



The impact of computer-based procedures on team performance, communication, and situation awareness



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ABSTRACT

In nuclear power plants, operating procedures are adopted to aid the operators in performing their tasks. With the evolution of computer hardware and software, the analog human-machine systems of the main control room in the nuclear power plant have been replaced with digital systems. Moreover, automated operations now outnumber manual operations. The purpose of this study was to evaluate the impact of computer-based procedures on the team performance, communication, and situation awareness of operators in the main control room. To achieve the purpose, a within-subjects experiment was designed and then a survey was conducted. The results showed that the teams had better objective performance and higher situation awareness when using computer-based procedures. In addition, the teams also had lower human error and lower communication rates when using computer-based procedures. This study proposes that computer-based procedures are advantageous to the operation of the systems of the main control rooms in nuclear power plants.

Relevance to industry: Computerized procedures system is one of the specific features for advanced nuclear power plant. This study explores and analyzes the team performance, communication, and situation awareness difference between paper-based, electronic, and computer-based procedures in detail. It may provide practical information for how to apply computer-based procedures to perform the tasks in the main control room of the advanced nuclear power plant.

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1. Introduction

The operating systems of the reactors in the main control room (MCR) of a nuclear power plant (NPP) are important, and human error must be avoided as much as possible because no risk of accidents can be tolerated. That is, safety is a major concern for running reactor systems in NPPs. The tasks in such operating systems are complex and usually accomplished by teamwork, especially during emergencies. The operating teams of advanced MCRs are comprised of one Reactor Operator (RO), one Assistant Reactor Operator (ARO), and one Shift Supervisor (SS) (Plott et al., 2004). They are required to monitor a massive quantity of system information from 45 video display units (VDUs) in the MCR. The operators can touch the screens of the VDUs to select the information they want to see, and they use the important and essential

information on the wide display panel (WDP). The operating teams must perform not only physical tasks but also elaborate perceptual and cognitive tasks (Endsley and Garland, 2000; Lin et al., 2013). They need to act as effective and timely decision makers in many complex and dynamic situations. Therefore, it is necessary to establish adaptive procedures for operators to handle various situations. The procedures in an NPP play an important role in the routine management of NPP operations (Jenkinson, 1992; Livingston, 1989; Trump and Stave, 1988). These procedures provide instructions to guide operators in monitoring displays, generating processing options, selecting an “optimal” option, and controlling the plant to minimize variation (O'Hara et al., 2000; O'Hara et al., 2002).

1.1. Operating procedures in an advanced MCR

In the conventional NPP, the operating procedures are paper-based and are not considered part of the human-system interface (HSI). Paper-based procedures (PBPs), which are provided on

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conventional hard copy media, are adopted despite the limitations on how much information can be presented to the operators. These limitations include the presentation of information in sequential form, the need for numerous iterations through steps, and cautions or warnings that may not be applicable for all system states (Wourms and Rankin, 1994; Mampaey et al., 1988). Such procedures are usually massive and rapidly become outdated. Operators must obtain real-time process information to execute the procedures by going to various instruments or displays, sometimes at multiple locations. Therefore, PBPs impose on the operator tasks that are not directly related to controlling the plant. To make the transition between procedural steps and documents, and to maintain awareness of the status of procedures that are in progress, operators must handle, arrange, scan, and read PBPs in parallel with monitoring and operating tasks.

Following the accidents at Three Mile Island and Chernobyl, the nuclear power industry recognized the importance of having technologically sound and easy-to-use procedures to handle major plant disturbances. Symptom-based emergency operating procedures (EOPs) have been widely employed to enhance the safety of NPPs through a reduction of operator workloads under emergency conditions (Park et al., 2001). Thanks to progress in information technology, operating procedures are now computerized and are expected to evolve to better support operators during emergencies or abnormal operations. The dynamic plant parameters can be embedded directly in the content, and with computerized procedures (CPs), the trends and changes in these parameters can be visualized for better understanding and evaluation of the current status. CPs can provide different levels of functionality and automation (Converse et al., 1992). They are designed and implemented based on the types of functionality according to the guidelines and criteria provided by a specific institute (e.g., the Electric Power Research Institute). Furthermore, CPs can also facilitate response planning and implementation through the instructions and embedded controls of the plant. Several studies have shown that CPs can provide a number of performance benefits; for example, tasks can be performed more quickly, overall workload can be reduced, cognitive workload can be minimized, and fewer errors may be made in transitioning through or between procedures (Portmann and Lipner, 2002; O'Hara et al., 2003; Fink et al., 2009; Yang et al., 2012; Le Blanc and Oxstrand, 2013).

This study approximately classifies two different types of CPs that are defined according to the functionality provided. CPs presented on computer-driven VDUs in text or graphical forms are called electronic procedures (EPs). EPs are essentially replicas of paper-based procedures but may include the ability to call up other EPs and/or include links to relevant indications or controls (Yang et al., 2012). CPs incorporating additional functionality not found in PBPs or EPs are called computer-based procedures (CBPs). The advanced functions of CBPs include automatic retrieval and display of specific information and/or controls to perform a step, automatic processing of step logic and displaying the results, automatic checking of prerequisites or preconditions, and providing cautions or warnings based on current plant conditions (O'Hara et al., 2000; Fink et al., 2009).

CBPs were not developed simply to support procedure management. They also have a range of capabilities that may support operators in controlling the plant and reduce the demands associated with PBPs. In their simplest form, CBPs show the same information on computer-driven VDUs (O'Hara et al., 2000). More advanced CBPs may include features to support managing procedures, detect and monitor the state and parameters of the plant's system, interpret its status, and select and execute actions. Note that CBPs, unlike EPs, automate the gathering and display of information relevant to a procedure step. They may also automate the

processing of procedure step logic and display results, including pass/fail indications. CBPs may suggest and prompt the operator to take actions or execute branches in a procedure. However, they do not by themselves make the decision to act – operators must make those decisions based on information provided to them by CBPs. Therefore, the operator needs to activate and confirm all procedure steps for CBPs to proceed, and they can suspend and perform place-keeping to check around the parameters of the reactor system at any time. Furthermore, the progress information of CBPs can be shared on each VDU in the MCR to support team discussion.

However, computerized operating procedures are not perfect. Since CBPs are displayed on VDUs, the amount of information that can be displayed is limited and could not be noted annotation manually. Even worse, it is possible that the use of CBPs incurs heavy cognitive and physiological workloads (Lee et al., 2005), for operators need to manipulate windows to navigate through the displays (Kim et al., 2014). Huang et al. (2007) found that when a return-to-normal alarm is reset automatically, operators may not be aware that such an alarm has occurred. These performance and safety consequences are viewed as out-of-the-loop (OOTL) performance problems (Endsley and Kiris, 1995). One study has also indicated that a high level of automation can make operating information insufficient (Lin et al., 2010a).

No matter what functions or limitations CBPs comprise, they are designed with the intention of enhancing operating efficiency. Therefore, the content and development of paper-based and computer-based procedures can be essentially the same. Both should be easy to use. However, there can be significant differences in how the procedures are presented, how information is presented to operators, and how operators interact with the procedures. The possible differences between paper-based and computer-based procedure systems, and among computer-based systems, such as those related to automation, should not limit the control or situational awareness of licensed operators, who must have full knowledge of the plant.

1.2. Communication and situation awareness in the advanced MCR

The advanced MCR of an NPP is a critical and complex work environment consisting of operators, the system and devices, actions, and conditions. It is necessary that team skills in the advanced MCR be efficient because operators interact with each other in order to achieve a common goal successfully and safely. To accomplish that common goal, all members of the teamwork must perform their roles and tasks with full and continuous comprehension and awareness of the dynamic situation. Ford and Schmidt (2000) noted that effective team skills are essential for a team to cope with a situation successfully. Such skills assist team members in their development of a shared mental model and help develop team leadership skills (Glickman et al., 1987; Cannon-Bowers et al., 1995; Ford and Schmidt, 2000; Lin et al., 2011). A number of studies have indicated that communication between team members is critical for the successful completion of team tasks (Scholtes, 1988; Pinto and Pinto, 1991; Patrashkova-Volzdoska et al., 2003; Lin et al., 2011). Communication is defined as information exchanges between humans. An instance of communication in the advanced MCR is described as follows.

Under normal operational conditions, operators need only to follow general operation procedures to maintain normal operations of the MCR. However, when incidents and accidents occur, the system sounds alarms and the wide display panel displays warning information. In such instances, operators must first verify the alarm information and closely monitor the relevant VDUs for information about the reactor system. They must then report abnormal conditions to the supervisor and ask how to solve them. Following this,

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