The Effect of Information Quantity on Cbp Interface in the Advanced Nuclear Power Plant

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Abstract. Computer-based procedures (CBP) are widely used in advanced nuclear power plant (NPP). In order to improve operators' performance and decrease the probability of human errors, several different CBP interface layouts have been provided by previous studies. However, there has been little research discussing the information quantity that present on the CBP interface. This study is to examine operator performance in using computerized procedures from an information quantity point of view. A simulated CBP system was developed to present three different information present styles, each with different task complexity. The results indicated that medium information quantity of CBP interface was better than other level of information quantity.

Keywords: Computer-based procedures; Nuclear power plant; interface; information quantity.

1 Introduction

The procedures of system control that guide operators in performing tasks are widely used in nuclear power plant (NPP) domain (Husseiny et al., 1989; Xu et al., 2008). Computerized procedures (CP) systems in a nuclear power plant (NPP) provide instructions to guide operators in monitoring, decision-making, and controlling the plant. The CP systems have been accepted by various regulatory authorities and are in use at several NPP around the world (Yang et al., 2012). The results of other research studies of CP systems show that CP systems can provide some performance benefits, such as tasks can be performed more quickly; mental workload can be reduced and minimized; fewer errors may be made in transitioning through or between procedures (NUREG/CR-6634; NUREG/CR-6749; Portmann and Lipner, 2002; O;Hara et al., 2003; Yang et al., 2012).

Computer-based procedure (CBP) was a human-system interaction technology that was found to be potentially safety significant (Yang et al., 2012). In order to improve operators' performance and decrease the probability of human errors, several different CBP interface layout have been provided by previous studies (Jung et al., 2004; Xu et al., 2008; Carvalho et al., 2008; Hong et al., 2009).

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Regarding to the control interface of CBP studies, Wourms & Rankin (1994) pointed out that flowchart is better than text in the procedure format because of its ability to relate procedure elements explicitly. Jun et al. (2004) published coherently coupled frames that reduced the number of navigation, and flowchart and success tree were used where total of the process information was shown on the interface. Xu et al. (2008) compared two mainstreams graphical computerized procedures such as flowchart procedures and success tree, the results showed that flowchart procedure was better than success tree. Because the flowchart procedure resulted in a lower error rate without introducing a longer task time and more workload. Carvalho et al. (2011) developed a new CBP interface, and compared it with existing interfaces. The results showed that the time spent by the operator to identify two accidents, through the new interface, was faster than the existing interface. Hong et al. (2009) also developed a computerized procedures system to assist operator executing the procedure tasks.

No matter what format that the procedure information presenting on CBP, however, there has been little research discussing the information quantity that present on the CBP interface. Operators who work in the NPP main control room might be influenced by the information quantity from the computer screen (Wickens, 2000). The objective of this study, therefore, is to examine operator performance in using computerized procedures from an information quantity point of view.

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

2 Methodology

The information quantity issues of CBP interface were investigated by experiment with subject participation. The details about independent and dependent variables, the experiment process, and the information quantity of CBP interface will be introduced in this section.

2.1 Independent Variables

Two independent factors were considered in this experiment: the information quantity of CBP interface and task complexity. Information quantity of CBP interface consisted of three levels and task complexity consisted two levels, as listed in Table 1. A between- and within-subjects mixed experiment design was adopted where a subject would participate in the experimental condition of one presentation style and both task complexity levels.

Table 1. Factors and levels in the experiments

Factor	Level 1	Level 2	Level 3
Information quantity	High	Medium	Low
Task complexity	Complex	Simple	-

2.2 Information Quantity of CBP Interface

Three information quantity of CBP interface (high, medium, and low) were adopted in this experiment. The measurement in information quantity used in this experiment lay in the number of events on the CBP interface, which can be expressed by the formula as follows (Wickens, 2000):

$$H_s = \log_2 N. \quad (1)$$

The information conveyed by an event H_s, in bits, and N is the number of alternative. For example, high information quantity in this experiment with at least eight events' information was shown on the CBP interface in each step, $\log_2 8 = 3$ bits. Medium information quantity in this experiment with at most four events' information was shown in each step, $\log_2 4 = 2$. Low information quantity in this experiment only have one event information was shown on the CBP interface, $\log_2 1 = 0$. Each level of factors included flowcharts and brief instructions. The flowcharts located on the left side of the computer screen displayed all steps of the procedure with the current step highlighted. The flowcharts located in the center of the computer screen displayed the detail structure of the current step. System states were located in the right side of the display.

2.3 Task Complexity

In this study, the degree in task complexity lay in the numbers of steps and parameters in the procedures (Xu et al., 2008). The procedure with high complexity had more steps and parameters than the one with low complexity (table 2).

Table 2. Procedures with complex and simple task

Task complexity	Number of steps	Number of parameters
Complex	9	99
Simple	5	45

2.4 Dependent Variables

Both objective and subjective indexes were used to evaluate operation performance. The objective indexes include operation time and secondary task performance; the National Aeronautics and Space Administration task load index (NASA TLX) was used to measure the subjective workload.

2.5 Participants and Experimental Task

Twenty-one college students from National Tsing Hua University were recruited as participants in this experiment. The average age of the participants was 25.5 years and ranged from 22 to 29 years. All participants were randomly assigned into one of three different information presentation styles. Half of the participants in each presentation style start the formal experiment from complex task, others participants start from simple task.

The CBP interface was simulated using a computer program developed by Adobe FLASH CS6, as shown in Fig. 1.

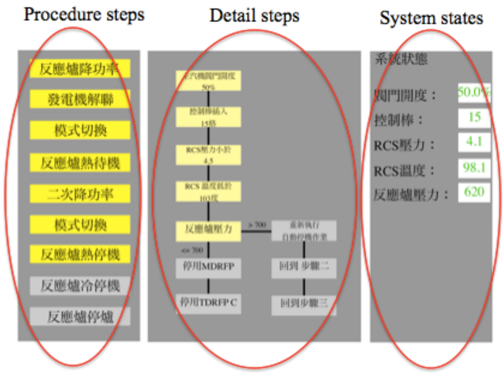

Fig. 1. Interface of the experiment platform (Information quantity: medium; Task: complex)

2.6 Experimental Procedure

The participants were told to try their best to perform the task and avoid any mistakes during the formal experiment. During the primary task, participants are required to detect signal as a searching task. This signals which are randomly showed on the board in front of the participant and the response time of participants were recorded. If the participants miss it and do not detect the signal in 15s, it is recorded as a miss.

Before the formal experiment, the participants needed to listen to the experiment explanation from the experimenter and practiced the CBP system 5 to 10 minutes. At the start of the formal experiment, the participants' operation time was recorded. After the participants finished an experiment treatment, they were asked to take the first NASA-TLX questionnaire and took a break and then continued to execute the other experiment treatment. Finally, the participants took the second NASA-TLX questionnaire and finished the experiment.

3 Results

In this experiment, all statistical analyses were carried out with MINITAB 16. Multivariate analysis of variance (MANOVA) was computed for the operation time, secondary task performance, and workload.

The results of MANOVA indicated that information quantity (Willks' $\lambda = 3.743$, $P < 0.01$), and task complexity (Willks' $\lambda = 10.289$, $P < 0.01$) had significant effects on the dependent measures, as shown in Table 3 and Table 4. There was no significant interaction between information quantity and task complexity on operation time, secondary task performance, nor workload (Willks' $\lambda = 3.484$, $P < 0.05$).

Table 3. MANOVA for information quantity

Criterion	Test Statistic	F	P
Wilks'	0.50943	3.743	0.003
Lawley-Hotelling	0.87084	3.919	0.003
Pillai's	0.53751	3.553	0.005
Roy's	0.74759		

Table 4. MANOVA for task complexity

Criterion	Test Statistic	F	P
Wilks'	0.47564	10.289	0.000
Lawley-Hotelling	1.10243	10.289	0.000
Pillai's	0.52436	10.289	0.000
Roy's	1.10243		

With regard to the individual dependent variables, information quantity significantly influenced the operation time ($F = 9.66$, $P < 0.01$), secondary task performance ($F = 5.37$, $P < 0.05$), and workload ($F = 5.41$, $P < 0.05$).

Figure 2 shows the operation time under each information quantity. Comparing the operation time between these three information quantities demonstrated that the operation time in the high and medium quantity was faster than that in the low quantity.

The secondary task performance under each information quantity is showed in Figure 3. The secondary task performance in the medium quantity was significantly better than that in the high and low information quantity.

Figure 4 shows the workload under each level of information quantity. Comparing the workload between these three information quantities demonstrated that the workload in the medium quantity were lower than that in the high and low quantity.

With regard to the individual dependent variables, task complexity significantly influenced the operation time ($F = 32.47$, $P < 0.01$), but not the workload nor secondary task performance.

Comparing the operation time between these two tasks complexity demonstrated that the operation time in the simple task was faster than that in the complex task.

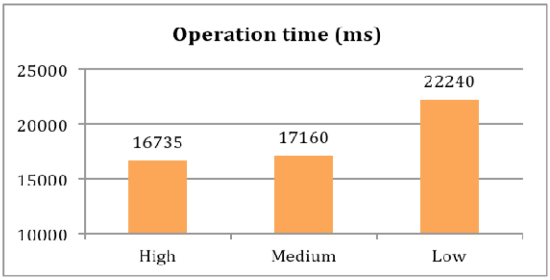

Fig. 2. Main effect plot for operation time

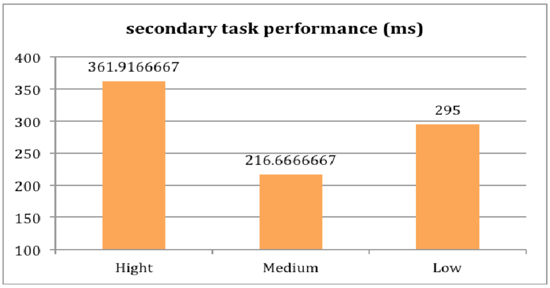

Fig. 3. Main effect plot for secondary task performance

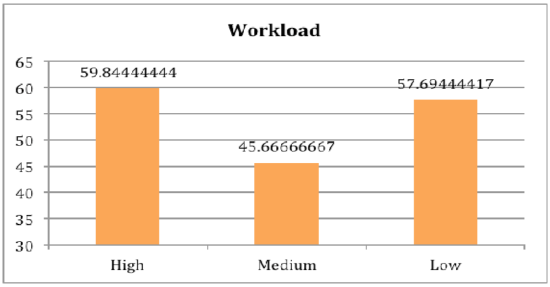

Fig. 4. Main effect plot for workload

4 Discussion and Conclusion

In this study, an experiment was designed to explore how the information quantity of CBP interface and task complexity influence the performance of operators from the criteria of operation time, secondary task performance, and subjective workload.

The information quantity significantly influenced the operation time, secondary task performance, and workload. When the CBP interface with high information quantity, the participants need to spend more time and pay more attention on the task, and may ignore the secondary task and increase mental workload. On the other hand, when the CBP interface with low information quantity, the participants need more actions to click on procedure steps producing a detailed system state of the procedure step, and thus the participants spent more time on the low information quantity task. The task complexity significantly influenced the operation time, in this experiment, and complex task corresponded to longer task time.

Three levels of information quantity were compared in this experiment. Medium information quantity could cause a significantly lower workload than high and low information quantity. Furthermore, Medium information quantity resulted in the highest secondary task performance. There are two reasons to explain the result of this experiment. First reason is that it decreases the information quantity of detailed system state from high information quantity of CBP interface. The other reason is that medium information quantity of CBP interface decreases the number of click CBP interface from low information quantity of CBP interface. Therefore, the participant could identify system state more efficiently, and induce lower mental workload. These results suggest that medium information quantity of CBP interface is better than other level of information quantity.

The interface in an advanced NPP main control room are modernized fully integrated digital design, where CBP have a range of capabilities that may support operators in controlling the NPP (Yang et al., 2012). This study verified the information quantity of CBP interface, including operation time, secondary task performance, and mental workload. In conclusions, the results of this study may be applied on the advanced NPP, as well as be generalized to the design of information display of other computerized system, such as process control system, air traffic control system and flight management system.

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