SUPPORTING THE INDUSTRY BY DEVELOPING A DESIGN GUIDANCE FOR COMPUTER-BASED PROCEDURES FOR FIELD WORKERS

Johanna Oxstrand and Katya Le Blanc
Idaho National Laboratory
2525 Fremont Ave, Idaho Falls, ID 83415
Johanna.Oxstrand@inl.gov; Katya.LeBlanc@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.

As a step toward the goal of improving procedure use performance, the U.S. Department of Energy Light Water Reactor Sustainability Program researchers, together with the nuclear industry, have been investigating the feasibility of replacing current paper-based procedures with CBPs.

The main purpose of the CBP research for nuclear field workers conducted at the Idaho National Laboratory was to provide design guidance to the nuclear industry to be used by both utilities and vendors. After studying existing design guidance for CBP systems, the researchers concluded that the majority of the existing guidance is intended for control room CBP systems, and does not necessarily address the challenges of designing CBP systems for instructions carried out in the field. Further, the guidance is often presented on a high level, which leaves the designer to interpret what is meant by the guidance and how to specifically implement it. The authors developed a design guidance to provide guidance specifically tailored to instructions that are carried out in the field based.

Key Words: computer-based procedures, field workers, design guidance

1 INTRODUCTION

All tasks conducted in a nuclear power plant are guided by procedures, which helps ensure safe and reliable operation of the plants. One prominent goal of the nuclear industry is to minimize the risk of human errors. To achieve this goal one has to ensure tasks are correctly and consistently executed. This is partly achieved by training and by a structured approach to task execution, which is provided by procedures and work instructions. There are many different type of users and types of procedures within the nuclear utility, for example operating procedures, administrative procedures, field operating procedures, and maintenance procedures.

The design guidance and requirements described in this paper focuses workers in the field, e.g., field operators and maintenance technicians. Procedures are used in the nuclear industry to direct these field workers' actions in a proper sequence. The governing idea is to minimize the reliance on memory and choices made in the field. However, the procedure document may not contain sufficient information to successfully complete the task. Therefore, the field worker might have to carry additional documents such as turnover sheets, operation experience, drawings, and other procedures to the work site.

Depending on task, the amount of documents the field worker needs to bring to the work site can be very large. Even though the paper process has helped keep the industry safe for decades, there are limitations to using paper. Paper procedures are static (i.e., the content does not change after the document is printed), difficult to search, and rely heavily on the field worker's situational awareness and ability to consistently meet the high expectation of human performance excellence.

In order for a paper procedure to be applicable to the constantly changing environment in the plant, the procedure has to be written to encompass multiple different scenarios. This makes the paper procedure bulky and hard to navigate, which forces the field worker to search through a large amount of irrelevant information to locate information applicable to the task at hand. This can take up valuable time the field worker could have spent on task execution, and it can potentially lead to unintentional deviations and errors. Other challenges related to use of paper procedures are management of multiple procedures, place keeping, finding the correct procedure for a task, and relying on other sources of additional information to ensure a functional and accurate understanding of the current plant status.

To address the limitations of paper procedures, improve efficiency, and enhance performance, Idaho National Laboratory (INL) researchers have developed a computer-based procedure (CBP) concept. The CBP system provides a streamlined work process and dynamic support to guide the field worker through the task execution, which will help them focus on the task at hand rather than on the process. The CBP guides the field worker seamlessly through the logical sequence of the procedure. In addition, the CBP system makes use of the inherent capabilities of the technology, such as incorporating computational aids, easy access to additional information, just in time training, and digital correct component verification. A CBP system offers a more dynamic means of presenting procedures to the field worker, displaying only the relevant steps based on operating mode, plant status, and task at hand. A dynamic presentation of the procedure guides the field worker down the path of relevant steps based on current conditions. This feature will reduce the field worker'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. Some of the key functionality of the CBP system are;

Automatic place-keeping. The CBP system highlights the active step (i.e., the step being conducted). Other steps are shown, but the field worker can only take actions related to the active step. This function 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. 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 a step with the actions needed to start Pump A or the step with the actions needed to start Pump B.

Component verification. There are multiple ways correct component verification can be implemented and improved by using technology. Researchers at INL have explored correct component verification (CCV) 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.

In order for a CBP system to be a viable option to the nuclear industry it has streamline work process not only for procedure execution, but in work planning, scheduling, and procedure development. The CBP solution must seamlessly encompass the process from start to finish. The dynamic capabilities and the computational capabilities in the CBP system will enhance performance and efficiency during the execution of the procedure. A successful CBP system will include a procedure conversion framework to provide capability to convert the tens of thousands of existing procedures into a structured data format, a procedure designer to be used when writing new procedures, and a commercial grade, well-designed, graphical interface for the field workers. In addition, for the CBP system to reach its full potential it needs to be integrated with other applications (e.g., electronic work package system) and plant systems (e.g., work management system). The CBP system needs to be able to effectively communicate with other applications to check available equipment, current plant status, access additional information, and to easily update plant systems with information gained throughout the procedure execution (e.g., plant configurations or the submittal of a condition report).

An effective field worker interface will address the limitations and challenges of paper procedures, incorporate strengths of the existing process, and add additional functionality that is available when using digital devices. In addition the CBP should be easy to use, allow for flexibility of use, and prevent human error. Between 2012 and 2016 the INL researchers conducted CBP research as a part of the U.S. Department of Energy Light Water Reactor Sustainability Program. Together with the nuclear industry the researchers investigated the possibility and feasibility of replacing current paper procedures with CBPs.

The researchers explored ways to use advanced technology to design a CBP prototype to include dynamic presentation of the procedure content, context driven job aids, and integrated human performance tools. All of these innovations help the field workers focus on the task at hand rather than the tools. The CBP prototype was developed from a user perspective and proved to increase efficiency and improve human performance [1-5]. The researchers sought input from across the nuclear industry and researchers actively collaborated with and/or received valuable feedback from Ameren, Arizona Public Service, Dominion, Duke Energy, Energy Northwest, Exelon Nuclear, First Energy, NextEra, Pacific Gas & Electric, SCANA, South Texas Project, Southern Nuclear, Talen Energy, Tennessee Valley Authority, and Xcel Energy. All of which were members of the Nuclear Electronic Work Package – Enterprise Requirements initiate, which was facilitated by the INL researchers [6]. This widespread collaboration helped to ensure the CBP concept was not only effective at enhancing efficiency and reducing error, but also applicable to the industry at large.

In summary, the research activities demonstrated several benefits, including increased efficiency and improved human performance by using automatic place-keeping and the ease of moving between and within procedures. Dynamic presentation of the procedure and simplified step logic were identified as highly desirable features. Context-sensitive cues in the procedure proved to increase the worker's focus on the task at hand. Digital component verification proved to reduce the risk of manipulating an incorrect component. Photos of components included in procedure steps increased efficiency and reduced the risk of human error. Computational aids, such as performing calculations based on worker inputs, were proven to reduce the risk of human errors.

2 SUMMARY OF DESIGN REQUIREMENTS GUIDANCE

The design guidance presented here is based on the design concepts evaluated throughout the research activities described above. The design guidance and its examples are drawn from experience with instructions from several different utilities and several different organizations within each utility. Therefore, the design guidance covers a wide range of instruction types and situations, which should provide CBP designers with a strong foundation for implementing the design requirements regardless of the specific context.

The design guidance is presented as eight high-level design principles that are essential for an effective CBP system. Following each high-level design principle are a several specific examples of situations in which the high-level principles were implemented. Detailed examples of how to implement the design guidance are presented in the report by Oxstrand, Le Blanc, and Bly [7].

2.1 Provide Context Sensitive Information Everywhere Possible

Compared to static paper-based procedures the procedure content can update based on the current situation in a dynamic context sensitive CBP. In other words, procedure will update based on current operation mode, plant conditions, and decisions made and values recorded previously in the task execution, which allows the worker to focus on the task at hand rather than spending effort on understanding which steps and conditions apply for the current task and plant state.

A CBP system designed this way will guide the worker through the applicable procedure path while automatically marking steps not applicable to the current context. This reduces the risk of unintentionally omitting steps or unintentionally conducting steps out of order.

One example of how to implement context sensitive cues is to use them embedded in the procedure steps. Research shows that non-invasive context sensitive cues in steps serve an effective, yet subtle reminder of the task at hand and actions required of the worker [1]. Another example of context sensitive cues is alerting the worker if the as found state is not within the accepted criteria. The systems should also provide information about the as left condition when the step is completed. Figure 1 shows how the left as equipment state is recorded and presented in the previously conducted step text. This allows the worker to go back and review previous actions to ensure they were conducted properly.

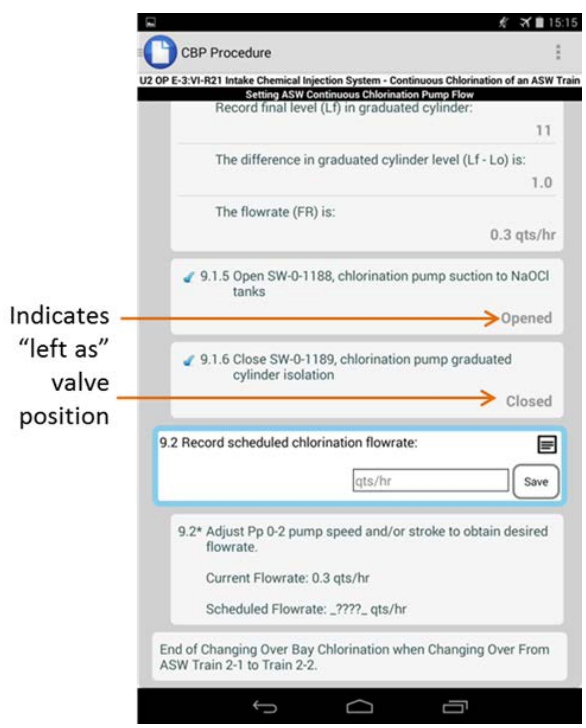

Figure 1. Example of context sensitive as left information

The CBP system should be context-sensitive anywhere that the necessary information is available. As discussed in detail in the Design Guidance for Computer-Based Procedures for Field Workers [7], context sensitive cues should be considered to communicate the items discusses above as well as equipment states, step instructions, decision points and branching, and for notes, cautions, and warnings.

2.2 Support All Expected Task Flow Characteristics

Task flow characteristics are the aspects of procedure usage that the procedure system must be able to address, regardless of whether it is a paper-based or a computer-based system. For example, the system must be support conditional steps and branching based on condition. The system should also provide additional support to the worker both in the form of supplemental information and as notes, cautions, and warnings. Table I below lists and describes task flow characteristics to be considered when designing a procedure system.

Table I. Task flow characteristics

Task Flow Characteristics	Description
Action step	An instruction written in active voice that directs the performer to perform an action and contains an action verb and an object.
Action verb	A verb that directs the action within a step to be taken by the performer.
Conditional step	An action step based on plant condition or combination of conditions to be satisfied prior to the performance of an action.
Multiple Action Steps	Contain actions that are functionally related and have to be performed simultaneously to obtain a single result.
Time dependent steps	A step to be completed within a specified time frame.
Bulleted steps	Bulleted steps within a single step may be performed in any order and shall be completed prior to proceeding to next step.
Continuously applicable steps	A step that is applicable over a period of time and requires periodic monitoring until a specific condition is met.
Concurrent verification	A series of actions by two individuals working together at the same time and place to separately confirm the condition of a component before, during, and after an action, when the consequences of an incorrect action would lead to immediate and possibly irreversible harm to the plant or personnel.
Independent verification	A series of actions by two individuals working independently to confirm the condition of a component after the original act that placed it in that condition.
Peer checks	Peer-checking allows another individual to observe or check the work of a performer to ensure correct performance of a specific set of actions.
Placekeeping	The process used to help users track performance of steps within a procedure by physically marking steps in a procedure that have been completed or are not applicable.
Notes	Statements that provide explanatory information to support a procedure step or series of steps.
Cautions	A statement placed immediately before applicable step(s) that informs users of undesirable equipment results such as potential for equipment damage, plant transients, or conditions that may adversely affect plant operation.
Warnings	A statement placed immediately before applicable step(s) to warn users of potential for personnel injury, loss of life, or health hazards.

Supplemental information	Procedure content that supports a procedure step or series of steps and provides explanatory information.
Attachments	Information separated from the main body of the procedure used in the performance or understanding of a procedure such as graphs, figures, tables, sketches, and forms. Appendices and enclosures are equivalent terms.
Branching steps	A step that directs the user to other steps or sections in the same or another procedure and the user does not return to the original step.
Hold points	A pre-selected step in a procedure that identifies a point beyond which work may not proceed until the required action is performed.
Hierarchical Step Structure	Step numbering schemes should differentiate between steps and substeps of the procedure by providing identifiable differences from one level or step level to the next.
Procedure specific information	For example: • Procedure title, procedure number, revision number, level of use • Purpose and scope, precautions and limitations, definitions, and precautions and initial conditions

Figure 2 below illustrates how the active step is clearly marked with a blue border and the background in the step is white. All completed steps and future steps are greyed out. The worker can view all completed and future steps by scrolling through the list of steps. However, action can only be taken on the active step.

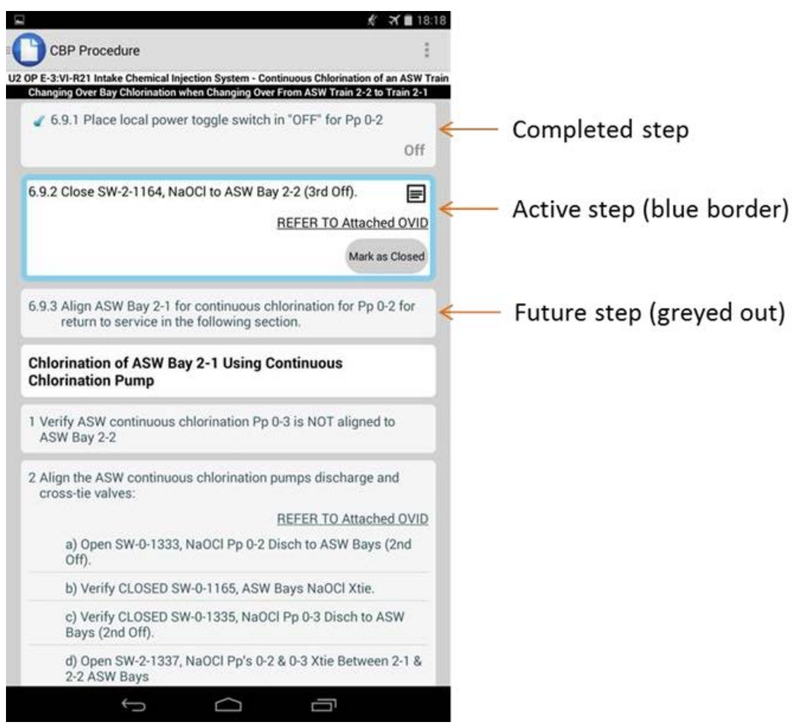

Figure 2. Example of completed step, active step, and future steps.

2.3 Support Expected Level of Flexibility in Performing Task

It is important to keep the worker focused on the task at hand rather than on cumbersome administrative processes in order to ensure successful task execution. To support the overall understanding of the task the CBP should present the active step as well as provide easy access to already executed steps and the outcome of these as well as easy access of future steps.

The research concluded that presenting one single step (i.e., the currently active step) at the time increases the risk of losing the overall understanding of the task execution [1]. Instead, it is recommended that the procedure steps are presented as a scrollable list of steps. The worker can navigate to previously conducted steps by scrolling up and access future steps by scrolling down. To minimize the amount of scrolling there should be an option to navigate directly back to the active step. Figure 3 depicts an example of an option to navigate back to the active step.

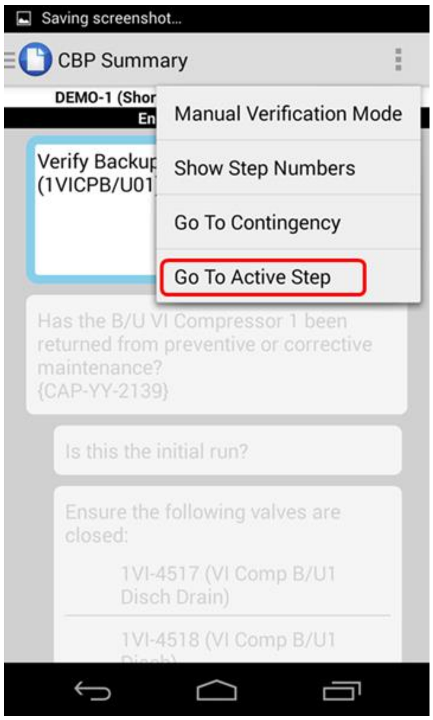

Figure 3. Navigation back to active step.

Additional capabilities that will ensure user flexibility are the ability to an incorrect or unintended action, deviate the step sequence if needed, and the option to toggle between manual and digital CCV.

2.4 Guide Worker Through Logical Sequence of the Procedure

The CBP system will guide the worker through the logical sequence or path of the procedure based on user input, previous actions or decisions, or plant status information. When the necessary information is available to the CBP, the procedure system should evaluate step logic and determine appropriate action or path forward. This shifts the burden of the evaluation to the system rather than the field worker. The procedure system can either prompt the worker of the relevant conditions needed to make a decision, or acquire the conditions from previous actions/decisions in the procedure or from a plant information database.

One of the main design principles for CBPs is the principle of simplified step logic. Simplified step logic is achieved by removing complexity from step instruction by presenting conditional steps in a simplified manner. The main way that step logic can be simplified for the worker is to present conditional statements such as IF/THEN, WHEN/THEN, AND, and OR as questions. For example, the statement “IF opening Valve A-1 THEN perform the following…” would be presented a “What valve do you want to open; Valve A-1 or Valve A-2?” Depending on the answer the procedure will take the worker to either a step with the actions needed to open valve A-1 or the step with the actions needed to open valve A-2. Figure 4 below illustrates an example of how to present a conditional statement and its outcome to the field worker.

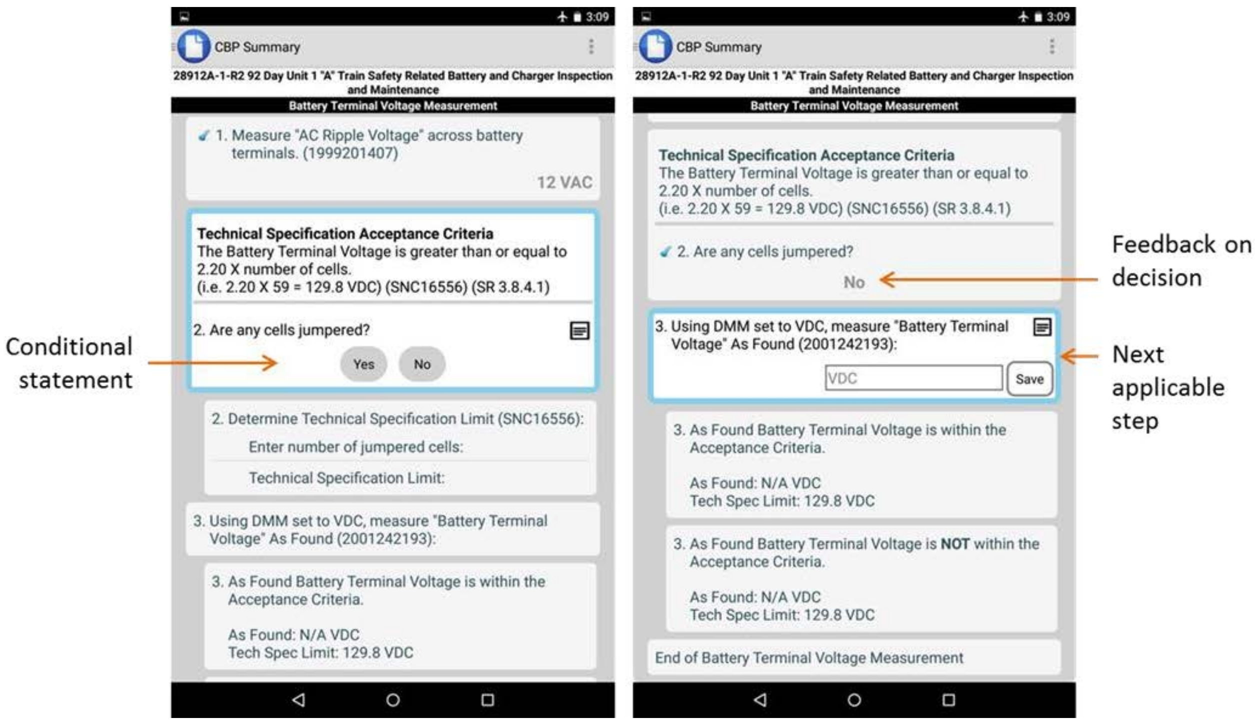

Figure 4. Example of a conditional statement

The section of steps that are not applicable based on the decision will automatically be marked as such. Hence, the worker can focus on the actual task at hand and not be burden by deciding which steps are not applicable and marking them as such. This minimizes the risk of the worker incorrectly identifying whether steps are applicable or not. The CBP should guide the worker to the next applicable step when the current action step is completed.

2.5 Provide Information Needed to Control Path Through the Procedure

It is important to find a balance between automation and keeping a high level of worker’s situational awareness. The best way to make sure the worker is in the loop is to assign the control of the pace and path through the procedure to the worker. To achieve this while still leveraging the computational power of a digital device the procedure system needs to provide worker information about decisions made and the values/data points used by the system to make the decision. In addition, the CBP should clearly state which actions were taken in previously conducted steps to provide a quick overview of the path taken. This overview will support the worker when assessing the decision made by the system.

In addition, the worker should have the option to go back and revise previous input and/or decisions. If an allowable revision, the path through the procedure should be updated. However, there will be situations where revision of a decision could have impact on current equipment status. Revision of such step should only be allowed with supervisor's approval.

2.6 Provide Computerized Support Where Appropriate and Possible

Even though humans have many strengths there are items or situations where technology can be used to further enhance human performance. For example, technology is more reliable when calculations need to be performed and recorded. By allocating calculations to the computerized support rather than the field worker does not only increase the success rate for the task, it also relieves the cognitive burden on the worker.

Taking correct action on an incorrect component or equipment can have negative consequences related to the safety of the plant. Computerized support can support improved human performance when verifying the correct component to take action on. The CBP system should support digital CCV where the computerized support is used to match the scanned component with the expected component. If the match is successful the worker will be allowed to proceed with the task. If the match is unsuccessful, the CBP system will notify the worker. Figure 5 shows a CCV being conducted using a barcode scanner. The same technology as used for CCV can also be used for first checks. The worker scans the location identifier and/or the equipment identification tag to verify correct unit and train.

Figure 5. A field worker conducts a CCV using a barcode scanner.

Most tasks in the field requires the worker to read a value and record it in the procedure. There are multiple reasons for why the worker might incorrectly capture the value. For example, the worker might be distracted by a pager message or a coworker might ask a question. Computerized tools can be used to minimize the risk of invalid input. The CBP system should ensure the requested value is recorded and that the input format is valid. The CBP system should also alert the worker when the recorded value either is in violation of an accepted range or if it is outside the technical specification.

The computerized support provided in the CBP system will help reduce time to execute the task by automatically populate data sheets with recorded values. In addition, input from previous completed tasks can be displayed in the active procedure as appropriate. The CBP system should also be able to automatically generate trends and plots needed to support the worker during the task execution.

2.7 Include Functionality That Improve Communication

Good communication between field workers, supervisors, and the control room is important in order to execute the task in the field in an efficient and timely manner. The CBP system could automate some of the common communication between the field worker and relevant roles or organizations.

The CBP system and mobile devices can aid the communication during shift turnover since all the data is stored and passed electronically. This allows workers at the end of a shift to upload and release the work that has been recorded during their shift on any given work order or procedure. The new shift should have immediate access to the data and be able to pick up where the other shift left off. The immediate access of the previous shift's work reduces the need to track down the paper work and reduces the time it takes to ensure the new shift has all information needed.

The CBP system will provide task status updates to the supervisor. Therefore, the supervisor does not need to contact the worker while at the work site to get status updates. This real time status updates, or near real time if full wireless coverage is not available, will provide the supervisor a better understanding of the work status and allow him/her to optimize the scheduling of resources. The shared work status between the supervisor and worker will also improve the communication in the case the worker has a question or request for the supervisor. The time spent on explaining the situation will be reduced by the fact that they both share a common understanding of the task progression up to the point of the communication. The CBP system provides the worker the ability to provide more context to the communication than only a verbal description by using photos and videos.

In addition, automatic notification triggers within the CBP system should notify the control room when conditions are met for a hand-off. The system will notify the field worker when work can be initiated in the field as well as notifying the control room when the field worker reaches a point where the control room needs to take action. This reduces the time needed for hand offs between the control room and the field.

2.8 Provide a Method to Review and Save Records

The utility is required to retain records of all tasks conducted at the plant. All information, decisions, and notes in the CBP are saved as data. In other words, the CBP system should be able to provide the saved data in a format that can be used to create a readable document as needed. The researchers hope that the need for archiving paper copies of the procedures will be reduced as electronic archiving becomes more and more acceptable in the industry. However, until the industry reach this point of acceptance there is still a need to consider archiving of paper copies.

3 CONCLUSIONS

The nuclear industry faces the opportunity to gain great improvements to both safety and human performance by leveraging technology and its inherent capabilities. However, these benefits are not automatically gained by installing a new system. Utilizing new technology may introduce new opportunities for errors. It is therefore important to understand the current work processes and the user needs, and to design a solution which provides improvements to the work process and addresses the user needs. The research team at INL collaborated with nuclear utilities 2012-2016 to study the work processes, identify user needs, and to evaluate design concepts. The outcome of that effort is a design guidance for CBPs for field workers, which is summarized in this paper. As of mid-2017, multiple customers (e.g., utilities and research laboratories) use the INL design guidance as a tool when interacting with potential vendors.

4 ACKNOWLEDGMENTS

The authors would like to express special gratitude to the following people for their collaboration and support of this research effort:

Thomas Waicosky, Catawba Nuclear Station, for supporting and hosting the laboratory evaluation study at Catawba's flowloop in 2012 and a field study 2013. Michael Grigsby, Palo Verde Nuclear Generating Station, for being the Palo Verde Management Sponsor for the research effort. Carlos Williams, Regina (Gina) Cunningham, and Christopher Kartes, and John Triolo, Palo Verde Nuclear Generating Station, for all their support of preparing and hosting the evaluation studies in 2012 and 2014. Bruce Gordon, Jarad Ping, and David Delong, Palo Verde Nuclear Generating Station, for their support in the process to expand the INL computer-based procedure system to handle maintenance work orders and for all their support to plan and conduct the field validation study in 2014. Dean Overland, K.R. Thompson, Adam Lyman, and Nicola Gaudiuso, Diablo Canyon Power Plant, for hosting a field study in 2015. James Flowers and Amy Houston (Southern Nuclear Company), and Tim Neal, Teresa Moore, Tracy Quick, and Toni Buxton (Plant Vogtle) for hosting a field study in 2015. John Hernandez and Lorenzo Slay, Palo Verde Nuclear Generating Station, for supporting and hosting a computer-based procedures for plant modifications pilot in 2016.

The research team wants to extend its gratitude to all the participants and others involved in the successful execution of all the evaluation studies and field studies. The feedback you provided over the years have been highly valuable to the effort.

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. J. Oxstrand, K. Le Blanc, & A. Bly, *Computer-Based Procedures for Field Workers: Results From Three Evaluation Studies (INL/EXT-13-30183),* Idaho Falls, USA (2013).
2. J. Oxstrand & K. Le Blanc, "Supporting the future nuclear workforce with computer-based procedures", *Nuclear Future - The official journal of the Nuclear Institute,* **12(1)**, pp. 34-39 (2016).
3. J. Oxstrand & K. Le Blanc, *Computer-Based Procedures for Field Workers – Identified Benefits (INL/EXT-14-33011),* Idaho Falls, USA (2014).
4. J. Oxstrand, A. Al Rashdan, K. Le Blanc, A. Bly, & V. Agarwal, *Light Water Reactor Sustainability Program Automated Work Package Prototype: Initial Design, Development, and Evaluation (INL/EXT-15-35825)*, Idaho Falls, USA (2015).
5. J. Oxstrand, K. Le Blanc, A. Bly, H. Medema, & W. Hill, *Computer-Based Procedures for Field Workers - Result and Insights from Three Usability and Interface Design Evaluations (INL/EXT-15-36658),* Idaho Falls, USA (2015).
6. J. Oxstrand, *Functional Requirements for an Electronic Work Package System (INL/EXT-16-40501, NITSL-INL-2016-01),* Idaho Falls, USA (2016).
7. J. Oxstrand, K. Le Blanc, & A. Bly, *Design Guidance for Computer-Based Procedures for Field Workers (INL/EXT-16-39808),* Idaho Falls, USA (2016).