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Validation of “alarm bar” alternative interface for digital control panel design: A preliminary experimental study

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ABSTRACT

Properly designed alarm systems can benefit operators in conducting routine and emergency tasks. With the digitization of main control rooms, the alarm interface can be designed in various ways that are different from the traditional “alarm tile” style. An innovative alarm bar interface is proposed in this paper. A preliminary lab experiment was conducted to compare the traditional alarm tile and the new alarm bar interfaces. Sixteen university students were recruited to participate in the experiment, in which two emergency scenarios, Loss of Coolant Accident and Steam Generator Tube Rupture, were tested. The experiment task included two parts: alarm detection and identification. The subjective ratings supported the innovative alarm bar design for better parameter trend perception. The objective performance measures showed that the simpler design of the alarm tile interface better aided the alarm detection performance, whereas the alarm bar interface had almost the same alarm identification performance as the alarm tile interface.

Relevance to industry: An alarm system is critical for a complex industrial system. The experimental results show that design evaluation is more complex than it may seem. Although it has not been proved to be overwhelmingly superior to the tile design, the alarm bar design shows promise for aiding operators and needs to be further validated.

1. Introduction

Alarm systems are found in many large systems, e.g., in control rooms/centers of power stations, chemical plants, railways, air traffic systems or military systems. Alarm systems are important because they provide a stimulus (typically both visual and audible warnings) to direct the operator's attention to an abnormal situation so that mitigation action can be taken (Bransby, 2001). Failings in alarm systems have contributed to several major accidents, such as the Three Mile Island accident in 1979 (Bransby, 2001), in which the large number of alarms contributed to the slow response of the operators in diagnosing the problem (O'Hara and Brown, 1991; Mattiasson, 1999).

A typical traditional nuclear power plant (NPP) has approximately 2000 alarms in the main control room (MCR) (Mo et al., 2007). The alarm systems in existing control rooms typically consist of hardwired, backlit, engraved alarm tiles, and operators rely extensively on alarm screens to detect problems (Mumaw et al., 2000). The alarm tile works as follows (EEMUA, 2007): When an alarm sounds, the associated alarm tile flashes in a specific color to alert the operator, and audible warnings are generated at the same time; after an operator has detected the triggered alarm, he/she goes to the corresponding control panel and presses the “acknowledgement” button to make the tile stop flashing and remain steadily lit; he/she can also press the “silence” button to stop the sound of the alarm; when the alarm has cleared, the tile is indicated in a different color or in a darker brightness, telling the operator that the alarm is cleared; the tile will be darkened after the operator presses the “reset” button. An important advantage of the fixed tile layout is that the operators can quickly associate patterns of lit tiles with various common plant conditions through a glance at what is going on (Fitch, 2002).

However, the traditional alarm system has been identified as a contributing factor to the escalation of events in a number of incidents and accidents (Mattiasson, 1999). The discordance between the dynamic process and the static alarm system makes important alarms difficult to locate, adding difficulty to operators' work (Mattiasson, 1999). The alarm floods during plant transients, mode

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changes or component failures make operators mentally overloaded, thus resulting in operator errors or an increase in the probability of operator errors (O'Hara and Brown, 1991; Mattiasson, 1999). Shahriari et al. (2006) summarized the problems in existing alarm systems in the process industry.

To overcome the problems of traditional alarm systems, new methods of alarm generation and alarm interface design have been proposed to ensure that the alarms provide only relevant, unambiguous and rapidly understood indications of the plant state (Hwang et al., 2008). New alarm generation methods can reduce the frequency of alarms and the effect of alarm flooding (Cheon et al., 1993; Hwang et al., 2008; Brooks et al., 2004), thus improving operators' situation awareness (SA). Alarm presentation is one of the major issues in alarm system design (O'Hara et al., 2000). Good alarm interface designs could serve as important information sources for operators who were responsible for preventing and responding to abnormal situations, thus mitigating the occurrence of possible safety incidents (Bullemer and Metzger, 2008). Brooks et al. (2004) pointed out that “any alarm system is only as good as the operator has confidence in it”.

The digitization of MCRs provides opportunities for new alarm interface designs. However, of various efforts to develop new digital alarm systems, alarm interfaces are mostly restricted to the traditional alarm tile format (for SA and navigation), the chronological alarm list (for alarm detail and sequence), or a combination of the two (Huang et al., 2006; Westinghouse, 2011). As stated by many researchers, a good digital alarm system should make new alarms obvious, make relevant information easily accessible to the operator, provide a clear indication for the problem, guide the operator to take proper actions, decrease his/her mental workload, maintain his/her SA level, and help prevent misinterpretation or operation errors (Bransby, 2001; Huang et al., 2006; Mattiasson, 1999). However, the alarm tile or alarm list formats used currently cannot directly provide parameter trending information to operators, require a high mental workload from operators, and do not support operators' SA very well (Zwaga and Hoonhout, 1994; Huang et al., 2006). In guidelines on alarm system design (e.g., NUREG 6105, NUREG 6684, EEMUA 191, etc.), it is pointed out that multiple alarm display formats may be necessary to satisfy all operator alarm information needs, and the alarm information content should include the status of the parameter (e.g., high, low, or inadequate) (O'Hara et al., 1994). However, there have been few trials on exploring the effects of new alarm interface designs on operator performance.

With the adoption of digitization technology, alarm interfaces might not be limited to the formats of the alarm tile or the alarm list. Laberge et al. (2014) developed a new alarm summary display, combining the benefits of list-based displays with time series presentation of alarm information, and found it effective when operators used a formal alarm response strategy. In this study, we attempted to design an innovative alarm bar interface, which combines dynamic parameter trending information, and conducted a preliminary experiment to test the effect on participants' subjective preferences and objective task performance. In the experiment, the alarm bar design was compared with the traditional alarm tile design under simple and complex scenarios.

2. Methodology

An experimental simulation system was used to study the participants' preferences and task performance of the two alarm interface designs.

2.1. Experiment interfaces and apparatus

Two alarm interfaces were designed to present an equivalent number of alarm items for an imaginary two-loop pressurized water reactor (PWR). The six most important components of an NPP were included, i.e., the reactor, reactor coolant system (RCS), steam generator, pressurizer, auxiliary safety system, and the containment. In total, 65 system status-related indicators and key operating parameters were chosen to be displayed on the interfaces. The critical status/values would trigger alarms such as the main pump failure of the RCS and the neutron flux of the reactor. Furthermore, plant-wide failures, such as reactor trip, turbine trip and containment rupture, would also be presented.

The alarm hierarchy was constructed based on Cheon et al.'s (1993) three-level method. Detailed alarm hierarchy and color coding information are shown in Table 1. Three plant-wide, severe incident/accident related signals made up the Level 1 alarms. The Level 2 alarms were system-wide ones, which could reflect the overall system operating mode and safety condition. The Level 3 alarms were within-system and parameter-driven alarms, which included the component pressure, temperature, liquid level, etc. Alarms of different levels were displayed in distinct formats (as shown in Figs. 1 and 2) to support the quick identification of the alarm hierarchy and the system that it was associated with. It should be noted that the Level 1 and Level 2 alarms were Boolean variables, whereas the Level 3 alarms were parameter driven.

On the alarm tile interface (Fig. 1), three Level 1 alarms were arranged in a group box indicated “Level 1” on the top left corner of the screen, whereas the Level 2 and Level 3 alarms were grouped by systems. Within each system, the Level 2 alarms had a label on the left top corner showing “Level 2”, whereas the Level 3 alarms had no labeling. During normal operation, all alarm tiles were filled with the color gray. Once an alarm was triggered, the Level 1 alarms would flash red, as red meant emergency and danger, and had good attention-getting performance; the Level 2 alarms would flash magenta, as magenta was used for important information about operations and was easily distinguishable; the Level 3 alarm would flash yellow, which was associated with alarm, hazard, caution, and

Table 1
The alarm hierarchy information.

Level 1	Sub-system	Level 2	Level 3
Reactor trip, Turbine trip, Containment rupture	Reactor	Packaging broken of fuel rods	Thermal power, Neutron flux, Liquid level, Mean temp of fuel rods, Temp of fuel package
	RCS	Main pump failure, Failure of uprush pump, Failure of discharge valve	Pressure, Mean temp, Coolant volume, Uprush flow, Discharge flow
	Containment	Spray system failure	Pressure, Air temp, Pit water level, Spray flow, Radioaction in air
	SG	Failure of feed-water pump, Failure of safety valve	Pressure of A, Liquid level of A, Feed-water flow of A, Steam flow of A, Safety valve flow of A, Pressure of B, Liquid level of B, Feed-water flow of B, Steam flow of B, Safety valve flow of B
	Pressurizer	Failure of ADS 1–3, Failure of ADS 4, Failure of spray valve, Failure of heater	Liquid level, Temp of saturated vapor, Flow of spray, Heating power, ADS 1–3 flow, ADS 4 flow, Decompression valve radioaction
	Auxiliary safety system	Failure of main feed-pump, Failure of PRHP, Failure of injection, Failure of turbine isolation	CMT flow, PRHR flow, Power of PRHR, Accumulator flow, IRWST flow, Steam pipeline radioaction