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Usability Evaluation of Computerized Operating Procedures in a High-Consequence Industrial Workplace

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Abstract

In domains encompassing high-consequence, low-probability events, the need to minimize human error is essential. Among the many extant tools and resources, procedures are used to help control the manner in which work is performed. Adherence to the procedures is strictly enforced to help produce a safe work environment. Consequently, the procedures must be designed with the user as a central element. This report evaluates a new electronic procedures system, which is in the process of replacing a traditional paper procedure system at a defense manufacturing facility. The methodology and findings of this usability evaluation relating to the new system are summarized, and recommendations for improving the user-computer interface are presented.

1 Introduction

The last half of the 20^{th} century was characterized by a shocking rate of industrial accidents having far-reaching impact on people, property, the environment, and the public trust. In some cases, the root causes for these accidents were directly traceable to breakdowns in human performance. For example, failure on the part of operations personnel to properly detect and respond to off-normal events lead to the partial core melt at Three Mile Island and the release of methocyanate at Bhopal. A devastating explosion occurred at Chernobyl when operators made the horrendous mistake of disabling the very defense systems that were in place to protect the plant from off-normal events (Reason, 1997). These situations, and many others of a similar catastrophic nature, share a common theme: Somewhere in the loop, a human being was charged with the responsibility for keeping the process systems in a safe state. A series of erroneous actions during a critical period of plant operation caused an accident; solutions were needed to eliminate the possibility that these erroneous actions, particularly those that could compromise plant safety, could happen again.

Of course, it is often difficult to discern exactly what those solutions should be. The solutions, whatever they might entail, must be both effective and reliable, so that a true prognosis for avoiding future accidents can be realized. Fortunately, there are lessons learned from the history of these accidents that can be used to guide the search for solutions. One such solution, formalized step-by-step operating procedures as a means for reducing erroneous actions, evolved from that history. Step-by-step operating procedures are appropriate to safety enhancement for any complex industrial system. The philosophical components of a program for step-by-step operating procedures establish the foundation for enforceable compliance in every facet of plant activity.

The step-by-step procedure provides detailed instructions for executing a task. Deviations from the instructions are not permitted. If the technician should encounter an anomalous condition that is inconsistent with a particular step, the entire procedure is placed on hold until corrective remedies can be enacted. Compliance is enforced by having the procedure document open to the page describing the actual work step taking place. Usually one technician will read aloud the step to be completed to another technician who performs the step. The performer verbally confirms with the reader that the required action associated with the step has actually been completed. Steps are checked off to document completion.

The concept of step-by-step procedures has been used at a defense manufacturing facility for many years. This facility has a primary mission for the assembly and disassembly of explosive components. In this circumstance, human errors could have profound consequences affecting employee safety. Hence, step-by-step procedures at this facility are an essential asset for ensuring that error possibilities are minimized. Until recently, the step-by-step procedures for these explosive processes existed only in paper form.

Over the past few years, the implementation of a new electronic procedures system has been in progress. This project will essentially replace the use of traditional paper-style procedures with a computerized delivery system. The electronic procedure system includes the hardware—consisting of an adjustable workstation using a touch screen interface—and the software for display of and user interaction with the work instructions. The system provides many benefits for improving the performance of shop-floor technicians. For example, it is expected that the electronic procedure system will improve adherence to procedural compliance by providing the technician with a workplace that minimizes opportunities for missing steps intended to be performed in a predefined sequence, the system requiring redundant verification from the user to confirm a procedure match to the correct explosive component. In addition, given the routine updating of changes, the new system will only maintain the most up-to-date version of the procedures, precluding technicians from using the wrong version. Furthermore, data will be compiled in one place, maximizing interaction between users on and off the shop floor. Reference sources and forms needed to carry out shop-floor tasks will be essentially integrated in one place for easy access and retrieval. The new system also facilitates the recording of data and information for a variety of activities associated with quality and surveillance programs. In this manner, the electronic procedure system will help technicians stay within a safety zone, in ways that paper procedures cannot, thereby minimizing certain hazards and incidents.

Naturally, the migration from a predominately paper-based environment to an electronic system is not without certain challenges. The tradeoffs between paper and electronic displays are not clearly delineated. Sellen & Harper (2003) have drawn upon the work of J. J. Gibson to characterize paper and digital technologies in terms of “affordances” offered to the user. For example, they point out that paper affords flexible navigation between pages, and allows for interweaved reading and writing. With paper, it is easy to lay down multiple documents and simultaneously read them. Conversely, digital technologies afford the capability to efficiently store, link, search, and access information. Digital technologies also accommodate multimedia presentation, thus appealing to a broader range of cognitive styles. Unlike paper, the content can be dynamically updated or modified.

A key observation from the project’s inception is that there are certain things that people can do with paper that they cannot do (or prefer not to do) with digital technology and vice versa. Consequently, the project had an imposed risk that electronic procedures might discard some of the positive qualities afforded by paper. There was also a deep awareness that the technicians were already intimately familiar with and adapted to paper-based procedures. The technicians also had an established notion that paper already worked pretty well, and so there was little reason in their minds to change anything. These issues necessitated that developers answer the following question: Will explosive activities be ultimately more reliable with computer-based operating procedures? In order to provide insight into this question, a usability evaluation was conducted to assess how well a sample of technicians would be able to use the new electronic procedures and to expose usability deficiencies before the release of the final system.

2 Description of the Electronic Procedure System

2.1 Touch Screen Workstand

A dedicated touch screen workstand was used for controlling and displaying the electronic procedures. The entire workstand was designed for adjustability and portability. A workstand that is typical of the type used for the usability evaluation is shown in Figure 1.

Figure 1: Workstand Employed for Usability Evaluation

2.2 User Interface Software

The electronic procedures employed a user interface with the functional "look and feel" of a Windows™ operating environment. The technicians interacted with the electronic procedures using touch screen control. The controls primarily consisted of buttons and tabs. Other control features included the pressing of textual and color-highlighted links within the body of the work instructions. Thumbnail pictures permitted the viewing of full-sized images in an adjacent side panel of the screen. Items within a list could be selected by pressing directly upon the item of interest. Both vertical and horizontal scroll bars were provided for moving displayed information. On-screen pop-up alphanumeric keyboard and numeric keypad were also available for data-input requests. Figure 2 illustrates the user-system interface architecture.

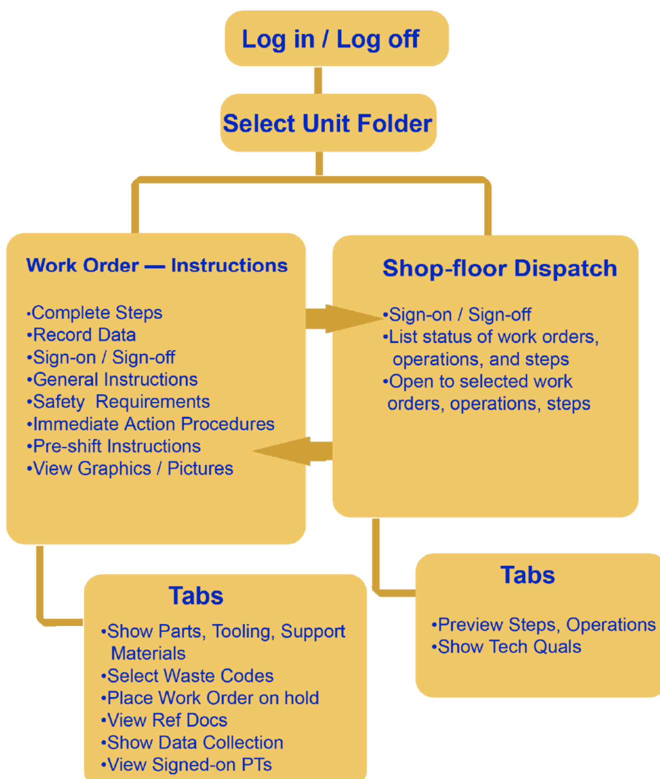

Figure 2: User-system Interface

As shown in Figure 2, the technician enters the system by logging on and selecting a Unit Folder. The Unit Folder defines the set of work orders that the technician must complete. In this fashion, the Unit Folder establishes the scope of work, namely the technician has access only to the work orders that are uniquely applicable to fulfilling the assigned activities. When the Unit Folder has been successfully defined, the technician is then provided access to the Shop Floor Dispatch screen. This screen primarily provides a hierarchical list of Work Orders, Operations, and Steps that are available to be worked on, together with a status indication describing the accepted order in which the work is allowed to be completed (e.g., ACTIVE, IN QUEUE). From the hierarchical list, the technician may select and go to an operation or step to work on as permitted by the authored logic for the individual work orders. The technician also has the ability to Sign On–Sign Off to the work order from the Shop Floor Dispatch. The Shop Floor Dispatch also contains a tab giving the technician a capability to preview a step or operation in advance before actually accessing it. An example of the Shop Floor Dispatch screen is shown in Figure 3.

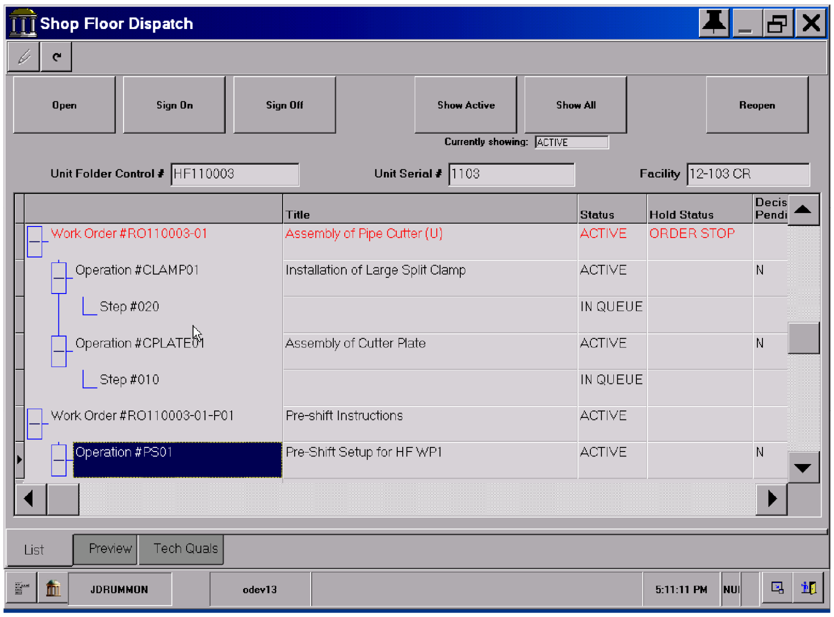

Figure 3: Shop Floor Dispatch Screen

Making a selection from the Shop Floor Dispatch screen will lead to the display of the chosen operation or step on the Work Order – Instructions screen. This screen includes the procedural contents that are to be accomplished by the technician. The Work Order – Instructions screen prompts the technician to read and complete procedures and record information as required by the individual work order. Steps can be completed either sequentially or nonsequentially depending upon predefined rules. Criterion-referenced branching can also be predefined, such that a technician's response to a given step will automatically advance the work order to the next applicable operation or step.

The Work Order – Instructions screen (Figure 4) also provides single-button access to various sections and supporting components of each work order such as, Safety Requirements, General Instructions, and Immediate Action Procedures. Each of these features can be immediately accessed at any time during work order execution. Sign On and Sign Off buttons are accessible from the Work Order – Instructions screen and are functionally the same as the Sign On and Sign Off buttons that are available on the Shop Floor Dispatch screen. Several tabs are used to support activities associated with the Work Order – Instructions screen. While executing a work order, the technician may either be prompted by a step or operation; or at his or her discretion, open a tab and act upon the information presented in it. These tabs predominately provide lists of parts, tooling, and support materials associated with a particular operation or step.

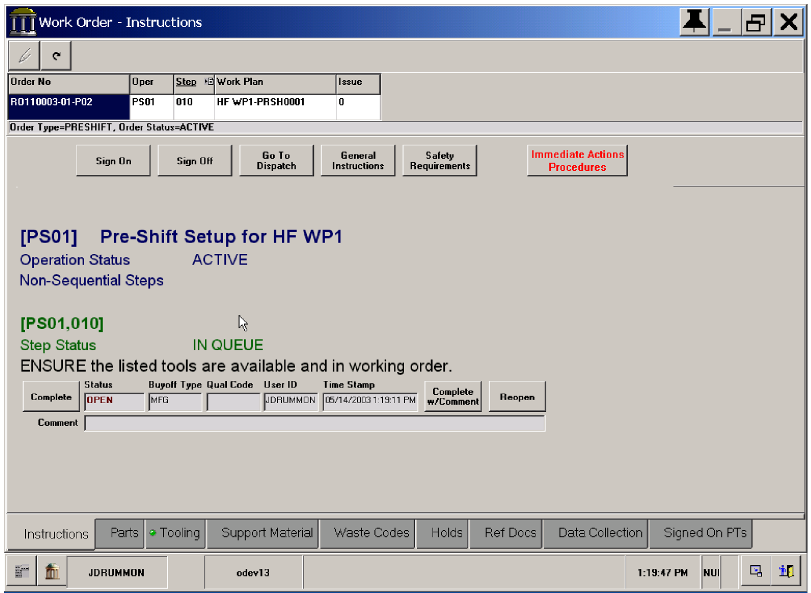

Figure 4: Work Order – Instructions Screen

3 Usability Evaluation: Methodology

3.1 Evaluation Participants

Fourteen technicians with a variety of work experiences on the production line, ranging from 2 to 21 years in duration, participated in the evaluation. Thirteen of the technicians reported having no previous experience working with electronically presented procedures; one disclosed experience using engine diagnostics equipment with a touch screen interface, characterizing that as a type of electronics-based procedure. The technicians rated their experience using a Windows-type system on a 7-point scale ranging from 1 ("Very Little Experience") to 7 ("A Lot of Experience"). Reponses ranged from "1" to "7" with a mean experience level of 4.1. This experience was typically obtained through a combination of working with Windows applications on the job and at home.

3.2 Evaluation Tasks

The technicians performed a simulated real-work task representative of the activities that they would actually perform on the job. The final set of tasks developed for the evaluation consisted of a procedural product assembly operation requiring technicians to assemble a pipe cutter. The technicians were also required to perform an operation with the assembled pipe cutter, namely, cutting a plastic "test coupon" into two sections. (The test coupons were fabricated specifically for purposes of the evaluation.) Finally, after the cut was completed, the technicians were instructed to perform electrical tests on one of the separated sections of the test coupon. Additional tasks involved clean up, preparation, and packaging the two previously cut sections into a wooden case. The tasks were divided into four work orders (Table 1). The parts and materials used during these tasks are shown in Figure 5.

Table 1: Work Orders Developed for the Evaluation

Work Order	Description
Work Order No. 1: Pipe Cutter Assembly	Assemble the pipe cutter given the unassembled parts and the necessary hand tools (provided).
Work Order No. 2: Test Coupon — Separation	Insert a test coupon into the pipe cutter and perform all operations required to cut the test coupon into two sections.
Work Order No. 3: Test Coupon — Test	Test the battery inside a section of the test coupon. Read voltage and verify that the battery will activate a small light bulb. Record test results.
Work Order No. 4: Test Coupon — Packaging and Closeout	Clean and swipe two sections of the test coupon. Place the sections into a wooden case.

Figure 5: Parts and Materials Used for the Evaluation Tasks

3.3 Procedure

The electronic procedure system was completely new to all the technicians who participated in the evaluation. Therefore, each technician received training on all major system functions before the evaluation began. After completion of training, each technician was given instructions that described the purpose of the evaluation and why their assistance was needed. The instructions outlined the purpose of the evaluation and assured anonymity to participants. After a short question and answer period, each technician was handed unique unit folder information that had to be entered into the system to access the set of work orders.

After entering the requested unit folder information, technicians were asked to navigate through the assigned work orders and to read the instructions to a second technician, a confederate of the evaluation team who had ample experience with execution of the work orders. The technicians were asked to use and navigate the system as best they could and were only aided by the evaluators when they became frustrated or asked for help. In this arrangement, evaluators simply observed technician interaction with the system and noted items that posed a problem. After completing work orders, technicians responded to data collection instruments intended to elicit opinions about their experience with the system, and subsequently, thanked and allowed to return to work.

3.4 Data Analysis

The following four data collection strategies were used:

1) **Technician Experience and Background Form** — Simple demographics inquiry addressing years of experience as a technician, prior knowledge working with electronic procedures, computer literacy (e.g., previous experience using a Windows-based operating system).
2) **Technician Appraisal Survey** — Rating scale administered to technicians at the end of the trial to delve into their attitudes, likes–dislikes, and best–worst features about the system.
3) **Evaluator-Observer Questionnaire** — Open-ended questions about specific problems that the technicians encountered, improvements they would like to see, and areas where they experienced the greatest problems.
4) **Evaluator Observations** — Notes and comments collected during the evaluation to record problems, errors, and slips, and perceived troubles that the technicians experienced while using the system. The observations include both positive and negative experiences.

The first three strategies were paper-and-pencil type questionnaires and rating instruments. These were administered to each participant at the conclusion of each evaluation session; by contrast, the fourth strategy entailed an evaluator simply observing the process and taking notes. Although the observations were loosely structured, as the technicians performed their assigned tasks, the evaluators focused on various key features of the electronic procedure system as follows:

- **Log-in/Start-Up/Exit —** Work order execution and entering–exiting system
- **Shop Floor Dispatch —** Navigation between work orders, operations, and steps
- **Work Order Instructions** — Flow of activities as governed by the work-order text and the ease with which steps were followed in completing work orders

Observing how the technicians interacted with these features helped the evaluators to document technician experiences during the evaluation. Specifically, the evaluators watched for the following aspects:

- functions within the system that were not intuitive to the technician or that hindered smooth navigation through a work order;
- the number of times the technician had to go back and reread the steps, or the number of clicks or touches that the technician required to arrive at the intended destination beyond the ones available for the most direct path;
- nonproductive time consumed in completing the tasks, such as staring at the screen for long periods with no apparent strategy in mind about where to go next.

All qualitative information was compiled to ascertain key points and themes relating to problems, inefficiencies, and favorable attributes reported by technicians during their interaction with the electronic procedure system. The quantitative information from the survey scales was compiled using descriptive analysis. Triangulation was achieved via the use of multiple methods, both qualitative and quantitative, to build checks and balances into the formulation of overall findings. Additionally, triangulation was evident by having at least two evaluators (in some cases three) present to collect observations and provide differing viewpoints throughout the duration of the evaluation. These techniques, multiple measures, and multiple evaluators, helped ensure that the final results were accurately determined to the greatest extent possible within the scope of the evaluation (Patton, 1987).[1]

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[1] While triangulation, via multiple measurement approaches, was conceptually advantageous, the actual results obtained from the evaluation proved otherwise. Responses from the Technician Appraisal Survey tended toward the "Strongly Agree" (or positive agreement) end of the scale. Many of these positively regarded responses were incongruent with certain results obtained by the other complementary data collection strategies. Given the divergent nature of the results, the survey responses were interpreted with caution, since biases may have compromised the usefulness of the data. One possible bias effect includes "acquiescence." Acquiescence is a response style described by Pedhazur and Schmelkin (1991, p. 141) as, ". . . the tendency of respondents to agree more than to disagree."

4 Results

4.1 Recommendations

Several recommendations for improving the electronic procedure interface were identified. All recommendations prepared by the evaluation team were discussed with the system developers for the purpose of elucidating the nature of each recommendation and planning a path forward for resolving them. Highlights of those recommendations are presented below.

4.1.1 System Feedback

While navigating through the system, technicians sometimes lacked feedback that situated and explained the context of their extant location within an operation. Major improvements were incorporated to provide more explicit feedback to the user in the form of clarifying messages and strategies for correcting errors. These improvements were found to be a particularly important asset for helping the user to transit to the next work order in the series as well as for proceeding to another activity within the same work order. Improvements to the system were made so that prompt and meaningful information would be displayed, informing the technicians of the status of a particular operation and how to proceed. Planned future enhancements will address techniques to augment user awareness in the system, such as graphical flow diagrams or site maps.

4.1.2 Buttons and Tabs

Two of the main navigation components of the touch screen interface were buttons and tabs. However, they did not have the capability or flexibility for providing visual feedback necessary for validation of user interaction, that is, buttons did not highlight or change color upon activation. For example, when users pressed the "complete" button for the buyoff on the Work Order screen, they could not tell if the button had been activated. In fact, during the study, when the users accidentally missed the button and nothing occurred, they would simply stop interacting with the system—not knowing what to do and believing that they had pressed the incorrect button. Highlighting or gray-scaling "pressed" buttons would let the user know that the step had been completed. Recommendations were made to expand the product's capabilities to allow for this type of feedback. Inadequate button sizes were among other concerns. Although many of these buttons might have been suitable for mouse input, they were wholly inadequate for finger-actuated input. A stylus was designed to address some of the problems that the technicians experienced with overly small buttons.

4.1.3 Selection of Terminology

An issue that created confusion for the users was the "Edit" button used to enter data on the Work Order – Instruction screen. The word "edit" was not intuitive to users as a data entry prompt. Some users thought that "edit" only applied to making changes rather than to entering data. This issue was addressed by changing the name of the button to "Record."

The terminology used on the buyoff status bar also proved to be confusing to the users. The status bar showed "Accept" when the buyoff has been accepted. However, to most users, this meant that the buyoff needed to be accepted not that it had already been accepted. Accepted buyoffs were changed to "Closed" to be consistent with established conventions and to remove any confusion that might be created by a word with two possible meanings.

4.2 Positive Features

Multiple features of the electronic procedures system were rated by the technicians as highly user friendly and conducive to improved procedure comprehension. Some of these positive features are discussed below.

4.2.1 Workplace and Equipment Usage

The technicians generally concurred that the screen can be viewed from their work location and that the workstand could be easily moved as needed to accommodate the work processes. These observations reinforce the view that the technicians were satisfied with a workstand that is adjustable to suit individual needs.

4.2.2 Pictures and Images

There was almost unanimous agreement that the Warnings, Cautions, and Notes stood out and were understandable. There was also broad agreement among the technicians that the photographs and other images were a positive addition and well liked.

4.2.3 Screen Organization and Layout

Ideally, the user interface should minimize the necessity to move back and forth across several screens to accomplish a task. The technicians agreed that all related information was appropriately grouped or easily accessible for the work they were asked to perform.

5 Discussion and Conclusion

The usability evaluation was beneficial in identifying deficiencies with the electronic procedure system. The ability to conduct the evaluation in a real-world setting with actual users provided evaluators tangible evidence with which to reveal to the system developers deficiencies and areas for rectification.

Overall, technicians reported that the system would reduce opportunities for missing a step within a given sequence, because the system checks that the previous step was completed before proceeding to the next step. This provided a safety factor against error, since the system would automatically track and monitor progress through a work order. Additionally, there was a general consensus that the electronic procedure system would diminish paperwork, thus reducing some of the burden associated with this activity. In particular, the concept of entering data directly into the computer-based procedure system as opposed to managing several paper-and-pencil forms was considered an added benefit. Given extended opportunities to "play" with the electronic procedures system, it appeared that the technicians were really beginning to "get it"—the implication being that increased familiarity might be expected to overcome the initial "fear factor" that often accompanies novelty in a work situation.

However, it was also recognized that not all technicians were completely "on board" with the idea of electronic procedures, and concerns for implementation lay ahead. Specific concerns were raised about the benefit of having some processes computerized while others remain paper based. Other responses were of an organizational nature, such as how time periods obtained from logging in and logging off of the system could be used as a tool for personnel management. Technicians also wanted assurances that the system would remain reliable, and what would happen if the system crashed. While paper procedures provide a tangible and known quantity, the reliability of a computerized alternative was viewed with skepticism. Still other technicians saw the concept as perhaps just another passing fad that might or might not be around for long.

Proof of success will depend on the ability to bring the system to the shop floor in a way that fully and proactively addresses the concerns noted by the study participants. To accomplish this, plans are underway to carry the evaluation effort forward throughout the product's lifecycle. Interviews and observations to check the system for usability issues in the field will be an ongoing process. In due time, it is expected that occurrences such as missed steps within a process will be reduced, while reports of satisfaction and acceptance by the technicians will increase.

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