WHEN SOFT CONTROLS GET SLIPPERY: USER INTERFACES AND HUMAN ERROR

William F. Stubler and John M. O'Hara
Brookhaven National Laboratory
Upton, New York

ABSTRACT

Many types of products and systems that have traditionally featured physical control devices are now being designed with soft controls - input formats appearing on computer-based display devices and operated by a variety of input devices. A review of complex human-machine systems found that soft controls are particularly prone to some types of errors and may affect overall system performance and safety. This paper discusses the application of design approaches for reducing the likelihood of these errors and for enhancing usability, user satisfaction, and system performance and safety.

INTRODUCTION

The past decade has seen a steady trend in many products and systems, ranging from consumer products to complex human-machine systems, toward computer-based user interfaces. Included in this trend is the increased use of soft controls - input formats presented on computer-based display devices and operated by a variety in input devices, such as touch screens, pointing devices, and key pads (Hoecker and Roth, 1996; Ranson and Woods, 1994; Degani, Palmer, and Bauersfeld, 1992). The U. S. Nuclear Regulatory Commission (NRC) sponsored a research program conducted by Brookhaven National Laboratory to examine the potential effects of new user interface technologies on nuclear power plant operations. In that study (O'Hara, Stubler, and Higgins, 1996), soft controls was identified as one of several topics potentially significant to plant safety. In a subsequent study (Stubler and O'Hara, 1998), human performance considerations associated with soft controls were examined. Human factors engineering guidance was developed for the review of soft controls. This paper presents some findings from the study of soft controls.

METHODOLOGY

Information was gathered from a range of sources. First, a review of operating experiences involving the use of soft controls was conducted using event reports and industry literature of a range of domains. Second, design characteristics of computer-based user interface technologies were identified through visits to the control rooms of five nuclear power plants, three fossil fuel power plants, and five chemical manufacturing plants, and also through a review of industry literature. Third, demands imposed on users by soft controls were identified through a set of walkthrough exercises, observations, and interviews conducted with operations, training, and design personnel. Additional demands were identified through reviews of research and industry literature. Finally, human factors guidance was developed based on: (a) principles of human-computer interface design, (b) results of the above studies and other empirical studies, and (c) accepted industry practices.

CHARACTERISTICS OF SOFT CONTROLS

Soft controls differ from physical control devices. Physical control devices, such as knobs, dials, and buttons, have evolved over many years and contain characteristics that support user interaction. For example, they usually have fixed locations on control panels and simple means of access and operation. By contrast, soft controls reside within the virtual space of displays. Rather than being accessed from a fixed location on a control panel, computer-based user interfaces must often be retrieved from a display system. This introduces new tasks for finding the correct display page. Once found, a separate action may be required to select the component to be controlled. This might be done by pointing to an icon or entering a command causing a user input field to be retrieved for that component. The user might then access the input field and perform a control action by entering a command or value using a keyboard or pointing interface. Figure 1 shows some of these characteristics for one type of soft control used in process control applications. The large rectangle represents a display screen, which contains a schematic representation of a plant system consisting of pumps, valves, and pipes. The rectangle to the right represents an input window for pump P212. The input window, which is overlaid upon the schematic display, was retrieved by clicking on the pump icon. Control setpoints for the pump are entered into the input field via keyboard or by manipulating the arrow buttons via a cursor. The control setpoint, 57 gallons per minute, appears in numerical form in the box under the label "Demand." It also appears in graphical form as a vertical barchart. The current flow rate of the pump (44 gallons per minute) appears to the right under the label "Actual."
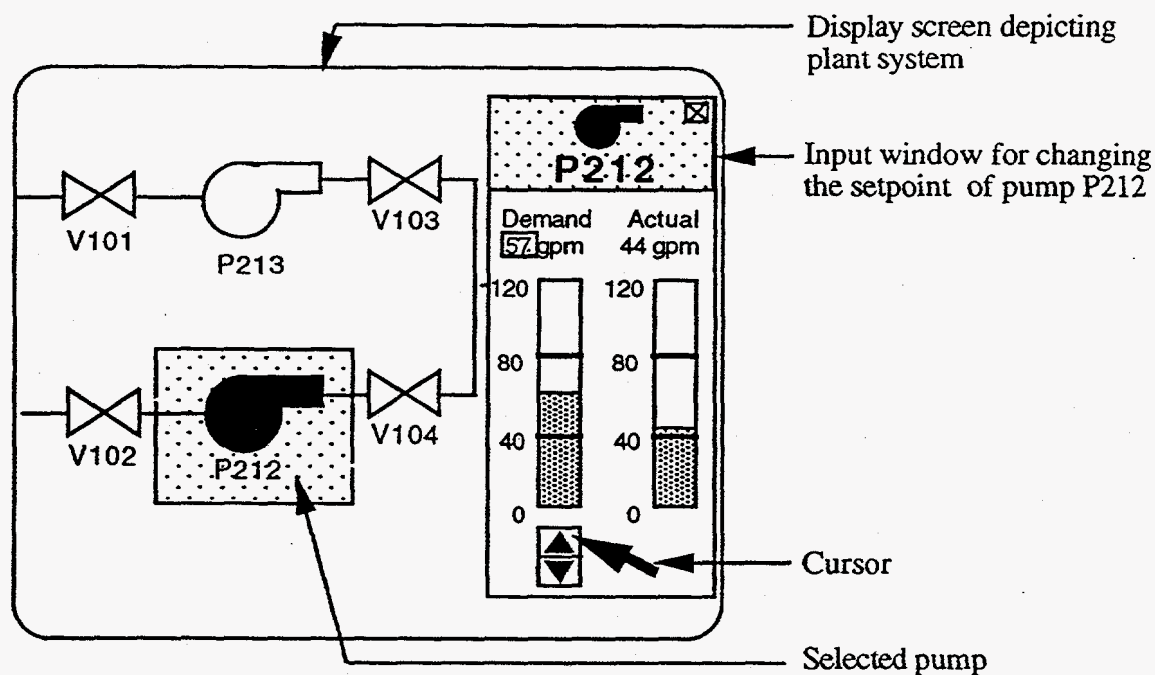
Figure 1. Typical soft control used in process control

FINDINGS

Errors involving soft controls were found to be important contributing factors in incidents occurring in a wide range of industries including process control, commercial aviation, and medicine. The following describes some of the human performance considerations. [For a complete discussion, see Stubler and O'Hara (1998).] In many cases, the types of user actions involved in these errors were similar (e.g., selecting the wrong control or typing the wrong value). However, the consequences varied greatly (e.g., from minor to severe) depending upon the operational context, such as the type of system being controlled and the status of the overall system.

One widely accepted scheme for classifying human errors divides errors into two major categories: *mistakes* and *slips* (Norman, 1988; Lewis and Norman, 1986; Norman, 1983; Reason, 1990). This distinction is based on consideration of intention - high-level specifications of action which start a chain of processing that normally results in the performance of actions. An error in intention formation, such as forming a plan that is not appropriate to the situation, is called a mistake. Slips are errors in carrying out intentions. During a slip, the user intends to do one thing but accomplishes another. Slips result from "automatic" human behavior when schema (i.e., subconscious actions that are intended to accomplish the intention) get waylaid en route to execution (Norman, 1983; Norman, 1988). As a result, slips tend to occur with skilled users rather than beginners learning new tasks. The highly practiced behavior of an expert can lead to a lack of focused attention, which increases the likelihood

that some form of slip will occur. This lack of attention can result in the incorrect activation and triggering of schemas.

Soft controls were found to be especially prone to the following types of slips: description errors, mode errors, misordering of components of an action sequence, capture errors, and loss-of-activation errors. The following are descriptions of these errors and user interface characteristics that can prevent their occurrence. These descriptions are based on categories of slips provided by Norman (1988, 1983) and Lewis and Norman (1986).

Description Errors

This slip occurs when the information used to activate the schema for a sequence of control actions is either ambiguous or undetected. The resulting ambiguity leads to an erroneous act, often closely related to the desired act. One type of description error that occurs in complex human-machine systems is selecting the wrong soft control from graphical displays. This may occur when controllable components are represented by icons. For example, the user may select the wrong component by pointing to the right type of icon located in the wrong position on the system schematic display.

Human factors guidelines for consistency in user interface design often recommend the use of a standard icon set for objects of a particular class (e.g., valves) and standard formats for human-system interactions (e.g., providing inputs). However, due to a lack of salient differences between similar icons or formats, the user may fail to discriminate between similar options and consequently select the wrong one. Design approaches for avoiding description errors include

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

(1) making options visually distinct, (2) separating similar options within displays or within the virtual space of a display system, and (3) arranging options to provide a context to support correct identification (e.g., grouping options by a characteristic such as function).

Mode Errors

This slip occurs when a user makes an erroneous classification of the mode of a device. This may lead the user to perform operations that are appropriate for one mode when the device is in another mode. Modes are created when equipment is designed to be used for more than one function. For example, a control device may be used to operate more than one variable, or a display device may be used to view more than one variable. Mode errors occur as a result of inadequate awareness of the current mode. Systems and devices that do not provide adequate feedback regarding their mode or the conditions that affect mode selection are especially prone to mode errors. Three approaches for preventing mode errors include (1) eliminating modes, (2) making modes distinct to improve mode awareness, and (3) coordinating acceptable inputs across modes such that an input that produces a benign effect in one mode does not produce negative consequences in other modes.

Misordered Action-Sequence Errors

These slips include skipped, reversed, and repeated steps within a sequence. Soft controls may be more prone to this type of slip than conventional controls because they introduce additional operations (interface management tasks) for accessing controls and displays and providing inputs. For example, rather than merely reaching for a physical control and operating it, the user of a soft control may have to perform a sequence of interface management tasks, as described earlier. Two operator tasks that are particularly prone to misordering errors are (1) performing sequential control operations and (2) entering numerical values.

Some control operations are sequential and repetitive. For example, an operator may be required to close a valve, start a pump, and then open a valve. This sequence may be repeated for several redundant systems that are nearly identical in appearance. Errors can occur when the sequence is not followed in the correct order (e.g., the pump is started before the valve is closed; the valve is closed on system A and then the pump is started in system B). When soft controls are used to perform sequential operations, the interface management tasks can interact with the sequential nature of the control tasks, making the task even more sequential. This can increase the likelihood of misordered action sequence errors. Also, because a number of displays may have to be retrieved to review previously completed steps, soft controls can impair the ability of users to keep track of their progress in sequential control tasks. For example, when sequential control operations are performed with physical control devices, the operator may be able to quickly glance at all of the controls in

a panel or use the physical location of the control device as a cue to remember which actions have already been performed. When these operations are performed using soft controls, there may be fewer physical cues and greater demands for display retrieval to make the same assessment. Misordered action sequence errors may be prevented by providing enhanced feedback regarding the status of sequential tasks. Examples may include displays that provide an overview of the sequential operation and history displays that describe recently performed control actions.

When entering numerical values, such as when providing a control setting via a key pad, misordering errors can result in the entry of incorrect values. Large errors in the magnitude of input values can result from omitted, transposed, or added digits. This occurs because the magnitude of the input value is not directly related to the actions used to enter data. With many physical input devices, the size of the change in a variable is usually related to the amount of movement that the user applies to the control (i.e., the bigger the movement, the bigger the change). For example, a large rotation of a physical dial produces a large change from its previous setting, while a smaller rotation produces a smaller change. However, when values are entered via a keypad, the data are encoded as symbols rather than as motion. The action of pressing keys bears little relation to the size of the change. Numerous events resulting from errors in typed input values have been reported in process plants, commercial aviation, medical devices, and other computer-based systems.

Design approaches for preventing these errors include using input methods and display formats that provide better feedback about the magnitude of the entered values. One approach is to use graphical representations, such as the barchart shown in Figure 1, to indicate the magnitude of the entered value. Another approach is to use interfaces that cause data to be entered incrementally, such as with the arrow buttons shown in Figure 1. In this example, the demand value is increased by pressing the up arrow and decreased by pressing the down arrow. When changing the demand value, the magnitude of the change is related to the number of times that an arrow button is pressed or the length of time it is held down.

Capture Errors

A capture error may occur when an *infrequently* performed action requires a sequence of operations that overlaps with the sequence required for a *frequently* performed action. In the course of attempting the infrequent action, the more frequent action is performed instead. For example, a user may intend to perform task 1, which is composed of operations A, B, C, and E, but instead executes the more-frequently performed task 2, which is composed of operations A, B, C, and D. If the more frequent action has been performed recently, a capture error is even more likely to occur. Because soft controls often require sequential interface management tasks, there may be more overlap in operations. For example, different control actions may require similar

navigation paths through display systems, similar dialogs, and manipulations of similar graphical objects. As a result, soft controls may be more prone to some capture errors than physical controls. That is, an intent to execute a less-frequently performed task may be captured by a more frequently performed task that requires similar interface management actions.

Two strategies for addressing capture errors are to: (1) minimize the overlap of sequences to reduce the occurrence of these errors and (2) improve the detection of these errors when they occur. Capture errors occur at the point where the frequently and infrequently performed sequences deviate. Therefore, the detection of these errors may be improved through design approaches that bring these critical points to the user's attention. For example, important choice points may be designed to be salient or require the user to focus attention on the choice point. This may be accomplished through dialogs that question the user about the intended action and provide advisory messages indicating the operational implications of various alternatives. Other approaches may track the operator actions and compare them to stated or inferred intentions.

Loss-of-Activation Errors

Loss-of-activation errors are one of the most common types of slips. They occur when schema that have been activated become deactivated due to decay and interference properties of human memory. Memory failure can occur when events intercede between the preparation of an intention and its execution. When this occurs the intention may partially or completely decay from memory. One cause of loss-of-activation is the keyhole effect - limitations on the number of displays that can be viewed at one time in the viewing space. Displays serve as reminders of tasks that must be completed. When they are removed from view so that other tasks may be performed, loss-of-activation errors may occur.

These errors may be addressed by design approaches that provide cues for refreshing or maintaining activated schema. One approach is to provide better management of the displays. For example, if additional display devices or multiple display windows are provided then one or more may be used to present displays for suspended tasks. Another approach is to use reminder mechanisms. For example, a reminder for a suspended task may be provided periodically to keep the schema active. Alternatively, the reminder may be provided only when it becomes necessary to perform the suspended task.

GUIDELINES DEVELOPMENT

Based on the human performance considerations that were identified during this research, human factors engineering guidance was developed for the review of soft controls. This guidance included a characterization of design features that should be addressed by design reviews and specific guidelines for reviewing these features. The guidance from this effort

will be incorporated into a future revision of the Human-System Interface Design Review Guideline (O'Hara, Brown, Stubler, Wachtel, and Persensky, 1996).

DISCUSSION

The design approaches discussed in this paper are part of the broader context of design for error tolerance. These approaches focused on error prevention. They reduce the likelihood of error by directing the user's attention to the input task or they minimize opportunities to provide incorrect inputs. A second error-tolerant design approach is to design systems to detect input errors and assist the user in correcting them. Lewis and Norman (1986) describe several such human-computer interaction styles. A third error-tolerant design approach is to design systems to mitigate errors. For example, design features may be provided to allow erroneous inputs to be quickly changed (e.g., undo commands). As an alternative, automatic protection systems may be actuated to mitigate negative consequences. All three of these approaches (error prevention, error detection, and error mitigation) should be considered when the consequences of errors are high and were addressed in the development of review guidance.

Our site visits and review of industry experience showed that while soft controls used in complex human-machine systems are especially prone to slips, design techniques for preventing and detecting slips often were not applied consistently or effectively. For example, industrial plants often had expensive safety protection systems for mitigating the consequences of errors, but lacked some relatively inexpensive features for preventing errors in the first place. Directing the design effort toward error prevention and detection may be a highly cost-effective strategy for enhancing system performance. These features can provide an extra level of protection for complex human-machine systems by reducing the likelihood of errors or increasing the likelihood of prompt error detection. As a result, there may be fewer situations in which automatic error mitigation systems will be needed to correct problems. In addition, design techniques for preventing and detecting slips may be effective in enhancing system usability and overall user satisfaction.

Our review of human factors literature also indicated that more research is needed in this area. While a technical basis was found for the development of guidance addressing individual approaches for error prevention, error detection, and error mitigation, little guidance was found regarding the relative effectiveness of these approaches or the benefits that may result from incorporating multiple approaches into the same user interface. During the development of new systems, designers and reviewers must make assessments of the overall adequacy of error-tolerant design features. Some considerations include, "Can the strengths of one approach compensate for weaknesses in the others?" and "How much protection is enough?". In the absence of specific guidance, reviewers and designers must rely on performance-based tests and iterative design approaches.

ACKNOWLEDGMENTS

REFERENCES

Degani, A. Palmer, E. A., and Bauersfeld, K. G. (1992). "Soft" controls for hard displays: Still a challenge. *Proceedings of the Human Factors and Ergonomics Society 36th Annual Meeting.* Santa Monica, CA: Human Factors Society.

Hoecker, D.G. and Roth, E.M. (1996). Operators' use of alternative soft control prototypes in a simulated control room task. In *Proceedings of the 1996 American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies* (pp. 209-216). La Grange, IL: American Nuclear Society.

Lewis, C and Norman, D. (1986). Designing for error. In D.A. Norman and S.W. Draper (Eds.), *User-Centered System Design* (pp. 411-432). Hillsdale, NJ: Erlbaum.

Norman, D. (1988). *The psychology of everyday things.* New York: Basic Books.

Norman, D. (1983). Design rules based on analyses of human error. *Communications of the ACM, 26,* 254-258.

Norman, D. (1981). Categorization of action slips, *Psychological Review, 88,* 1-15.

O'Hara, J., Brown, W., Stubler, W., Wachtel, J., and Persensky, J. (1996). *Human system interface design review guideline* (NUREG-0700, Rev 1.). Washington, D.C.: U.S. Nuclear Regulatory Commission.

O'Hara, J.M., Stubler, W.F., and Higgins, J.C. (1996). *Hybrid human-system interfaces: Human factors considerations* (Draft BNL Technical Report J6012-T1-4/96). Upton, New York: Brookhaven National Laboratory.

Ranson, D. and Woods, D. (1994). *Controlling what's important with soft controls: Problems, opportunities, and benefits* (CSEL Report No. 1994-01, Rev 1). Ohio: The Ohio State University, Cognitive Systems Engineering Laboratory.

Reason, J. (1990). *Human error.* New York: Press Syndicate of the University of Cambridge.

Stubler, W. and O'Hara, J. (1998). *Soft controls: Review guidance and technical basis* (BNL Draft Report J6012-T3-2-5/98). Upton, New York: Brookhaven National Laboratory.