BNL-72802-2004-CP

INFORMATION DISPLAY: CONSIDERATIONS FOR DESIGNING COMPUTER-BASED DISPLAY SYSTEMS

John M. O'Hara
Brookhaven National Laboratory
Upton, New York USA 11973
ohara@bnl.gov

Dominique Pirus
EDF, Energy Branch, Engineering Division, Septen
12-14, Avenue Dutriévoz - 69628 VILLEURBANNE CEDEX
FRANCE
dominique.pirus@edf.fr

Leo Beltratcchi
Wilmington, NC 28411
lxxb@ec.rr.com

Presented at the 4th International Topical Meeting on Nuclear Plant Instrumentation Control and Human Machine Interface Technologies
Columbus, Ohio
September 19-22, 2004

Energy Sciences and Technology Department

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

Managed by
Brookhaven Science Associates, LLC
for the United States Department of Energy under
Contract No. DE-AC02-98CH10886

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

FOR UNCLASSIFIED, UNLIMITED STI PRODUCTS

Available electronically at:

OSTI:

http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
Phone: (865) 576-8401
Facsimile: (865) 576-5728
E-mail: reports@adonis.osti.gov

National Technical Information Service (NTIS):

Available for sale to the public from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22131
Phone: (800) 553-6847
Facsimile: (703) 605-6900
Online ordering: http://www.ntis.gov/ordering.htm

Fourth American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Controls and Human-Machine Interface Technologies (NPIC&HMIT 2004), Columbus, Ohio, September, 2004

INFORMATION DISPLAY: CONSIDERATIONS FOR DESIGNING COMPUTER-BASED DISPLAY SYSTEMS

John M. O'Hara
Brookhaven National Laboratory
Upton, New York USA 11973
ohara@bnl.gov

Dominique Pirus
EDF, Energy Branch, Engineering Division, Septen
12-14, Avenue Dutriévoz - 69628 VILLEURBANNE CEDEX
FRANCE
dominique.pirus@edf.fr

Leo Beltratcchi
Wilmington, NC 28411
lxxb@ec.rr.com

Keywords: Information systems, control rooms, display design, human-system interface

ABSTRACT

This paper discussed the presentation of information in computer-based control rooms. Issues associated with the typical displays currently in use are discussed. It is concluded that these displays should be augmented with new displays designed to better meet the information needs of plant personnel and to minimize the need for interface management tasks (the activities personnel have to do to access and organize the information they need). Several approaches to information design are discussed, specifically addressing: (1) monitoring, detection, and situation assessment; (2) routine task performance; and (3) teamwork, crew coordination, collaborative work.

1. INTRODUCTION

New computer-based information displays are clear improvements over the information displays provided on control panels in old control rooms, e.g., analog indicators and strip charts. However, in many respects, their similarity in both information content and overall display logic is apparent. The displays are largely system-oriented, that is, information is basically organized around plant systems with indications and controls linked by mimic lines, much like the piping and instrumentation diagrams they are based on. While this type of information presentation is very useful for much of what plant personnel have to do, they have been associated with limitations in some areas, e.g., for obtaining the "big picture" about the overall plant status. There are simply too many displays to monitor and the information is not synthesized to a level that provides high-level status (thus operators have to mentally integrate information). Even when large "wall panel" or "group-view" displays are provided to help provide an overview, personnel still have to access many individual displays to obtain all the

information they need. Display retrieval is an "interface management" task (the activities personnel have to do to access and organize the information they need) and can significantly add to workload and create distractions (O'Hara and Brown, 2002).

System-oriented displays also do not match routine tasks very well. Typically operators need parts of several displays to perform their tasks. Thus the time personnel must spend performing interface management tasks increases. In part, this additional time is due to the added mental workload imposed when the user needs to know what information is needed, where it is in the computer system, how to manipulate the human-system interface (HSI) to get to it, and how to configure the display to clearly present the information needed. In some situations, the added time means that the abnormal conditions will last longer, and as a result, get worse. If the situation is exacerbated by a "mistake" caused by faulty memory or inadequate experience, the situation can worsen. The situation can be worsened when the viewing area provided is limited to a small number of monitors. In particularly bad situations, they may be forced to make repetitive transitions among displays.

Another issue faced by crews using computer-based information systems is that teamwork and crew coordination can be made more difficult relative to an analog control room where everyone's actions can be observed. When operators perform tasks at computer workstations, it is more difficult to help each other out, to know what each other is doing, and to provide peer checking and supervision. Separate operator workstations can increase isolation and decrease communication between crewmembers.

The main implications of this issue are that: displays should be designed to best meet the information needs of plant personnel, and HSIs should be designed to minimize the need for interface management tasks, especially under high workload situations. In this paper, approaches to address these issues will be examined, specifically in the areas of: (1) monitoring, detection, and situation assessment; (2) routine task performance; and (3) teamwork, crew coordination, collaborative work. Detailed guidance and its technical basis for each area were reported in O'Hara, Pirus, and Beltratcchi (2003). The results are summarized below.

2. DISPLAY DESIGN FOR PLANT MONITORING, DETECTION, AND SITUATION ASSESSMENT

An analysis of the cognitive processes underlying human monitoring, detection, and situation assessment was conducted. Based on the results, the following general principles for display design to support monitoring, detection, and situation assessment can be derived:

- An operator's information needs are very broad, both in terms of range of information and the level of abstraction that has to be considered. Personnel monitor the status of the plant from high-level functions to lower-level equipment conditions. They also need to identify the nature of problems when detected. Thus displays should to present information at varying levels.
- Information presentation should take into account the operator's goals and the information required to make goal-directed decisions. Information should be organized in terms of what the operator is trying to accomplish.

- Information should reflect real on-line status of functions and components in a manner that makes it easy to understand and accept. Operators should not be required to mentally process data in order to obtain the needed information. It should be expressed in terms that are at the level that will directly impact situation assessment, e.g., processed and integrated to meet the operators' need to comprehend the current situation.
- Information about plant functions and the operator's mental model (understanding of how the plant operates) should be highly correlated. This is necessary to ensure that the displays trigger the appropriate mental representation of the situation. Since situation awareness depends on activating the appropriate mental representation for the situation, the critical cues needed to do so should be determined and displays should make these cues salient.
- Displays should support the projection of future states of the system.

These general principles were used to develop detailed guidance for the design of displays for supporting monitoring, detection, and situation assessment. The basic elements of the displays are:

- a hierarchy of displays at various "levels of abstraction" from high-level summary information to very detailed information
- top-level overview displays suitable for plant monitoring
- displays providing progressively more detailed information suitable for situation assessment in the event something is not normal
- navigation aids to enable users to quickly and easily move from higher-level displays to lower-level displays in the hierarchy

Providing information in this way enables crews to quickly visualize plant status, the complexity of the process, and the propagation of failures from low levels to high functional levels. The key step in designing displays is defining the type of hierarchy to be used to organize and define the displays. An abstraction hierarchy (AH) should:

- completely describe the entire plant in terms of its main purposes or missions
- reveal goal status at each level
- reveal both physical and functional relationships
- reveal interactions and dependencies of the hierarchy elements
- be applicable to all operational situations and reflect differences associated with different operating modes (from fuel load to full power, including outages)
- be meaningful to the users

One approach to establishing an AH is based on a plant's two principle missions of supplying power to the grid and maintaining safety. This approach uses the plant's natural hierarchal structure of functions, processes, systems, and components. Figure 1 illustrates a partial hierarchy for supplying power to the grid.

Once a hierarchy is specified, displays can be designed to provide information about each level. At the higher-levels of the hierarchy, information is provided so the crew can easily monitor plant status. These displays can include:

- overall summary measures for mission achievement, such as megawatt production and integrity of critical safety functions

- information about the integrated status of functions. Model-based displays can be used for this purpose, e.g., mass and energy balance displays (Beltracchi, 1995 and Appendix B, Model-Based Displays of O'Hara, Pirus, and Beltratcchi, 2003). These could show identified and unidentified RCS leakage rates (calculated and measured), as well as real-time measurements that depict the overall plant thermal efficiency for overall electricity production cycle (including nuclear, thermal, and electric measurements). When problems are identified, such as increasing leakage rates or a drop in efficiency, operators can consult the lower-level displays.
- performance or status indicators of important plant functions. These indicators may be based on synthesis of many lower level conditions and parameters.

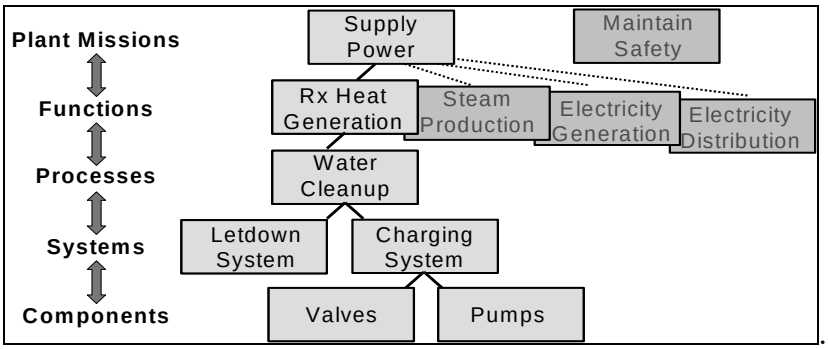

Fig. 1 Plant abstraction hierarchy for supplying power to grid. (Note: Only a portion of the hierarchy is shown.)

At the intermediate levels, plant processes and systems are shown. While some functions directly link to systems, there are times when an intermediate process can be defined that is accomplished be several systems. Examples include "Reactor Water Cleanup" under the Supply Electricity to the Grid mission and "Feed and Bleed" under the Maintain Safety mission. The detailed information needed to support troubleshooting or more detailed status monitoring is provided in lower level displays.

With respect to monitoring and situation assessment, one of the main things that the users care about is whether or not the function/system/component, etc. is working properly or not. If it is not, then they need to determine the next appropriate alternative that can be used to achieve the satisfaction of the current control goal. Thus each function/system/component has to be depicted in terms of its status and its purpose or goal. While, procedures need to be considered as part of the process by which users' choose between alternatives, this activity can be supported by the HSI and its real-time indication as to the current status and of possible alternative choices that are available in case the function/system/component becomes degraded or fails. To achieve this goal, displays should include:

- a representation of the main elements of the plant's AH appropriate to the level of abstraction of the individual display
- indication of important modes relevant to the information contained in the display
- overall status indicator for key AH elements
- performance indicators for key AH elements
- dynamic information (where information is changing at important rates)
- signaling of conditions requiring operator actions

- signaling for results of automatic control system automatic actions that result in changes to process equipment configuration or state
- signaling of changes to other displays above and below in the hierarchy

All this information not need to be on a single display page, but on sets of related display pages. To be effectively used, operators have to be able to move easily through the hierarchy. This can be accomplished through a combination of navigational aids, such as direct links between related displays, such as moving up and down the hierarchy, and aids that provide random access, such as display menus and keyboard commands.

An example of an HSI that reflects this type of functional approach is provided by Pirus (See O'Hara, Pirus, and Beltratcchi (2003), Appendix A, "The FITNESS Approach To Functional Analysis And Information Presentation" for a description of FITNESS; and Anderson, Friberg, Teigen, and Pirus, 2004).

3. DISPLAY DESIGN FOR TASK PERFORMANCE

While monitoring and handling disturbances are important activities, personnel spend much of their time engaged in routine tasks, such as plant start-up, conducting surveillance activities, and performing maintenance. These tasks often involves many individual system-oriented displays and thus they are subject to the interface management issues discussed above. Task-based displays can address this situation.

It is not practical or even possible to develop specific displays for every conceivable task. Thus guidance is needed to identify candidate tasks to be supported. The identification is based on three main factors: human performance reliability improvements, efficiency improvements, and interface management reduction.

Tasks requiring *highly-reliable human performance* should be considered for task-based display support. These tasks have the following characteristics:

- important to nuclear or personnel safety
- important to maintaining power generation
- important to equipment protection for significant items such as the main turbine or generator
- time limited
- complex

Task-based displays can help support reliable performance by reducing the demands on human memory to remember information from one display to the next and by reducing the distracting effects of performing interface management tasks. Some examples of the types of general tasks that might be considered as candidates for task based displays include starting up and shutting down the plant, changing system configurations, and following of plant procedures. Examples of some specific tasks for which task-based displays would be useful include: letdown and makeup for a PWR, RCP operations for a PWR, feed and bleed for a PWR, and BWR suppression pool cooling.

Another type of task to consider is one for which *improved efficiency* is desired. Task-based displays may support efficient performance by reducing the time taken to

perform a task. Candidate tasks falling into this category are ones that are performed frequently and/or ones that take a long time to perform, e.g., maintaining operating logs.

Finally, tasks that would have *high-interface management and navigation demands* if performed without a task-based display should be considered.

The final selection of tasks for which task-based displays swill be developed should be made with input from final users, e.g., operators, because they are familiar with and regularly deal with the complexities of actual task performance.

Once candidate tasks have been selected, the requirements for those tasks should be identified. Task-based displays are obviously closely coupled to task requirements and this information comes from established procedures and task analysis. Additional information can be obtained from manuals, training materials, and from interviews with appropriate personnel or subject matter experts.

The specific requirements for any one task are unique, but the task elements needed to design the displays include:

- information indicating that the task is needed
- necessary preconditions
- task instructions
- plant information needed to perform the task
- cautions and warnings
- task-related alarms
- controls needed to perform the task
- task termination criteria

Task-based displays are made up of information presented in a variety of forms, including system mimics, trend displays, etc. Their defining characteristic is that the specific information presented in the display is organized around task requirements.

4. DISPLAY DESIGN FOR TEAMWORK, CREW COORDINATION, AND COLLABORATIVE WORK

A nuclear plant crew works as a team. They share information and perform their tasks in a coordinated fashion to achieve the goal of safe plant operation. Several crewmembers may perform a task cooperatively from one location; while in other cases, a control room operator may have to coordinate tasks with an operator in a remote location. Computer-based displays can support teamwork while helping to overcome some of the problems raised earlier. We refer to these as computer-supported cooperative work (CSCW) displays. The key elements of CSCW displays include: (1) providing a common frames-of-reference for the entire crew, (2) supporting awareness of the activities of others, and (3) the availability of collaborative workspaces and tools for team interaction with CSCW displays

A *common frame-of-reference* can be achieved in two ways. First, a high-level overview display such as those representing the upper levels of the display hierarchy (as discussed above) can be shared by all crewmembers. An example is a large "group-view" or "wall panel" display that is visible from anywhere in the control room and is permanently in view. In addition to supporting plant monitoring, the display provides a

common frame of reference for the entire crew, especially for activities such as shift turnover.

It is also important to provide a second frame-of-reference that is operator addressable. That is, crewmembers should have a workspace in which they can put displays that they wish other crewmembers to see. Attempting to coordinate activities when looking at different displays can be very difficult. If crewmembers need to collaborate on some aspect of a task, they should be able to view the same information, whether locally or remotely. This will enable multiple personnel to work on the same task without leaving their workstation. While it is ideal if such a space is provided in a group-view display, it can also be presented at individual workstations. This type of functionality can also support the coordination of actions at different locations, e.g., between the main control room, local control stations, Technical Support Center (TSC), and the Emergency Operations Facility (EOF).

CSCW displays can also assist crewmembers in maintaining *awareness of the activities of the other crewmembers*, so that separate activities can be coordinated and operators can monitor each other's tasks to help check for errors and promptly lend support when needed. This assistance may take many forms, including providing information about operators' locations in the display system, locations in ongoing procedures, and actions performed using computer-based controls. For example, such a display can allow personnel to observe a control action, such as the alignment of a fluid processing system. In this case, a mimic display, in which operators manipulate graphical objects, may provide more useful information to an observer than if the same task were performed via text commands on a keyboard. This is because the display conveys to the observer physical characteristics of the task, such as the type of valve being operated, and functional characteristics, such as the relationship of the valve to the overall piping system. This provides the observer with a better understanding of what action has been performed and its significance to the plant system

A *collaborative workspace* is an interactive display that is common to all crewmembers. Collaboration requires that the display should provide tools that enable crewmembers to interact with the display and engage in coordinated activity.

When considering the implementation of CSCW displays, it should be recognized that it may constitute specific new displays that are a part of the overall information display system, or it may be implemented as functionality that is added onto the other monitoring/situation assessment, or task-based displays already available.

5. DISCUSSION

Well-designed displays can serve to integrate information in ways that are unachievable with analog hard-wired technology. Computer based HSIs provide the opportunity to present information at just the right level needed for the task at hand. With good information design there is little need to transform or mentally integrate the information to make it useful, little demand on memory, and little to distract users from their tasks. In addition, the information displays can be designed to require far less interface management workload. Navigation cues embedded in high-level displays can provide access to lower level formats for greater detail, thus easing the burdens of

interface management. For example, a sensor symbol associated with a process variable can serve as a cue for the display of a trend plot for the measured process variable.

Using the information design approaches described in this paper, displays can be developed that augment the typical system-oriented display formats used in many modernized and computer-based control rooms. The new displays will enable the HSI to better support a broader range of user tasks, while significantly reducing the need for crews to engage in distracting interface management tasks.

The guidance from this effort will be included in guidance on Hybrid Control Rooms and Digital Instrumentation and Control Systems being developed jointly by the Electric Power Research Institute and the U.S. Department of Energy. An interim overall guidance report is currently available (see EPRI-1003696).

ACKNOWLEDGMENTS

This paper describes research sponsored by EPRI and the U.S. Department of Energy under the Nuclear Energy Plant Optimization (NEPO) Program (NEPO Task: 5-110). The authors wish to thank Joseph Naser (EPRI) and Glenn Morris (DOE) for their guidance and support. The authors would also like to thank their project colleagues: Lewis Hanes, Robert Fink, and Doug Hill; and the project's industry working group for their insightful comments and recommendations.

REFERENCES

Beltracchi, L. (1995). An OLE interface concept for Rankine cycle based heat engines. In *Proceedings of the Topical Meeting on Computer-Based Human Support Systems: Technology, Methods and Future*. LaGrange Park, IL: American Nuclear Society, Human Factors Division.

O'Hara, J. & Brown, W. (2002). *The Effects Of Interface Management Tasks On Crew Performance And Safety In Complex, Computer-Based Systems*. (NUREG/CR-6690). Washington, D.C.: U.S. Nuclear Regulatory Commission.

O'Hara, J. Pirus, D., Beltratcchi, L., (2003). *Information Display: Considerations for Designing Modern Computer-Based Display Systems* (EPRI-1002830). Palo Alto, CA: Electric Power Research Institute.

Gisle Andresen, Mårten Friberg, Arild Teigen and Dominique Pirus (2004). *Function-Oriented Display System: Background and First Prototypes* (HWR-752). Halden, Norway: Institute for Energiteknikk – OECD Halden Reactor Project.