Available online at www.sciencedirect.com

ScienceDirect

Reliability Engineering and System Safety 93 (2008) 1500–1511

RELIABILITY ENGINEERING & SYSTEM SAFETY

www.elsevier.com/locate/ress

An ergonomics study of computerized emergency operating procedures: Presentation style, task complexity, and training level

Song Xu[a], Fei Song[a], Zhizhong Li[a,*], Qianyi Zhao[a], Wei Luo[a], Xuhong He[b], Gavriel Salvendy[a]

[a]*Department of Industrial Engineering, Tsinghua University, Beijing 100084, PR China*

[b]*Scanpower Risk Management China Inc., Towercrest International Plaza, No. 3 Maizidian West Road, Chaoyang District, Beijing 100016, PR China*

Received 21 July 2007; received in revised form 8 August 2007; accepted 16 September 2007
Available online 22 September 2007

Abstract

Emergency operating procedures (EOPs) are widely used in nuclear power plants (NPPs). With the development of information technology, computerized EOPs are taking the place of paper-based ones. Unlike paper-based EOPs, the industrial practice of computerized EOPs is still quite limited. Ergonomics issues of computerized EOPs have not been studied adequately. This study focuses on the effects of EOP presentation style, task complexity, and training level on the performance of the operators in the execution of computerized EOPs. One simulated computerized EOP system was developed to present two EOPs, each with different task complexity levels, by two presentation styles (Style A: one- and two-dimensional flowcharts combination; Style B: two-dimensional flowchart and success logic tree combination). Forty subjects participated in the experiment of EOP execution using the simulated system. Statistical analysis of the experimental results indicates that: (1) complexity, presentation style, and training level all can significantly influence the error rate. High-complexity tasks and lack of sufficient training may lead to a higher error rate. Style B caused a significantly higher error rate than style A did in the skilled phase. So the designers of computerized procedures should take the presentation styles of EOPs into account. (2) Task complexity and training level can significantly influence operation time. No significant difference was found in operation time between the two presentation styles. (3) Training level can also significantly influence the subjective workload of EOPs operations. This implies that adequate training is very important for the performance of computerized EOPs even if emergency responses with computerized EOPs are much more simple and easy than that with paper-based EOPs.

Keywords: Emergency operating procedure; Presentation style; Task complexity; Training level; NPP

1. Introduction

Procedures that guide operators in performing tasks are widely used in civil and military fields such as aviation [1], navigation [2], chemical plants [3], and nuclear power plants (NPPs) [4]. With sufficient training and rich experience, operators in NPPs can deal with general tasks without any help from manuals [5]. However, this is not true in some special situations, for example, emergency response. Even during normal plant startup and shutdown, most operators have reported feeling physically and cognitively overburdened [6]. In emergency situations, operators refer to paper-based or computer-based procedures. Emergency operating procedures (EOPs) are traditionally available as printed documents. Paper-based EOPs have obvious disadvantages in the convenience of information acquisition and interactive capabilities [7]. The development of information technology has made computerized presentation of EOPs possible [8]. Computerized procedure systems (CPSs) have been widely introduced in newly built or rebuilt NPPs since the 1980s. Examples of CPSs include COPMA, COMPRO, the N4 Procedure, and DIAM [9,10].

The content of procedures has been continuously changed to adapt to the development of control technology and automation in NPP control rooms; however, the structure of the procedures has basically remained the same [8].

*Corresponding author. Tel.: +86 10 62773923; fax: +86 10 62794399.
E-mail address: zzli@tsinghua.edu.cn (Z. Li).

0951-8320/$ - see front matter
doi:10.1016/j.ress.2007.09.006

As one important component of human–machine interaction systems, a poorly designed procedure may greatly influence an operator's performance and reliability. Generally, there are three important objectives in the design of a procedure: (1) ensure the procedure is technically correct; (2) make sure the presentation of the procedure can be clearly understood without introducing task overload; (3) make sure the correct procedure can be executed without mistakes [8,9].

Peng and Hwang [11] found that EOPs supported by computers could improve the traditional support method under emergency conditions. Compared with procedures based on hard copy, computerized procedures have the advantages of convenience of requisition and interactive capability [7]; however, the transformation of hard copy procedures to computerized ones has caused some problems in the format, representation, wording, and the content of the procedure [12]. After the Three Mile Island accident, symptom-oriented procedure design has gradually been adopted; however, symptom-oriented procedures require much more decision making and increases the mental load [13]. Consequently, a well-designed symptom-oriented CPS is very important to the operation of NPPs, especially in emergency situations. However, the current NPPs have different presentation styles of EOPs. Designed according to the Westinghouse Owners Group Emergency Response Guidelines, the EOP of COMPRO guides operators through the procedures by textual displays and prompts [14]. COPMA II, which was developed by the Halden Reactor Project in Norway, shows one-dimensional flowchart of a procedure, detailed instructions, and related plant information in different frames [15]. The CPS for the Korean Next Generation Reactor (KNGR), which was proposed by Chang et al. [5], consists of one-dimensional flowcharts and text description. Another CPS for the KNGR proposed in 2000 based on the Computerized Procedure Manual II consists of one-dimensional and two-dimensional flowcharts and automatic step logic checking [16]. Jung et al. [9,15] developed a new CPS with a flowchart and simple success tree adopting an N-out-of-M logic operator.

The difference between computerized procedures and hard copy procedures is not only the medium of presentation but also the structure of the information, namely, the presentation style. Research based on experiments has shown that presenting a procedure simply by computerizing a hard copy of the text procedure is inferior to a graphical presentation [8]. However, there has been little research comparing the mainstream graphical computerized procedures such as flowchart procedures, success trees, and their combinations. The objective of this study is to examine operator performance in using computerized EOPs from an ergonomics point of view.

This paper is organized as follows: Section 2 describes the research method including the experiment design; Section 3 presents the results of our experiment; Section 4 includes discussions and conclusions drawn from the study.

2. Methodology

The ergonomics issues of computerized EOPs were investigated by experiment with subject participation. The details about selected EOPs, independent and dependent variables, the experiment platform, and subjects will be introduced in this section.

2.1. Independent variables

Three independent factors were considered in this study: the presentation style of the EOP, task complexity, and training level. Each factor had two levels, as listed in Table 1. A between- and within-subjects mixed experiment design was adopted since a subject would participate in the experiment of one presentation style and one task complexity level but both training levels, as to be further discussed in Section 2.4.

2.1.1. Presentation style

Two typical presentation styles (Styles A and B) were adopted in this experiment (see Fig. 1). Style A included one- and two-dimensional flowcharts and brief instructions. The one-dimensional flowchart, located on the left side of the computer screen, listed all the steps of an EOP, with the current step highlighted. The two-dimensional flowchart, located in the center of the screen, described the detailed logical structure of the current step. Brief instructions and system parameters were located in the right side of the display. Style B included a two-dimensional flowchart and a success tree. The two-dimensional flowchart was located on the left side in Style B, and was briefer than that in Style A. The success tree and text instruction on the right side presented detailed information of the current step. At the bottom right corner of the screen, some buttons were presented for manual control if required in the current step. The subjects should click on proper buttons to perform the control such as switch on/off a valve.

2.1.2. Task complexity

Accidents such as Steam Generator Tube Rupture (SGTR), Loss of Coolant Accident, Loss of All Feed Water, and Loss of Off-site Power are common in the operation of NPPs [17]. In this study, a shortened SGTR procedure was selected as a target procedure with high complexity, and a shortened emergency shutdown

Table 1
Factors and levels in the experiments

Factor	Level 1	Level 2	Factor type
Presentation style	Style A	Style B	Between-subjects
Task complexity	High	Low	Between-subjects
Training level	Skilled	Unskilled	Within-subjects