INL/CON-11-23631
PREPRINT

Model of Procedure Usage – Results from a Qualitative Study to Inform Design of Computer-Based Procedures

8th ANNUAL NUCLEAR PLANT INSTRUMENTATION, CONTROL, AND HUMAN-MACHINE INTERFACE TECHNOLOGIES (NPIC & HMIT)

Katya Le Blanc
Johanna Oxstrand
Thomas Waicosky

July 2012

The INL is a
U.S. Department of Energy
National Laboratory
operated by
Battelle Energy Alliance

Idaho National Laboratory

Model of Procedure Usage – Results from a Qualitative Study to Inform Design of Computer-Based Procedures

Katya Le Blanc and Johanna Oxstrand
Idaho National Laboratory
Battelle Energy Alliance
P.O. Box 1625
Idaho Falls, ID 83415-(3605)
katya.leblanc@inl.gov; johanna.oxstrand@inl.gov

Thomas Waicosky
Duke Energy Carolinas, LLC
CT01A / 4800 Concord Rd.
York, SC 29745
thomas.waicosky@duke-energy.com

ABSTRACT

The nuclear industry is constantly trying to find ways to decrease the human error rate, especially the human errors associated with procedure use. As a step toward the goal of improving procedure use performance, researchers, together with the nuclear industry, have been looking at replacing the current paper-based procedures with computer-based procedure systems. The concept of computer-based procedures is not new by any means; however most research has focused on procedures used in the main control room. Procedures reviewed in these efforts are mainly emergency operating procedures and normal operating procedures. Based on lessons learned for these previous efforts we are now exploring a more unknown application for computer based procedures - field procedures, i.e. procedures used by nuclear equipment operators and maintenance technicians. The Idaho National Laboratory and participants from the U.S. commercial nuclear industry are collaborating in an applied research effort with the objective of developing requirements and specifications for a computer-based procedure system to be used by field workers. The goal is to identify the types of human errors that can be mitigated by using computer-based procedures and how to best design the computer-based procedures to do so. This paper describes the development of a Model of Procedure Use and the qualitative study on which the model is based. The study was conducted in collaboration with four nuclear utilities and five research institutes. During the qualitative study and the model development requirements and for computer-based procedures were identified.

Key Words: Computer-Based Procedures, Field Operators, Nuclear Power Industry

1 INTRODUCTION

The commercial nuclear power industry is a complex, high-risk work environment. In order to manage that complexity and to ensure safety, most work activities in the nuclear industry are guided by procedures. These procedures are used to direct main control room operators, field operators, and maintenance personnel. Currently, procedures are typically presented and maintained on paper. While these paper-based procedures (PBPs) are viewed as necessary to manage human performance in the nuclear power industry, they have also been identified as potential contributors to human error. Many of the challenges associated with the use of PBPs are attributed to the fact that they are static, and do not necessarily reflect actual plant conditions (Fink, Killian, Hanes, & Naser, 2009, O'Hara et al., 2000). Additionally, managing multiple procedures, place-keeping, and finding the correct procedure can be challenging with paper-based systems (Fink et al., 2009, Converse, 1995).

Plans to upgrade existing plants with digital equipment and wireless technology provide an opportunity to enhance procedures by transforming the existing PBPs to computer-based procedures (CBPs). CBPs are not a new concept; they have been investigated as a potential solution to many of the challenges associated with PBPs since the early 1980s (Fink et al., 2009). However, most of those efforts have focused on normal and emergency operating procedures used in the main control room. Even though the focus has been on control room operating and emergency procedures, very few plants have implemented a computer-based system for these procedures. This is mainly due to the amount of regulation and scrutiny that applies procedures in the control room. Recent work has suggested that CBPs may be a viable option for enhancing human performance for field operators (Farris & Oxstrand, in press).

Currently, the Idaho National Laboratory (INL) and participants from the U.S. commercial nuclear industry are collaborating in a research effort to explore CBPs for field workers including field operators and maintenance technicians. This application of computer-based procedures is relatively unexplored. However it might prove to be easier for the industry to make the transition from PBPs to CBPs for field procedures than for procedures used in the control room. This is due to the fact that these procedures are not as strictly scrutinized by the regulatory body as control room emergency procedures. CBPs for field workers can show that performance can be improved by CBPs, which will provide a justification for enhancing control room procedures in the future. This research effort and collaboration aims to identify a common vision for CBPs across the nuclear industry, and to help define a path forward for implementing CBPs starting with procedures for field operators.

As an emerging alternative to PBPs, CBPs could potentially increase reliability, efficiency, and safety at the plant by reducing operator workload and reducing the rate of human errors. CBPs could include features such as automatic place-keeping and integration of plant status information. Additionally, operational experience and just-in-time training could be incorporated into the procedures. Clearly, CBPs have great potential; however, a poorly designed CBP system could have negative effects on both human and plant performance. In order to avoid unintended and potentially negative consequences for human performance, thorough human factors research has to be conducted to build the theoretical and technical basis for the system design.

In order to understand how procedure performance can be improved with CBPs, it is important to first understand how current paper-based systems are actually used in the field. Identification of how procedures support the operators and technicians in their everyday tasks as well as identification of where additional support is needed is an important first step in defining the requirements for CBPs. It is also essential to identify areas where the computer-based procedures could help improve the process and hence improve human performance. To accomplish this, the focus should be on what features from the use of paper-based procedures should be kept, what should features should not be incorporated and what new features or work processes should be added to CBPs. The researchers from INL collaborated with four U.S. nuclear power utilities and five research institutes to conduct a study aimed at identifying the actual use of procedures as well as factors that contribute to both intentional deviations and unintentional errors in the procedure following process. The research effort also identified desirable features to be incorporated in the computer-based procedure system, and used the information gathered to develop an initial model of procedure usage. This model will be the basis for development of concepts and prototypes in the next stage of the research effort. This paper describes the study, the construction of the model of procedure use, and the requirements identified so far.

2 METHOD

The study consists of three main parts: 1) benchmark previous research and existing literature on CBPs; 2) develop a problem statement; and 3) gather information during a plant visit to inform a model of paper-based procedure usage and develop of requirements for CBPs (the qualitative study).

2.1 Benchmark Literature on CBPs

The first step in the study was to benchmark previous research and existing literature on CBPs. The majority of research conducted on CBPs has focused on procedures used in the main control room. However, some guidance documents reviewed included field operating procedures in their scope (e.g., IEEE, 2011; O'Hara et al., 2000). Additionally, some recent work has investigated the potential use of technology to improve field workers' work processes in the nuclear industry (Farris & Oxstrand, in press). Results from that research (derived from surveys and focus group discussions) were considered and incorporated into our problem statement and hypothesis. The specific insights that were applied to the current research effort were:

- Correct component verification (CCV) was indicated to be one of the most error-prone tasks for field operators and maintenance technicians
- Field operators and maintenance technicians need to have maximum mobility (they often need to climb ladders, crawl through tight spaces, etc.) and should not be burdened with multiple devices

Finally, documents from both the Institute for Nuclear Power Operations (INPO, 2009) and nuclear power utilities related to procedure use and adherence as well as documents related to human performance were also reviewed as a part of the benchmarking exercise.

2.2 Defining the Problem Statement

The results from the benchmarking step fed into the development of an overall problem statement. The problem statement was verified by plant personnel at two utilities to ensure that it was consistent with industry concerns related to procedure use.

Problem statement: Numerous events and subsequent corrective actions are attributed to procedural use and adherence issues in nuclear power plants. The paper-based procedures currently utilized pose challenges in that they are static while actual plant conditions are dynamic. Therefore, the procedures may include sections or steps not applicable to the current situation as well as cautions or warnings that are misleading or confusing given the current plant status. These issues are all known to lead to unintended or erroneous actions.

Figure 1 illustrates the issues identified in the problem statement. Essentially, there are two global gaps in the ability of procedures to support operators in accomplishing their particular goal. The first gap (Gap A) occurs because procedures can only be written for anticipated situations. Unanticipated events or conditions may cause the plant state to be outside the scope of written procedures. CBPs can do little to close Gap A. The second gap (Gap B) illustrates the gap between how a procedure was intended to be used and what actually happens. For most procedural tasks, Gap B is non-existent (meaning that the intended use matches the actual use) however, intentional deviations from procedures (e.g., workarounds) as well as unintended errors may occasionally widen the gap. The main objective of qualitative study was to identify the factors that contribute to both intentional deviations and unintentional errors in the procedure following process.

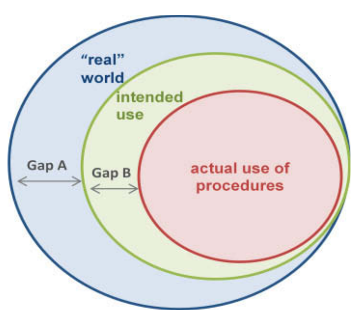


Figure 1. Relationship between reality, intended procedure use and actual procedure use

2.3 Qualitative Study

The qualitative study was conducted during a plant visit and consisted of three data gathering activities: 1) On-the-job observation of field operators, 2) Structured interviews, and 3) Participation in focus group discussions.

The duration of the plant visit was four days. It was conducted at the same time as another research effort that demonstrated a prototype of how technology could be used to improve human performance in the field.

2.3.1 Observation of field operators

The researchers observed a shift turn-over including individual turn-overs and a shift brief. They also observed two field operators conducting rounds. The researchers were able to observe how the operators were using Personal Digital Assistants (PDAs) as a tool during their rounds guiding them to components to inspect and values to record. Researchers recorded the following information in their observations:

1. A timeline of the tasks the operator executed
2. Answers to the following questions about information flow
    a. What information is needed in the field?
    b. When is it needed?
    c. How is it presented? Is it committed to memory?
    d. Who needs it?
    e. How is information communicated?
    f. What information is needed in parallel?

The operators also volunteered some information regarding conditions and factors that contribute to errors in their everyday tasks during the observation. Those comments were also recorded.

2.3.2 Interviews of field workers

The researchers conducted semi-structured interviews with ten field operators and five maintenance technicians. One-third of the interviews were conducted in relation to the observations and the remaining interviews were conducted throughout the week that the researchers spent at the plant and in the plant's training facility. The researchers asked the following questions in order to develop the model of procedure use:

1. What are the most common reasons for deviating from a procedure?
2. During a typical procedural task, do you have the overall goal of the procedure in mind, or are you focused on executing the current step?
3. When executing a procedural action, do you feel you understand the consequences of that action on the plant?
4. What kind of things would cause you to stop and question whether you can complete a procedure as expected/written?
5. Can you walk me through the process of following a procedure step? What are the subtasks of following a procedure step?
6. On a typical day, how often do you consider stopping the procedure because you are unsure, but ultimately decide not to and go ahead with the procedure? What are your reasons?
7. What kind of information/criteria do you use to decide whether you need to stop and contact a supervisor?

The researchers also came up with several *ad hoc* questions they needed to ask in order to better understand how CBPs could improve work processes

2.3.3 Focus groups

Thirty-four people participated in focus groups that were conducted during the course of the week. Table 1 shows the distribution of the participants in the focus groups. Four nuclear power stations and five research institutions were represented. The group labeled 'Other' consisted of people working with human performance, radiation protection, managers, and one representative from a technology vendor. The purpose of the focus groups was to discuss how technology can support workers in the field and what is needed from a computer-based procedure system in order to be useful for the field operators and maintenance technicians.

Table 1 - Distribution of Focus Group Participants

Field Ops	Maintenance	IT	Researchers	Other
5	5	4	10	10

The study also focused on identifying requirements for the computer-based procedure system as well as the device the field workers would use to access the procedures. Items such as usability, user-interface, software features, and practical issues such as size and how to carry the device were addressed.

2.3.4 Development of model of procedure use

The qualitative data gathered during the observations, interviews, and focus groups informed the mapping of the flow of information and the use of procedures and work processes. Specifically, the operators responses to the questions presented in section 2.2.3 were used to build a task flow for executing a procedure step (i.e., the model of procedure usage), and to develop the factors that contribute to errors.

3 RESULTS

3.1 Task Flow

The first step in developing the model of procedure usage and requirements for CBPs was identification of task flow for all of the tasks an operator completes in a typical day. The primary purpose of identifying the task flow was to understand what an operator does to prepare for a job before he goes out into the plant and actually executes a procedure. A secondary purpose was to identify the information that an operator needs to perform a procedure. The task flow was constructed using the structured observation of operators on-the-job. Input from structured interviews was also included to fill in any elements not identified in the observations. In developing the task flow, the following elements were considered:

- The timeline of tasks and subtasks completed in an operator's typical work day
- The information the operator needs to complete those tasks, where that information comes from , and how it is presented
- The tools and equipment the operator uses to complete those tasks (e.g., paper procedures, flashlight, measuring tape, etc.)

The overall task flow included all activities a field operator would execute including individual shift turnovers, shift briefs, rounds, and procedures.

In developing the task flow, the researchers concluded that the steps an operator takes to prepare for executing a procedure can vary greatly depending on several factors including the level of risk associated with the task, the frequency of the task, and the complexity of the task. Therefore it is difficult to define a generalized task flow for procedure execution. However, for all tasks, an operator spends some time reviewing the procedure and some time reviewing any potential errors that may occur in the execution of the procedure. Therefore, before an operator goes out into the plant, he should understand the goals of the procedure and the effect it should have on the plant.

Generally, after being assigned to a task the operator reviews the printed procedures needed to execute the task. This review is called a task preview or job walk-down. The operator reads the procedure and makes sure he understands the steps involved, the potential risks and hazards, and how to mitigate error-prone situations. The operator might at times conduct a physical walk-down, i.e. visit the task site to gain a better understanding or the environment and equipment involved. When the operator feels confident he has a good understanding of the task, he and other operators involved will conduct a pre-job brief. The purpose of the brief is to ensure that all risks are identified, all necessary preparations have been taken, and to discuss the supervisor's expectations. The operators also share and discuss previous operational experience related to the task. Before heading to the work site the operator checks with the main control room that the prerequisites are met and that no other work is in progress that would affect the task at hand (and to ensure that the work in the field will not affect anything that is being done in the control room).

If everything is clear, the operator heads out to the field and performs the task. In general, the only information that an operator takes out into the plant with him to execute a procedure is the procedure itself (although, depending on the task, he may also have equipment drawings). The operator relies on his memory for the rest of the information he has gathered in preparation for the task (e.g., information contained in the pre-job brief).

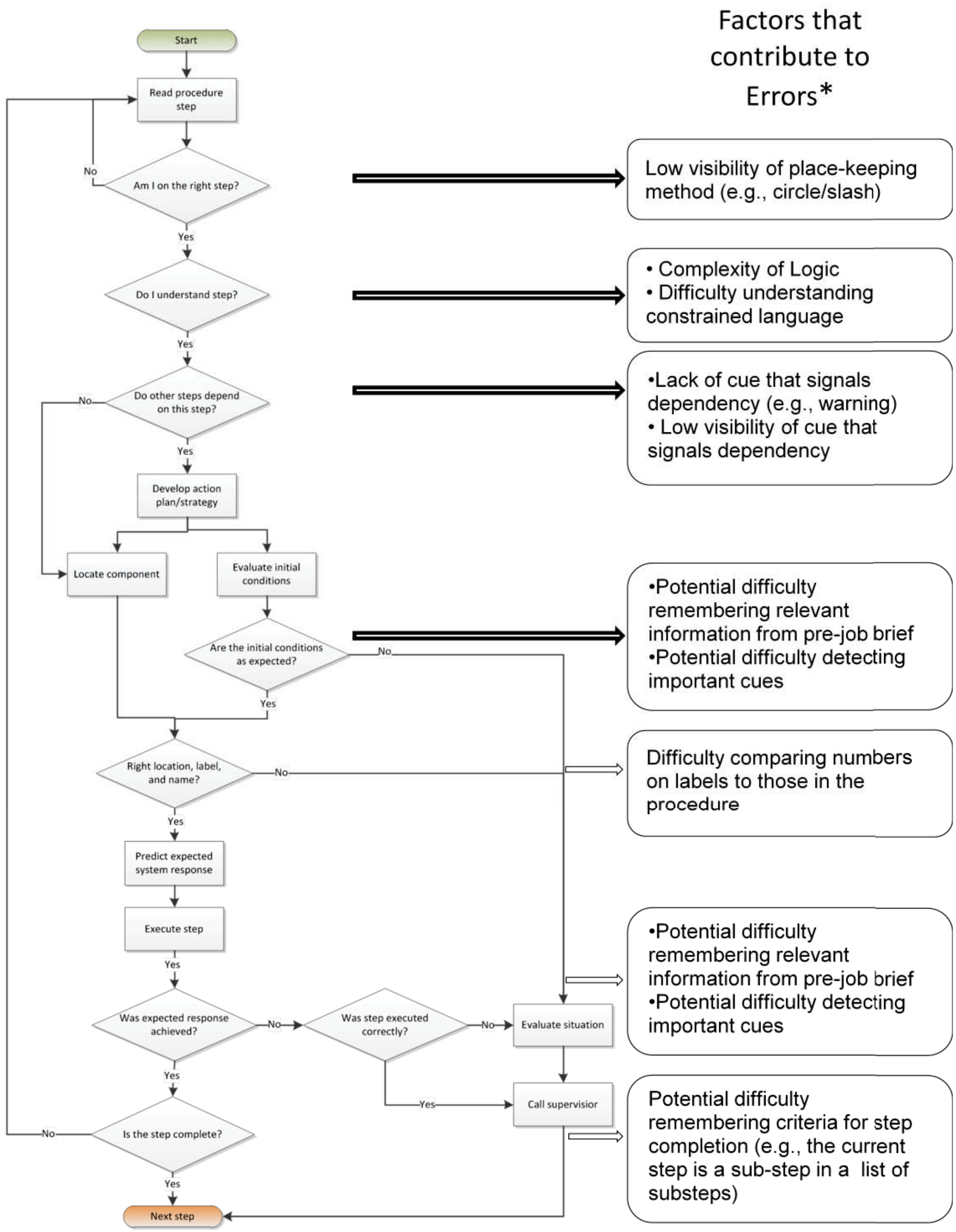
3.2 Construction of Model of Procedure Usage

Though researchers considered all work activities in the task flow, the focus of this portion of the research is how operators interact with procedures. Procedures are designed to guide operators through complex tasks. In a perfect world, procedures would cover all possible situations and operators would be able to follow procedures exactly as written. In reality, procedures cannot cover all possible situations, and operators must make judgments as to whether they are in a situation that is outside of the scope of the procedure. The criteria by which operators make these judgments are dictated by the procedural adherence standards adopted by the organization and by their own knowledge, experience and training. In situations where the procedures do cover the current situation perfectly, limitations in human perception and cognition make it possible for human operators to make errors in executing a procedure even when they intended to take the actions specified in the procedure.

In order to understand what errors can occur in execution of a procedure and how to mitigate them, it is necessary to understand the processes involved in following a procedure. Unfortunately, the process of following a procedure is more complex than simply reading a step and then executing it. There are several elements that an operator must go through in order to complete something as simple a single procedure step. Based on their observations and interviews, the researchers developed a model of the elements that an operator goes through in the process of following a procedure. The researchers chose the execution of a single procedure step as the scope for the model of procedure usage because at that level, it is possible to break down the process into the specific elements that an operator goes through in order to execute the step.

3.3 Model

Figure 2 illustrates the simplified process of following a single procedure step. Please note that even though most of the elements in the model are presented in a linear flow, some of the elements may be executed in parallel, or reiterated. Also note that this model represents a general and ideal flow of the elements that go into procedure step execution. Some of the elements may not apply in a particular situation or they may be unintentionally omitted by the operator. Also illustrated in Figure 2 is a brief description of the factors that contribute to errors that occur in each of the elements in the procedure following process. These were identified by operators or researchers based on interviews and observations. The factors are discussed in detail in section 3.4.1.



*This is not meant to be an exhaustive list of factors contributing to errors, it is simply a specific list of factors that were developed based on the qualitative study

Figure 2. Model of Procedure Usage and Accompanying Error-contributing Factors

3.4 Develop Requirements for CBPs

3.4.1 Analysis of the model of procedure usage

The development of requirements was based on an in-depth analysis of the model of procedure usage. In this analysis, researchers identified the elements of procedure step execution that are particularly error-prone and which could be improved by the used of CBPs.

The elements identified as error-prone in the model of procedure usage help to illustrate the points in the procedure-following process where operators may need to make subjective judgments about whether the procedure is going as expected. These judgments are based on many sources of information including, the instructions in the procedure itself, the pre-job briefs and walk-downs, the operator's training and experience, and equipment response, as well as the operator's comfort in stopping and asking for help. It's important for an operator to feel safe in asking for help. Additionally by examining the model of procedure usage it is possible to determine where errors could occur and identify potential solutions that might be implemented with CBPs. Each of the error-prone elements is discussed below.

Am I on the right step? Before executing any procedural action, the operator has to make sure he is on the correct procedure step. This includes checking that no prior steps are unintentionally omitted. This is typically done with place-keeping protocols. Many plants use the "circle-slash" approach to place-keeping in procedures. When a step is started, the operator draws a circle near the step, when a step is completed the operator draws a slash through the circle. One other approach is to make the operators sign their initials by each step. A current trend is to make the operators use both approaches, i.e. circle the step when it is initiated, slash through the circle when completed, and finally sign initial by the slashed circle. While these methods are generally effective, the burden of place-keeping can still be quite large. There is a risk of forcing the operators to focus more on the secondary tasks and processes (i.e., place-keeping and initialing) than the primary task (i.e., actually manipulating the equipment). This can potentially lead to reduced awareness of the environment and situation, and hence lead to an increased human error rate.

Do I understand the procedure step? One of the most common difficulties in understanding procedure steps is correctly identifying the meaning of the constrained language used in the procedure. That is, some steps imply taking action on equipment (e.g., open and ensure) while others do not allow for action (e.g., verify). Further, if a step states that a valve should be opened, but it is already opened, operators are instructed not to simply move on in the procedure. An operator may read the step, and mistakenly think that he should open a valve, when it simply says to verify that the valve is open. Misidentification of the actions that are to be taken (or not taken) in a particular step is one cause of operator errors. Even if an operator correctly identifies the action to be taken on the initial reading of the step, some time may elapse between reading the step and executing the step. As seen in the model above, there are also several elements in the process of following a procedure that may occur between reading a step and executing it. The operator may misremember the action he is supposed to take by the time he actually executes the step.

Another issue related to understanding of the procedure step is the step logic can sometimes be cognitively demanding to process (e.g., If this, and that, then do x). Finally, a large portion of the text in a procedure step is devoted to long sequences of numbers and letters to identify equipment (tag, location, etc.). While these tags are absolutely necessary for CCV in PBPs, they may obscure the actual meaning of the procedure step, potentially contributing to errors.

Do other steps depend on this step? In many cases, an operator needs to know what steps are coming up in the procedure because the subsequent steps either need to be executed quickly or they need to be executed based on some condition that occurs after executing the previous step. In some cases, there is a caution or warning alerting the operator to that type of situation. Operators also tend to read ahead several steps to check for this situation. However, in some cases operators may omit this element the procedure following process and therefore execute a subsequent step too late or incorrectly. This is especially likely in situations where there is no warning or when the dependent steps appear on the following page. Another situation when dependencies may occur are in "When/Then" steps. There are cases when operators can proceed in a procedure past a "When/Then " step and when the stated conditions are met, the operator must go back to perform that step. CBPs that have access to real-time plant data can inform the operator when he or she needs need to perform this type of step.

Are the initial conditions as expected? Before executing a step, the operator must assess the surroundings to verify that the initial conditions are what is expected based on current plant status, ongoing work/procedures, equipment status, and so on. Much of the information that goes into this assessment must come from the operator's memory (from training, previous experience, the shift brief, pre-job brief and/or walk-down, etc.). The operator may not remember pertinent details, or he may be unaware of them. Therefore, the operator might make incorrect assumptions based on an incomplete understanding of the situation. The operator may also risk conducting an incomplete check to see if the initial conditions are as expected.

Right Location, Label, and Name? (i.e., am I on the right component?) CCV was identified as one the most error-prone elements in executing a procedure. The operator must locate each component among a sea of very similar components. Complicating matters is the fact that components for different systems may be located next to one another and have very similar labels (e.g., MFW-11A for train A and MFW-11B for train B). Because of the way that humans process text (i.e., holistically), it is possible for even the most highly trained, diligent operator to misread a label and manipulate the wrong component.

Was the Expected Response Achieved? The operator has to assess the surroundings prior to the step execution as well as after the execution to ensure that the conditions are as expected. After the step execution the operator needs to assess if the plant responded in the manner that match both his understanding of the situation and what is described in the procedure. The operator uses visible, tactile, and/or audible cues to assess the plant response. If the operator has an incorrect understanding of the task at hand or of the current plant situation there is a risk that he will not identify an unexpected plant response.

Was the Step Executed Correctly? If the operator identifies an unexpected response after executing the procedure step he will have to go back to the procedure to check that the step was executed correctly. The operator will have to assess the situation and back-track his actions in order to conclude if step was executed correctly or not. If the operator's perception of how the step should be conducted do not match the actual writing in the procedure (e.g., due to a recent procedure revision) there is a risk that the operator will not correctly identify his own deviation.

3.4.2 Requirements for CBPs

Analysis of the model of procedure usage identified several elements in the process that are particularly error-prone. Many of these issues have clear, attainable solutions in the domain of CBPs. The researchers developed a list of requirements based on those issues and the potential solutions. They are discussed briefly below. Some of the requirements developed in this research effort are similar to guidance put forth in IEEE 1786 (IEEE, 2011) and O'Hara (2000), however the intent is different. The following list defines features of CBPs that are *essential* if they are going to improve human performance compared to PBPs (i.e., a CBP system without these features is unlikely to be successful in supporting operators).

1. *CBPs should Guide Operators through the logical sequence of the procedure*. The CBPs should be designed so that they automatically take the operators through the specified procedure path based on initial conditions and operator input.
2. *CBPs should ease the burden of place-keeping for the operator.* CBPs should keep track of where the operator is in the procedure, should mark steps as completed, and should highlight the current step.

3. *CBPs should make the action steps more distinguishable from information gathering* steps. CBPs should use some method to differentiate steps for which an operator must actually manipulate the plant versus when he must simply check a condition or value

4. *CBPs should alert operator to dependencies in steps more visibly.* Typically, the operator has to rely on previous experience or on a caution or warning in order to identify the situations in which he needs to read ahead in the steps. CBPs should alert the operator when he reaches a step with dependencies, rather than relying on him to read ahead (or remember from previous experience) to detect the dependency. Additionally, if a CBP system has access to real-time plant data the system should alert the operator when plant status changes in a manner that affects the operator's task at hand.

5. *CBPs should ease the burden of CCV for the operator.* CBPs should employ some method to automate CCV (e.g., include barcode scanning or text recognition functionality).

6. *CBPs should ease the identification and support assessment of the expected initial conditions.* Some method of illustrating the expected initial conditions in a simple and easy to understand manner should be available to the operator through the CBPs. For example a schematic or piping and instrument diagram of the relevant equipment could be available on-demand.

7. *CBPs should ease the identification and support assessment of the expected plant and equipment response.* Some method of illustrating the expected equipment and plant response in a simple and easy to understand manner should be available to the operator through the CBPs. For example a schematic or Piping and Instrument diagram of the relevant equipment could be available on-demand.

8. *CBPs should include functionality that improves communication.* In the event that an operator encounters a situation that he needs to contact a supervisor to resolve, he needs to be able to efficiently and accurately describe the problem. Tools such as texting, capturing photographs and streaming video have all been identified as highly desirable to have built into any device that display CBPs.

3.4.3 Opportunities

In addition to the requirements developed above, the researchers identified several areas that can potentially be improved with CBPs, but which may introduce unintended consequences. These issues need to be researched thoroughly before they are implemented into CBP systems

Improve understandability of procedure steps. As mentioned above, much of the text in a procedure step is devoted to sequences of letters and numbers used to help identify the component. With CBPs it is possible to make this information available on-demand so that it does not obscure the instructions. Additionally, this information might not be needed as often with the use of barcode scanning for CCV. It is also possible to make the make the logical flow of the procedure steps more transparent. For example: If, then steps could be presented as two steps

- Is desired condition met?
- Execute desired action.

Similarly, it is possible to explicitly present the logic of the constrained language in the procedure text. For example, "ensure Valve A is open" could be broken into two possible steps

- Is valve 'A' open?
- If the response in "no" then the procedure would prompt the operator to open the valve

Improve tailoring of procedures to match plant status. Because paper-based procedures are static and the plant is dynamic, they are designed to cover a wide variety of conditions and situations. For example, there are often built-in contingencies for equipment that is out of service; those steps would not be relevant in most cases. Digital technology and wireless networks make it possible for a procedure to be updated with current plant status (e.g., work in progress, lock out/tag outs, etc) as well as plant mode on a real-time basis. This would make it possible to only present the information (e.g. cautions and warnings) and procedure steps that apply in the current situation to an operator.

4 CONCLUSIONS

The purpose of this study was to develop an initial model of procedure usage and derive from that a list of requirements that are necessary for CBPs to improve human performance. The model presented in this paper is a first step in defining how operators interact with procedures, and where errors can occur in that process. The researchers learned that procedural deviations are typically unintentional errors that occur while an operator is attempting to follow the procedure as written. These errors are associated with difficulties in identifying the correct component, understanding the procedure logic and omission of important elements in the process of following a procedure step such as verifying that the expected response was achieved.

The results of this study were based on input from a limited sample of the nuclear industry. Detailed interviews were conducted with operators from a single plant. Insights gained from focus groups that included representatives from a total of four utilities as well as five research institutes also informed the results of this study. The type of information gathered to construct the model of procedure usage (especially with respect to procedure adherence), and ultimately develop the requirements depends largely on the organizational culture that defines the behaviors and attitudes of the field operators studied. Therefore, before the recommendations presented here are adopted by those wishing to implement CBPs, the results need to be validated to ensure that they are representative of the nuclear industry at large.

The next logical step in this research effort is to validate and extend the findings presented here. The researchers are currently gathering data from another set of utilities to verify the validity of the model of procedure usage and to fill in any gaps. Additionally, the researchers are extending the model to include an in-depth description of the cognitive factors that affect the successful execution of procedures. Both of these efforts will inform a refined list of requirements for CBPs.

While demonstrating opportunities to improve procedure use with CBPs is the main objective of this research, it became apparent during the plant visit that there are many opportunities to improve work processes not directly related to the use of procedures using technology. In a typical day, operators have to gather information from a large number of sources, many of which are maintained on paper or rely on the operator's ability to correctly remember and recall the information when needed. If much of this information could be gathered automatically it could save the operator a lot of time. In order to maximize the human performance improvements that advanced technology can provide, the device that houses the CBP should also have access to all the other forms of information that the operator uses in his day-to-day activities (e.g., work requests, shift turn-over sheets, etc.). Additionally, the CBP system and other work-related instructions housed on the device should have access to the most up-to date information about plant status, evolutions in progress, and equipments status. This information should be automatically imported into the relevant systems. This may require a great deal of infrastructure improvement for most plants, however, projects that include CBPs systems and other upgrades should consider this.

CBPs provide an opportunity to enhance the safety, efficiency, and accuracy of procedural tasks in the nuclear power industry. If CBPs are to be accepted by operators, utilities, and regulators, they must be designed to take advantage of human capabilities and to mitigate human limitations. An important first step in identifying how CBPs need to be designed to optimally support operators is characterizing what aspects of the current paper-based systems contribute to errors. The model of procedure usage developed in this research effort will help to inform that characterization. Future efforts will refine the model and use the requirements developed from that model to inform the design of a CBP prototype.

5 REFERENCES

Converse, S. (1995). Evaluation of the Computerized Procedure Manual II (COPMA II) (NUREG/CR-6398). U.S. Nuclear Regulatory Commission, Washington, DC.

Farris, R. &, Medema, H. (In Press) Integrating Human Performance Into Technology. In proceedings of 8th International Conference Onnuclear Plant Instrumentation, Control, And Human-Machine Interface Technologies (NPIC & HMIT 2012).

Fink, R., Killian, C., Hanes, L., & Naser, J. (2009). Guidelines for the design and implementation of computerized procedures. Nuclear News. VOL 52 (3), 85-88, 90.

IEEE. (2011). Human Factors Guide for Applications of Computerized Operating Procedure Systems at Nuclear Power Generating Stations and other Nuclear Facilities (P1786). P. 2, New York, NY: Institute of Electrical and Electronics Engineers.

Institute for Nuclear Power. (2009). Procedure Use & Adherence (INPO 09-004). Rev. 0

O'Hara, J., Higgins, J. C., Stubler, W. F., and Kramer, J. (2000). NUREG/CR-6634 Computer-Based Procedure Systems: Technical Basis and Human Factors Review Guidance, US Nuclear Regulatory Commission, Washington, DC.