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Light Water Reactor Sustainability Program

Computer-Based Procedures for Field Workers – FY16 Research Activities

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SUMMARY

The Computer-Based Procedure (CBP) research effort is a part of the Light-Water Reactor Sustainability (LWRS) Program, which is a research and development program sponsored by Department of Energy (DOE) and performed in close collaboration with industry research and development programs that provides the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants. One of the primary missions of the LWRS program is to help the U.S. nuclear industry adopt new technologies and engineering solutions that facilitate the continued safe operation of the plants and extension of the current operating licenses.

One area that could yield tremendous savings in increased efficiency and safety is in improving procedure use. Nearly all activities in the nuclear power industry are guided by procedures, which today are printed and executed on paper. This paper-based procedure process has proven to ensure safety; however, there are improvements to be gained. Due to its inherent dynamic nature, a CBP provides the opportunity to incorporate context driven job aids, such as drawings, photos, and just-in-time training. Compared to the static state of paper-based procedures (PBPs), the presentation of information in CBPs can be much more flexible and tailored to the task, actual plant condition, and operation mode. The dynamic presentation of the procedure will guide the user down the path of relevant steps, thus minimizing time spent by the field worker to evaluate plant conditions and decisions related to the applicability of each step. This dynamic presentation of the procedure also minimizes the risk of conducting steps out of order and/or incorrectly assessed applicability of steps.

Between 2012 and 2015 the researchers conducted a series of laboratory and field studies to evaluate the developed design concepts and the CBP system's overall impact on human performance.

In 2016 the researchers facilitated the industry wide Nuclear Electronic Work Packages – Enterprise Requirements initiative along with other collaborations with both utilities and vendors. The final feedback from the field study hosted by Plant Vogtle was gathered and a pilot was conducted at Palo Verde Nuclear Generating Station to investigate how a CBP system can enhance the plant design modification process. The researchers composed a Design Guidance for Computer-Based Procedure for Field Workers in 2016, which compiles all insights gained through the years of CBP research. In addition, the research team was awarded DOE funding to move the CBP system towards a product which can be commercialized. The commercialization effort will begin in 2017.

This report provides a summary of the main research activities conducted in the Computer-Based Procedures for Field Workers effort since 2012. The main focus of the report is on the research activities conducted in fiscal year 2016, which is the final year of the effort. The activities discussed are the Nuclear Electronic Work Packages – Enterprise Requirements initiative, the development of a design guidance for CBPs, the facilitation of vendor studies at the Idaho National Laboratory (INL) Advanced Test Reactor (ATR), a pilot study for how to enhance the plant design modification work process, the collection of feedback from a field evaluation study at Plant Vogtle, and path forward to commercialize INL's CBP system.

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ACRONYMS

AO	Auxiliary Operator
APS	Arizona Public Services
ASW	Auxiliary Salt Water
ATR	Advanced Test Reactor
CBP	Computer-Based Procedures
CBU	Controlled By User
DCPP	Diablo Canyon Power Plant
DIWO	Design Implementation Work Order
DOE	Department Of Energy
EPRI	Electric Power Research Institute
INL	Idaho National Laboratory
LWRS	Light Water Reactor Sustainability
MCR	Main Control Room
NEWPER	Nuclear Electronic Work Packages – Enterprise Requirements
NITSL	Nuclear Information Technology Strategic Leadership
OTT	Office of Technology Transition
PBP	Paper-Based Procedures
PVNGS	Palo Verde Nuclear Generating Station
TCF	Technology Commercialization Fund

COMPUTER-BASED PROCEDURES FOR FIELD WORKERS – FY16 RESEARCH ACTIVITIES

1. INTRODUCTION

Nearly all activities that involve human interaction with nuclear power plant systems are guided by procedures, instructions, or checklists. Paper-based procedures currently used by most industries have a demonstrated history of ensuring safety; however, improving procedure use could yield significant savings in increased efficiency, as well as improved safety through human performance gains. The nuclear industry is constantly trying to find ways to decrease human error rates, especially human errors associated with procedure use. As a step toward the goal of improving procedure use performance, the U.S. Department of Energy Light Water Reactor Sustainability (LWRS) Program researchers, together with the nuclear industry, have been investigating the possibility and feasibility of replacing current paper-based procedures with compute-based procedures (CBPs). A prototype CBP system has already been developed and evaluated. The initial purpose of the CBP system was to evaluate different design concepts. Additional functionality was added to the original CBP system, which now rivals, and in some aspects, outperforms the current "off-the-shelf" products. The purpose of this project is to optimize our existing CBP tool and demonstrate it in a commercial application, with a utility sponsor providing in-kind assistance.

A CBP is defined as a dynamic electronic presentation of a procedure that guides the worker seamlessly through the logical sequence of pre-determined steps. In addition, the CBP system makes use of the inherent capabilities of the technology, such as incorporating computational aids, easy access to additional information (e.g., drawings, procedures, and operational experience), just-in-time training at the job location in the field, and digital correct component verification. 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 "off-the-shelf" products. A CBP system offers a more dynamic means of presenting procedures to the worker and displaying only relevant steps based on operating mode, plant status, and tasks at hand. A dynamic presentation of the procedure guides the worker down the path of relevant steps based on the current conditions. This feature will reduce the worker's workload, and inherently reduce the risks of incorrectly marking a step as not applicable and of incorrectly performing a step that should be marked as not applicable.

Context-driven job aids, such as corrective action documentation, drawings, photos, and just-in-time training are accessible directly from the CBP system as needed. One obvious advantage is reducing the time spent searching for applicable documentation. Furthermore, human performance tools are embedded in the CBP system in such ways that they let the worker focus on the task at hand 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.

The CBP research targeted questions related to how best to design a CBP system from a human factors perspective. The researchers were taking the concept of CBP further than the vendors' existing electronic work package and procedure systems. The researchers are exploring ways to use the advanced technology to design a CBP system to include dynamic presentation of the procedure content, context driven job aids, and integrated human performance tools. All of these innovations would help the worker focus on the task at hand rather than the tools. The whole system is developed from a user perspective and is proven to increase efficiency and improve human performance.

The research has yielded valuable results supporting the hypothesis that a well-designed CBP system can improve efficiency, safety, and human performance. The researchers provided results that support the industry and vendors in moving toward CBP systems that encompass more advanced capabilities.

Thomas, Lawrie, and Niedermuller (2015) recently developed a business case for dynamic electronic work orders for the nuclear industry. They concluded that, in the future, approximately $3.5M (about $3.3M of harvestable labor savings and $0.2M of non-labor savings) could be saved annually by using an eWP system, which would allow an investment of over $20M in present terms. However, it is important to point out that potential cost savings will depend on the solution and its specific implementation. The main cost-saving opportunities identified in the business case are from reduced human errors and more streamlined work processes. This business case focused on a system for field workers and maintenance technicians.

Instead of navigating through a maze of cross references, computer-based tools enable intelligent work path navigation that accounts for past decisions and observation, thereby enabling more efficient and safe task completion (Oxstrand et al. 2015a; Oxstrand et al. 2015b). In other words, a streamlined work process and dynamic support to guide the worker through task execution will help them focus on the task at hand rather than on the process (Le Blanc and Oxstrand 2012; Oxstrand and Le Blanc 2012; Le Blanc, Oxstrand, and Waicosky 2012).

This report provides a summary of the main research activities conducted in the Computer-Based Procedures for Field Workers effort since 2012. The main focus of the report is on the research activities conducted in fiscal year 2016, which is the final year of the effort. The activities discussed are the Nuclear Electronic Work Packages – Enterprise Requirements initiative, the development of a design guidance for CBPs, the facilitation of vendor studies at the Idaho National Laboratory (INL) Advanced Test Reactor (ATR), a pilot study for how to enhance the plant design modification work process, the collection of feedback from a field evaluation study at Plant Vogtle, and path forward to commercialize INL's CBP system.

1.1 Introduction to CBP Research

This section provides a high level summary of the main research activities conducted between 2012 and 2015. These activities are the development of a model of procedure usage, three evaluation studies conducted in nuclear utilities' training facilities, and four field evaluations studies.

The CBP research effort has mainly focused on procedure usage outside the main control room. In other words, instruction or procedure driven activities conducted by workers in the field such as auxiliary operators and maintenance technicians. However, in 2015 the researchers applied the CBP design concepts to control room procedures as well.

1.1.1 Model of Procedure Usage

The overarching focus of the research effort is to define how to design a CBP system that will increase efficiency while also improving human performance. This includes both identifying the underlying structure and content of the procedures as well identifying the appropriate user interface characteristics of the CBP.

As a first step, researchers conducted a qualitative study to investigate the current use of procedures in the nuclear power industry (Le Blanc, Oxstrand and Waicosky, 2012; Oxstrand and Le Blanc, 2012). The purpose was to identify error-likely situations in procedure execution as well as potential improvements to the process through the use of technology. The researchers shadowed auxiliary operators as they conducted rounds, and conducted semi-structured interviews with operators and trainers. In addition, researchers mapped the flow of information in the procedure process to identify what information needs to be available in the computer-based procedure and who would need to have access to the information. The study identified which aspects of the existing paper-based process should be retained when designing a CBP system, e.g., providing an overview of the task and keeping the operator focused on the task at hand. Areas in which a CBP could improve upon the paper-based process were also identified, such as the processes for placekeeping and correct component verification.

1.1.2 Laboratory Studies

Industry acceptance of advanced technology and CBP systems is vital in order to move the industry closer to fleet-wide deployment of such systems. One way to gain this acceptance is to put the technology in the hands of the end users. In the case of the CBP research, the end users are auxiliary operators, maintenance technicians, chemistry technicians, etc. Hence, it was important to engage end users early in the design process of the CBP system.

Based on the findings from the qualitative study, the researchers identified an initial set of design requirements (Le Blanc, Oxstrand & Waicosky, 2012; Oxstrand and Le Blanc, 2012), which was used to design the first version of the CBP prototype system. Each revision of the prototype was evaluated through empirical research conducted in laboratory settings at the collaborating utilities. Four laboratory evaluation studies were conducted overall. Three were hosted by collaborating utilities and were conducted in their training facilities (flow loop, electrical laboratory, and instrument and control laboratory). One study was conducted during a Light Water Reactor Sustainability Utility Working Group meeting at INL. The study participants conducted scenarios using both a paper-based procedure and a computer-based version of the same procedure. The researchers compared the participants' performance using both types of procedures. The studies evaluated the CBP design from a human factors perspective, i.e., evaluated the usability of the design, the impact on human performance, and error reduction possibilities. The researchers gathered input on deviations from specified path, performance time, mental workload, and the general usability of device and interface (Oxstrand, Le Blanc, and Hays, 2012; Oxstrand, Le Blanc, and Bly, 2013).

The main objective of the evaluation studies was to collect feedback on the design of the user interface of the CBP as well as to identify the appropriate functionality of the CBP. The researchers incorporated suggestions from the users as well as insights gained from carefully observing the participants carry out the procedures using the CBP. In addition to gathering information about usability and functionality, the researchers aimed to evaluate the effect a CBP may have on performance and efficiency of the procedural task.

The results of the first two laboratory evaluation studies indicate that well-designed CBPs may reduce errors (Le Blanc & Oxstrand, 2013). The procedure used in the first study was incredibly simple, and none of the participants made an error in executing the procedure, making it impossible to compare performance between the CBP and PBP. The second evaluation study revealed that in a more complex procedure, the CBP could potentially reduce the number of errors. Participants committed a total of thirteen errors when using the PBP compared to a total of one error using the CBP.

The evaluation studies also indicated that it might take more time to execute the procedure using a CBP (Le Blanc & Oxstrand, 2013; Oxstrand, Le Blanc, and Bly, 2013). It took an average of two minutes longer to complete the procedure with the CBP in the first study, and an average of eight minutes longer to complete the procedure with the CBP in the second study. The researchers suggested that the longer time could be partially due to a lack of familiarity with the CBP. Participants had only ten minutes of training on how to use the CBP, but had been using PBPs for their entire careers as operators. However, researchers also acknowledged that there might be a legitimate tradeoff between reduced errors and longer completion time when using CBPs.

A third laboratory evaluation study was conducted in the I&C Laboratory at the Arizona Public Service Palo Verde Nuclear Generating Station (PVNGS) in February, 2014 to incorporate improvements to the CBP system and to expand the functionality to prepare for demonstrating the system with real-world procedures. The CBP system was revised to incorporate automated calculations, continuous action steps, and links to supplemental information. Fourteen operators and technicians participated in the study. Each participant carried out the procedure twice; once with the CBP and once with a traditional PBP. The results from the study yielded that the participants committed 95 errors when using the PBP and 48 when using the CBP version of the same procedure. The most common error committed in both the PBP and CBP conditions was a failure to conduct proper correct component verification and the second most common error was in executing a calculation of the volume required to fill a tank. In addition, the results showed that it did not take more time to execute the procedure using the CBP compared to the PBP, which indicates that the potential tradeoff between reduced errors and a longer time to execute the procedure might not be inevitable. It might be possible to reduce errors without increasing procedure execution time with a CBP system.

1.1.3 Field Studies

In order to fully test the degree to which CBPs can reduce errors and increase efficiency, research needs to be conducted over longer period of time and in a more realistic setting than in laboratories and training facilities. The laboratory evaluation studies were successful in evaluating the usability of the CBP system and its potential impact on human performance. However, the studies were limited in scope and the participants only went through the task once with the CBP system. This does not provide sufficient information to conclude if the CBP system actually will have a positive impact on human performance and safety in the plant. Therefore, the researchers planned field evaluations of the CBP system, which would use real plant procedures and occur over several months.

A pilot field evaluation study was conducted at Duke Energy's Catawba Nuclear Station between April and June, 2014. The study and its result are documented in the report *Computer-Based Procedures for Field Activities: Results from Three Evaluations at Nuclear Power Plants* (Oxstrand, Le Blanc, and Bly, 2014). The main objectives of the pilot field study 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 result from the study indicates that all of the auxiliary operators (AOs) who used the CBP preferred it to the PBP. The CBP did not slow down the execution of the task. 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. Instead, there was at least one instance in which the CBP may have increased efficiency compared to the PBP. Lessons learned from the pilot study include the importance of becoming familiar with the users and task early in the design phase of the CBP version and to plan for sufficient time for the users to become familiar with the CBP system and slightly modified work flow before any major disturbances such as an outage occurs.

A second field evaluation study was initiated at PVNGS in early September, 2014. The research team decided to base the study on a preventive maintenance work order as a step to incorporate more aspects of the work package process used in the nuclear power industry. Figure 1 shows a maintenance technician participating in the PVNGS study.

As a result of the study, the maintenance technicians identified instances in the work order where the system could provide even more distinct cues and information. In addition, the research team identified a couple of lessons learned while they conducted a pre-validation activity before initiating the field study. One example of these lessons learned is the importance to select a work instruction that is executed in a location where visitors such as the research team can access in some manner. In order to design a CBP that will help improve human performance it is of great value to be able to observe the field workers as they execute the task with their current paper-based process. The second field study is described in more detail in the report *Light Water Reactor Sustainability Program Automated Work Package Prototype: Initial Design, Development, and Evaluation.* (Oxstrand et. al, 2015a).

Figure 1. A maintenance technician uses a work order during the PVNGS field study.

The third field study was hosted by Pacific Gas and Electric Diablo Canyon Power Plant (DCPP) starting April, 2015. In collaboration with DCPP, two tasks were identified to be used in the field evaluation: Swap of ventilation supply and exhaust fan sets and swap of auxiliary salt water (ASW) pumps. The fan set swap is a straightforward task, using one procedure, while the ASW pump swap is a task coordinated between the operators in the main control room (MCR) and the operators in the field. The task is conducted using two procedures; one used in the MCR to swap the ASW pumps and the second used in the field to swap chlorination trains to match the ASW pump swap. Figure 2 shows a control room operator and a field worker validating the CBP system at DCPP.

The results from the DCPP field study shows that the 15 out of 18 control room operators who used the CBP system found the CBP system to be a positive change compared to the paper-based process. All 18 field workers in the study indicated that they preferred the CBP system. The most appreciated features of the CBP system are the automatic placekeeping, the digital correct component verification, and photo and drawings directly linked to applicable steps. The report *Computer-Based Procedures for Field Workers - Result and Insights from Three Usability and Interface Design Evaluations* (Oxstrand et. al, 2015b) discusses the DCPP field study in great detail.

Figure 2. A DCPP control-room operator and a field worker validate the CBP system.

The final field evaluation study was hosted by Southern Nuclear Company's plant Vogtle, Units 1 and 2. The study was initiated in June, 2015. The study focused on battery and charger test and safety related inspection maintenance. The initial results from the Vogtle study indicates that the maintenance technicians appreciate the digital correct component verification, which was used to ensure the task was conducted in the correct unit, on the correct train, in the correct room. Figure 3 depicts a maintenance technician preforming the task used for the Plant Vogtle study.

The technicians also like the streamlined task execution compared to the paper process. The greatest efficiency gain seems to be the automated generation of the data sheets. When using the paper version, the technicians spend a large amount of time going between the procedure steps and the data sheets. The automatic generation of the data sheets also has the potential to reduce risk of human errors commonly associated with frequent movement within a procedure, such as unintentionally missing a procedure step or conducting steps out of sequence. The Vogtle study and its initial results are documented in *Light Water Reactor Sustainability Program Automated Work Package Prototype: Initial Design, Development, and Evaluation* (Oxstrand et al., 2015a). The final result of the study is discussed in Section 6 of this report.

Figure 3. A maintenance technician at Plant Vogtle performs the battery and charger test and inspection work order.

2. THE NUCLEAR ELECTRONIC WORK PACKAGES – ENTERPRISE REQUIREMENTS (NEWPER) INITIATIVE

The Nuclear Electronic Work Packages - Enterprise Requirements (NEWPER) initiative is a step toward a vision of implementing an eWP framework that includes many types of eWPs. This will enable immediate paper-related cost savings in work management and provide a path to future labor efficiency gains through enhanced integration and process improvement in support of the Nuclear Promise (Nuclear Energy Institute 2016).

The NEWPER initiative was organized by the Nuclear Information Technology Strategic Leadership (NITSL) group, which is an organization that brings together leaders from the nuclear utility industry and regulatory agencies to address issues involved with information technology used in nuclear-power utilities. NITSL strives to maintain awareness of industry information technology-related initiatives and events and communicates those events to its membership. NITSL and LWRS Program researchers have been coordinating activities, including joint organization of NEWPER-related meetings and report development.

The main goal of the NEWPER initiative was to develop a set of utility generic functional requirements for eWP systems. This set of requirements will support each utility in their process of identifying plant-specific functional and non-functional requirements. The overall goals of the initiative are as follows:

- Define core components of an eWP system
- Define functional requirements for these core components, covering the full spectrum of eWPs from basic pdfs to dynamic smart documents
- Share operational experience that is related to ongoing eWP implementation activities in industry (e.g., benefits gained and identified issues)
- Communicate utilities needs and wants to vendors
- Standardize terminology related to eWP and smart documents.

In addition, the NEWPER initiative provided an opportunity for establishing new or reinforcing existing relationships between utilities and eWP vendors. The NEWPER initiative was started in October 2015 and is planned to be closed by December 2016.

The NEWPER initiative has 129 members. Figure 4 illustrates the distribution of members. The largest group of members consists of 18 commercial nuclear utilities that represent the vast majority of the U.S. commercial nuclear industry. The second largest member group includes 11 of the most prominent vendors of eWP solutions, along with two management consultant companies. The “other organizations” group consists of organizations such as the Electric Power Research Institute (EPRI), the Institute of Nuclear Power Operations, and EDF Energy. Three national research laboratories are also included in this group: Idaho National Laboratory, Los Alamos National Laboratory, and Savannah River National Laboratory. In addition to NITSL, the Nuclear Information and Records Management Association and the Procedure Professionals Association are also represented in the member pool.

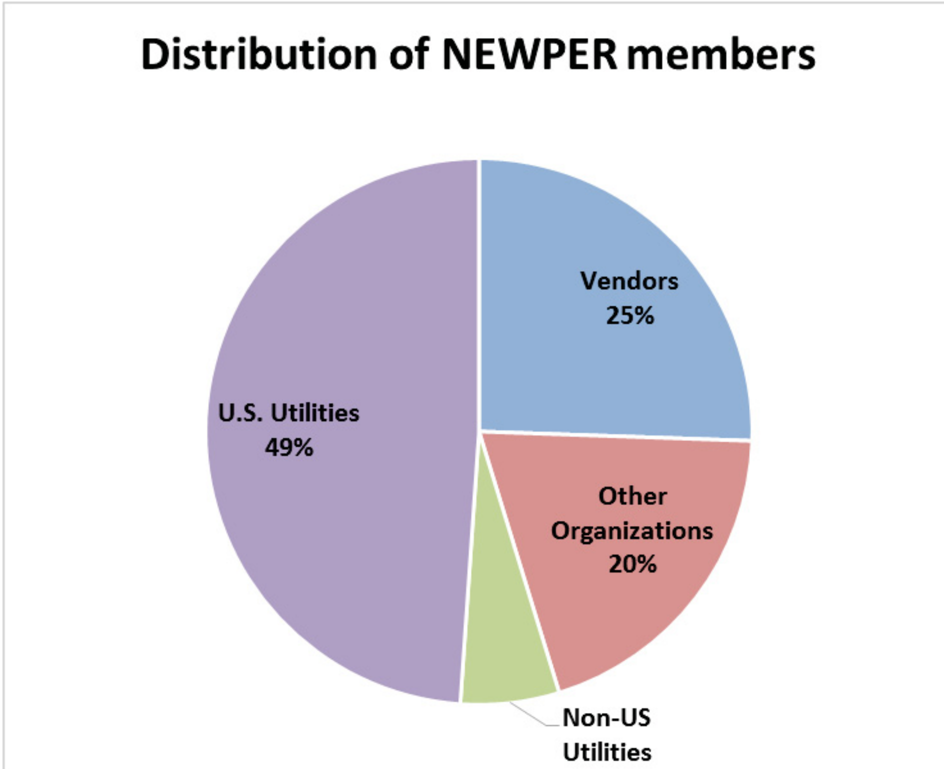

Figure 4. NEWPER member distribution.

Activities in NEWPER were mainly conducted via telephone conferences and face-to-face workshops. The NEWPER planning committee (see Figure 5) plans and organizes all NEWPER activities in 2016.

The first NEWPER workshop was hosted by Arizona Public Service and was conducted from December 8 to 10, 2015, in Avondale, Arizona. The 68 participants represented 63% of the U.S. commercial nuclear industry, 10 vendors, and other organizations such as the Institute of Nuclear Power Operations, EPRI, the Advanced Test Reactor at Idaho National Laboratory, and Los Alamos National Laboratory.

The workshop successfully established a dialogue between all parties (i.e., utilities and vendors), where valuable operational experience was shared and ideas and concerns were discussed. The main workshop objectives were to define a vision statement for eWP system implementation, define a common taxonomy for eWPs and the documents included in these eWPs, and identify generic minimum requirements for eWP systems.

The following vision statement was developed during the workshop: "Implement an open eWP framework, which covers the entire eWP spectrum, enabling immediate paper-related cost savings in work management and providing a path to future labor efficiency gains through enhanced integration and process improvement in support of the nuclear promise."

Figure 5. The NEWPER Planning Committee: P. Muller (Exelon), C. Williams (APS), N. Camilli (EPRI), A. Bly (INL), B. Gordon (APS), E. Jurotich (Southern Company), and J. Oxstrand (INL). Also, the LWRS Program Pathway Lead, B. Hallbert (INL).

The participants agreed to use a slightly revised version of EPRI's taxonomy for smart documents that is described in EPRI (2015). Figure 6 represents the revised version of the taxonomy. The part of the eWP that is most affected as the level of incorporated technical solutions increase will be the documents. Hence, the taxonomy only refers to documents and not to the work package as a whole.

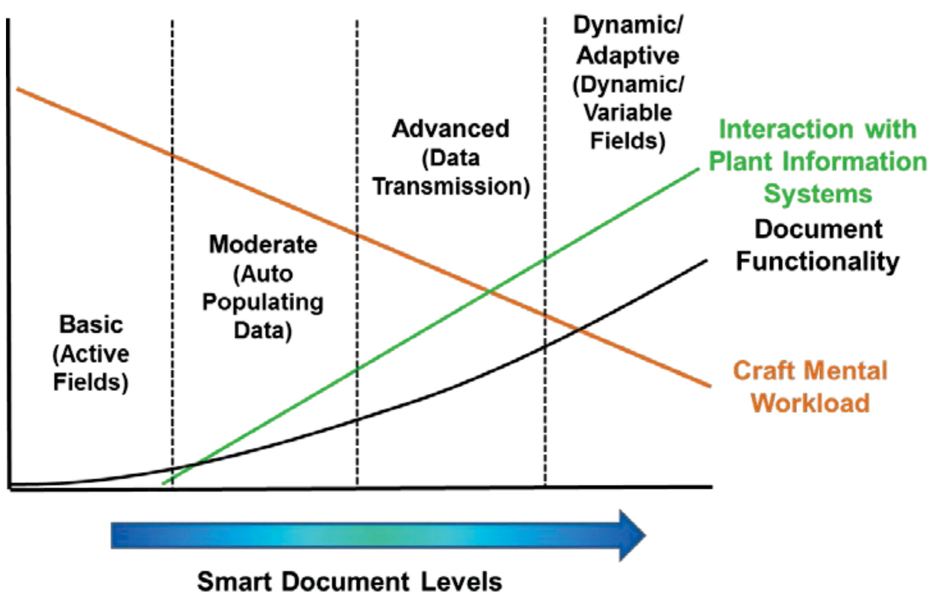

Figure 6. The NEWPER taxonomy for smart documents, which is based on a taxonomy developed by EPRI, EPRI (2015).

One of the main differences between the NEWPER taxonomy and EPRI's taxonomy is the exclusion of wireless network needs. It was concluded that other solutions (such as docking stations and Wi-Fi hot spots) could be sufficient for gaining benefits from different types of smart documents. The taxonomy consists of four levels: (1) basic, (2) moderate, (3) advanced, and (4) adaptive. Table 1 summarizes each of the levels.

Table 1. Summary of smart document levels.

Level	Summary
Basic (Active Fields)	The document has fields for recording input such as text, dates, numbers, and equipment status.
Moderate (Automatic Population of Data)	The document incorporates additional functionalities such as form field data "type" validation (e.g. date, text, number, and signature) of data entered and/or self-populated basic document information (usually from existing host application meta data) on the form when the user first opens it.
Advanced (Data Transmission)	The document provides the capability to transmit data entered into other data systems.
Adaptive (Dynamic/Variable Fields)	The document uses variable (i.e., dynamic) field options based on previously completed data entries or links to other electronic documents or media.

The identified minimum requirements include an authoring tool, compatibility with legacy plant systems, a human-factored user interface, and the system has to be operational in both online and offline modes. These minimum requirements served as starting point for the next NEWPER activity, where utility generic functional requirements for eWP systems (more specifically for basic and moderate levels of smart documents) were identified.

A second workshop was hosted by EPRI in Charlotte from March 22 to 23, 2016. The purpose of the workshop was for utility representatives to define a set of utility generic functional requirements for an eWP system and capture any non-functional requirements identified in the process.

Two of the participants, Exelon and Los Alamos National Laboratory, have already implemented eWP systems at their sites. These two participants have implemented solutions from different vendors. The operational experience and lessons learned from both Exelon and Los Alamos National Laboratory were very valuable to the exercise of identifying functional requirements.

The outcome of the March workshop was a set of high-level functional requirements for a generic eWP system. A set of more detailed requirements related to each of the high-level requirements was also identified. The 72 identified high-level requirements were grouped into role-based categories. Table 2 shows most of the categories and examples of high-level requirements:

Table 2. Examples of high-level requirements for basic and moderate smart documents and eWP systems.

Planner	
	Ability to validate that documents are in the most current revision
	Ability to add hold points, critical steps, and other status markers
	Ability to route work package for approvals
Supervisor	
	Ability to create and complete work packages for unplanned tasks
	Ability to assign craft or crew to a work package
	Ability to monitor work and track status during execution
Craft	
	Ability to execute task in the field

	Ability to use the mobile device to conduct a walkdown of the work package prior to work execution to determine workability and acceptability
	Ability to use multiple types of input (e.g., text input, camera, barcodes, and voice-to-text)
	Ability to capture annotations
Operations	
	Ability to create pre-authorization of work order tasks
	Ability to conduct sign-offs prior to task execution
Supporting Functions	
	Ability for recorded inputs/data to be routed to other organizations and users for review
	Ability to coordinate with additional disciplines and teams during work execution via alerts or notifications
	Ability to present task status on an outage control center dashboard for outage management
Records	
	Ability to generate a quality assurance record
	Ability to identify which document types are not retained as quality assurance records
	Ability to capture data points recorded in the work package
Information Technology	
	The eWP application must work in offline mode
	Ability to support multiple form factors (e.g., devices and operation systems)
	Ability for eWP system to interface with legacy systems
	Ability for eWP system to adjust status in work management systems and/or work control systems

A need for a set of functional requirements for advanced and dynamic smart documents was also identified during the March workshop. The development of the requirements for advanced and dynamic smart documents became a parallel activity within the initiative. Two sets of requirements were developed of the smart documents; a set of high level requirements, and a set of detailed functional requirements.

Examples of high level requirements are optimized for human performance, optimized for worker efficiency, optimized for navigation, and digital data entry with backend system data utilization. The detailed functional requirements are grouped into different categories, such as step types, branching and referencing, data management, attachments and tables, and record requirements. Below are five examples of detailed functional requirements identified for advanced and dynamic smart documents.

1. Provides the ability to perform the appropriate portion of a Smart Document (either partially or completely executed).
2. Provides the ability for a specific data entry occurrence to be configured to automatically populate the same data in multiple locations throughout the Smart Document.
3. Provides the ability for calculations to be set up and performed based on entered data.
4. Provides the ability to always know what step is the Active Step and its position within the Smart Document.
5. Provides the ability to easily navigate to any section or attachment.

The two activities to identify functional requirements for eWP systems and advanced and dynamic smart documents will result in two reports where all requirements are listed and described in detail. These reports will be published in the fall of 2016. The publication of these reports will mark the end of the NEWPER initiative.

3. DESIGN GUIDANCE DEVELOPMENT

The main purpose of the research effort is 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 researchers developed a document to provide guidance specifically tailored to instructions that are carried out in the field based on their experience developing and evaluating CBPs for several types of work instruction including maintenance procedures, field operating procedure, surveillance procedures, and work orders. The design guidance in intended as both a looking glass to show what can be possible in the near future and a tool for utilities and vendors to use when communicating the design concepts.

The *Design Guidance for Computer-Based Procedures for Field Workers* was published in September, 2016 (Oxstrand, Le Blanc, and Bly). Eight high level design requirements are introduced in the guidance. Also provided are specific examples of how to implement the guidance. The high level design requirements and the specific examples of each which are discussed in the design guidance document are;

1. Provide Context Sensitive Information Everywhere Possible
   - Examples; Equipment state, Expected as found state, As left state, Step instruction, Notes and cautions, and Decision points and branching
2. Support all Expected Task Flow Characteristics
   - Examples; Conditional steps, Multiple action steps, Continuous applicable steps, Peer-checking, concurrent and independent verification, Placekeeping, Notes, cautions, and warnings, Supplemental information and attachments, Branching step, Hold points, Hierarchical step structure, and Procedure specific information
3. Support Expected Level of Flexibility in Performing Task
   - Examples; Navigation within the procedure, Ability to undo an unintended or incorrect action, Deviation from step sequence, and Backup methods for currently unavailable functions
4. Guide Worker Through Logical Sequence of the Procedure
   - Examples; Conditional statement, Nested conditional statement, Decision based on previous input, and Automatic identification of not applicable steps
5. Provide Information Needed to Control Path Through the Procedure
   - Examples: Decision points and branches and Revision of incorrect input or decision
6. Provide Computerized Support Where Appropriate and Possible
   - Examples; Calculations based on manual input, Calculations when the necessary information is available, Branching, Correct component verification, Automatically validate user input, Alert users when procedure steps or conditions are at risk to be violated, Automatically populate relevant previous log information, and Automatically populate future steps and/or data sheets
7. Include Functionality That Improve Communication
   - Examples; Functionality to be used during/between shift turnover, field worker and supervisor, and control room operators and field worker
8. Provide a Method to Review and Save Records
   - Examples; Paper archives and Electronic archives

4. VENDOR COLLABORATION AND DEMONSTRATIONS

The overarching goal of the CBP research effort is to support the industry in its effort to transition from the traditional use of PBPs to eWPs and CBP systems. As a part of this mission the researchers collaborated with multiple vendors throughout FY16. The researchers offered high level human factors guidance or suggestions of various degree to vendors such as NextAxiom, ATR Inc., Curtiss Wright, DevonWay, and Westinghouse.

The vendor collaboration was extended beyond general human factors support for two vendors; Westinghouse and DevonWay. These two vendors requested feedback on their software from both a user interface and a human factors engineering perspective. The request for feedback aligned with the Idaho National Laboratory's Advanced Test Reactor (ATR) investigation of potential vendors to provide a new eWP system.

The collaboration with the Westinghouse and DevonWay involved telephone conferences where the researchers and representatives from ATR provided feedback of the two systems. Two workshops (one with each vendor) were hosted by ATR and facilitated by the researchers.

During the workshops, which were held on February 25, the vendors provided a demonstration of their Authoring tool and mobile CBP system to the planners at ATR. The demonstrations by the vendors were done by either a WebEx session or in person. After the demo was completed the planners were given time to provide their feedback and ask questions for further clarification on functionality provided by each vendors' software.

The Westinghouse demonstration was done through a WebEx session. The Project Lead for the mobile application and planner tool, from Westinghouse provided the demonstration of their Planner Tool and mobile application used by the workers in the field.

Westinghouse's Planner Tool was a desktop application that allowed the planners to create procedures. The planners could open a word document and have the tool convert the procedure into the tools format and allowing the tool to show each step. Then after conversion of the procedure the planners would need to verify the steps and apply any logic needed in order to create the adaptive aspect of the procedure. This included step types such as Decision, Branching, and Input Steps, and the resultant effects they had on the other steps in the procedure. This conversion facilitated the ability of the planners to work with existing procedures and not have to start from scratch with all their procedures. The tool also allowed users to open any Microsoft Word document or PDF from within the tool and easily copy and paste text in to the steps of the procedure.

The demonstration participants were the ATR Operations Manager and five planners from ATR. The feedback given was mostly positive. It was stated that the planner tool had an overall intuitive feel as to its functionality. The planners did mention that their seemed to be a lot of complexity setting up the logic required to enable the adaptive functionality of the CBP.

The DevonWay demonstration was given by the Chief Technology Officer of DevonWay, who conducted the demonstration in person. The demonstration focused on how to create a procedure using the DevonWay's Planner Tool.

DevonWay's Planner Tool was a web based system as a module from within the DevonWay Platform. The Planner Tool allowed the users to create procedures from scratch. A conversion tool was not available at the time of the demonstration. DevonWay was able to demonstrate how their tool was able to gather information of equipment associated to a step by being a part of DevonWay's platform and having access to equipment data that existed in their platform. DevonWay was able to create and XML fie that could be utilized by INL's CBP prototype system to be used out in the field due to DevonWay's system not having the capability to work offline.

The demonstration participants were the ATR Operations Manager and five planners from ATR. Feedback from the planners stated that the logic creation process to create branching looking simple as it was done primarily through drop down lists that the planners used to pick the decision or branching step and then select which step the procedure would jump to when a particular option was chosen.

There were some common questions raised by the planners in both workshops:

- How much effort would be involved in converting existing work orders and procedures to the CBP system?
- Can a work order be worked on concurrently by more than one field worker?
- Does the system work offline?
- How is placekeeping handled within the procedure?

The concern about the level of effort to convert existing work orders to the new CBP system was addressed by each vendor. Westinghouse’s ability to convert most instructions from word documents into the new format could cut down a lot of time needed to create the basic step structure of the instructions. DevonWay mentioned that they would be looking into a conversion tool that would be able to support a quicker method of converting existing work packages.

Neither system had the capability to handle the question about allowing multiple users to concurrently perform the work in the work package on separate devices. Both said they would look into handling the capability.

Working offline was a capability that Westinghouse already provided. DevonWay did not have this functionality yet.

Both Westinghouse and DevonWay have implemented a placekeeping scheme similar to what is described in the CBP design guidance documentation (Oxstrand, Le Blanc, and Bly, 2016).

Overall the demonstrations were well received by the planners. However, it was noted that there seem to be a couple of years left before a production ready intelligent and adaptive CBP system would be available.

The planners expressed that it would be a waste of time to implement eWP system that only had the capability to produce procedures in a PDF format. It might cost more in training to start with simply a PDF format on a mobile device since workers would need to be initially trained to use the PDF format to later have to be trained again when the intelligent and adaptive capabilities are available.

5. ENHANCE THE PLANT DESIGN MODIFICATION PROCESS

The design concepts developed through the CBP research effort applies to more situations and work processes than field workers. Most activities driven by procedures or checklists can be enhanced by transitioning from a paper-based process to a computer-supported process.

During FY17 the researchers collaborated with PVNGS in an effort to apply the CBP design concepts to their plant design modification process. More specifically, the researchers focused on how to support the revision process when the worker in the field notice a discrepancy between the documentation in the design implementation work order (DIWO) and the actual equipment in the plant.

Figure 7 below provides a high level overview of the revision process. When the craft in the field identifies a discrepancy between the DIWO and what they see in the plant they contact the engineer. The engineer has to assess the situation, which commonly means the engineer has to go out to the work site. A pen and ink revision can be made if the revision needed does not change the scope or intent of the modification. Example of a pen and ink revisions are to add a step to the procedure or to revise a drawing. If the revision needed changes the scope or intent then a new 50:59 assessment has to be conducted.

If the pen and ink revision does not require changes to the work order (e.g., no steps need to be added or step text needs to be revised) then the engineer can make the revision and send the document back to the craft. If changes to the DIWO are needed, the engineer will notify the planner about the revisions needed. The planner will update the DIWO and send the revised version to the craft.

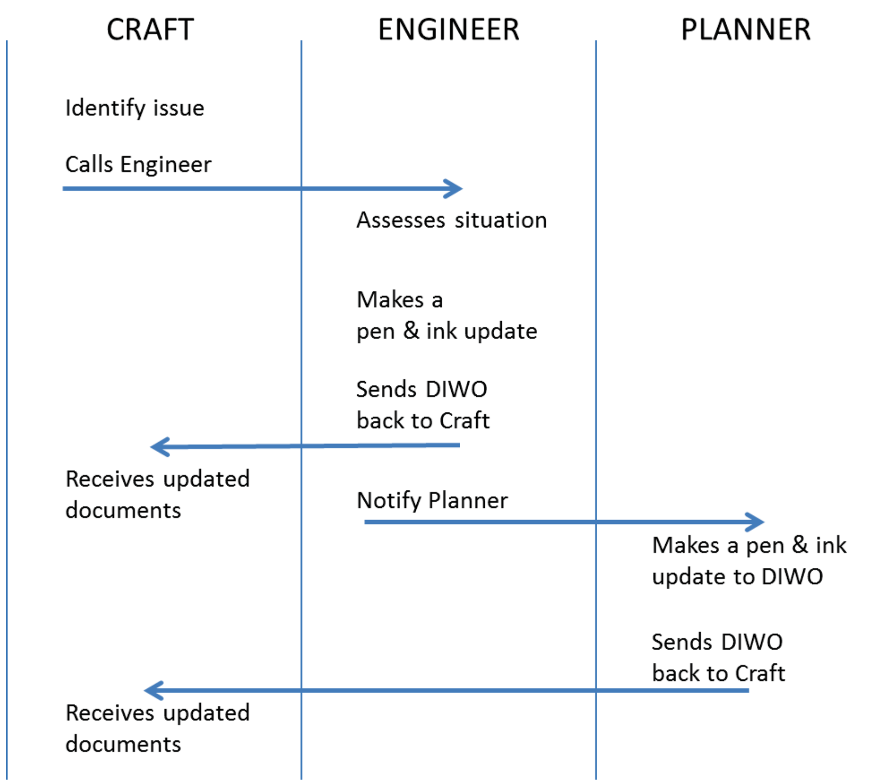

Figure 7. A high level overview of the revision process.

The printed copies of documents (e.g., drawings) the craft uses is the field are stamped as controlled by user (CBU). To make sure the craft work on the correct revision of the documentation there can only be one CBU copy of each document at one point in time. The CBUs are issued at the beginning of the work. When a drawing is revised the old drawing has to be replaced by the new one. The CBU documents need to be returned from the field at the completion of the plant design modification. It's not uncommon that some CBUs are missing when the work is complete. Hence, there is no good way of tracking these CBU paper documents with the current process.

5.1 Plant Design Modification Process Pilot

The goal for the 2017 study was to pilot a proof-of-concept of pen and ink updates, such as revisions of CBUs and revisions of procedure step.

Figure 8 illustrates the infrastructure required for the pilot. The craft uses a digital DIWO (i.e., a computer-based version of the DIWO) on a hand held device to conduct the work. The device communicates over a wireless network with a server to send and receive updates. The server is the hub between the planner, engineer, and the craft. Examples of updates shared via the server are completed steps and revised CBUs and DIWO. The server also tracks all CBUs that are linked to work orders.

There are two slightly different work processes explored in the study. Most commonly, the pen and ink revisions are conducted from the work station in the planner or engineer's office. During high workload situations it is more time efficient and sometimes necessary to be able to conduct the pen and ink revisions while being out in the field. To enable this, the option to do pen and ink revisions from a handheld device was explored as well. However, the main focus of the pilot was on conducting pen and ink revisions from the planner or engineer's office.

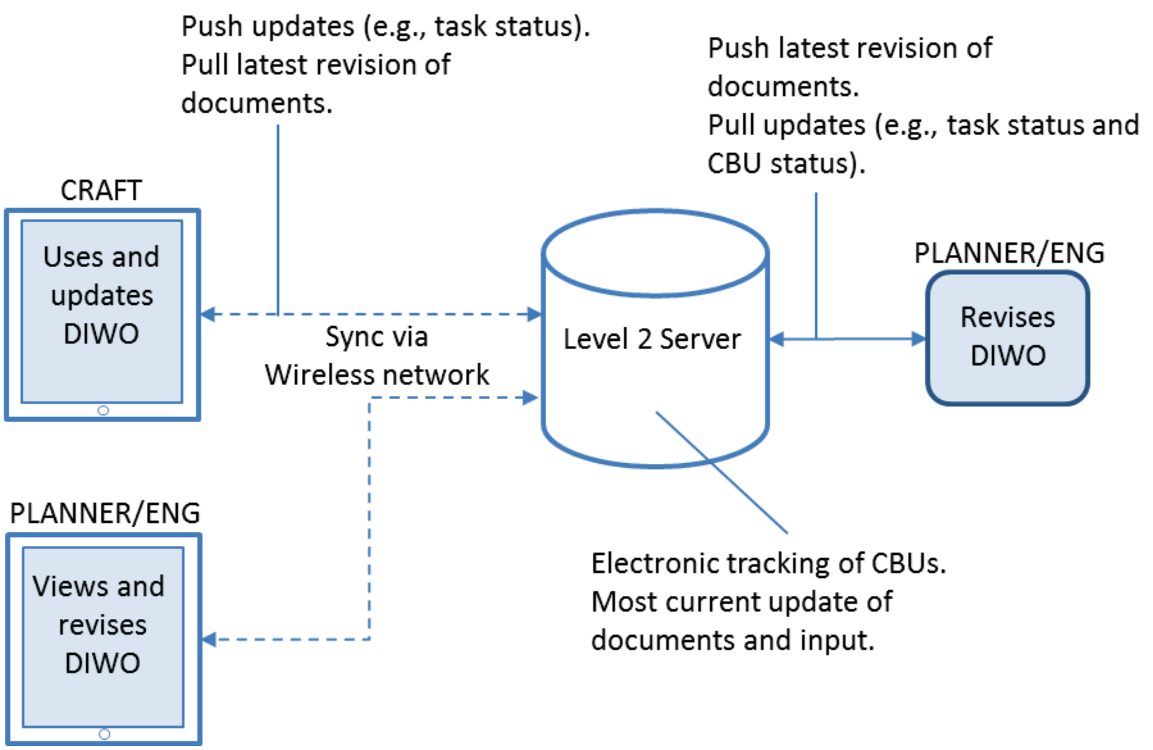

Figure 8. The required infrastructure for the pilot.

5.1.1 Prototype Development

To adequately demonstrate how the pen and ink process can be made more streamlined and efficient both a performance tool (i.e., the CBP to be used on a hand held device) and a DIWO authoring tool needed to be developed.

The prototype for the performance tool was developed based on the proven CBP design concepts. The new functionality added to support the plant design modification process were the ability to check out assigned work orders and to receive notifications when the DIWO was revised by the planner or engineer.

Figure 9 below illustrates the view of assigned work orders as presented to the worker in the field. Before starting work the worker needs to check out the work order associated with the task at hand. It the work order is already checked out by the worker, the worker only needs to load it. By clicking "Load" the worker will navigate to the selected work order and hence can start work.

Number/Task	Title	Status	User	
1213456-1	Backup Compressor Remote Surveilance	Checkedout	blyad	Load
1234568-1	Manual Startup of VI Compressors D,E, or F Using VI Compressor CMC Control Panel	Checkedout	hanste	
1234567-0	Maintenance Integrated Work Control Process	Checkedout	blyad	Load
1234569-0	Manual Shutdown and Isolation of VI Compressor D, E, or F Using VI Compressor CMC Control Panel	Ready		Checkout
1234599-0	Manipulation of VI Compressors Using VI Compressor ASC Computer	Ready		Checkout
2345678-1	Startup of Instrument Air Dryers	Ready		Checkout
2345679-3	Shifting Instrument Air Filters	Ready		Checkout
2345698-0	Shifting and Parallel Operation of Instrument Air Filter/Dryer Trains	Ready		Checkout
3216549-0	Aligning the VI System to Supply the VS System	Ready		Checkout
3321654-0	Backup Starting Air System Alignment for VI Compressors	Ready		Checkout
3214546-0	In Service Use of B/U VI Compressor 1	Ready		Checkout
2345678-0	Functional Test of B/U VI Compressor 1	Checkedout	oxstjh	

Figure 9. Overview of assigned work orders.

When the planner or engineer revise the DIWO and upload the new version to the server, the server will send the revised version to the handheld device in the field. The worker will receive a notification stating which revisions were made. Figure 10 shows an example of the notification and change log. As seen in this example, a reference document was added, step 6 was revised, and a new step was added.

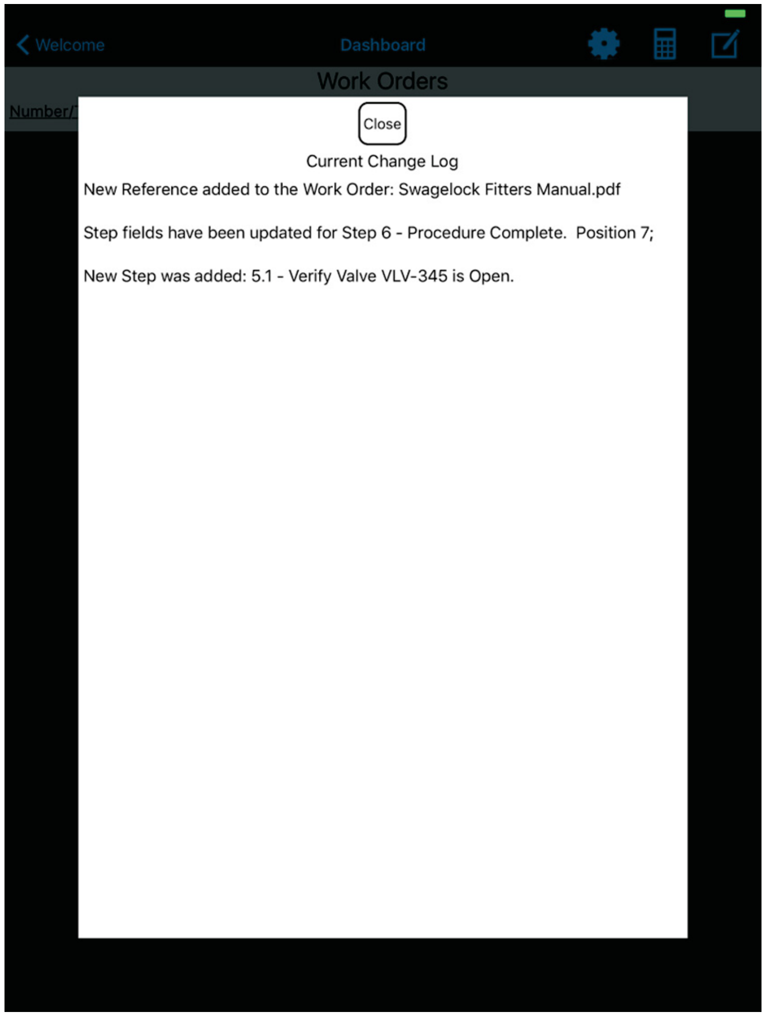

Figure 10. Example of notification and change log.

Another difference between the prototype developed for the plant modification process and the previously developed versions of the CBP prototype is the operating system and devices used. The approved operating system and devices at PVNGS are Apple's iOS and iPads. Hence, the researchers developed a prototype to be used on a 9.7 inch iPad Pro. The intended users for the performance tool are workers in the field executing the DIWO.

The authoring tool prototype was developed as a web-based system. The main intended users of the authoring tool are planners. However, the tool can be used by engineers to send revised CBUs back to the craft. The description of the authoring tool below is from a planner's perspective.

The first page the planner will see when logging on to the authoring tool is a list of all current action items, see Figure 11. This list contains both new work orders the planner is currently working on and work orders sent to the planner to revise.

Figure 11. View of planner's action items.

To make changes to a work order, the planner clicks the Edit button by the specific work order. This brings up a summary view. The planner can review which reference documents are attached to the work order as well as view an abbreviated view of the procedure steps. The authoring tool also provides information about the date the work order was created, by whom, and last time it was edited, see Figure 12. From this page the planner can add a reference export the work order (i.e., send it to the craft), delete the work order, and revise steps.

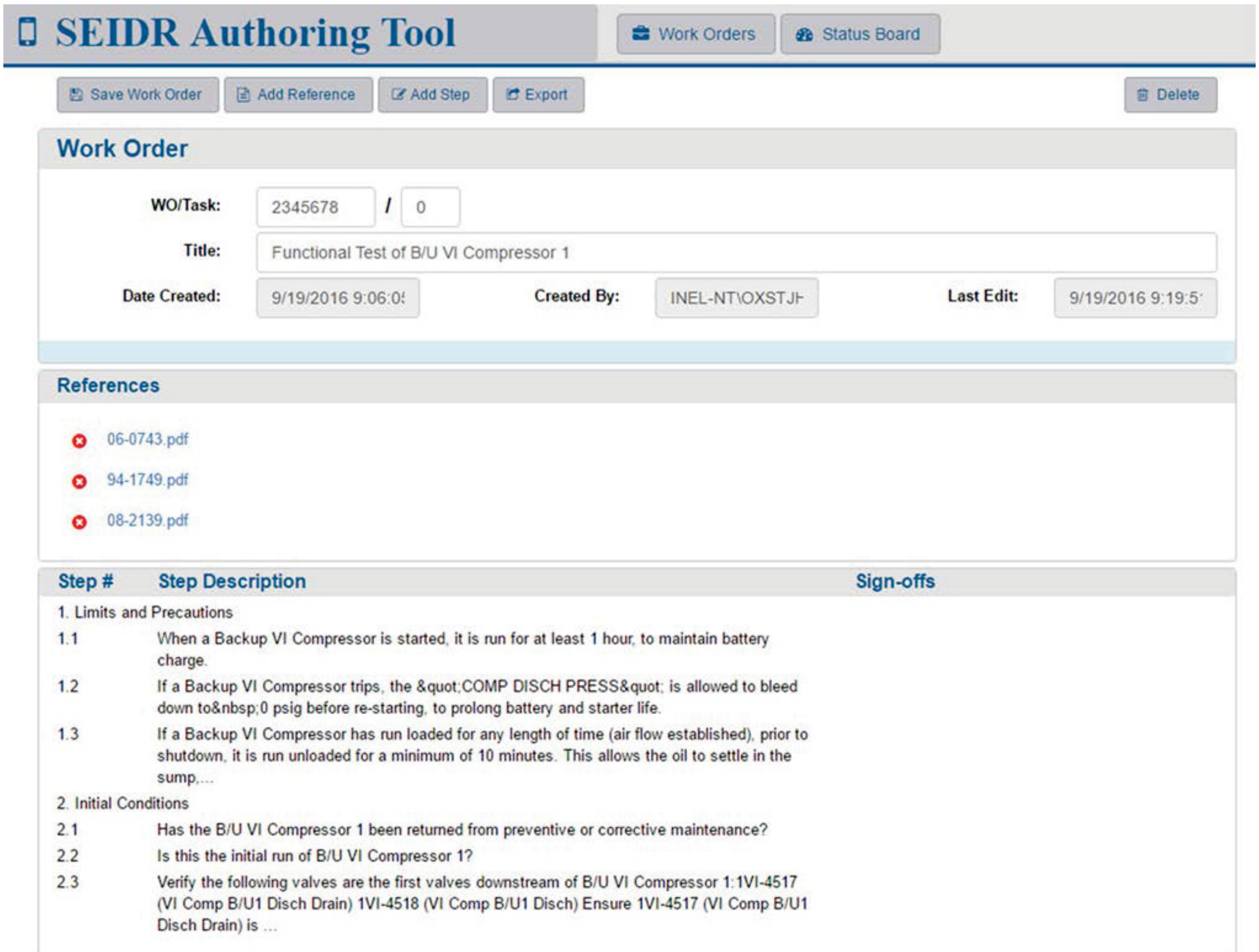

Figure 12. Summary view of selected work order.

To add, remove, or otherwise revise a step in the procedure, the planner clicks on the “Add Step” button. The system will navigate to a more detailed view of the procedure and its steps. As illustrated in the top part of Figure 13, the system provides context about the work order title and number at all times to ensure the planner knows which work order is currently being revised. In addition, in this view the system provides information about which steps has assigned sign-offs and references. The planner also gets information about what types of steps are used in the work order. In the example below, step both 2.1 and 2.2 are conditional (i.e., decision) steps indicated by the branching icon located between the step number and step description. Other types of steps that will be easily identified from this view are input, calculations, bulleted, and multi-action steps.

To add a step the planner clicks on a step number, which will bring up the menu shown in Figure 13. From this menu the planner can add a step, add a section title, manage references, copy and paste steps, and delete a step. Both Add Step and Add Section Title gives the planner the option to add the new item either above or below the current step (i.e., the step clicked on to access the menu).

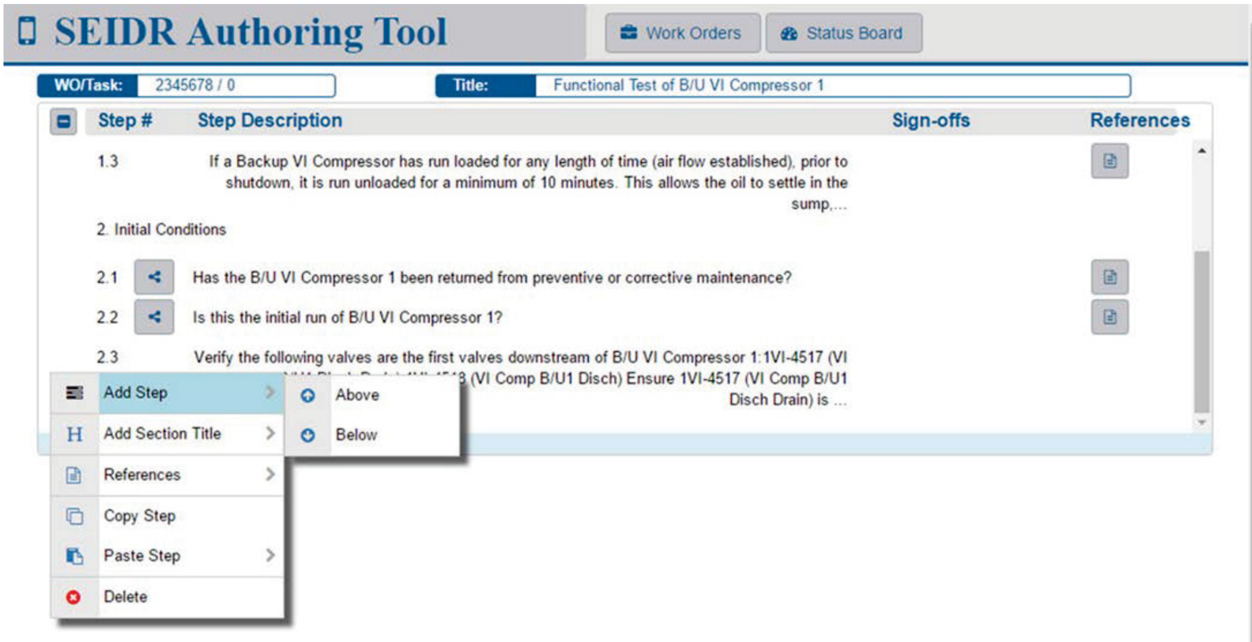

Figure 13. Menu used to revise work order.

When the option to add a step is selected the Step Inputs view is presented, as shown in Figure 14. From this view the planner can add step text, add sign-offs, assign certain roles (e.g., Operations, Maintenance, or Supervisor) to the sign-off, and add a correct component verification for a specific equipment or component. As soon as any information has been added, the system will remind the planner to save the changes.

In the example below, the planner decided to add an input step. This is done by selecting Input from the dropdown menu. The other step type options in this dropdown menu are Decision, Calculation, Bulleted, Multi-Action, and Informational steps. Depending on which step type is selected, the system will prompt the planner for additional information. For an input step, the planner will have to provide the type of input (e.g., text or numeric) and if there is a specific range the input needs to comply to. In this example, it is a numeric input to record the engine speed. The acceptable range is between 0-1500 rpm. After saving the new step it will be listed with an Input icon next to it, just like the step 3.1 above it which requires a text input of the person notified.

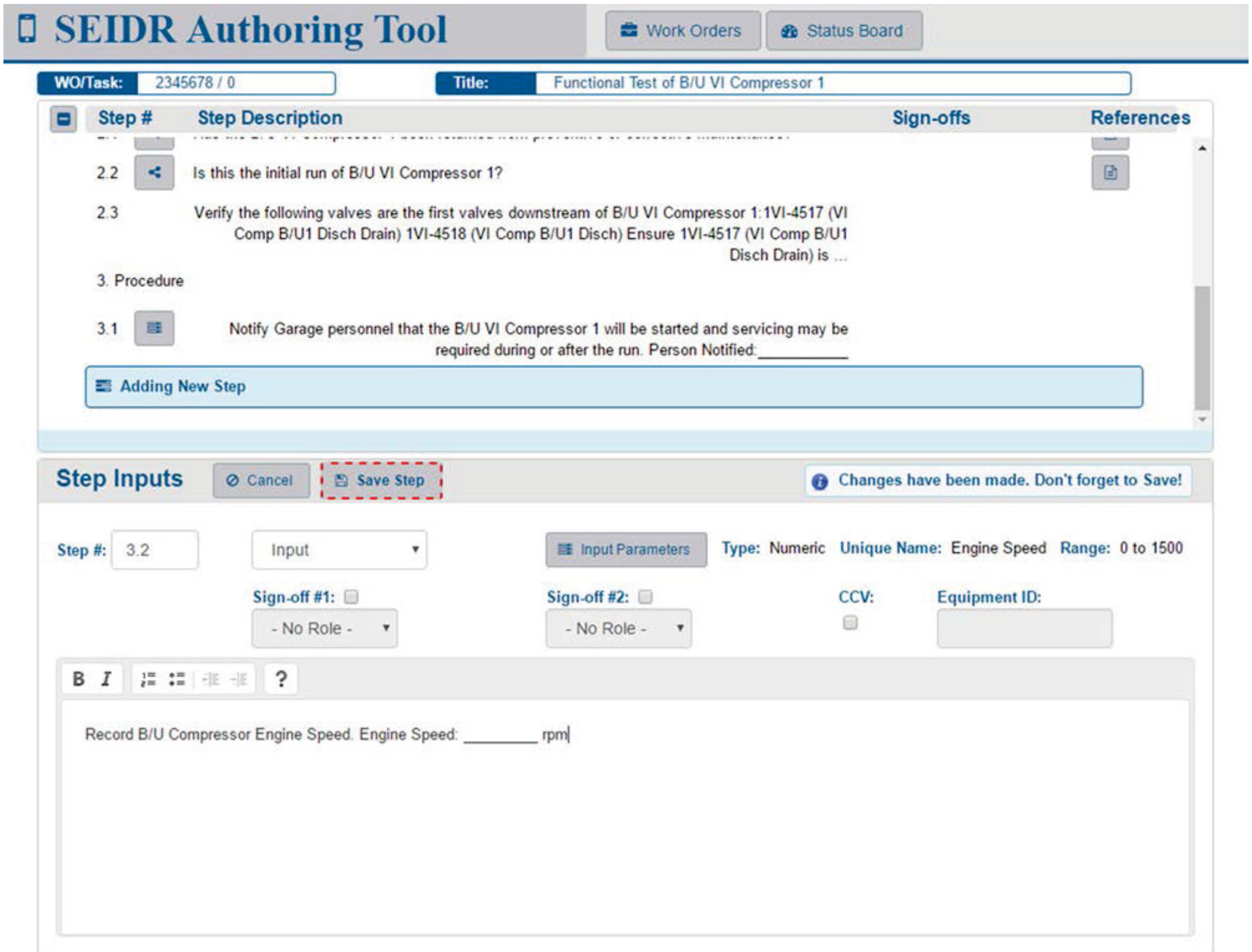

Figure 14. The step inputs view.

There are two different options to add a reference to a step. As shown in Figure 15, the planner can either upload a new reference document or assign a reference already used in the work order. There is also an option to view the references already linked to the step. When the planner selects the option to select a reference from the work order the authoring tool will display a list of all references used in the specific work order. The planner uses the list to select the references to be added to the step.

Managing references is the only editing functionality available to the engineer. After conducting a pen and ink revision to a CBU the engineer will remove the old document and upload the revised one. The engineer also has the ability to export the work order to the craft, which sends the work order including the new CBU to the worker in the field.

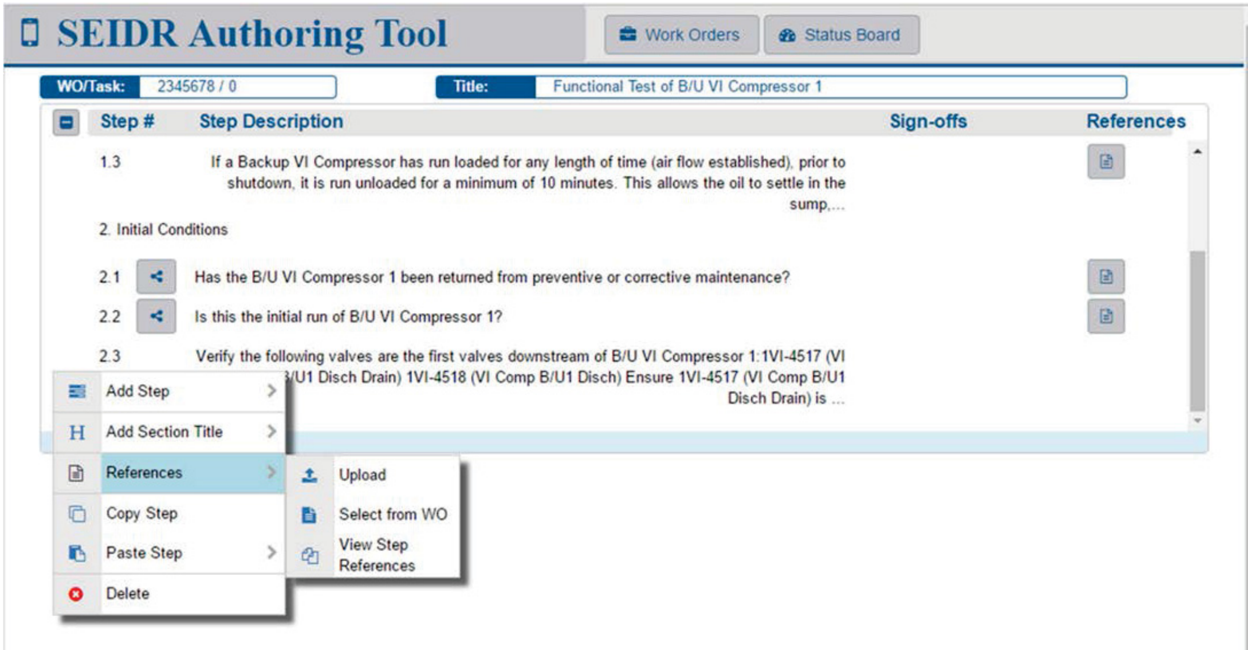

Figure 15. Reference management menu items.

In addition to creating or revising work orders, the authoring tool provides a status board, illustrated in Figure 16. The status board lists all work orders that have been checked out by the craft. From this view, the planner can see who checked out a specific work order. In addition, the planner will get status information such as whether the work is in progress and how many steps has been completed. Yellow indicates that a work order has been checked out by the craft while green indicates that the work packages has not yet been checked out.

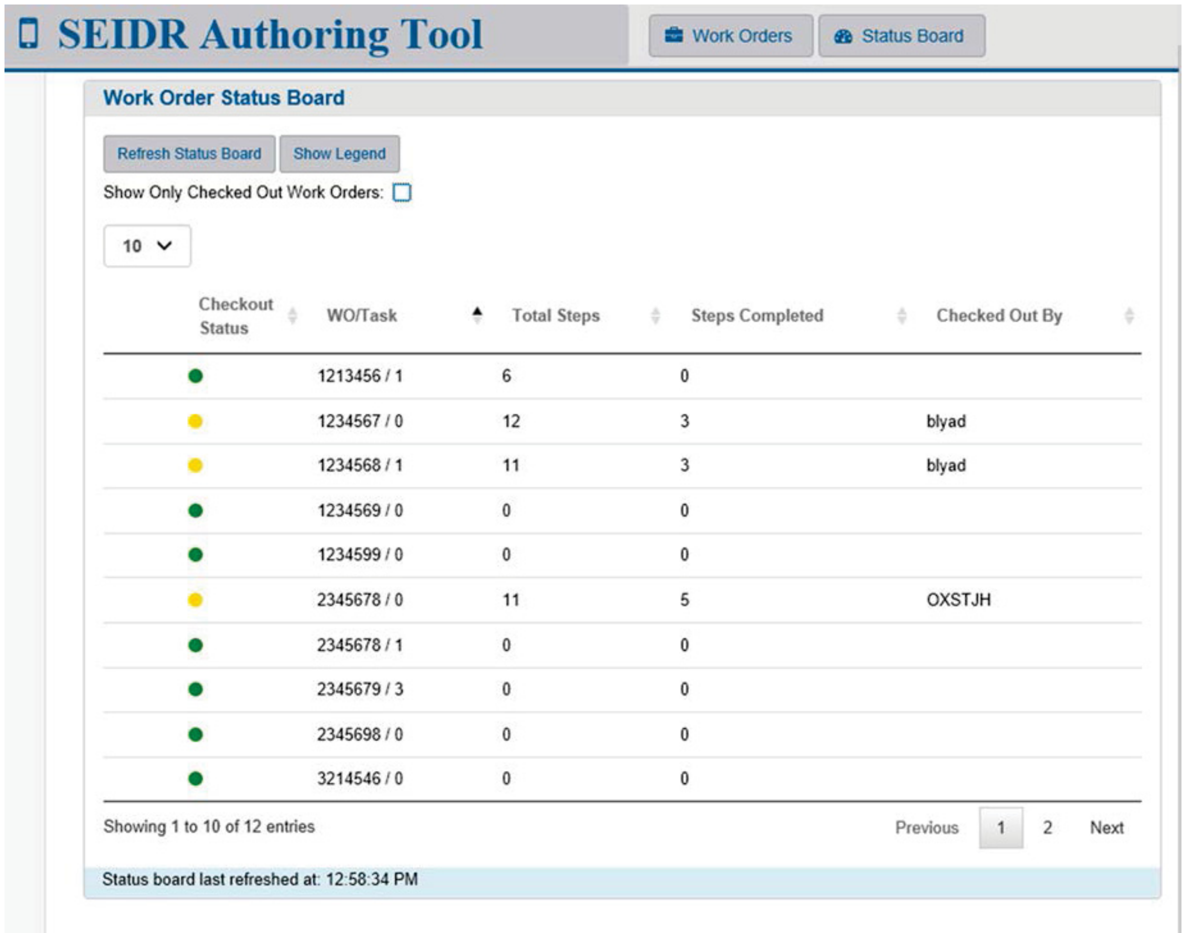

Figure 16. The status board view in the authoring tool.

5.1.2 Method

PVNGS hosted the pilot study in September 2016. The researchers demonstrated both the authoring tool and the performance tool in an office setting. Feedback was gathered from one planner and one engineer. Both participants were encouraged to provide feedback on functionality needed to even better support the pen and ink revision process.

No representative from the craft was involved in the pilot since the vast majority of design concepts used in the development of the performance tool have already been evaluated in prior research activities.

5.1.3 Results

The feedback gathered during the pilot was aggregated and summarized by categories. The feedback categories used are; General Feedback, Revision Management, Work Order Management, and Craft Specific Feedback.

5.1.3.1 General feedback

The web-based implementation of the authoring tool was greatly appreciated. Using a new application in a familiar web browser is perceived as less of a barrier than a new desktop application. Hence, the web-based interface will help reduce some of the resistance associated with the transition from the current work process of using templates in Microsoft Word to a new work process.

The planner should be able to easily render a copy of how the work order would look like on the mobile device while the work order is revised. The rendering functionality should be integrated in the authoring tool. It is not acceptable to have to download the instruction to a device before looking at it. It needs to be streamlined and easy.

The authoring tool needs to be connected with the work management system so that equipment lists and other work order related information can be automatically populated when the work order is created.

5.1.3.2 Revision management

There should be an option to select if the revision is a Pen and Ink or an amendment. Based on the selection the system should guide the planner through the required process. For example, in the case of an amendment the planner need to select the type of reviews and approvals needed as well as assigning reviewers.

Any steps that have been amended needs to be clearly marked in the work order. There should also be easy to identify which steps are associates with a specific amendment. Currently, a letter is added to the step number, e.g.., A.1, A.2, B.7, and B.9 to indicate if a step is a part of the A or B amendment.

5.1.3.3 Work order management

To streamline the creation of work orders there should be predefined templates in the authoring tool. There should also be a search or filter function to easily find the template applicable for the specific work order or work discipline the planner wants to write.

There should be an ability to save steps so they can be reused by the same planner later on.

It is nice to be able to insert new steps before or after exiting steps in the work order. However, it would be great if there was a “drag and drop” functionality to easily rearrange the steps.

Tables are very frequently used in the traditional paper-based work orders. Even though some of the current applications for tables will change when using a computerized work order, there is still a need to be able to create and edit tables.

An As Found value out of specification or range is usually not a cause to stop work. Most commonly, the more important value to check is the As Left. If the worker encounters an As Found value that is out of specification, then the worker should take the prescribed actions to ensure the As Left value is within specification. However, there are cases when the worker should be allowed to proceed with the task even if the As Left value could not be made to comply with the specification. In these cases, the worker should be required to provide a justification to why the task needs to progress. The worker should also be able to issue a condition report directly from the field using the performance tool.

The cross-reference of values, i.e., automatically populate previous recorded value, is a function which will provide great support to the worker in the field. Rather than searching for the previous step where the value was recorded, the worker will be able to focus on the active procedure step. The active step contains all the information needed to complete the step due to the cross-referenced value.

5.1.3.4 Craft specific feedback

Even though most of the work order can be conducted from the handheld device the worker needs to be able to print out specific parts of the procedure. For example, instructions or tables used for fabrication of a component should be printable. This type of fabrication can take a few days and the worker should not have to use the tablet at all times during this time.

For work orders with multiple sections which can be conducted in any order there needs to be an easy way to navigate between these sections. There should also be an indication about which of the sections are in progress, complete, or not started.

5.1.4 Future Work – Plant Design Modification Process

To better support the revision process associated with plant design modifications one should incorporate the feedback gathered during the pilot study. Other functionality which should be assessed are ways to improve communication between the craft and engineering, e.g., using marked up photos, sharing videos of plant conditions, or using video chat. The graphical user interface of the authoring tool should also be evaluated and revised accordingly to ensure a high level of human performance and efficiency gains. Both are important component when building a business case for the transition to a more dynamic computer-based work process.

6. FEEDBACK FROM FIELD EVALUATION STUDY AT PLANT VOGTLE

As mentioned in Section 1.1.3, a field evaluation study was hosted by Southern Nuclear Company Plan Vogtle 1 and 2. The methodology, prototype development, and the initial results are described in *Light Water Reactor Sustainability Program Automated Work Package Prototype: Initial Design, Development, and Evaluation* (Oxstrand et al., 2015a). The procedures used in Battery surveillances were incorporated into the prototype and then the mobile devices were left at the plant so that workers could use the CBP system and provide feedback on any features they thought were good, which needed improvement and any new features they thought could enhance performance.

One of the research team members met with Vogtle representatives in September 2016 to collect additional feedback on the CBP system from field workers. The feedback collection was conducted through unstructured interviews of the participants. A member from the Outage Planning Group and a representative from Plant Vogtle IT participated. Additional feedback was provided by a field worker (electrician) via email.

The field study was launched in the summer of 2015. Workers used the CBP system until there had been a change to the procedures which was not available in the CBP system. The research team was unaware of the change, hence the CBP was not updated to include the changes.

The feedback given was in general positive. As the two participants were not field workers they could only provide comments that the workers had expressed to them. Overall the workers had reported that the CBP was easy to use and performed well.

The workers liked the CBP system's ability to present readings or data previously recorded by the worker anywhere the procedure could be impacted by the recorded value. This reduced the need for the worker to have to go back through the procedure and search for the value. In a PBP this usually resulted in flipping back several pages and finding the recorded value and then returning to the current step being performed. This also eliminated the need to record certain values twice, once in a procedure step and again in an accompanying data sheet.

The participants were asked what, if any, obstacles based on their experience could impede the deployment of a eWP or CBP system at the plant. They expressed concerns about the ability to control revisions of the procedures and the ability to verify that the worker was using the correct released version of the procedure. Also concern regarding the time it would take to keep up with the constant changes that can occur in the procedures might be an obstacle. They suggested that an ability to pull the latest approved-for-work version of the procedure from their work management system might minimize the impact on the ability for the plant to adopt a CBP system.

7. FUTURE WORK - COMMERCIALIZATION OF CBP SYSTEM

The DOE's Office of Technology Transitions (OTT) works to expand the commercial impact of DOE's portfolio of research, development, demonstration and deployment activities. In February of 2016, OTT announced the first solicitation to the DOE National Laboratories for Technology Commercialization Fund (TCF) funding proposals.

The call for proposals were for projects in two topic areas;

- Topic Area 1: Projects for which additional technology maturation is needed to attract a private partner; and
- Topic Area 2: Cooperative development projects between a lab and industry partner(s), designed to bolster the commercial application of a lab developed technology.

The CBP researchers submitted a Topic 1 proposal with the purpose to bring the CBP prototype closer to commercialization. The proposal was supported by letters from Southern Company Services, Los Alamos National Laboratory, NextAxiom, and Transatomic Power Corporation. The proposal and the supporting letters are to be found in Appendix B and C. The proposal competed with 103 other applications. In June 2016, the DOE announced the decision to provide nearly $16 million in funding to support 54 projects at 12 national laboratories. The CBP proposal was one of the 54 projects to be funded. The project will start in October 2016 and must be completed in 12 months.

The project's goal is to reach a state in which INL's CBP system for work execution in the field is optimized for commercial use, which includes capabilities needed to increase plant efficiency, improve human performance during field work, improve plant design modification processes, and integrate with other plant systems (e.g., component databases, scheduling software, and work management systems).

The CBP research team at INL has identified how best to design a CBP system that will deliver the intended benefits of increased efficiency and improved human performance. Currently, no commercial "off-the-shelf" technology exists for the type of highly dynamic CBP system that is being investigated. There are no products available on the market that target both work orders/procedures used by field workers and engineers. There is a need to support plant engineers' design modification processes, which will result in cost savings for the utilities. Several utilities are interested in collaborating to achieve this end result. The letters of support confirm the need for this capability within the nuclear industry.

The commercial nuclear industry needs to reduce operation and maintenance costs in order to continue operating in competitive energy markets. A viable electronic work order system that meets all of the needs summarized in this proposal would increase the amount of time devoted to conducting work while reducing waiting time and administrative burdens. Maturing the CBP technology to the point at which it can enable commercialization of a dynamic electronic work package system will enable more effective and efficient completion of work in the nuclear power industry.

Within 12 months, INL will reach a state at which the CBP system is optimized for commercial use. The system will support work execution in the field using computer-based dynamic instructions, which includes the communication with necessary plant systems (e.g., component databases, scheduling software, and work management systems). The system will also have capabilities to support other instruction-driven tasks, such as plant design modification work orders and security surveillance.

INL's team will be collaborating with both the nuclear industry and with vendors to gain a deeper understanding of industry needs, existing vendors and their products, and how to design INL's system to be compatible with existing products as well as support technology advancements in the industry.

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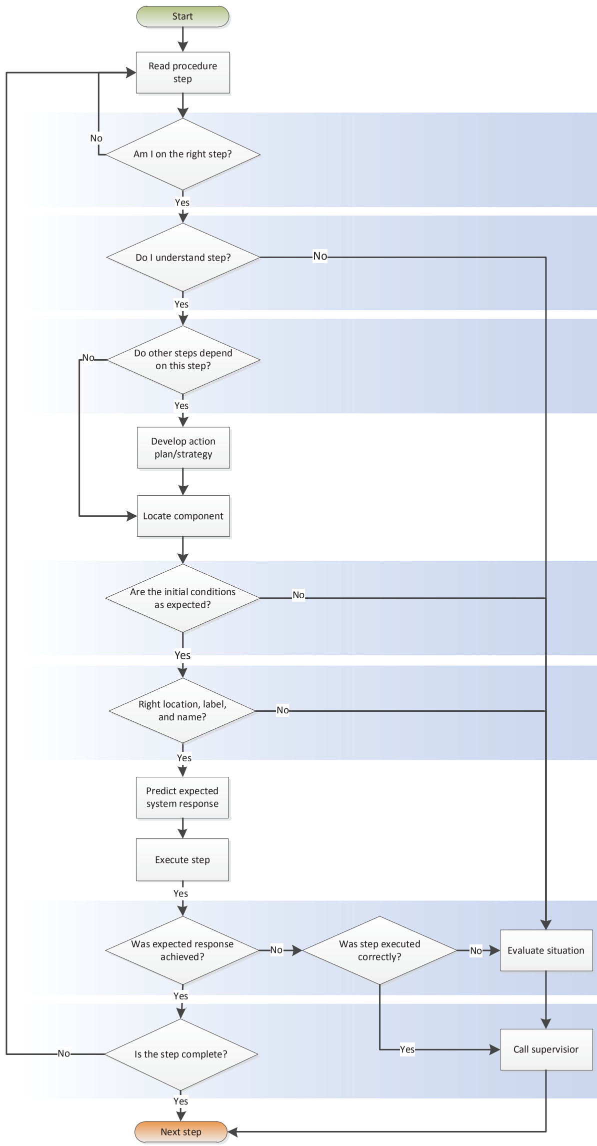
Appendix A

Model of Procedure Usage



Technique	Conditions that must be satisfied to ensure task success	Cognitive factors that determine task success or failure
Locate place-keeping function on page	Visibility of place-keeping function	Visual search: Number of distracters and saliency of those distracters
• Identify actions to be taken • Compare actions to mental model	• Understanding of constrained language • Complexity of step logic • Accuracy of mental model	• Working Memory • Long-term Memory
Identification of cues that signal dependency (i.e., warning)	• Existence of cue that signals dependency • Visibility of cue	• Prospective Memory • Salience of cues
Compare expected conditions to actual conditions	• Accuracy of mental model that dictates expected conditions • Detection of cues that indicate departure from expected conditions	• Salience of cues that indicate departure of expected conditions • Long-term Memory
Compare location, label, and equipment description in procedure to those on the actual equipment	• Ability to correctly read both the procedure and the equipment information • Ability to integrate the values/text read and compare them accurately	• Text comprehension • Working Memory
Compare expected conditions to actual conditions	• Accuracy of mental model that dictates expected conditions • Detection of cues that indicate departure from expected conditions	• Long-term Memory • Salience of cues that indicate departure of expected conditions
Check for indications that there are more parts to the step (e.g., was the current action a sub-step?)	• Existence of indications that signal the step is not complete • Visibility of indications that step is not complete	• Prospective Memory • Salience of cues

Appendix B

DOE Technology Commercialization Fund Proposal

Project Description

This project's goal is to reach a state in which INL's computer-based procedure (CBP) for work execution in the field system is optimized for commercial use, which includes capabilities needed to increase plant efficiency, improve human performance during field work, improve plant design modification processes, and integrate with other plant systems (e.g., component databases, scheduling software, and work management systems).

Nearly all activities that involve human interaction with nuclear power plant systems are guided by procedures, instructions, or checklists. Paper-based procedures currently used by most industries have a demonstrated history of ensuring safety; however, improving procedure use could yield significant savings in increased efficiency, as well as improved safety through human performance gains. The nuclear industry is constantly trying to find ways to decrease human error rates, especially human errors associated with procedure use. As a step toward the goal of improving procedure use performance, the U.S. Department of Energy Light Water Reactor Sustainability (LWRS) Program researchers, together with the nuclear industry, have been investigating the possibility and feasibility of replacing current paper-based procedures with CBPs. A prototype CBP system has already been developed and evaluated. The initial purpose of the CBP system was to evaluate different design concepts. Additional functionality was added to the original CBP system, which now rivals, and in some aspects, outperforms the current "off-the-shelf" products. The purpose of this project is to optimize our existing CBP tool and demonstrate it in a commercial application, with a utility sponsor providing in-kind assistance.

A CBP is defined as a dynamic electronic presentation of a procedure that guides the worker seamlessly through the logical sequence of pre-determined steps. In addition, the CBP system makes use of the inherent capabilities of the technology, such as incorporating computational aids, easy access to additional information (e.g., drawings, procedures, and operational experience), just-in-time training at the job location in the field, and digital correct component verification. 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 "off-the-shelf" products. A CBP system offers a more dynamic means of presenting procedures to the worker and displaying only relevant steps based on operating mode, plant status, and tasks at hand. A dynamic presentation of the procedure guides the worker down the path of relevant steps based on the current conditions. This feature will reduce the worker's workload, and inherently reduce the risks of incorrectly marking a step as not applicable and of incorrectly performing a step that should be marked as not applicable.

Context-driven job aids, such as corrective action documentation, drawings, photos, and just-in-time training are accessible directly from the CBP system as needed. One obvious advantage is reducing the time spent searching for applicable documentation. Furthermore, human performance tools are embedded in the CBP system in such ways that they let the worker focus on the task at hand 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.

The CBP research targeted questions related to how best to design a CBP system from a human factors perspective. The researchers were taking the concept of CBP further than the vendors' existing electronic work package and procedure systems. The researchers are exploring ways to use the advanced technology to design a CBP system to include dynamic presentation of the procedure content, context driven job aids, and integrated human performance tools. All of these innovations would help the worker focus on the task at hand rather than the tools. The whole system is developed from a user perspective and is proven to increase efficiency and improve human performance.

The research has yielded valuable results supporting the hypothesis that a well-designed CBP system can improve efficiency, safety, and human performance. The researchers provided results that support the industry and vendors in moving toward CBP systems that encompass more advanced capabilities, as well as provided the basis of a sound business case for transitioning to a CBP system.

Technology Maturity

Field studies (conducted in 2014–2016) resulted in a Technology Readiness Level of 5. In order to move to a TRL 6 and higher, the CBP software needs to be revised from being a research tool to a production-quality product that can be field demonstrated in an actual operating environment.

Reducing worker workload using CBPs requires a balance among automation and decision support, worker engagement, and the procedure execution process. The high-level solution to the problem is to provide information to the worker about completed steps, steps marked not applicable, future steps, and decisions made that influence the path through the procedure. The key functionality of the prototype CBP system includes automatic place keeping, simplified step logic, automatic correct component verification, and an intuitive user interface.

The researchers have developed a system that ensures a high level of human performance and system efficiency while requiring minimal training. Three evaluation studies were conducted in training facilities at collaborating nuclear utilities using actual field workers as participants: Arizona Public Service's (APS) electrical laboratory, Duke Energy's flow loop facility, and APS's instrumentation and control laboratory (Oxstrand, Le Blanc, & Bly, 2013). In addition, four field evaluation studies have been conducted at nuclear power plants operated by APS, Duke Energy, Pacific Gas and Electric, and Southern Nuclear (Oxstrand & Le Blanc, 2014; Oxstrand, Al Rashdan, Le Blanc, Bly, & Agarwal, 2015; Oxstrand, Le Blanc, Bly, Medema, & Hill, 2015). In each field study, a small set of procedures was converted to the CBP system and then used by the field workers during normal operation for a couple of months. The field workers then provided feedback to the researchers about the system's usability and potential areas of improvement.

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 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.

Thomas, K., Lawrie, S., & Niedermuller, J. (2015). *Advance Instrumentation, Information, and Control System Technologies - Pilot Project Technology Business Case: Mobile Work Packages*. Idaho National Laboratory (INL/EXT-15-35327).

Commercial Impact

The CBP research team at INL has identified how best to design a CBP system that will deliver the intended benefits of increased efficiency and improved human performance. Currently, no commercial "off-the-shelf" technology exists for the type of highly dynamic CBP system that is being investigated. There are no products available on the market that target both work orders/procedures used by field workers and engineers. There is a need to support plant engineers' design modification processes, which will result in cost savings for the utilities. Several utilities are interested in collaborating to achieve this end result. Letters of support from Transatomic Power Corp., Southern Company, Los Alamos National Laboratory, and NextAxiom confirm the need for this capability within the nuclear industry. (Appendix B)

The commercial nuclear industry needs to reduce operation and maintenance costs in order to continue operating in competitive energy markets. A viable electronic work order system that meets all of the needs summarized in this proposal would increase the amount of time devoted to conducting work while reducing waiting time and administrative burdens. Maturing the CBP technology to the point at which it can enable commercialization of a dynamic electronic work package system will enable more effective and efficient completion of work in the nuclear power industry.

Thomas, Lawrie, and Niedermuller developed a business case for highly dynamic electronic work orders for the nuclear industry. They conclude that approximately $3.5 million ($3.3 million of harvestable labor savings and $0.2 million of non-labor savings) can be saved annually by using an electronic work package system, which would allow an investment of over $20 million in present terms (Thomas, Lawrie, & Niedermuller, 2015). The main cost-saving opportunities identified in the business case are from reduced human errors and a more streamlined work process. The CBP field study at Southern Nuclear was used as the basis for the business case. The business case focused on a system for field workers and maintenance technicians. By adding capabilities to support other organizations and activities, such as chemistry activities in the field, engineering's plant design modifications, and plant surveillance, the annual savings will be even greater.

Project Plan

Within 12 months, INL will reach a state at which the CBP system is optimized for commercial use. The system will support work execution in the field using computer-based dynamic instructions, which includes the communication with necessary plant systems (e.g., component databases, scheduling software, and work management systems). The system will also have capabilities to support other instruction-driven tasks, such as plant design modification work orders and security surveillance.

INL's team will be collaborating with both the nuclear industry and with vendors to gain a deeper understanding of industry needs, existing vendors and their products, and how to design INL's system to be compatible with existing products as well as support technology advancements in the industry.

It is important to involve end-users in the testing phase to gather their feedback about system usability and design and make sure the system will be of great value to the industry. Another identified challenge is related to linking the CBP system with plant systems and databases. To ensure efficiency gains and cost savings to the utility, there is a need to connect and communicate with systems such as component databases, scheduling tools, and the work management system. The researchers will collaborate with a nuclear utility to address these challenges. A working prototype already exists, and there is minimal risk of not achieving the optimization and connectivity goals outlined in this proposal.

Appendix C

Letters of Support

TRANSATOMIC
POWER
CORPORATION

U.S. Department of Energy
Office of Technology Transitions

Subject: FY16 Technology Commercialization Fund Laboratory Call, Computer-Based Procedures

To Whom it May Concern:

This letter is to express Transatomic Power Corporation's need for a dynamic electronic work package system. As we develop the next generation of molten salt reactors it will be very beneficial to be able to transition from the current industry practice of paper-based work instructions to a computer based system using tablets of other electronic devices. Accurate, up-to-date, work instructions, along with human performance tools, ensure safety and task success; however, leveraging the capabilities of digital technology for these work instructions will drastically improve efficiency and task performance. Moving to a digital system will enhance our ability to recruit and retain the next generation workforce by providing them with tools that are consistent with the latest available technology.

Idaho National Laboratory (INL) has demonstrated a computer-based procedures (CBP) concept in which the content in the procedure updates based on the current situation and information to allow the worker to focus on the task at hand rather than spending a great effort on understanding the procedure and its content. With the CBPs the stack of papers may be reduced to the size of a small tablet or even a smart phone. Instead of navigating through a maze of cross-references, CBPs enable intelligent work path navigation which accounts for past decisions and observations, thereby enabling more efficient and safe task completion. We are especially interested in the following system capabilities:

- Tracking and trending of recorded data
- Validations of calculations and recorded data
- Efficient revision processes
- Correct component verification using component tags using, for example, barcodes, RFID, or Optical Character Recognition
- Easy access of additional information, such as drawings, operational experience, photos, and videos.

Currently, no electronic work package system available from vendors offers these dynamic capabilities. There is a gap in what industry needs to improve workforce efficiency and what is on the market. It would greatly benefit Transatomic Power and the nuclear industry as whole if this technology were made commercially available. Transatomic Power is very interested in participating in next year's Topic 2 request for proposals and looks forward to the possibility of working with INL.

Sincerely,

Leslie Dewan

Dr. Leslie Dewan, CEO

Eric Jurotich
Southern Company Services
42 Inverness Center Parkway
Birmingham, AL 35242
esjuroti@southernco.com
(205) 992-5276

To Whom It May Concern:

This letter is to express Southern Nuclear's need for a dynamic electronic work package system. At Southern Nuclear, we use paper-based work instructions for a variety of activities on a daily basis. These work instructions, along with human performance tools, ensure safety and task success. However, leveraging the capabilities of digital technology for these work instructions will drastically improve efficiency and task performance. It will also enhance our ability to recruit and retain the future workforce by providing them with tools that are consistent with the technology that encounter in their daily lives.

Idaho National Laboratory has demonstrated computer-based procedures (CBP) concepts in which the content in the procedure updates based on the current situation and information to allow the worker to focus on the task at hand rather than spending a great effort on understanding the procedure and its content. With the CBPs, the binder of paper instructions and supporting documentation will be reduced to a tablet device. Instead of navigating through a maze of cross-references, CBPs enable intelligent work path navigation enables more efficient and safe task completion.

CPB's will be especially useful on the most critical work, ensuring that the correct path through the procedure is taken based on readings, performing calculations accurately, and providing a simplified means of sharing collected data with other systems.

Currently, none of the electronic work package systems available from vendors offer these dynamic capabilities. There is a gap in what industry needs to improve workforce efficiency and what is on the market. A system that extended the current commercial offerings by providing CBP functionality would greatly benefit Southern Nuclear, and the nuclear industry as whole, if it were to be made commercially available.

Sincerely,

Eric Jurotich
Principal IT Analyst

NextAxiom Technology, Inc.
600 Montgomery, 45th Floor
San Francisco, CA 94111
Phone: 415-393-1890

March 23, 2016

To Whom it May Concern:

NextAxiom Technology, Inc. is a direct supplier of an Electronic Work Package (eWP) solution that we initially created in a partnership with the US Department of Energy at Savannah River Site. Our Mobile Work Package (MWP) software solution is currently providing outstanding ROI benefits for the DOE sites at Savannah River and Los Alamos National Lab and we have just begun implementing our MWP at Idaho National Lab.

We are finding that nuclear facilities (DOE and Commercial) are readily adopting the first generation of eWP which eliminates the paper-based processes for creation and processing of the work package. Up to now the work task process has been automated but the actual work procedures are still grounded in static electronic documents in eWP. There is great interest within the DOE nuclear sites and commercial nuclear Utilities in taking the next logical step for eWPs which is computer-based procedures (CBP).

At a recent NEWPER meeting we met members of the Idaho National Laboratory research team and saw a demonstration of a CBP prototype in which the procedure updates electronically based on the current situation and provides information which allows the craft worker to focus on the particular task rather than spending time and effort interpreting the procedure and its content.

We are planning to incorporate CBP in a future version of our MWP product and are looking to help commercialize CBP capabilities. We believe that CBP will greatly improve workforce efficiency and safety. CBPs enable intelligent work path navigation while accounting for past decisions and observation, so it enables more efficient and safe task completion.

We encourage continued research by Idaho National Lab that can lead to a viable CBP product that can be incorporated into the first generation of eWP products currently installed.

Should you have any questions, please do not hesitate to contact the undersigned directly.

Yours truly,

Ash Massoudi, CEO
NextAxiom Technology, Inc.
Phone 650-996-0825

Oxstrand, Johanna H <johanna.oxstrand@inl.gov>

Dynamic Procedures at LANL

1 message

Smith, Adam Wesley <awsmith@lanl.gov> Wed, Mar 23, 2016 at 3:38 AM
To: "Berl, Frederick John" <fberl@lanl.gov>
Cc: "Oxstrand, Johanna H" <johanna.oxstrand@inl.gov>

Maintenance & Site Services
Maintenance Manager, Work Control
Los Alamos National Lab

Mr. Fred Berl,

This memo is to express Los Alamos National Lab (LANL) need for a dynamic electronic work package system. At LANL, we use both paper-based work instructions and electronic work package for a variety of activities on a daily basis. These work instructions, along with human performance tools, ensure safety and task success; however leveraging the capabilities of digital technology for these work instructions will drastically improve efficiency and task performance. It will also enhance our ability to recruit and retain the future workforce by providing them with tools that are consistent with the technology that they regularly encounter in their daily lives.

Idaho National Laboratory has demonstrated computer-based procedures (CBP) concepts in which the content in the procedure updates based on the current situation and information to allow the worker to focus on the task at hand rather than spending a great effort on understanding the procedure and its content. With the CBPs the stack of papers may be reduced to the size of a small tablet or even a smart phone. Instead of navigating through a maze of cross-references, CBPs enable intelligent work path navigation which accounts for past decisions and observation, thereby enabling more efficient and safe task completion.

Specifically, we are interested in expanding the use of our electronic mobile work package system by using dynamic procedures for the following:

- Tracking and trending of recorded data
- Validations of calculations and recorded data
- Coordination between worker in the field, verifiers, supervisors, and other craft
- Efficient revision process
- Automatic placekeeping
- Correct component verification using component tags (e.g., using barcodes, RFID, or Optical Character Recognition)
- Easy access of additional information (e.g., drawings, operational experience, photos, and

videos)

Currently, none of the electronic work package systems available from vendors offer these dynamic capabilities. There is a gap in what industry needs to improve workforce efficiency and what is on the market. It would greatly benefit LANL and the nuclear industry as whole, if this technology were made commercially available. Please contact me with any questions.

Thank you,

Adam Smith
Maintenance & Site Services
Central Work Control Team Lead
Los Alamos National Lab