support system could filter out unrelated information and AOPs and gather some symptoms related to the current event. In addition, it could provide the operator with some suitable AOPs. The operator could refer to the advice of the support system and consider what to do next. According to the AOPs, there are many symptoms related to abnormal events, but it is not necessary to present every symptom listed in the AOPs. Moreover, since some symptoms might belong to several AOPs, the support system can select the related AOPs when an unusual symptom occurs. After the similarity analysis, the operator can refer to the information for decision making. Because all the decision rules of the support system are based on abnormal operating procedures, the more complete AOPs make the decision support system more powerful.

3.1.1. Constructing the abnormal symptom database

Before constructing a decision support system, a database that contains the symptoms of abnormal events must be constructed. The steps for constructing such a database are as follows: (1) collecting all the abnormal symptoms from the AOPs; (2) classifying the symptoms by information source type; and (3) constructing the abnormal symptom matrix. In step 3, the abnormal symptom matrix can be constructed by using the attributes of the information. It is straightforward to place the information sources of system level alarms, plant level alarms, plant status tiles, and individual alarms into "symptom occurs" and "symptom does not occur" categories. In the abnormal symptom matrix, the "symptom occurs" category is designated by "1", and the "symptom does not occur"