INL/CON-14-32990
PREPRINT

The Next Step in Deployment of Computer Based Procedures For Field Workers: Insights And Results From Field Evaluations at Nuclear Power Plants

ANS NPIC&HMIT

Johanna Oxstrand, Katya Le Blanc, and Aaron Bly

February 2015

THE NEXT STEP IN DEPLOYMENT OF COMPUTER BASED PROCEDURES FOR FIELD WORKERS: INSIGHTS AND RESULTS FROM FIELD EVALUATIONS AT NUCLEAR POWER PLANTS

Johanna Oxstrand*, Katya Le Blanc, and Aaron Bly

Idaho National Laboratory

Idaho Falls, Idaho, 83415, USA

Johanna.Oxstrand@inl.gov, Katya.LeBlanc@inl.gov, and Aaron.Bly@inl.gov

ABSTRACT

The paper-based procedures currently used for nearly all activities in the commercial nuclear power industry have a long history of ensuring safe operation of the plants. However, there is potential to greatly increase efficiency and safety by improving how the human interacts with the procedures, which can be achieved through the use of computer-based procedures (CBPs). A CBP system offers a vast variety of improvements, such as context driven job aids, integrated human performance tools and dynamic step presentation.

The research team at the Idaho National Laboratory has developed a prototype CBP system for field workers, which has been evaluated through a series of laboratory studies. However, a crucial step to get the field workers' acceptance is to put the system in their hands and let them use it as a part of their everyday work activities.

A pilot field evaluation of the CBP system was conducted at a nuclear power plant early 2014. The task used in the pilot field evaluation was a functional test of backup air compressors, which is conducted weekly by auxiliary operators. A second field evaluation activity was initiated at a second utility. For this field evaluation a preventive maintenance work order for the HVAC system is used.

This paper describes the studies and their results as well as describing the path forward.

Key Words: computer-based procedures, auxiliary operators, field workers, human performance improvement.

1 INTRODUCTION

Nearly all activities that involve human interaction with the systems of a nuclear power plant are guided by procedures. The paper-based procedures (PBPs) currently used by industry have a demonstrated history of ensuring safety; however, improving procedure use could yield significant savings in increased efficiency as well as improved nuclear safety through human performance gains. 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, Idaho National Laboratory (INL) researchers, together with the nuclear industry, have been investigating the possibility and feasibility of replacing the current PBPs with computer-based procedures (CBPs).

In the context of the current research effort, a CBP is defined as a dynamic presentation of a procedure that guides the user seamlessly through the logical sequence of the procedure. In addition, a CBP system makes use of the inherent capabilities of the technology, which provide the opportunity to incorporate context driven job aids. For example, a CBP system should encompass computational aids, easy access to additional information (e.g., photos and drawings), just-in-time training, and digital correct component verification. The technological advancements in the CBP system allow human performance improvement features to be even more integrated into both the procedure and the overall work process compared to the electronic procedures. For example, a CBP system offers a more dynamic means of presenting procedures to the user, displaying only the relevant steps based on operating mode, plant status, and task at hand. A dynamic presentation of the procedure guides the user down the path of relevant steps based on the current conditions. This feature will reduce the user's workload and inherently reduce the risk of incorrectly marking a step as not applicable and the risk of incorrectly performing a step that should be marked as not applicable. Furthermore, human performance tools are embedded in the CBP system to enable the worker to focus on the task rather than the human performance tools. Some tools can be completely incorporated into the CBP system, such as pre-job briefs, place-keeping, correct component verification, and peer checks. Other tools can be partly integrated in a fashion that reduces the time and labor required, such as concurrent and independent verification. Note that a CBP and CBP system refers to slightly different things. The procedure system (CBP system) can contain many procedures (CBPs). In other words, the system is the technology or tool used to conduct tasks guided by procedures.

1.1 Previous Activities

Researchers conducted a qualitative study at an operating nuclear power plant to investigate the current use of procedures in the nuclear power industry. The researchers shadowed auxiliary operators (AOs) as they conducted rounds, and conducted semi-structured interviews with AOs and trainers, see [1] and [3] for more information. The study helped identify error-likely situations in procedure execution as well as potential improvements to the process through the use of technology. The qualitative study resulted in the development of a model of procedure usage and the identification of an initial set of design requirements for a CBP system. The design requirements focused on identifying ways to improve human performance through the use of dynamic context sensitive presentation of the procedure and to eliminate irrelevant or redundant information while providing context sensitive guidance and jobs aids to the operator.

Three laboratory studies were conducted at the training facilities of collaborating utilities (flow loop, electrical laboratory, and instrument and control laboratory) to evaluate the CBP design from a human factors standpoint [3, 4, and 5]. Nuclear power plant field workers participated in realistic work scenarios using both a paper-based procedure and CBP. The evaluation studies compared deviations from the specified path, performance time, mental workload, and the general usability of device and interface. The main objective was to evaluate the CBP design and identify ways to maximize human performance of procedural tasks using the CBP. The researchers collected feedback on the design of the user interface and the usability of the CBP. Suggestions from the participants as well as insights gained from carefully observing how the participants carry out the procedures using the CBP were incorporated in the future revisions of the prototype. Another objective of the studies was to evaluate the effect a CBP may have on performance and efficiency of the procedural task. The three laboratory research activities demonstrated several benefits:

- Automatic place-keeping and the ease of moving between and within procedures when having to transfer to other procedures or conducting continuous action steps increased both efficiency and human performance.
- Context-sensitivity and simplified step logic are highly desirable features. Context-sensitive cues (e.g., labels on buttons provide cues to what action needs to be taken) in the procedure increase the field worker focus on the task at hand.
- Digital Correct Component Verification (CCV) reduces the risk of manipulating an incorrect component. The use of barcodes to verify a correct component is generally viewed as an effective implementation of the human performance tool.

- Photos of components included in procedure steps increased efficiency and reduced the risk of human error when locating specific components and equipment, as well as when conducting component verification.
- Computational aids, such as performing calculations based on user inputs (e.g., recorded tank levels, temperature, engine speed), were proven to reduce human errors.

The laboratory studies provided insight on how to design dynamic presentation of a procedure and how to incorporate human performance tools into the workflow. However, a key success factor in field workers' acceptance of such systems is to put the system in their hands and let them use it as a part of their everyday work activities. This is achieved by field evaluations, as described in Section 2.

1.2 Functionality of the CBP System

It is important to distinguish between an electronic procedure and a CBP. In its simplest form, an electronic procedure is an electronic copy of the paper procedure (i.e., a PDF or similar document that displays the procedure content in a manner that is very similar to the paper-version of the procedure). The more advanced electronic procedures use hyperlinks to provide additional information (e.g., photos and appendices), some user inputs (e.g., recorded values), links between procedures, and mark-up capability (e.g., writing notes and conduct traditional place-keeping in the PDF). Electronic procedures are currently offered by a variety of vendors. The system developed for this research is a CBP system, not a system for electronic procedures.

Early on the researchers identified all physical and cognitive actions the field worker has to conduct to execute one single procedure step. These actions became the basis for a model of procedure usage [2]. The model revealed that the current usage of procedures adds a large amount of workload to the field worker. It is easy to assume an automatic reduction of workload and efficiency increase when switching to a computerized system. However, this is not always true. Automation decision support and automated aids may lead to reduced workload and increased efficiency, but could also result in reduced field worker engagement. Reduced engagement can lead to a reduction of human performance. The researchers attempt to find the ideal balance between automated decision support and aids while keeping the field workers engaged in the process. To achieve this, the researchers developed the high-level design concepts described below:

Automatic place-keeping. The CBP system highlights the active step (i.e., the step being conducted). Other steps are shown, but the user can only take actions related to the active step. The CBP system decides what step is next in line to be executed and what step(s) to mark as Not Applicable based on action taken in previous steps, user inputs, and plant status. The automatic place-keeping makes it easy for the field worker to stay on the specified path. This built-in procedural adherence has proven to reduce the amount and severity of human errors.

Simplified step logic. A conditional step in a procedure is a step that is based on plant conditions or a combination of conditions to be satisfied prior to the performance of an action. The CBP removes complexity from step descriptions by presenting conditional statements as simple questions, paired with condition-specific instructions. For example, statements such as "IF starting pump A, THEN perform the following..." are presented as "What pump do you want to start; Pump A or Pump B?" Depending on the answer, the procedure will take the field worker to either the step with the action needed to initiate the start Pump A, or the step with the action needed to start Pump B.

Component verification. Before taking an action on a component or piece of equipment, the field worker is required to verify that he/she is at the right component. This is called correct component verification (CCV). Currently, this is carried out by looking at the procedure and reading the component identification out loud. Then, the field worker will touch the component's label and read the component identification out loud. If there is a match, the correct component has been verified. However, incidents where the field worker manipulates the incorrect component still occur. There are multiple ways correct component verification can be implemented and improved by using technology. Researchers have explored correct component verification via barcodes, optical character recognition, and manual input. When using barcodes or optical character recognition, the system will match the input with a component database. If the correct component is verified, the field worker will be able to continue on with the step. If the correct component is not verified, the field worker will have to find the correct component before being able to proceed through the procedure. There is always the option to conduct component verification manually.

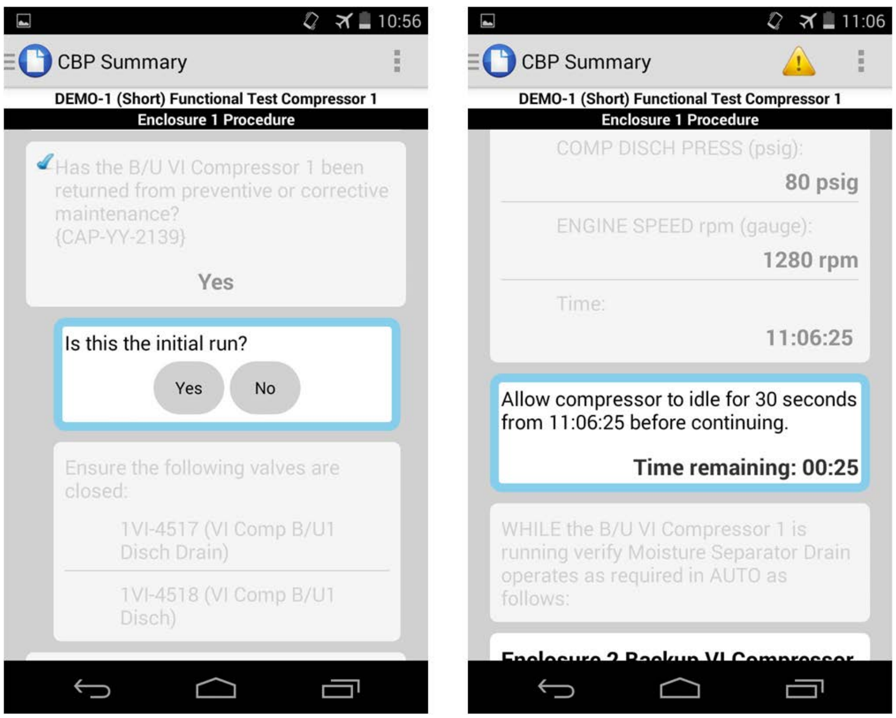

Figure 1. Screenshots from the CBP prototype showing examples of automatic place-keeping (checkmark for conducted step and blue boarder for active step), simplified step logic (Yes/No questions), and timestamps.

The CBP system is loaded on to handheld devices to be used by the field workers. Different types and sizes of devices have been used throughout the research effort, such as iPod Touch, Nexus 4, and Nexus 7. The researchers are not promoting any specific software platform or form factor. Based on interviews of field workers in the qualitative study, the researchers learned that some groups of field workers (e.g., AOs) move throughout the plant including climbing ladders/stairs and crawling in tight spaces while conducting their tasks. These workers preferred to have a handheld device which can easily be stored in a pocket when the worker needs to have his/her hands free. Other groups, such as maintenance technicians, might prefer a larger device when conducting tasks that are more stationary, e.g., repair of a valve or pump.

2 FIELD EVALUATIONS

The laboratory studies provided insights on how to design dynamic presentation of procedures and how to incorporate human performance tools into the work flow. The previous research activities conducted by the INL researchers demonstrate that the use of CBPs can improve human performance in the field. However, a key success factor in the field workers' acceptance of a CBP system is to put it in their hands and let them use it as a part of their everyday work activities. This is achieved by field evaluations.

2.1 Pilot Field Evaluation

The main objectives of the pilot field evaluation were to evaluate the feasibility of using a CBP system in the actual plant during everyday operations, evaluate the usability of the revised CBP system, and to gather insights about how to best conduct a field evaluation study (i.e., lessons learned about what went well in the method used and what needs to be tweaked or approached slightly different in the future). The pilot field evaluation was conducted at Duke Energy Catawba Nuclear Generating Station (CNS) in the spring of 2014. This was the first time a CBP system has been tested in an actual plant, during normal operation, and over the duration of a couple of months.

The procedure used in the pilot evaluation study was low-risk, high frequency task with enough complexity to test and evaluate the majority of the CBP system's functionality. The procedure selected was a functional test of backup air compressors. The functional test is conducted on one of the three backup air compressors once per week. The procedure selected for the pilot field evaluation was more complex than any of the procedures used in the previous laboratory studies. Therefore, new functionality needed to be built into the CBP prototype before the evaluation study could be conducted. The new functionality included handling of continuous action steps, handling of contingencies, ability to check revision of procedure before starting the activity, creation of a printable copy of the procedure as executed for archiving purposes, ability to review decisions and data input in previous steps, improved ability to edit previous steps, and an improved data structure to handle the new functionality.

2.1.1 Pre-validation activity

The researchers conducted a pre-validation activity at Catawba Nuclear Station the week prior to launching the field evaluation study. The purpose of the pre-validation was to conduct walkdowns of the task using the CBP system and to gather feedback from plant staff.

Feedback was collected from twenty-six staff members via informal interviews where the individual provided feedback as he/she "played" with the CBP system. When needed, the researchers asked additional questions for clarification purposes. The staff members that provided feedback were from all levels in the organizations including the site vice president, plant manager, operations shift supervisors, procedure writers, and AOs.

Five walkdowns were conducted where the computer-based version of the procedure were validated out in the field with the purpose to validate the procedure flow and to identify areas for improvement. During the walkdowns the participants made a direct comparison between the CBP and the paper-based procedure to make sure that the logical flow in the CBP did not deviate from the controlling (paper-based) procedure. One operations instructor, one procedure writer, and three AOs simulated the task at the job site. In other words, the participants pretended to start/stop pumps and open/close valves, while using the CBP system. The researchers observed each walkdown and each participant was debriefed afterwards.

During the walkdowns the participants identified several areas for improvement, such as the need for stronger visual feedback when a digital CCV is conducted on an incorrect component and the fact that using the CBP system outside in bright sunlight made it hard differentiate between the active step and future steps in the procedure.

All but one identified area for improvement were resolved during the duration of the pre-validation activity. The AOs reviewed and approved the revisions made to the CBP system. The one remaining area for improvement is to resolve the issue of back-up in the event the handheld device either malfunctions or gets damaged.

Figure 2. Catawba plant staff conducts walkdowns using the CBP system.

2.1.2 Field evaluation method

During the duration of the pilot study two AOs conducted the functional test of the backup compressor, one AO used the CBP and the other used the paper-based procedure. The pilot field evaluation was planned to last for nine weeks, and eighteen AOs were expected to participate in the study.

The researchers developed a web-based survey which the participants were asked to fill out after completing the task using the CBP system. The survey was developed to assess the usability of the CBP system and to gain more detailed feedback on the design of the user interface and the overall experience using the CBP. The researchers were mindful to not add much additional burden to the participants and therefore intentionally made the survey brief. The questions were reviewed by plant personnel to ensure participants would feel comfortable answering the questions candidly.

- Did the CBP lead you down a path where you conducted an error (e.g., mistake, near-miss, deviation, etc.)?
- Did the CBP stop you from committing an error (e.g., mistake, near-miss, deviation, etc.)?
- Did the CBP cause any confusion or behave in a way that was unexpected while you executed the procedure?
- After executing the procedure with the CBP, do you prefer using paper or the CBP?

During the pre-validation activity the research team provided training on the CBP system to the AOs they interacted with. These AOs were instructed to train their peers on the CBP system.

At the day of the functional test the participants assigned to the task started out with a pre-job brief with their supervisor that included a review of the procedure, a discussion of the conditions that would be encountered at the job site, as well as a discussion of the potential safety issues associated with the task. After the pre-job brief the participants filled out an informed consent form. The form was provided as a link on their work desktop. The link took them to a web-based version of the informed consent form. The research team provided a job aid, which included a short description of the expected work process (from the consent form to printing a copy of the executed procedure) as well as a brief overview of the functionality of the CBP system. The job aid was printed on a piece of paper that was laminated and located by their work computer. The participants reviewed the job aid before walking to the job site. At the job site the CBP system was used in conjunction with the PBP during the execution of the task. One of the AOs conducted the task with the PBP while the second AO followed along and simulated conducting the task while using the CBP system. The senior management at the plant decided to approve the use of the CBP system only if it was used in conjunction with the current PBP. This was due to the fact that the handheld device and the CBP system are not part of the plant's licensing basis. When the task was complete the AOs returned to the office and printed out a paper-copy from the CBP system. This paper-copy showed who conducted the procedure, what steps were conducted, what steps were marked as not applicable, time and date stamps, etc. In other words, the printed version contained all the information the PBP did after the completion of the task. Before continuing with other tasks both AOs filled out the web-based questionnaire.

2.1.3 Results

A total of three AOs participated in the pilot field evaluation and were able to experience using the CBP system while following along with the task. According to the responses to the survey all of the AOs who used the CBP said they preferred it to the PBP. The AOs rated the CBP as highly usable at an average of 9.67 on a 10 point scale. They also indicated that there was no situation in which the CBP caused errors or error-likely situations.

The pilot field evaluation also revealed at least one instance in which the CBP may have increased efficiency compared to the PBP. During the execution of the task, the AOs encountered a situation where an expected automatic plant response was not received and therefore the AOs had to manually operate the equipment. This requires a fair amount of flipping back and forth in the PBP. The AO using CBP system commented that the CBP system handled the situation perfectly. All the steps needed were presented in order and at the right time based on the AO's input to the system. Because the conditional logic was presented in a simplified manner, there was no need to go back and forth in the procedure to find correct enclosures and steps.

Figure 3. PVNGS plant staff evaluates the usability and interface design of the CBP system.

One concern brought up during the pre-validation activity was the potential for the CBP system to have a negative effect on the time it takes to perform the task. Specifically, the AOs expressed a concern that the digital CCV (scanning barcodes) would slow down the execution. Based on the observations and debrief conducted with the AOs, it was concluded that the CBP system was not slowing them down. The AOs were very pleased with how much faster the CBP system was when transferring back and forth between sections in the procedure compared to doing the same with the paper procedure. Based on all the feedback gathered it can be concluded that the most appreciated features of the CBP system were the digital correct component verification, automation of calculations, and the automatic place-keeping. The inclusion of relevant photos and documents was also highly appreciated.

The main lessons learned from the pilot evaluation study were the importance of early familiarization of the task to involve the actual users (in this case the AOs) as early as possible. It was also noted that, if possible, identify a task where the CBP can be used as the primary procedure rather than shadowing the traditional paper procedure. The user experience, and hence the type of feedback provided by the participants, is believed to differ whether or not the task is executed by using the CBP system as the primary procedure. In addition, it is also important to plan for sufficient familiarization time so the use of the CBP system will not seem as a burden in the case of a planned outage.

2.2 Second Field Evaluation

The overarching goal for the CBP research effort is to define requirements for computer-based work instructions. In order to reach this goal the research has to encompass different types of instructions used throughout the nuclear power plant. The focus of previous activities was on mobile applications for AOs' procedures. In the second field evaluation study the scope was expanded to work orders, which are conducted by field workers such as maintenance technicians rather than AOs. The second field evaluation study was hosted by Arizona Public Service and conducted at the Palo Verde Nuclear Generating Station (PVNGS) [5 and 6].

Staff at PVNGS selected a heating, venting, and air conditioning (HVAC) preventative maintenance work order to use for this field evaluation. The work order provides instructions for taking weekly readings from the plant's four HVAC chillers (and related equipment) and for handling out-of-range readings. The task is executed weekly for each of the three units at PVGNS.

The original work order instructions contain redundant information, require multiple recordings of values and calculations, and there is no electronic record of the recorded values or the conducted procedures. The procedure prompts the technician to record the last logged value of a component, and he/she has to go through a binder with the previously conducted procedures to find the value. In addition, the recorded values are currently reported to the engineer on paper. The engineer has to transfer the values to electronic format in order to log trends. This process includes multiple opportunities for human error and is inefficient and time-consuming. Converting this work order and procedure to the CBP system will demonstrate the benefits of an electronic work order/procedure system while the plant staff is actually using it in their own plant. The revised version of the CBP system will be referred to as the Computer-Based Work Order (CBWO) system from here on.

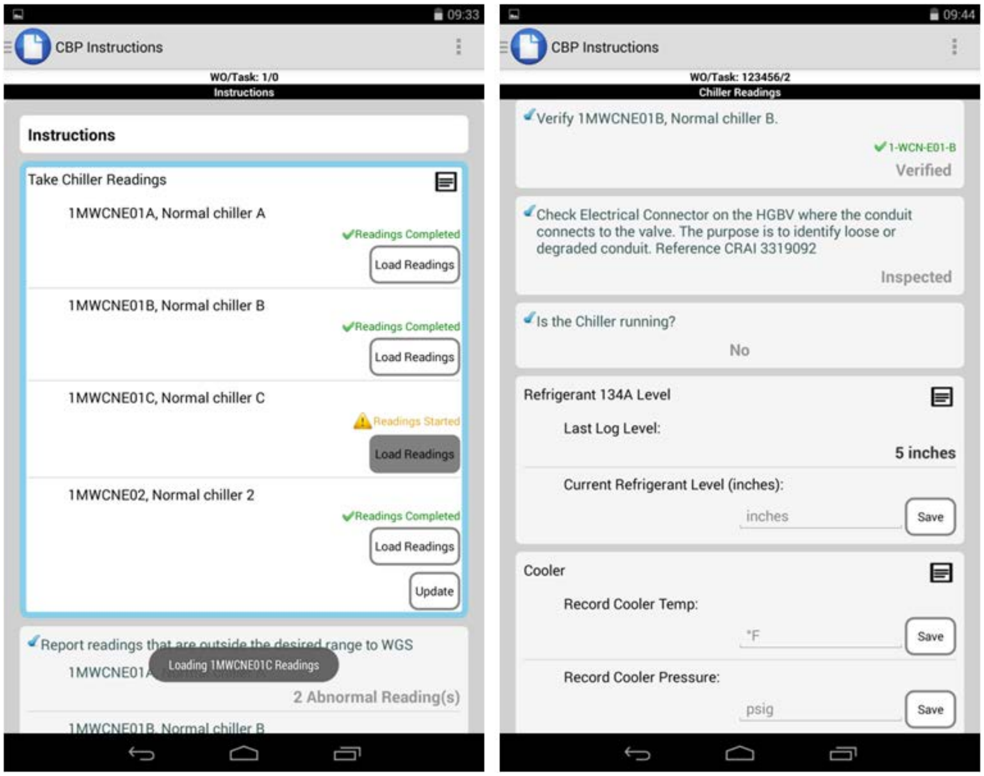

Figure 4. Screenshots from the CBWO used at PVNGS. Left image shows progress status indications and the right image illustrates the presentations of instructions to take readings.

The added functionality to the prototype included the ability to store readings data for trending, import previous readings into current work order, export data to be used for trending, take notes while executing the work order, match readings data to acceptable ranges, alert users to out-of-range conditions, and provide a list of actions for out-of-range readings, enable sections of steps to be performed in any sequence as the task allows, execute the work order across multiple days and with multiple users, activate conditional steps based on multiple conditions, and the ability to handle new functionality by utilizing an improved data structure.

2.2.1 Pre-validation activity

Similar to the pilot study, the researchers conducted a pre-validation activity the week prior to launching the field evaluation study. The goals of the activity were to validate the computer-based version of the work order, gather feedback from plant staff, make revisions to the computer-based work order system if needed, and provide training to the HVAC technicians.

During that week the research team had the opportunity to meet and brief multiple employees from the plant including two senior HVAC technicians, the HVAC planner, and a procedure writer.

2.2.2 Field evaluation method

The participants in the second evaluation study include the HVAC technicians tasked to take the chiller readings each week throughout the duration of the study. During the pre-validation activity the research team provided training on the CBWO system to the HVAC maintenance technicians they interacted with. These technicians were instructed to train their peers on the CBWO system.

The duration of the study is planned to be 26 weeks long. It is expected that the study will result in data for 78 uses of the CBWO system; however, it is likely that several participants will conduct the task multiple times.

A survey similar to the one used in the pilot evaluation study was developed and the participants were asked to fill it out after completing the task with the CBWO system. The goal of the survey was to assess the usability of the CBWO system and device. The survey was also developed to gain more detailed feedback on the design of the user interface and the overall experience using the CBWO.

2.2.3 Initial results

At the time when this paper was composed the study was still in progress, so there were no official results. However, the following user interface issues were identified and addressed during the pre-validation activity:

- The technicians at PVNGS desired more contrast on the no-active steps (both conducted and future steps) to increase their readability.
- The technicians noted that the sub-steps in the instruction list should provide information about what sub-steps are not started, in progress, and completed. The sub-step should say "reading started" and preferably have a warning triangle to indicate the readings are in progress.
- Although many of the desired actions are triggered by out-of-range readings, the task requires that technicians be able to override those actions by either not executing them or by taking different actions as required. Therefore, the technicians noted that the action to be taken should be recorded in a pop-up display that summarizes the out-of-range (i.e., abnormal) readings.

The main lessons learned from the second evaluation study to date are the importance of selecting a procedure and task that can be easily observed, the complexity of balancing how much of the required skill of the craft should be proceduralized, and the added complexity of tasks that require more autonomy than strictly sequential tasks.

2.3 Future Evaluations

To provide the highest value to the nuclear power industry, a CBP system needs to encompass more than just procedures. The system needs to integrate everything from identifying the need for a task, planning, execution, and reporting. Examples of items that are needed are all types of instructions, checklists, pre-job briefs, forms, and means to report unexpected conditions. In other words, the system needs to cover all aspects of the process associated with work orders.

The field evaluations conducted to date demonstrated that the CBP system can be used in a real-world context with real-world procedures. The field evaluations have also demonstrated that the CBP concepts developed for field operations procedures can be translated to work orders.

The vision is for all the different organizations within the plant to use the same system. To achieve that goal, the researchers need to ensure that the system will be able to handle a broad variety of tasks and situations; therefore, collaborating with multiple utilities and multiple organizations within the utility (e.g., Operations, Maintenance, and Chemistry) is essential. A series of field evaluations will be conducted to ensure that the results from this research are applicable at other plant sites.

Two additional utilities have expressed their interest to host field evaluation studies. Two studies, one at each utility, are planned to be conducted in 2015. For each field evaluation planned and conducted, the CBP system will be revised to include additional functionality needed to bring it closer to handle all aspects of a work package, i.e., the full process from initiating work request, planning, execution, and archiving.

3 CONCLUSION

The researchers proved through a series of laboratory systems that CBPs and a CBP system can provide efficiency gains as well as improve human performance in the field. However, to gain the acceptance needed by the end-users the CBP system has to be tested in the actual work environment during normal operations. The research team concluded that conducting a research activity where plant staff uses a prototype CBP system as a part of their daily work activities over an extensive amount of time, has never been conducted. Hence, the pilot field evaluation study conducted at Catawba Nuclear Station was a first-of-a-kind study.

The pilot field evaluation study concluded that the streamlined presentation and context sensitivity in the CBP system can increase efficiency and reduce workload. The participants were pleased with how much faster the CBP system was when transferring back and forth between sections in the procedure compared to doing the same with the paper procedure. The results from the pilot field evaluation indicates that the most appreciated features of the CBP system were the digital CCV, automation of calculations, and the automatic place-keeping.

In order to reach the main goal of defining requirements for computer-based work instructions the CBP prototype system has to encompass different types of instructions used throughout the nuclear power plant, not only procedures used by AOs. In the second field evaluation study the scope was expanded to work orders used by maintenance technicians. The transition from a CBP system to a system that can handle CBWOs required new functionality to be added to the system, such as non-sequential steps and the opportunity of multiple maintenance technicians conducting the task over multiple days.

Moving forward, the researchers will continue to conduct field evaluations where they collaborate with multiple organizations within the utilities to ensure that a variety of tasks and situations will be explored. Within the next year two field evaluations will be conducted at two additional nuclear power utilities. Future studies may include procedures that involve control room operators and chemistry technicians, as well as AOs and maintenance technicians. The intent of the upcoming field evaluations is to select tasks which require new functionality to be incorporated into the existing CBP system and to incorporate additional parts of the overall work order process into the system. The researchers will also focus on the need for an authoring tool and continue to develop the underlying data structure, which as described earlier is an essential part of the puzzle when transitioning from PBPs to CBPs.

4 ACKNOWLEDGMENTS

This paper was prepared as an account of work sponsored by an agency of the U.S. Government under Contract DE-AC07-051D14517. The views and opinions of the author expressed herein do not necessarily state or reflect those of the U.S. government or any agency thereof.

5 REFERENCES

1. Le Blanc, K.L., Oxstrand, J.H., and Waicosky, T. (2012). “Model of procedure usage – results from a qualitative study to inform design of computer-based procedures”, *Proceedings of the Seventh American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies NPIC&HMIT 2012*, San Diego, California.

2. Oxstrand, J.H. and Le Blanc, K.L. (2012). *Computer-Based Procedures for Field Workers in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements*, Idaho National Laboratory External Report, INL/EXT-12-25671, Rev. 0, Idaho Falls, Idaho.

3. Oxstrand, J.H., Le Blanc, K.L., and Hays, S. (2012). *Evaluation of Computer-Based Procedure System Prototype*, Idaho National Laboratory External Report, INL/EXT-12-27155, Rev. 0, Idaho Falls, Idaho.

4. Oxstrand, J.H., Le Blanc, K.L., and Bly, A. (2013). *Computer-Based Procedures for Field Workers: Results From Three Evaluation Studies*, Idaho National Laboratory External Report, INL/EXT-13-30183, Rev 0, Idaho Falls, Idaho.

5. Oxstrand, J.H., Le Blanc, K.L., and Bly, A. (2014). *Computer-Based Procedures for Field Activities: Results from Three Evaluations at Nuclear Power Plants*, Idaho National Laboratory External Report, INL/EXT-14-33212, Rev. 0, Idaho Falls, Idaho.

6. Agarwal, V., Oxstrand, J.H., and Le Blanc, K.L., (2014). *Automated Work Packages: An Initial Set of Human Factors and Instrumentation and Control Requirements,* Idaho National Laboratory External Report, INL/EXT-14-33172, Rev. 0, Idaho Falls, Idaho.