Balancing Human-machine Interface (HMI) Design in Complex Supervisory Tasks

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1. Introduction

As the design of instrumentation and control (I&C) systems for various plant systems including nuclear power plants (NPPs) is rapidly moving toward fully digitalized I&C, much attention has been paid to human factors studies. The authors have developed an evaluation system of human performance in NPP Main Control Rooms (MCRs) which was named as "HUPESS (HUman Performance Evaluation Support System)"[1]. Human performance aspects such as plant performance, personnel task performance, situation awareness, cognitive workload, teamwork, and anthropometric/physiological factor are evaluated with the HUPESS. Even though the HUPESS provides evaluation results in each of the performance aspects for the integrated system validation (ISV), additional researches have been needed to develop methods on how to find out design deficiency leading to poor performance and give a solution for design improvement in HMI. The authors have developed a method of HMI design improvement for the monitoring and detection tasks which was named as "DEMIS (Difficulty Evaluation Method in Information Searching)"[2]. The DEMIS is a HMI evaluation method which bridge poor performance and design improvement. Lessons learned from the existing studies lead to a question about how to optimize the whole HMI design. Human factors principles provide the foundation for guidelines of various codes and standards in designing HMIs. Also in NPPs, a lot of guidelines directly from various codes and standard and derived from various research and development projects are available for designing MCR HMIs.

In this study, a balancing principle and relevant two measures for HMI design optimization are proposed to be used in the HMI design of complex supervisory tasks in NPPs. The balancing principle is that a HMI element (e.g., an indicator or a push button) should be designed according to its importance.

2. A Balancing Principle for HMI Design

To balance the HMI elements with their importance, a ratio measure, named as Design preference to Importance Ratio (DIR), is defined as follows;

$$\mathrm{DIR}\,(\mathrm{i}) = \frac{\dfrac{\prod_{j=1}^{l} DP_{ij} - \min\left(\prod_{j=1}^{l} DP_{ij}\right)}{\max\left(\prod_{j=1}^{l} DP_{ij}\right) - \min\left(\prod_{j=1}^{l} DP_{ij}\right)}}{\dfrac{\prod_{k=1}^{m} I_{ik} - min\left(\prod_{k=1}^{m} I_{ik}\right)}{max\left(\prod_{k=1}^{m} I_{ik}\right) - min\left(\prod_{k=1}^{m} I_{ik}\right)}} \quad (1)$$

$DIR\ (i)$ = DIR of HMI element-*i*
DP_{ij} = Design Preference of HMI element-*i* in design attribute-*j*
I_{ik} = Importance of HMI element-*i* in importance attribute-*k*
l = the total number of design attributes
m = the total number of importance attributes
n = the total number of HMI elements
min (A) = minimum value of variable A
max (A) = maximum value of variable A

The numerator and the denominator of equation (1) represent normalized values of design preferences evaluated over all design attributes and of importance evaluated over all importance attributes for HMI element-*i*, respectively. Both the numerator and the denominator range from 0 to 1. *DIR(i)* is a relative measure representing the relative extent of design preferences compared to the relative extent of importance of HMI element-*i*. The numerator should be equal to the denominator in order to optimally balance the design of HMI element-*i* with its importance. Hence all *DIR(i)* values should approach unity for optimal balance. Now another measure, named as Balancing Index (BI), is defined to consider all HMI elements as a whole.

$$\mathrm{BI} = \frac{\sum_{k=1}^{n} \log_{10} DIR(i)}{n} \quad (2)$$

The BI should approach zero to optimize the balance of HMI design for all HMI elements. The BI can be interpreted as an overall measure incorporating all *DIR(i)*. Design preference (the numerator) and importance (the denominator) of HMI elements need to be evaluated in a quantitative manner to be used with Equation (1) and (2).

3. An Approach to Monitoring and Detection Tasks

It is explained in this section how to apply the balancing principle and Equation (1) and (2) with an example tasks (monitoring and detection tasks). Information searching behaviors in NPPs are dependent on expectancy, value, salience, and effort [3]. The authors had developed a human performance model for the monitoring and detection tasks as shown in Fig.1.

Expectancy and value of a HMI element can be transferred to its functional importance, while salience and effort are manageable attributes for HMI design. A Highly expected and valued HMI element should be designed to be accessed easily (with increased salience and decreased effort).

Fig. 1. A human performance model for monitoring and detection tasks in NPPs [3].

There are usually considerable correlations between process variables in NPPs. Such correlations could permit an observer to monitor a subset of the displays and to provide estimates of other variables. Such correlations lead to expectancy for required information sources and prioritization (assessment of value) of information sources and form obvious rules of the behavior of a plant system which are transferred into the knowledge to be taught to NPP operators. The knowledge of such correlations is established as a form of the operator's mental model, which determines the importance of information sources. This kind of importance was defined as an informational importance in the authors' previous studies [2, 4]. The informational importance can be considered as a function of its ability to discriminate among competing hypotheses (abnormal states) of the cause of a plant symptom. The AHP (Analytic Hierarchy Process) was used as a tool to quantify the informational importance in the authors' previous study. Other importance attributes can be defined as well. For example, a risk-informed approach can be applied to this approach. The well-known Fussel-Vesely (FV) importance, Risk Achievement Worth (RAW), and Risk Reduction Worth (RRW) may be applied with careful consideration on the relationship between the risk-informed components and relevant HMI elements.

Salience and effort are manageable design attributes. More important HMI elements should be designed with more salience and less effort to access. Hence, design preferences mean increased salience and decreased effort in the monitoring and detection tasks. Next problem is how to evaluate and quantify the HMI design preference in each of design attributes such as salience and effort. Empirical method based on human factors guidelines can be developed with an evaluation table. Assuming a GUI design with 3-level hierarchy as shown in Fig. 2, in which the lower level display can only be accessed through the higher level display. The easiest display to access is Level-1 and the most difficult display to access is one of Level-3s. Evaluation scale can be given to Level-1 (3 marks), Level-2 (2marks), and Level-3 (1 mark). As seen in Equation (1) and (2), the evaluation scale is not so important, because the evaluation value will be eventually normalized.

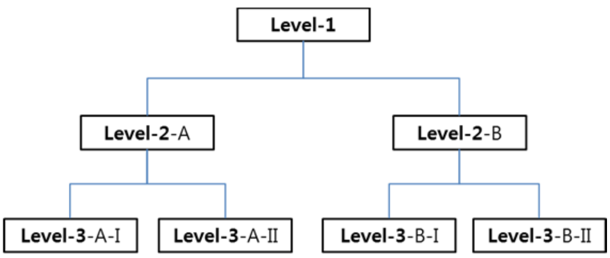

Fig. 2. An example of GUI design with 3-level hierarchy.

Also salience can be evaluated in a similar way. Empirical method based on human factors guidelines on salient HMI design can be used to make an evaluation table.

4. Recommendation and Further Study

In this study, a balancing principle for HMI design optimization is proposed to be used in the HMI design of complex supervisory tasks in NPPs. Two measures, Design preference to Importance Ratio (DIR) and Balancing Index (BI), based on the balancing principle are introduced as well. An approach to the monitoring and detection tasks in NPPs is conceptually discussed and explained to see the feasibility. The balancing principle and approach discussed will be applied to an HMI design to validate them as a further study.

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