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THE DEVELOPMENT OF DETAILED HUMAN FACTORS ENGINEERING GUIDELINES FOR DIGITAL CONTROL ROOM UPGRADES

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ABSTRACT

As part of the Department of Energy and Electric Power Research Institute's hybrid control room project, detailed human factors engineering guidance was developed for designing human-system interfaces that may be affected by introduction of additional digital technology during modernization of nuclear power plants. The guidance addresses several aspects of human-system interaction: information display, interface management, soft controls, alarms, computer-based procedures, computerized operator support systems, communications, and workstation/workplace design. In this paper, the ways in which digital upgrades might affect users' interaction with systems in each of these contexts are briefly described, and the contents of the guidance developed for each of the topics is also described.

1. INTRODUCTION

Nuclear power plant personnel interact with the plant's systems and components through the human-system interfaces (HSIs), which provide the resources with which personnel perform their functions and tasks. These resources include alarms, displays, procedures, support systems, and controls. As part of the Department of Energy and Electric Power Research Institute's hybrid control room project, detailed human factors engineering (HFE) guidance was developed for the design of these HSI resources in the context of plant modernizations involving digital instrumentation and control (I&C). The objective was to develop and evaluate guidance that is technically valid, practical, and usable.

This paper briefly describes some of the HFE-related aspects of digital upgrades and the guidance that was developed to address them.

2. HUMAN-SYSTEM INTERFACE GUIDELINES

HFE guidelines were developed for several topics. The guidelines are organized into the following subsections:

- Information Display
- User-Interface Interaction and Management
- Soft Controls
- Alarms

- Computer-Based Procedures
- Computerized Operator Support Systems
- Communications
- Workstation and Workplace Design

The relationships among the subsections are shown in Fig. 1. The first two sections address the basic building blocks of computer-based HSIs: information display and user-interface interaction and management. With these building blocks, HSI resources can be developed to support other specific cognitive functions, such as monitoring and detection (alarms), situation assessment (computerized operator support systems), response planning (computer-based procedures), and response implementation (soft controls). There are unique display and interaction needs for each. Since nuclear power plant crews work as teams, communication resources are needed for most personnel tasks. Finally, HSI resources are integrated into workstations and workplaces, so guidance for these considerations is provided. A brief description of each subsection follows.

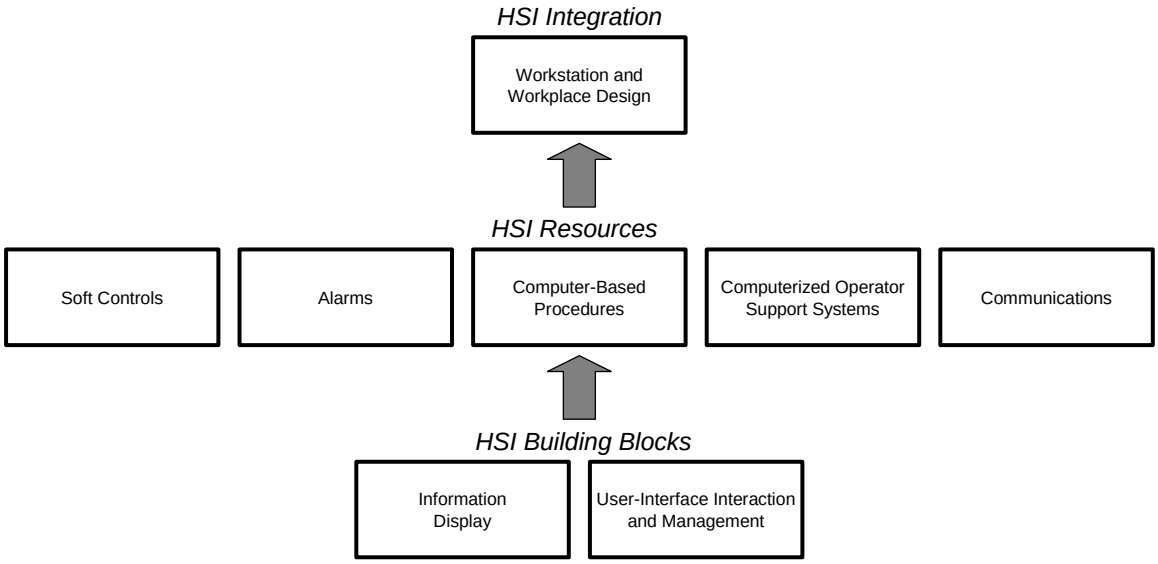

Fig. 1 Human-system interface topics

2.1 Information Display

Introduction of digital I&C and computer-based HSI will significantly affect how personnel get information about plant systems, processes, and conditions. The guidance in this subsection addresses the design of information display systems. Its organization reflects a design process that proceeds from general issues surrounding computer-based display of information to specific aspects of display design. The subsection begins with a detailed consideration of the implications of computer-mediated access to information for the design of information systems. It addresses at a high-level the functions that the

information system serves (e.g., monitoring and situation assessment, task performance, and teamwork) and describes approaches for structuring information effectively and for identifying information needed to support the tasks that comprise user functions.

The guidance next considers information representation, i.e., the way in which that information is presented. This consists of the following hierarchically related aspects: display pages, formats, and elements. The information needed to support a particular task is typically arranged and presented on one or more display pages. The type of information to be presented and the use that will be made of it determine the display formats (e.g., mimics, trend graphs, tables, bar charts, digital parameter displays, and high-level displays) that are used on a page. Display formats are made up of display elements, such as alphanumeric characters, icons, arrows, and axes. Guidance addressing all of these aspects of information display is included in this subsection. The use of displayed information also depends on its quality (how valid the information is, i.e., whether the operators trust the information) and update rate (how current the information is); guidance is also provided for these considerations.

2.2 User-Interface Interaction and Management

User-interface interaction and management comprises a wide range of tasks users undertake when accessing information and controls needed to operate or maintain the plant. These tasks, and the means used to perform them, are quite varied. Nevertheless, several design objectives can be identified that apply regardless of the particular function to be performed or specific interface feature to be employed. The guidance begins with these general interface design objectives, which include simplicity, consistency, and minimization of demands on the user. Interfaces tend to serve one or more general functions; design guidance for these basic functions (e.g., mediating user input, controlling displays, providing feedback) is also given. Finally, interfaces also contain certain basic components, such as windows and cursors.

2.3 Soft Controls

Personnel interact with plant functions, processes, systems, components, and variables by means of controls. From a HSI standpoint, controls can be hard and soft. Hard controls are physical hardware devices, such as j-handles, position switches, and pushbuttons, which are typically mounted on control panels. Soft controls, on the other hand, are user input devices presented as displays on a computer screen. They have important advantages when the endpoint vision for the modernization program involves the following types of modifications:

- transition to computer-based workstations with seated operators
- the consolidation of controls
- the integration of controls with relevant displays and other information
- an increased level of automation
- computerized procedures
- increased flexibility in the presentation of controls and displays.

In this subsection, guidance is first provided to support the decision as to whether controls should be implemented as hard controls, dedicated soft controls, or retrievable soft controls. When controls are retrievable, then a selection display (from which to retrieve the controls) is needed. Guidance on the design of selection displays is provided. The centerpiece of a soft control is the control display. The guidance on control displays addresses (1) the identification and management of control displays; (2) the display of control modes, logic, and constraints; and (3) control input and commands. Guidance for the design of feedback and monitoring aspects of soft controls is also provided. This subsection contains an appendix on error tolerant design as well.

2.4 Alarms

The operators' task of monitoring the operating condition of the plant and detecting problems is supported by alarms. Digital I&C improvements offer the opportunity to make major improvements in a plant's alarms. Computer-based alarms provide increased capabilities that can make them more effective and provide added features not practical with conventional, hardwired alarm technology. Because the alarms are one of the primary means by which abnormalities and failures come to the attention of plant personnel, there is a major operational incentive to make them as effective as practical.

This guidance addresses how the new digital alarm capabilities can be implemented effectively as part of control room modernization. It is recognized that not all modernization projects will require an extensive upgrading of the alarms or provide a practical opportunity for such major changes. However, virtually any new digital system will require some consideration of changes to the alarms, so the information provided in this subsection will help designers identify the options available to them and the human factors engineering principles that should be applied when making the changes.

This subsection first addresses general design considerations for alarm system modifications. It then provides guidance for defining alarms and developing approaches to their prioritization and processing. The latter are ways to reduce the number of alarms to manageable levels. In modern alarm systems, designers have choices as to how to display alarms, e.g., in dedicated displays (such as alarm tiles), on alarm message lists, or integrated into other displays (such as mimic displays). Guidance for making these decisions and for the design of each, including their auditory characteristics, is provided. Guidance is also provided for alarm control and management, e.g., the sorting of alarms according to time and priority. Finally, alarm response procedures are addressed.

2.5 Computer-Based Procedures

Computer-based procedures (CBP) assist personnel by presenting procedural information, such as decision and action steps, in a manner that help users effectively, efficiently, and reliably achieve procedure goals. The guidance in this subsection first addresses the scope and functionality aspects of CBP. CBP functionality ranges from translations of traditional procedures for use via a computer-driven display, to systems

that integrate process and equipment information and alarms with procedure steps, and provide control and automation features to aid the execution of tasks.

The design of CBP systems requires three types of guidance. The first type addresses the presentation of procedures per se. This includes the presentation of procedure identifying information, basic action steps, cautions and warnings, etc. The second type of guidance covers CBP functionality, such as integrating real-time process information with procedure information, resolving step logic, and helping users manage concurrent procedures or monitor continuously applicable steps in an ongoing operation. Finally, there are guidelines for degraded conditions and CBP failure. Design considerations for the initial translation of CBPs from paper procedures and CBP maintenance are addressed in an appendix.

2.6 Computerized Operator Support Systems

The term 'computerized operator support system' (COSS) is used to represent various classes of systems. We use the term to denote systems that support the operator in performing cognitive tasks, e.g., monitoring and diagnosis. This subsection provides recommendations on whether these kinds of systems should be introduced as part of a specific plant upgrade, and how it should be done.

Three broad categories COSSs are considered:

- Process Monitoring, Fault Detection and Diagnosis
- Core Surveillance
- Emergency Management

This subsection contains both guidance that applies generally to COSS, and guidance associated with the three specific types of COSS. It is recognized that systems for providing comprehensive computer-supported operations planning and optimization (e.g., short and long term prediction and planning of operations based on current status) may include elements from more than one of the types of systems considered here. For example, condition monitoring and core surveillance may very well be integrated into a single COSS.

2.7 Communications

Advanced digital or hybrid systems may change the way operators interact with each other or the type and content of the information and instructions that are exchanged. For example, changes to instrumentation can affect the way personnel communicate; e.g., overview displays can provide information simultaneously to multiple crew members, enhancing communication and coordination. Examples of other I&C system modernization modification features that can have significant impact on communications include the handling and presentations of alarms, computer-based procedures, and computerized operator support systems.

This subsection provides HFE guidelines for the design of speech- and computer-mediated communication among plant personnel, e.g., preparing, addressing, transmitting, and receiving messages. It contains guidance both for addressing modifications to existing communication systems necessitated by digital upgrades and modifications to communication systems per se. (Because the layout of the workplace is an important design input that can have a major impact on communications, communication related guidance is also given in that subsection.)

2.8 Workstation and Workplace Design

This subsection contains guidance for addressing changes to workstations and workplaces associated with digital upgrades. Workstations, including consoles and panels, are locations where individual HSI resources (i.e., alarms, displays, and controls) are situated to provide the means for personnel to perform their tasks. Even if the basic layout of the workplace is not changed, individual workstations and panels will be affected by the incorporation of digital technology. The main design considerations for workstations include their configuration, arrangement of HSI devices such as displays and controls, and labeling and demarcations.

A workplace is defined as the location where the personnel perform their functions and tasks. This typically refers to the main control room, but is also understood to include remote shutdown stations, the Technical Support Center, and the Emergency Operations Facility. Workplaces often include operator workstations, overview displays, vertical panels, wraparound benchboards, laydown space, procedure storage, a supervisor area, etc. One of the main considerations for the workplace design is the layout, location, and orientation of this equipment. Design of the control room environment is another important workspace consideration. Control room modernizations, even those that are limited in scope, can affect aspects of the workplace environment (e.g., lighting and noise).

Another important consideration is the management of modifications; e.g., the need to support crew performance during modifications that take place while the control room is still in use and across successive outages. Guidance is provided for this topic as well.

3. CURRENT STATUS

An interim version of the guidance described above has been published (EPRI, 2003). Final revisions of all of the guidance subsections described above have been completed, and preparation of the overall document (including, in addition to the HFE guidance described here, guidance for planning, the design process, and licensing considerations) is in progress.

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