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An experimental investigation on relationship between PSFs and operator performances in the digital main control room

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ABSTRACT

This study designs an experiment to investigate the relationship between performance shaping factors (PSFs) and operator performances. This study involves selecting three PSFs that are controllable in the experiments: (1) experience, (2) complexity, and (3) urgency. Six scenarios are developed to reflect the PSFs. The experiment involves the participation of licensed operators and the use of an APR1400 simulator. During the experiment, operator performances, such as completion time, error, secondary task, workload, and situation awareness, are measured and collected. The experimental result indicates that the operator's experience is most effective on the overall performances. The task complexity influences the secondary tasks and situation awareness.

1. Introduction

Performance shaping factors (PSFs) are factors that influence human performance in human reliability analysis (HRA) (Dhillon, 2014; U.S. NRC, 1983). Most currently applicable HRA methods for nuclear power plants (NPPs) use PSFs to highlight human error contributors as well as to adjust basic human error probabilities (HEPs) that assume nominal conditions of NPPs (U.S. NRC, 1983, 2000a; Jung and Kang, 2005). Typical examples of PSFs include experience, adequacy of procedure, stress, and task complexity.

In order to adjust basic HEPs in HRAs, it is necessary to quantitatively estimate the extent to which a PSF influences operator performances with respect to the condition of interest. Methods to quantitatively estimate PSF influences can be divided into the following three approaches (Groth, 2007):

- Data from actual historical measurements
- Expert judgment
- Data from simulator studies and experimental researches

First, using data from actual historical measurements is the optimal method to most realistically estimate PSF influences on operator performances. However, data scarcity is a disadvantage of this approach because accidents, near misses, and human errors are very rare in actual NPPs. Additionally, it is impossible to control the NPP factors to estimate the influences of PSFs under various conditions such as varying the quality of procedure in actual operations. Second, the expert judgment approach relies on the experience and knowledge possessed by experts to quantify the effect of PSFs. Several HRA methods have applied this approach to estimate HEPs as well as the impact of PSFs on HEPs (Kirwan, 1996; Williams, 1986). Although this appears easier than other approaches in the quantification process, it requires a considerable amount of caution to avoid subjectiveness and bias in selecting experts and aggregating their expertise. Third, using simulator studies and experimental researches is considered as a good alternative to compensate for the weaknesses of the other approaches. This is because this approach can collect more data when compared with approaches that use data from historical measurement, and it can also minimize the effect of subjectiveness and bias issues in expert judgment. However, the fidelity of experimental environment (i.e., degree to which the experimental environment corresponds to actual NPP conditions) is a key issue in obtaining useful data. For example, a simulated environment should replicate exact conditions of events that occur in a real NPP situation. Additionally, there is a possibility that participants may not treat the activity as seriously as a real event. Despite this issue, several studies were recently performed to use simulators and

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experiments for collecting HEP and PSF data for analog main control rooms (MCRs) in NPPs (Jung et al., 2007; OECD, 2008; Park et al., 2014; U.S. NRC, 2014; Valentina et al., 2015).

Application of digital technology is a recent trend in the design of an MCR. Features distinguishing digital control rooms from conventional rooms and analog rooms in NPPs include advanced alarm systems, graphic information display systems, computerized procedure systems, and soft control. These features could cause changes in operator tasks by changing the task characteristics or creating new tasks. Additionally, although this new technology has the potential to improve human performance, it also holds the potential to negatively influence the performance and create precursors to human error (O'Hara and Roth, 2006; Zhou et al., 2012).

The features of digital control rooms are already implemented in new or upgraded NPPs. However, these features cannot be attributed to HRAs due to HRA issues related to digital MCR wherein there is a paucity of data on the influence of technology on human performance and on adjusting human error probabilities (HEPs) with respect to PSFs. A few previous studies were conducted on the influence of new design features on operator performances, such as advanced alarm systems (EPRI, 1990; Hogg et al., 1995; U.S. NRC, 2000b, 2000c), graphic display (Collier, 2005; O'hara et al., 2004; Skraaning and Nihlwing, 2008; Véronique, 1987), computerized procedure systems (Chung et al., 2002; Hong et al., 2009; Hwang and Hwang, 2003; O'hara et al., 2004), and soft control (Harbi et al., 2013; Jang et al., 2014; Kim et al., 2015; Rivera, 2000). However, very few studies examined the effect of PSFs on operator performances with respect to digital MCR.

Hence, this study aims to experimentally investigate the effect of PSFs on operator performances by using an NPP simulator with a high fidelity. A randomized factorial experiment is designed to examine whether PSFs affect operator performances. This study selects three PSFs, namely, operator experience, urgency, and task complexity, which are representative PSFs in the HRA as well as controllable in the experiment. Six operator performances, such as time to enter the cooldown of the reactor coolant system, average completion time per instruction, number of secondary tasks, error rate, workload, and situation awareness, are measured and analyzed. An APR1400 simulator equipped with a fully digitalized human-system interface was used and four crews of operators participated in the experiment. A statistical analysis was also performed to show the relationship between the PSFs and operator performances.

2. Evaluation of PSFs in digital control rooms

2.1. Digital main control rooms in nuclear power plants

Rapid progress of digital and computer technology has led to the incorporation of advanced technology by NPPs in the design of MCRs. Newly constructed NPPs around the world, such as APR1400 in Korea (Ha et al., 2007; Lee et al., 2009), AP1000 in USA (Cummins et al., 2003), and EPR-1600 in France (Twilley, 2004), adopt fully digitalized and computerized control rooms.

There are three major trends in the evolution of digital MCRs, namely (1) increased automation, (2) use of computer-based human-system interface (HSI), and (3) intelligent operator aids (O'hara and Hall, 1992). Computer-based HSIs and operator aids include features such as advanced alarm systems, graphic display systems, computerized procedure systems and soft controls. Advanced alarm systems provide processed alarms by eliminating nuisance and/or redundant alarms and prioritizing, filtering, and suppressing alarms (U.S. NRC, 2000b). Graphic display systems contain a variety of display types including graphic process displays that provide plant parameter information organized around plant system mimics and predefined as well as operator defined trend displays of plant parameters. The graphic display system can be accessed from any of the operator workstations. Computerized procedure systems provide different levels of functionality including systems that simply display a replica of paper-based procedures on a computer screen, systems that automatically retrieve relevant process data to form a procedure step and process the step logic as an aid to the operator, and systems that include procedure-based automation (EPRI, 2010). Soft controls use the input interface connected with control and display systems that are mediated by software instead of direct physical connections in analog MCRs (U.S. NRC, 2000d). Fig. 1 shows the primary tasks of NPP operators and the potential supportiveness of new features in digital MCRs (Kim and Dang, 2011).

These features may lead to changes in operator tasks by changing task characteristics or creating new tasks. The computerized HSI may influence the functioning of operators as a crew (U.S. NRC, 2002a). For example, computerized procedure and graphic display systems can provide a shift supervisor with plant parameter data required to work through the procedures. This may have two direct effects, namely reducing the need for low-level communication between the shift operators and the board operators and reducing cognitive workloads of board operators (Roth and O'Hara, 1999). Furthermore, this new technology may introduce a new task that did not previously exist in the analog MCR. An example of this is the secondary task, which is also called an interface management task. Secondary tasks are performed to access information from workstations including configuring, navigating, arranging, interrogating, and automating. Interface management effects have the potential to increase the likelihood of human errors when the interface is poorly designed (U.S. NRC, 2002b).

2.2. Performance shaping factors in digital main control rooms

A PSF is defined as any factor that influences human performance (Dhillon, 2014; U.S. NRC, 1983). In the ATHEANA Method (U.S. NRC, 2000a), PSFs represent a set of influences on the performance of an operating crew that result from human-related characteristics of the plant, the crew, and the individual operators. The most commonly used HRA methods in the nuclear industry employ PSFs to adjust HEPs in different conditions. PSFs are also known by different terms based on the method. These terms include performance influence factors (PIFs), influencing factors (IFs), performance affecting factors (PAFs), error producing conditions (EPCs), and common performance conditions (CPCs) (Kim and Jung, 2003). HRA methods generally provide analysis and guidelines with respect to PSFs to assess the state of a PSF through direct measurement or extrapolation. As shown in Table 1, Kim et al. (2016) summarized PSFs and assessment approaches suggested by HRA methods. Most HRA methods rely on expert judgment and literature survey to identify PSFs and evaluate their effects.

Only a few studies reported the use of PSFs in digital MCRs. Lee et al. (2011) suggested a systematic approach for qualitatively evaluating PSFs in a digital MCR through a literature review. This study considered the context changes that occurred in the use of computerized procedure systems, graphic information displays, and soft controls. Previous studies empirically investigated the effect of training and task complexity in the use of computerized procedure systems (Xu et al., 2008). However, more studies that use experimental conditions of high fidelity to actual NPPs need to be performed to obtain insights on the effect of PSFs on operator performances in digital MCRs.