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Effect of user interface layout on the operators' mental workload in emergency operating procedures in nuclear power plants

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HIGHLIGHTS

- Different interface design has a significant effect on the operators' mental workload.
- Improving interface design based on human factor plays a significant role in reducing operator's mental workload.
- NASA Task Load Index tool and eye movement technique are useful for assessing human – computer interface designs.

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ABSTRACT

The improved control interface designs in nuclear power plants (NPPs) have been constantly developed in order to satisfy actual requirements. In this article, the effect of user interface layout on mental workload (MWL) of operators in emergency operating procedures in NPPs is analyzed. The control circuit interface of the Chemical and Volume Control system (RCV) was redesigned based on some human factor criterions and it was compared to the original interface during the procedure of system boots. The multi-index evaluation method based on performance measures (i.e., time to complete and error rate), subjective rating (i.e., NASA Task Load Index (NASA-TLX)) and physiological measure (i.e., eye movement) was used to evaluate MWL of operators. Twenty-two engineering students tested both interfaces in randomized order. The results showed that interface design has a significant effect on operators' MWL. Specifically, the redesigned interface was rated significantly lower in overall workload, time to complete, and fixation indices, but higher blink rate. The results suggested that human factor criterions have a significant effect on operators' MWL so they should be considered during designing of interface, and using of NASA-TLX tool and eye movement technique is useful for assessing of human-computer interface (HCI) designs in NPPs.

1. Introduction

The interface design of control room is constantly improved in order to make it more consistent with actual requirements because poor interface design can cause user stress, lower work rates, decreased job satisfaction and even cause absenteeism (Booth, 1989). In nuclear power plants (NPPs), user control interface is often complex and has many emergency operating procedures (EOPs) needed to process a large amount of information in a short time and to respond quickly with the decision, which easily leads to generation of very high mental workload (MWL). Poor user interfaces have effect on operators' MWL, which further affects efficiency and reliability of the entire system. Statistics show that human error is a causal factor in significant number of industrial accidents. Although, human error is rarely the sole cause of accidents in NPPs, human error is major contributor of about 70–90% of accidents (Isaac et al., 2002). Hitherto, the number of occurred nuclear incidents is relatively small, but if serious accident happens it will be a big disaster for people and environment. Therefore, operators have to be attentive all the time and good interface design will enable operators to accomplish their tasks efficiently and effectively with minimal errors (Ikuma et al., 2014).

Presently, there are no structured methods for all human-computer interface (HCI) design. Reality shows that it is easy to find

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interface design defects when we have a physical interface to analysis and evaluation. It is also important to separate design of the interface from other components in the system, so defects in the interface do not propagate faults through the system, yet this method sometimes is complicated and expensive. Burns (1991) proposed architecture to separate HCI from hard real-time systems, which reduces complexity and timing constraints. Currently, one of the best available methods is iterative design. This methodology is based on a cyclic process of prototyping, testing, analyzing, evaluating, and redesign. Based on these results many iterations of design, changes and refinements have been made recently. Namely, if we could perform efficient evaluations and correctly identify as many defects as possible, the interface would be significantly improved.

One of the commonly used methods for interface evaluation is the evaluation based on operators' MWL. This technique has become an important measure for evaluation of HCI in work environment, and the number of studies on MWL measurement has been increasing since 1960s (Seker, 2014). Moray (1988) demonstrated that optimization of MWL allocation could reduce human errors, improve system safety, and increase users' satisfaction. Many of studies focus on optimization of MWL by creating the appropriate designs and interfaces (Hertzum and Holmegaard, 2013). There are many studies which show that a well-designed interface can provide a suitable operator MWL (Parasuraman et al., 2000). Niemelä and Saarinen (2000) studied the effect of icons and spatial grouping on scanning speed in computer interface and results showed that design of graphics-based interfaces, such as effective arrangement of icons in interface, had a significant positive effect on scanning speed, which means there is a change in user's MWL. In addition, there are also studies related to spatial menu layout and color contrast of user interface and their impact on visual search performance, and their conclusion showed similar result (Michalski and Grobelny, 2008; Van Schaik and Ling, 2001).

Interface evaluation is not only understanding of task, its environment and the way the user interacts with the system, but also an appreciation of capabilities and cognitive demands of future users. However, the evaluation of industrial control interface based on MWL still has some limitations, because the focus is mainly on impact of workload level, and there is a lack of studies on impact of interface design. Especially in NPPs, many information sources should be monitored, but the operators have limited capacity of attention and memory (Ha and Seong, 2009). Since it is impossible to monitor all information sources, the operators continuously decide where to allocate their attention in order to select important things and ignore irrelevant things. Particularly in emergency situations, the provision of a set of well-designed procedures is necessary to reduce MWL of operators and to compensate degradation of operations (Jimmieson and Terry, 1998; Wood et al., 1990). Therefore, user interfaces should be designed such that can achieve suitable operator MWL. Thus, this study focuses on effect of user interface layout on operators' MWL in emergency operating procedures. The interface of control circuit in Chemical and Volume Control system (RCV) was redesigned after its limitations were analyzed based on cognitive psychology principles in layout design and then it was compared to original interface during operating the procedure of system boots. It was concluded that interface layout has a significant effect on MWL because redesigned interface had lower operators' MWL than original interface.

2. Methodology

2.1. Participants

This study considers the effect of interface layout on operators' MWL during searching for information in NPP user interface. Presently, operator performance in this domain necessitates mastering of all knowledge and capabilities accompanied by a great deal of concentrated training and repetition to attain such mastery. However, access to these experts is not readily available, hence this study presents experiment with participants who were trained for the task they were asked to do. Based on the results of these participants, we expect similar patterns exist for real operators, but further study is needed to confirm it.

Twenty-two man engineering students who were 22 ± 1.6 (mean ± SD) years old voluntarily participated in our experiment. All participants were familiar with the computer operations, but none of them was familiar with the operation of NPPs. They were also required to have good vision ability and to be right-handed. The experimental process was overseen by professors and experts who are specialized in human factors and ergonomics. All participants completed and signed an informed consent form approved by the university institutional review board and were compensated with extra credit in extracurricular activities in their course.

2.2. Mental workload measures

The MWL measurement methods can be divided into three main categories: performance measurement methods, physiological measurement methods and subjective rating methods (Tsang and Vidulich, 2006). Performance measurement methods evaluate synchronized data collected during primary tasks and secondary tasks in designed modules. Physiological measurement methods are based on indirect measurement of observed physiological changes, such as heartbeat, nasal tip temperature, eye movement, body and face temperature, and so on, while subjective measures can be measured by asking users about their experience of demands imposed by current or recently completed task.

Although there are many different ways to measure human MWL, there is no universal method because each method has its disadvantage. For instance, psychophysiological signals are measured using specialized equipment and that equipment could be costly because of capabilities of purchased system. Besides, when in experiments some apparatuses are attached to user body that constrains user movements and breaks naturalness of interaction. Physiological methods also can be influenced by physical and emotional factors. In subjective rating methods, rating scale results can be affected by characteristics of respondents, like biases, response sets, errors and protest attitudes (Dyer et al., 1976). Hence, use of workload rating scales is not recommended, when it is likely that raters would fake results, have low motivation and prejudices, guess randomly, etc. However, compared with performance measurement and physiological measurement methods, subjective measurement methods are more efficient regarding the application requirements and they are frequently used because of their large MWL measurement range, lower cost and less required effort. With the aim to reduce disadvantages of MWL measurement method and to improve the reliability of assessment results, this study applies the multi-index evaluation method, including performance measurement, physiological measurement and subjective ratings, to evaluate operators' MWL.

Performance measures can be classified into many categories such as accuracy, task time, worst-case performance, and so on (Gawron, 2008). In this study, time to complete (or speed of task) and error rate are used as performance measures because of following reasons: (1) Operating time is an important criterion of operating emergency procedures; in order to prevent incidents during operation of these procedures, operators need to process information and to respond with the correct decision quickly. (2) Operating errors involve risky behaviors that need to be understood in order to prevent incidents, because that directly relates to the effectiveness and safety of operating of NPPs system.