International Journal of Industrial Ergonomics 51 (2016) 30–42

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Systematic layout planning in human–system interface: An evaluation of alarm displays with spatial proximity for accidents diagnosis of advanced boiling water reactor

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A R T I C L E I N F O

Article history:
Available online 9 January 2015

Keywords:
Alarm system
Human–system interface
Proximity compatibility principle

A B S T R A C T

To ensure safety in nuclear power plants, this study investigated the interface design of a digital alarm system by analyzing the diagnosing process of operating information. This study focused on the layout planning of alarm windows and followed proximity compatibility principle and nuclear human–system interface design review guidelines to improve the human–system interface. This study adopt systematic layout planning to modify the design of alarm windows. The time of alarm handling, and accuracy, as well as human reliability were evaluated to compare the original layout with the improved one. In the end, according to the results of the comparison, an alternative alarm window layout human–system interface, which fits diagnosing process, is suggested.

Relevance to industry: The similar layout planning process could be applied to design control centers in high reliability organizations, in particular which need decision-making by person.

1. Introduction

After the digitization of automation control systems, large control panels and display devices can be replaced by a few computers. However, a high degree of automation has some risks. For example, in nuclear power plants, failures in the instrumentation and control devices could stop the operation of the plant and even a small accident could have catastrophic repercussions. In the recent nuclear accident occurred in Japan on March 11, 2011, the decision making problem in response of the event in nuclear power plant was emphasized again (Fujita, 2012; Hsieh et al., 2012). Following a thorough literature review, we determined how operators performed monitoring activities in general cases and identified difficulties in using digital instrumentation during monitoring activities such as system complexity and reliability, confusion caused by alarm system design, and poor design of displays and controls. In Taiwan, the newest nuclear power plant, Lungman, uses an advanced boiling water reactor (ABWR) to generate electrical power and has adopted an advanced digital operating interface. Therefore, this study used the Lungman nuclear power plant as a case system to optimize alarm system design and improve safety of nuclear power plants.

In nuclear power plants, operators must maintain their attention on current process states as well as predict future process states to control the process and attain operational goals. A good alarm system should assist the operator in managing a large number of individual alarms since most people cannot divide their attention among too many alarms and a variety of situations.

This study focused on planning of the alarm window layout to improve the human–system interface. To compare differences between the original and improved systems, decision time, accuracy, and human reliability were evaluated. Lastly, according to the results of experiment, an improved human–system interface that fits operators' diagnosing process is suggested.

2. Backgrounds and methods

2.1. Digital instrumentation and control systems

Different from the former analog technology used on instrumentation and control systems in nuclear power plants, digital

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http://dx.doi.org/10.1016/j.ergon.2014.12.014
0169-8141/

technologies have many merits in realizing the upgrade of control functions, reducing components of systems, designing circuits that are capable of making complicated logical judgments, graphical information displays to easily understand process parameters such as flow rates and pressures, and operational states of pumps and values. Therefore, instrumentation and control systems used for safety protection systems to insure reactor safety are required to be reliable in, not only advanced technology and devices, but also in the operator's accurate decision-making.

Presently, many nuclear power plants that have adopted modernized automatic monitoring systems expect that the system will pass information to operators accurately and efficiently and that operators can quickly deal with the information provided. Randall et al. (2000) examined how operators perform monitoring activities in general cases and identified the difficulties of using digital instrumentation in monitoring activities such as system complexity and reliability, confusion caused by alarm system design, and poor design in displays and controls. Consequently, according to the information process model, Wickens et al. (2004) proposed a criterion for human–system interface design: (1) displays must consider human perception, cognitive models, and principles of attention and memory and (2) controls must consider the complexity of decision-making, expected response, consistency, operation feedback, and trade-off between speed and accuracy (Wickens et al., 2004).

2.2. Alarm systems

In any process industry, safety issues are of prime importance as any accident can have severe consequences to both human life and the environment (Mohammed et al., 2006). Thus, increasing efforts to minimize hazards connected to the control of power plants have always been of highest priority. Operators in the modern system must make a decision, correct minor problems, and avoid unforeseen risks using information from alarm systems (Noyes and Bransby, 2001). Specifically, in nuclear power plants, operators must maintain their attention on current process states and predict future process states to control the process and attain operational goals. Further, alarm systems should assist operators to identify process problems; however, a large number of alarms might interfere with an operator's judgment, alertness, and awareness to diagnose the situation, which might cause errors.

Traditional alarms are spatially dedicated alarms that occupy a physical position in space and are directly accessible to the operator. Kim et al. (2001) proposed that the conventional hardwired alarm system, which is characterized by one sensor-one indicator, may lead control room operators to be confused with an avalanche of alarms during plant transients. Currently, in digitalized systems, alarms can also be shown in mimics or a list window (Kim et al., 2001); however, as the complexity and scale of the system grows, the sheer number of alarms becomes overwhelming to the operator (Huang et al., 2007).

The safety of digital instrumentation and control systems gained attention following the Three Mile Island nuclear accident that occurred in the United States and, since this time, many design principles have been proposed and developed. Concerning the main control room in a nuclear power plant, the United States Nuclear Regulatory Agency (NRC) proposed a number of digital instrument control principles on human factors. Chang and Chou also emphasized that the human–system interface design process should follow NUREG-0700 and NUREG-0711 (Chang and Chou, 2008). Further, a number of scholars have emphasized that consistency and flexibility cannot be ignored within such guidelines. This is especially the case during high mental workload situations (e.g., in an emergency) as appropriate system flexibility is very important (Thunberg and Osvalder, 2007). Among the systems located in a control room, the alarm system indicates an unexpected abnormal state of the system provides visual and auditory stimulation to warn operators (increasing their attention to the event) and provide adequate system information. Such alarms are intended to change the operator's psychological state to alert in order for the operator to respond and take preventive action. Therefore, the alarm system plays a very important role in abnormal conditions (Noyes and Bransby, 2001; Stanton, 1994; Huang et al., 2006).

Concerning human–system interface designs, Ponsa and Díaz (2007) developed cognitive ergonomics guidelines, GEDIS (ergonomic guideline for supervisory control interface design), to improve the efficiency of the human–machine system in industrial automation. The combinative scope of different guidelines covers almost everything from general systems design to specific and detail devices. Nevertheless, different guidelines emphasize different points and could be used in different situations. There are also diverse priorities or weight given to the same guideline according to the state of the system. Therefore, to integrate these many guidelines, Thunberg and Osvalder (2007) organized these guidelines and declared that improvements in system design should be prioritized based on the existing design guideline and designers' or operators' experiences to facilitate them in modernization systems. Therefore, on the basis of general principle and sorted details of the criteria (e.g., color, font size, etc.) The new system, together with the existing technology in the control room, should be experienced as one system since consistency in the design is a fundamental human factors requirement.

2.3. The layout planning

Wickens and Carswell (1995) published the proximity compatibility principle (PCP), a guideline to use in determining where a display should be located, given its relatedness to other displays. The PCP mentioned six proximity manipulations which were spatial proximity, connections, source similarity, code homogeneity, object integration (contiguity, contour, and spatial integration), and configuration. The most obvious one, display proximity can be increased by increasing the spatial proximity of the information channels. Proximity means nearness in space, time or a series (Collins and Anderson, 2014). Spatial proximity, which focuses on nearness in space, was defined as closeness among displays in space (Wickens and Carswell, 1995). The spatial proximity of displays is helpful to decrease “information access costs”. The closer the location of relevant information, the better performance is when dividing attention. The spatial proximity is widely used on the layout of displays in monitoring task (Wickens et al., 1996; Blasio and Bisantz, 2002). However, in some cases, it may result in confusion during interpretation if location of the information is too close. Therefore, the position of the message displayed must be based on the similarity of the information source. On the other hand, for independent tasks, increasing the distance between displays will enhance the performance of the individual tasks. Past studies about the PCP in nuclear power plants usually explored the spatial integration (one sub-manipulation of object integration) of parameters and graphical information displayed on the wide display panel (WDP) or the visual display unit (VDU) (Goldberg and Kovtal, 1999; Burns, 2000; Hegarty, 2011). Different from previous studies, this research tried to focus on the spatial proximity and apply it on alarm display layout. By applying the principles of design alarms proposed in NUREG-0700, alarm functional groups should be visually distinct from one another and segregating alarm messages by plant system may allow operators to direct their attention more effectively (NRC, 2002).