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Revision 0

Evaluation of Computer-Based Procedure System Prototype

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EXECUTIVE SUMMARY

This research effort is a part of the Light-Water Reactor Sustainability (LWRS) Program, which is a research and development (R&D) program sponsored by Department of Energy (DOE) and performed in close collaboration with industry R&D programs that provides the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants. The LWRS program serves 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.

The introduction of advanced technology in existing nuclear power plants may help to manage the effects of aging systems, structures, and components. Advantages are being sought by developing and deploying technologies that will increase safety and efficiency. One significant opportunity for existing plants to increase efficiency is to phase out the paper-based procedures (PBPs) currently used at most nuclear power plants and replace them, where feasible, with computer-based procedures (CBPs).

Although CBPs have been investigated as a way to enhance operator performance on procedural tasks in the nuclear industry for almost 30 years, they currently are not widely deployed at United States utilities. Much of the previous research has focused on CBPs in the main control room for new plants with highly integrated systems. Adopting CBPs for older plant with less integrated systems poses many challenges that are not present in new plants. Additionally, CBPs for the main control room may be more challenging to implement than CBPs for field workers. Thus, the current research focuses on CBPs for field workers.

The long-term goal of the current research effort is to develop an industry-wide path forward for deployment of CBP systems, which includes guidance utilities can use in their discussions with potential vendors. The purpose of the guidance is to help ensure that CBP systems address the specific needs of the nuclear industry. The current short-term goals of the research effort are to develop a prototype and evaluate a CBP system based on requirements for CBPs used in the field. These requirements have been identified by the research team through a series of research activities including a literature review, qualitative analysis, user needs assessment, and the development of a model of procedure usage. These activities are described in detail in *Computer-Based Procedures for Field Workers in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements* (Oxstrand and Le Blanc, 2012). The research effort aims to move past the idea of simply displaying existing PBPs on an electronic device and to streamline and distill the information in the PBP to increase efficiency, improve the ease of use, and reduce opportunities for errors. The main focus of this report is to describe the development of an initial prototype CBP system based on requirements identified and the study conducted to evaluate the CBP prototype.

The model of procedure usage, which was developed in an earlier phase of the research effort, was used to guide the development of a mock-up CBP. The purpose of detailed mock-up was to ensure that everyone involved in the effort has the same mental model of the prototype CBP's graphical user interface. The

mock-up is also a great tool to ensure that the CBP features and functions will be implemented in a manner that meets the industry collaborating partners' expectations. The research team elicited feedback from the collaboration partners as well as other human factors researchers at the INL. The mock-up development was an iterative process in which feedback was continuously incorporated into subsequent versions of the mock-up.

Based on the model of procedure usage and the two sets of requirements identified earlier in the research effort as well as the mock-up the team selected functionalities to implement and which requirements to address in this first iteration of the prototype. The main focus was on context sensitivity, simplified step logic, automatic place-keeping, and automated correct component verification.

One of the main features of the CBP prototype is context-sensitivity. Context-sensitivity basically means that the CBP only presents steps that are relevant to the current conditions. For this version of the prototype the decision of what is relevant is made based on user input, however in the future, the CBP system can also use plant state and other available plant information to make this decision.

Another feature of the CBP prototype is simplified step logic. The prototype reduces the complexity of step logic by presenting If/then statements as a question regarding the conditions followed by condition-relevant instructions.

Automated Correct component verification is achieved by utilizing equipment barcodes and matching the equipment information to a database on the device. If the correct component is scanned, the operator is allowed to proceed with the procedure step.

Place-keeping is automatically conducted by the CBP system. The research team implemented a single step view, i.e. one procedure step is displayed at the time and only one step can be active at the time. When a step is completed the CBP system displays the next relevant step to be performed. This reduces the risk of unintentionally skipping steps.

The evaluation study was conducted in an electrical training lab on-site at Palo Verde Nuclear Generating Station (PVNGS). The evaluation study was designed to be an objective assessment of the initial CBP prototype. The main goal of the study was to gain input on how to improve the functionality and user interface of the CBP prototype. Another goal was an initial test of whether the CBP prototype offered any performance improvements over its paper-based counter-parts by directly comparing performance using the CBP and the PBP.

The evaluation study was focused on obtaining input on several specific aspects of the CBP interface that might have unintended consequences when actually used. For example, in order to make the procedure readable on a device as small as an iPod the prototype presents one procedure step per page. The researchers were concerned that this might affect the procedure performer's awareness of where they are in the overall context of the procedure. The materials used in this study were designed to elicit specific feedback on several potential consequences of introducing new technology.

Researchers compared performance between the CBP prototype and the traditional PBP using both objective measures (deviations from optimal procedure path and time to complete the scenario) as well as a subjective workload assessment. Additionally, researchers elicited feedback regarding the usability of the CBP interface.

The participants in the evaluation study were 13 technicians Palo Verde Nuclear Generating Station (PVNGS). The procedure used in the evaluation study was a plant procedure for “racking out a breaker” adapted for use in PVNGS’s electrical training lab. The use of a training lab in the evaluation study allowed for a realistic setting, in which technicians could take actions on the equipment without affecting the plant.

In addition to objective measures mentioned above, researchers used several surveys to assess the CBP prototype. Computerized interfaces are typically intended to ease workload for the user; however interface management tasks can actually increase workload rather than decrease it (O’Hara, 2002). In order to assess the workload associated with using the CBP prototype compared with the traditional PBPs, researchers used the NASA TLX (Hart & Staveland, 1988). The research team developed their own usability survey to assess the interface of the CBP prototype. The 8-item survey targeted the availability of information, ease of navigation, and ease of use of the CBP interface. The research team developed a 6-item usability survey to assess the usability of the device (in this case, the iPod). The research team also developed a debrief questionnaire to gain more detailed feedback on the design of the user interface and the overall experience using the CBP. The questions on this survey were open-ended.

The most important finding in this evaluation study is that technicians were able to successfully execute a procedure with the CBP prototype. Additionally, successful execution of the procedure with the CBP occurred with minimal training, indicating that the CBP interface is easily learned and relatively intuitive to use. Another important finding is that the main feature of the prototype (i.e., context-sensitivity) was well-received by the participants and utility partners. All the participants preferred the context sensitive procedure over the current PBPs. The context-sensitivity is an important innovation of this research effort, and is therefore a topic that the research team will continue to refine and improve.

Moving forward the research effort will conduct two additional major studies in collaboration with two different utility partners within the first half of FY13. One of the overarching objectives for both of the planned studies is to keep exploring the concept of context-sensitive procedures. At this point in the research effort the focus will be on context-sensitivity based on user input, either from the field worker while executing the procedure or on information collected at the planning stage. The long-term objective is to look at context sensitivity based on real time plant status information. The research team together with the utility collaboration partners will define additional short-term goals and objectives based on the result from both studies. Future research activities to address these goals and objectives will be identified, planed, and conducted.

ACKNOWLEDMENTS

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The research team also wants to extend its gratitude to all the participants and others involved in the successful execution of the evaluation study.

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ACRONYMS

CBP	Computer-Based Procedures
CCV	Correct Component Verification
DOE	Department of Energy
FY	Fiscal Year
INL	Idaho National Laboratory
LWRS	Light-Water Reactor Sustainability
PBP	Paper-Based Procedures
PVNGS	Palo Verde Nuclear Generating Station
R&D	Research and Development
TLX	Task Load Index
XML	Extensible Markup Language

1. INTRODUCTION

This research effort is a part of the Light-Water Reactor Sustainability (LWRS) Program, which is a research and development (R&D) program sponsored by Department of Energy (DOE) and performed in close collaboration with industry R&D programs that provides the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants. The LWRS program serves 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.

The introduction of advanced technology in existing nuclear power plants may help to manage the effects of aging systems, structures, and components. In addition, the incorporation of advanced technology in the existing LWR fleet may entice the future workforce, who will be familiar with advanced technology, to work for these utilities rather than more newly built nuclear power plants. One significant opportunity for existing plants to increase efficiency is to phase out the paper-based procedures (PBPs) currently used at most nuclear power plants and replace them, where feasible, with computer-based procedures (CBPs).

PBPs have ensured safe operation of plants for decades, but limitations in paper-based systems do not allow them to reach the full potential for procedures to prevent human errors. The environment in a nuclear power plant is constantly changing, depending on current plant status and operating mode. PBPs, which are static by nature, are being applied to a constantly changing context. This constraint often results in PBPs that are written in a manner that is intended to cover many potential operating scenarios. Hence, the procedure layout forces the operator to search through a large amount of irrelevant information to locate the pieces of information relevant for the task and situation at hand, which has potential consequences of taking up valuable time when operators must be responding to the situation, and potentially leading operators down an incorrect response path. Other challenges related to use of PBPs are management of multiple procedures, place-keeping, finding the correct procedure for a task, and relying on other sources of additional information to ensure a functional and accurate understanding of the current plant status (Converse, 1995; Fink, Killian, Hanes, and Naser, 2009; Le Blanc, Oxstrand, and Waicosky, 2012).

Although CBPs have been investigated as a way to enhance operator performance on procedural tasks in the nuclear industry for almost 30 years, they currently are not widely deployed at United States utilities. The existing CBP research tends to have a strong emphasis on procedures for new designs and highly integrated systems. However, the current NPP fleet does not have the same level of integrated systems as new builds, and the implementation of completely new systems, such as a standalone CBP system, into the existing plants can be very costly. This is one of the reasons why it can be difficult for the nuclear industry to adapt the research conducted for CBPs in highly integrated systems into the existing plant systems. Therefore, the requirements of CBPs use, design, and implementation will be different for the current fleet than for new-builds. The existing fleet needs guidance on ways to incorporate the use of CBPs with the existing systems.

The existing research also has a focus on CBP systems for operations in the main control room, and more specifically on emergency operating procedures. There has been very little research conducted that focuses on CBPs for field workers and how research can help these field organizations to increase their efficiency and improve human performance. Utilities have expressed a need for research tailored to the specific needs of field workers, because the limitations of PBPs are particularly relevant for fieldwork. For example, the field worker has to travel from the job site to the office location each time procedures need to be signed off by the supervisor. Another example is the case of encountering something unexpected. The field worker must make a note, either mentally or on a piece of paper, and then return to the office to explain the situation to the supervisor and to receive instructions on how to proceed. All this travelling between the field and the office location takes time away from the field worker's assigned tasks. A system that allows the field worker to communicate with the supervisor and other relevant personnel as well as provide the ability to access supplemental information at the work site rather than back at the office location will be very beneficial for all different types of field worker organizations at nuclear plants.

The long-term goal of the current research effort is to develop an industry-wide path forward for deployment of CBP systems, which includes guidance for utilities to use in their discussions with potential vendors. The purpose of the guidance is to help ensure that the end product (i.e., the CBP system) addresses the specific needs of the nuclear industry. CBP systems have been around for many years, but almost no nuclear utilities use them. The existing CBP systems are tailored to other industries, such as medical, military, and aerospace. Each industry has different expectations of procedure use and adherence as well as different requirements of levels of detail in the procedure. Hence, this research effort aims to develop guidance that the nuclear utilities can use to ensure that the system will be tailored to meet the specific needs of the nuclear industry. The path to reach the long-term goal consists of several short-term goals, which are described in Figure 1. Additional short-term goals will be defined until the long-term goal is achieved.

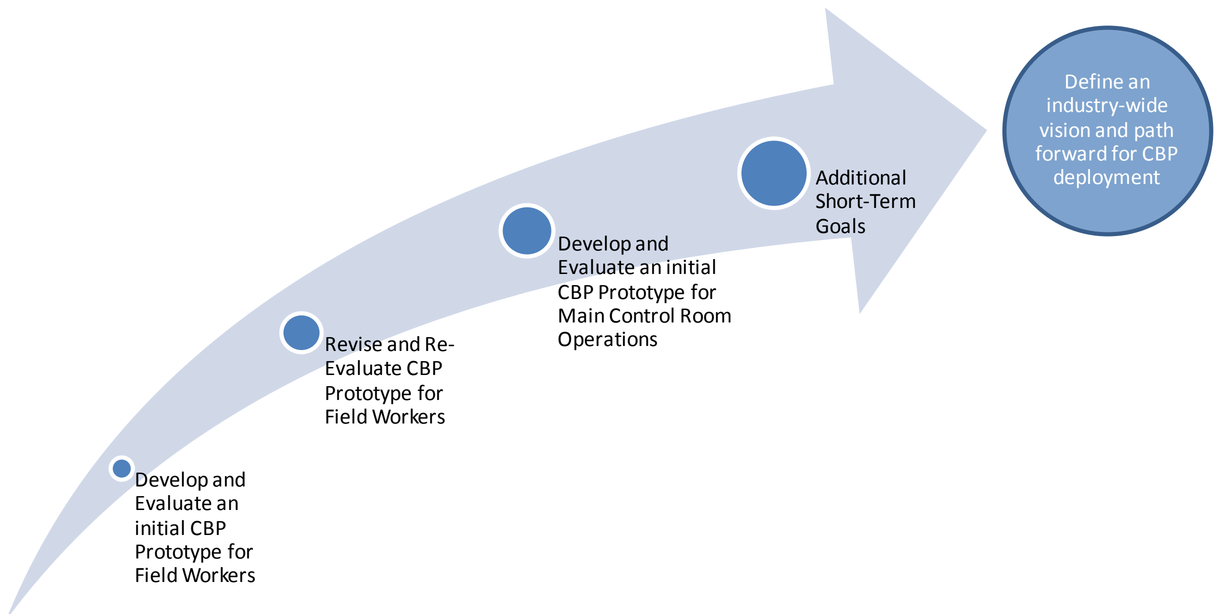


Figure 1. The Path to the Long-Term Goal

The current short-term goals of the research effort are to develop a prototype and evaluate a CBP system based on requirements for CBPs used in the field. The research team has identified these requirements through a series of research activities, including a literature review, qualitative analysis, user needs assessment, and the development of a model of procedure usage. These activities are described in detail in *Computer-Based Procedures for Field Workers in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements* (Oxstrand and Le Blanc, 2012). The purpose of the effort is to further refine the identified requirements to ensure that the CBPs are an improvement over current PBPs. The overall goal of this research effort is to move past the idea of simply displaying existing PBPs on an electronic device and to streamline and distill the information in the PBP to increase efficiency, improve the ease of use, and reduce opportunities for errors.

The research activities conducted in FY12 address the four objectives depicted in Figure 2. This report will briefly describe the activities conducted earlier this year to meet the first two objectives. This summary is provided in Section 1.1 below.

The focus of this report is to describe the research activities conducted to address the remaining two objectives: develop a prototype CBP system based on requirements identified and evaluate the CBP prototype. The emphasis will be on the evaluation of an initial CBP prototype at a nuclear power plant.

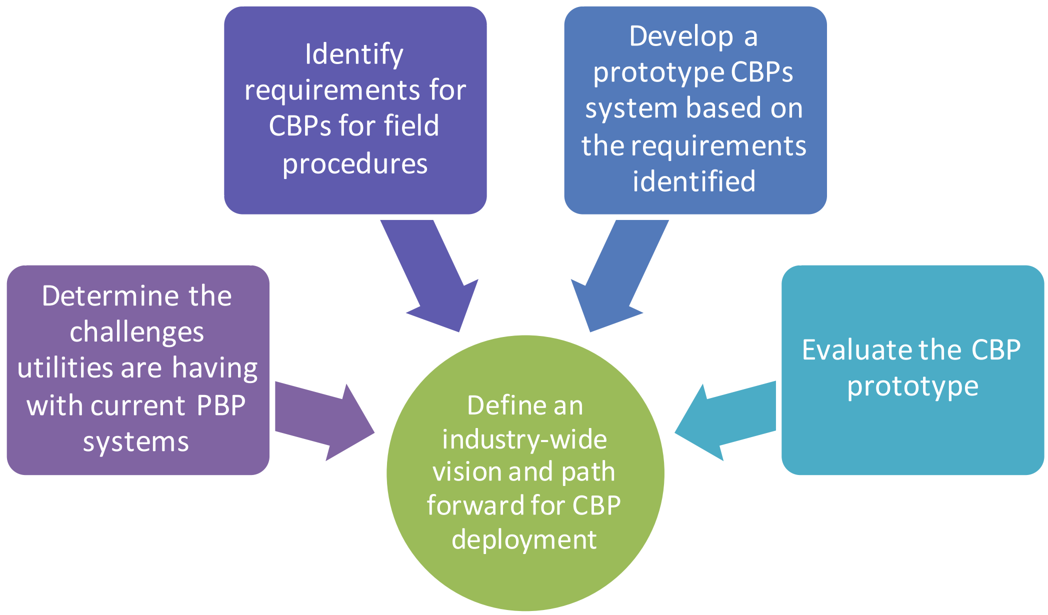


Figure 2. The Main Objectives for FY12

1.1 Summary of Previous Research Activities

This section will summarize the activities conducted to address the first two objectives. The activities conducted in relation to the remaining two objectives will be described in detail in Sections 2 and 3 of this report.

The first objective – determine the challenges utilities are having with current PBP systems – was addressed initially by a literature review of current and existing research related to CBPs and human factors. As a part of the literature review, the researchers also benchmarked existing and proposed CBP systems. The three main literature categories reviewed are 1) evaluation of CBPs, 2) nuclear industry documents focusing on procedure use and adherence, and 3) design, development, and review guidelines for CBPs.

The primary conclusion from the literature review is that there is a large gap between the existing literature and what is needed to address the nuclear industry's needs regarding design guidelines for CBPs. The existing research also does not sufficiently address CBPs for field workers.

The results from the literature review and the benchmark provided a framework for the qualitative study that was conducted to address the second objective – identify requirements for CBPs for field procedures. The primary purpose of the qualitative study was to develop a model of procedure usage that characterizes the current use of PBPs and highlights potential sources of errors that could be mitigated with CBPs. The model of procedure usage served to highlight the identified requirements for CBPs.

The qualitative study consisted of three information-gathering efforts: observations, interviews, and focus groups. The study was conducted over four days and involved participants from four nuclear power utilities and five research institutes.

During the observations, researchers collected information necessary to construct the model of procedure usage, including task flow and information flow. The research team observed individual turnovers, a shift brief, and pre-job brief. The researchers also observed two field operators performing rounds in the turbine building, service building, and outside areas including the cooling towers.

The researchers used the interviews to gain a deeper understanding of the process operators use to follow a procedure to further refine the model of procedure usage. The goal of the interviews was to understand what would cause the operator to deviate from the procedure, what would cause the operator to stop work and contact the supervisor, and what physical and cognitive functions are involved in the execution of a procedure steps. Fifteen semi-structured interviews were conducted, out of which ten interviews were with field operators and five with maintenance technicians.

The primary purpose of the focus groups was to discuss how technology can support field workers in their everyday work tasks. The focus groups also discussed requirements and functions that would need to be addressed to make CBPs on a mobile device useful for field workers. Thirty-four people participated in focus group discussions distributed throughout the course of the qualitative study.

The primary insight from the qualitative study was the need for a set of requirements and standards for CBPs that would guide the design of the CBP in a manner that would enhance the field workers' performance compared to PBPs. A CBP system that simply mimics PBPs and displays them on an electronic device would not be enough of an improvement to justify a migration to CBPs.

In addition to the qualitative study, a user needs assessment was conducted. The purpose of the user needs assessment was to gain a better understanding of the nuclear utilities' current plans for implementing CBPs, the current infrastructure in place to support CBPs, as well as the perceived or real barriers to implement CBPs systems. The focus group discussions in the qualitative study were an initial step to gain this understanding. The user needs assessment was designed to capture information needed to close gaps that remained after the qualitative study. The user needs assessment was conducted in the form of a survey. The survey was distributed to 15 individuals representing six nuclear power utilities.

The main finding from the user needs assessment was that there is substantial utility interest in implementing CBPs. All of the participating utilities reported that CBPs for field operators were part of their long-term vision. Sixty-six percent reported that CBPs for control room operators were in the long-term vision. Another finding is that the two most critical needs for utilities to move forward with a CBP project are 1) a set of standards and guidance for CBPs, and 2) a successful deployment of CBPs at another utility.

The research team developed a model of procedure usage based on the insights gained from the qualitative study. The purpose of the model is to identify the physical and cognitive actions involved in the execution of one procedure step, as well as potential error traps and what factors affect the risk of these human errors. The model consists of a detailed task flow describing the execution of one procedure step, decision making techniques, and the cognitive factors that influence the likelihood for success or failure. The research team used the model in both processes of identifying requirements for CBPs and prototype development.

Based on the literature review and an analysis of the model of procedure usage, the research team developed a set of general requirements for CBPs. The complete set of general requirements as well as the selection criteria used to identify them are presented in *Computer-Based Procedures for Field Workers in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements* (Oxstrand and Le Blanc, 2012). For example, the CBP should:

- Guide operators through the logical sequence of the procedure
- Ease the burden of place-keeping for the operator
- Make the action steps distinguishable from information gathering steps.

The research team developed a set of specific requirements based on review of existing CBP guidance. The full set of specific requirements is presented in *Requirements for Computer Based-*

Procedures for Nuclear Power Plant Field Operators (Le Blanc and Oxstrand, 2012a). Examples of these specific requirements are that the CBP should:

1. Be designed so that the operator controls the procedure pace.
2. Make calculations when the necessary information is available.
3. Alert users when procedure steps or conditions are at risk of being violated.

The two sets of requirements and the detailed understanding provided by the research activities were essential in the process of developing user interfaces for a CBP system. This report describes how the research team has utilized the results from the activities described above as technical basis for the development of a prototype CBP system. The report also describes an evaluation study where the use and execution of the CBP prototype were compared to the current use and execution of the PBP version of the same procedure. The CBP's user interface design was evaluated in terms of usability, acceptability, and potential increased process efficiency. The development of the CBP prototype and the evaluation study covers the two final objectives of this year's research activities.

2. Development of the Computer-Based Procedure Prototype

The model of procedure usage and the resulting requirements served as the basis for the design of the initial CBP prototype. The model of procedure usage highlighted portions of the procedure execution process that the paper-based procedures do not support, to the extent that is possible with digital technology. The researchers identified the features of a CBP system that would support those portions of the procedure-following process. Figure 3 illustrates how the model of procedure usage and the requirements were used to identify which CBP features or functionalities would be built into the prototype. The selection criteria for the features were 1) what is needed to support successful execution of the procedure step, and 2) is the feature essential to show potential benefits to using CBP instead of PBP. Based on the selected features, the research team developed a revised model of procedure usage (see Figure 3). The features, as well as hardware and software requirements specific to these features are listed in Appendix A, “Functionality and its requirements for the computer-based procedure prototype”.

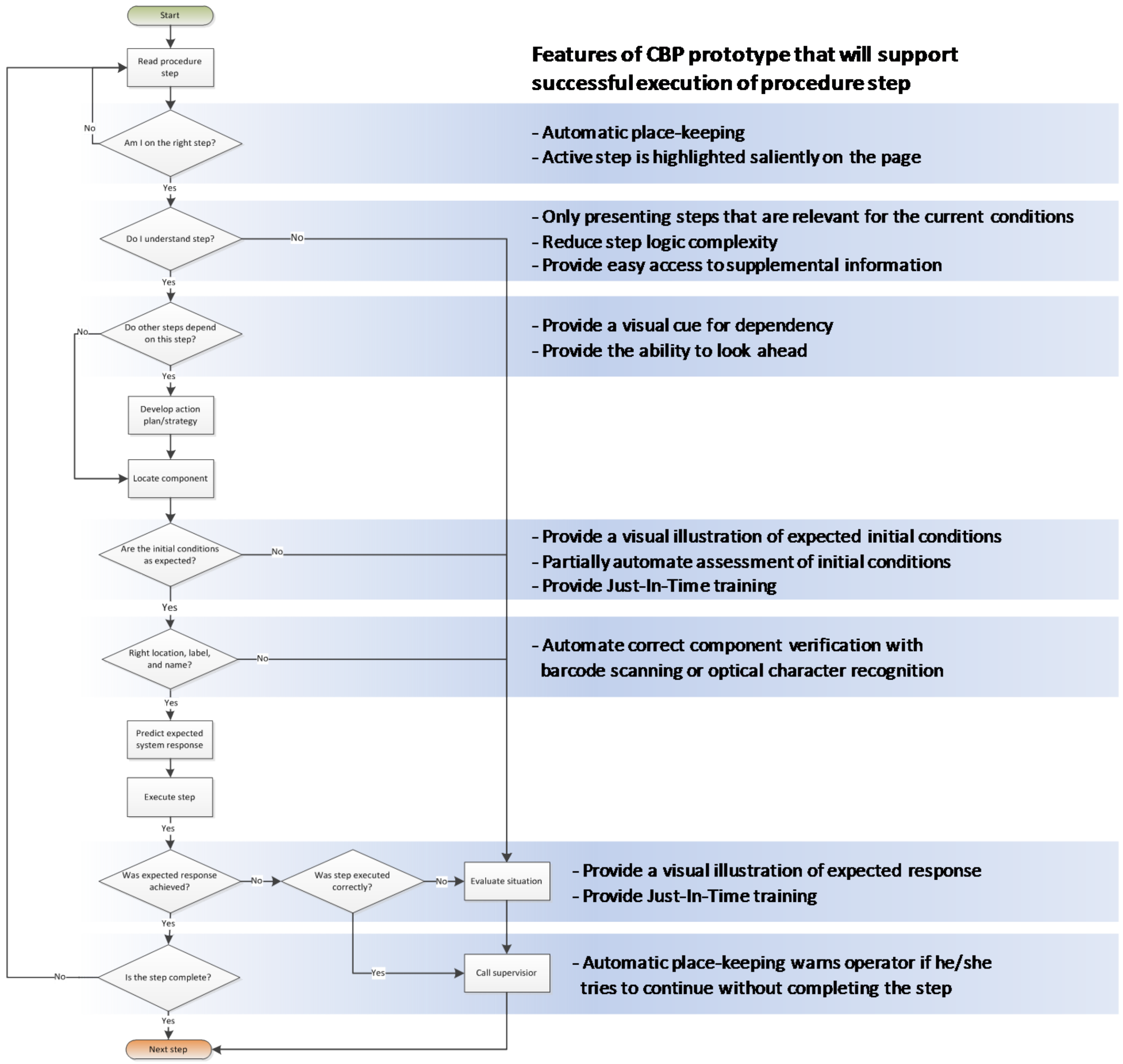


Figure 3. Features of CBP Prototype That Will Support Successful Execution of Procedure Step

2.1 Technology Selection

One of the purposes of the current research effort is to guide the nuclear industry toward introducing CBP technology in their plants. However, industry might not be ready for deployment of CBP technology immediately. Therefore, it is important to ensure that the guidance developed for CBP deployment will not be obsolete when the industry is ready to deploy their own CBP systems simply because the software and hardware solutions that were chosen are out of date. In pursuit of this purpose, the researchers established the main criterion for both the hardware and software selection: the CBP prototype should be platform-independent, to the maximum extent possible.

Today's digital environment can require multiple iterations of a single software product to match the requirements of a vast number of hardware interfaces. To reduce the time and money requirements involved in keeping software solutions compliant across different devices, an intermediate architecture is required. The architecture that most met the needs of the research effort was the Rhomobile Development Suite. Rhomobile is developed and maintained by Motorola Solutions. By sitting on top of device-specific software, Rhomobile allows engineers to focus on the development of the solution rather than maintaining the programmatic nuances between different platforms. This allows the CBP system to be ported to iOS, Android, Windows Mobile, Windows Phone, Blackberry, and Motorola devices with minimal changes to the software. In other words, Rhomobile ensures that the CBP solution works across platforms. Figure 4 illustrates the relationship between Rhomobile and the other building blocks needed to build the CBP system.

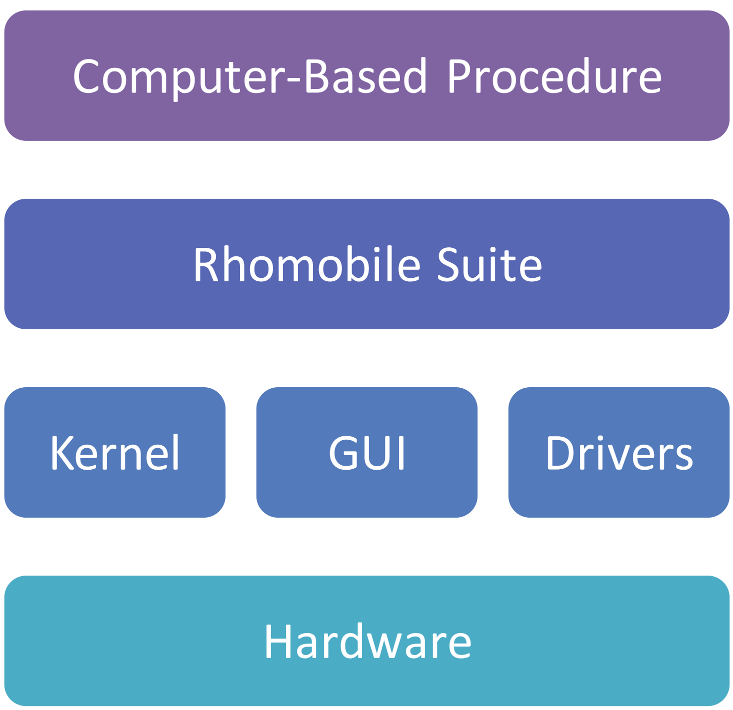


Figure 4. Relationships between building blocks

All other selection criteria are requirements that are directly linked to the functionality the CBP prototype should support (a full list is presented in Appendix A). Two examples of these requirements are listed in Table 1.

Table 1. Examples of Requirements to Support Prototype Functionality

Functionality	Example	Hardware requirements	Software requirements
Check worker credentials through badge scan	Does the operator have the necessary qualifications and training to conduct the activity/procedure?	Ability to scan barcode on badge (or enter badge number)	Access to database of operator training and qualifications, and access to database that stores qualifications for the specific procedure about to be executed. Ability to compare the two.
Correct component verification via barcode scanning and/or character recognition	An operator must scan the equipment barcode to verify he is on the right component before he takes a procedural action.	Camera or barcode scanner (or both)	Access to database of components and ability to compare scanned code with one in procedure.

In addition to the requirements based on functionality, more general software selection criteria were developed. Even though the current focus is to develop a prototype, the team recognized the benefit of using software that potential vendors of CBP systems can use in the future. The process of reconciling a software solution for the CBP prototype focused on the five selection criteria listed below:

1. Is the software platform mature enough for immediate development?
2. Does the current platform environment appear to be stable enough for both the short and long term usage without major changes to the code base in the interim?
3. Does the platform have a stable hardware solution to accompany the software development platform?
4. How secure is the deployment mechanism for the overall product?
5. How easy is the deployment mechanism for the overall product?

The selection process led to two main mobile platforms; the Android Operating System and the iOS. Note that Microsoft's new mobile platform was not available at the time of this decision and was therefore not considered. The iOS has a single deployment mechanism, i.e. the Apple App Store. All applications that are distributed through the Apple App Store undergo a third party inspection to mitigate against hardware threats and bad actors. The Android would require setting up a deployment mechanism or using a third party deployment system that does not have the same third party reviewer process. The iOS has a standardized and versioned hardware system with the iPad, iPod, and iPhone. The android has a variety of options across different vendors with device support varying between these vendors. Additionally Android's kernel was undergoing rapid development changes as it attempted to stabilize its mobile platform in terms of performance and accessibility. The research team compared the two main platforms and arrived at the conclusion that the iOS was the most stable in terms of both security and in its deployment mechanism.

The selection criteria for the hardware technologies were: 1) portability, 2) screen size, 3) software platform, and 4) familiarization. Table 2 provides a description for each criterion. The selection criteria were defined based on what was regarded most important to make the evaluation study successful.

Table 2. Hardware Technology Selection Criteria

Selection Criteria	Description
Portability	The field worker must be able to bring the device out to the field and the device should not add much noticeable burden to the field worker.
Screen size	To find the optimal layout for CBPs at least two different screen sizes should be tested.
Software platform	The hardware technology must be compatible with the software platform to be used for the CBP prototype.
Familiarization	To limit the training needed before conducting the evaluation study technologies that most people are familiar with should be used.

The optimal screen size for user comfort depends largely on the task the device is used for; A large tablet is well suited for casual personal use (e.g., internet usage, watching videos, and reading ebooks), it may or may not be optimal for procedure-based work applications such as those tasks that NPP field workers commonly have to complete. In the nuclear power plant environment, hardware used field work must be sufficiently comfortable that field workers can carry the device with them and use it without difficulty or strain as they work through a procedure. To determine the optimal handheld device size for field work, the researchers decided to test the two most common mobile device sizes in the current research activity: a phone-sized device (3.5-in screen) and a tablet-sized device (10-in screen). The devices the research team selected to include in the present study are iPod Touch 4 and iPad 2. Devices of this size have a proven consumer marketability as well as user familiarity, which supports the rationale that devices of these dimensions will likely be available in the future.

2.2 Mock-Up Development

Researchers used the revised model (Figure 3) to guide the development of a detailed mock-up CBP. The purpose of the detailed mock-up was to ensure that everyone involved in the effort had the same mental model of the prototype CBP's graphical user interface. The mock-up was also used to ensure that the CBP features and functions were implemented in a manner that meets the industry collaborating partners' expectations. Researchers used the results from the qualitative study (Oxstrand and Le Blanc, 2012; Le Blanc and Oxstrand 2012a, 2012b, in press) to inform the design of the CBP mock-up. The following is a summary of the major design decisions for the mock-up accompanied by a discussion of how the previous research informed the decision and a brief description of how the design was implemented in the mock-up (and ultimately, in the CBP prototype).

For the first stage of the prototype development and evaluation, the researchers chose to focus on development for a single screen size. Feedback from field operators and maintenance technicians in the qualitative study suggested that the optimal screen size depends largely on the setting in which the CBP prototype is used. Field operators emphasized the need for a device that you could easily store in your pocket, but maintenance technicians often reference drawings, so a larger device would be better for that application. Researchers chose to initially develop the CBP for the iPod because it could be easily slipped into a pocket. Additionally, designing a CBP for an iPod would impose more constraints than a larger device, and as such, it should be easier to adjust the initial design to fit a larger device than it would be to go the other way around.

2.2.1 Major Features of the CBP

Context-sensitivity. Due to the fact that PBPs must be applied in many different situations and under a variety of conditions, there are commonly more steps in the procedure than are actually performed. The field worker and the supervisor typically identify steps that will not be carried out before the worker heads out in the field. However, there are many situations where the field worker either has to mark steps as not applicable (also referred to as N/A–ing steps) or select a path in the procedure based on input from the plant, e.g. readings or current position of components. Even though it is uncommon, field workers do at times select an incorrect path or N/A steps that they should not have.

One of the main conclusions of the qualitative study is the development of the hypothesis that “the risk of unintentional operator errors or erroneous actions conducted by plant personnel can be greatly reduced with the development of procedures that are both dynamic and context sensitive” (Oxstrand and Le Blanc, 2012). In other words, to minimize the risk of error and to make it easier for the field worker to take the correct action, the research team decided to incorporate context-sensitivity into the CBP.

Context-sensitivity means that the CBP only presents the relevant steps to the user. At this stage in the prototype development, relevant steps are selected based on user input. However, in the future the CBP system can also use plant state and other available plant information to select the relevant steps. The mock-up was designed to illustrate how the CBP system should automatically take the operator through the specified procedure path based on initial conditions and operator input.

Simplified Step Logic. A requirement identified by the research team states that when the necessary information is available to the CBP, the procedure system should evaluate the step logic. This shifts the burden of the evaluation to the system rather than the field worker. Thus, the researchers chose to revise the presentation of conditional steps. Instead of presenting the step as an IF/Then statement, the mock-up illustrates how the CBP would prompt the user to enter the relevant conditions (or acquire the conditions from a plant database), and then present the appropriate path.

Automatic Correct Component Verification. Manipulating the wrong component was identified as one of the most common errors during procedure execution in the qualitative study. The CBP mockup illustrates how the CBP system should prompt the user to scan the barcode (or take a photograph of the label for optical character recognition) before proceeding with a step. The CBP system would verify that the scanned component was the correct component before allowing the operator to execute the step.

Automatic Place Keeping. Another common error that operators make during procedure execution is execution of steps out of sequence, or omitting a step. This has been attributed to the fact that place keeping in PBPs is difficult due to the lack of salience in the place keeping method. The mock-up illustrates how the CBP system keeps track of where the field worker is in the procedure, marks steps as completed, and highlights the currently active step. The CBP mock-up also illustrates how the operator can quickly navigate to the currently active step from anywhere in the procedure interface by clicking on a continuously available link to the active step. Additionally, the mock-up illustrates how the CBP system should prevent the operator from executing any step other than the currently active one. This is an example of how procedure adherence requirements can be built into the CBP.

2.2.2 General User Interface Design

Step Presentation. Presenting a procedure on a small device such as an iPod poses many challenges. In order to display all of the relevant information is a manner that is readable, the researchers decided to present the procedure one step at a time. This was set as the default presentation style.

Ability To Look Ahead. It is essential that the CBP system allows the field worker to look ahead and back in the procedure as well as finding where in the procedure the field worker is at all times. The mock-up illustrates how the user can navigate to any step in the procedure from any place in the procedure. The user can swipe the screen or push buttons marked “next” and ‘”previous” to move through the procedure. As stated above, there is also a continuously available button labeled ‘active step” which will immediately take the user back to the currently active step.

Overview Mode. Users often need to review the procedure before they execute it; users also frequently need to review future steps during execution to maintain an accurate mental model of their progress through the procedure. As an alternative to the single-step presentation style, the researchers developed an overview mode, which displays all of the steps so that a user can continuously scroll through the entire procedure.

Flexible Navigation. The mock-up was designed to illustrate how a user can navigate through the procedure in multiple ways. The user can use gestures to move left and right to other steps in the single step presentation. The interface has a back button that will always take them back to the previous screen.

Ability To Get More Information When Needed. The procedure should allow for a flexible amount of information to be presented. In several situations, the user may want additional information including: information regarding how they ended up in a particular path, information about how to actually use the procedure system, information, etc. The mock-up illustrates how the availability of additional information will be indicated with a small icon.

Highlight The Most Important Information. The mock-up illustrates how the interface will highlight the critical information that a user needs to accomplish his task. The elements that are continuously presented (e.g., navigational buttons) on the screen are presented in muted colors (gray). Steps that are not yet activated, are "grayed out" making them readable, but indicating that they are disabled. The action verb is one of the most important elements in procedure steps because it tells the user what she or he is going to actually do to the equipment. However, researchers discovered that in some cases, the action verb does not actually indicate an action, but rather indicates that user should gather information. Thus, the mock-up illustrates how the action verbs that imply action are distinguished from verbs that simply call for gathering information. If an action verb indicates that the operator should actually act on equipment (e.g., ensure), then the word is highlighted in bold purple. If the action verb simply calls for information gathering (e.g., verify), then the word is highlighted in bold, but is black.

Researchers used Balsamiq software to develop a wireframe mock-up of the CBP user interface. Figure 5 shows a screen shot from the mock-up[a]. This specific screen depicts a procedure step wherein the operator is asked to ensure that the filter is in the basket. In order to confirm that the operator is looking at the right component, i.e. the automatic drip coffee maker, the operator is prompted to scan the component's label. The mock-up simulates the scanning and the correct component verification. The figure also indicates that the operator currently is viewing the procedure in the single step mode and that easy access the procedure overview is provided. The blue "i" indicates that more information related to the step can be provided if needed.

[a] The research team decided to use a simplified procedure for the mock-up. The main reason for using a simplified procedure (and not using a plant procedure) in the mock-up phase was to facilitate multiple feedback elicitations from the collaboration partners. The multiple iterations helped develop one unified expectation across the whole team (both researchers and industry). The procedure selected for the mock-up was a procedure describing how to brew coffee. The research team developed the procedure and made that the procedure was written according to the procedure writing guide provided by one of the collaboration partners.

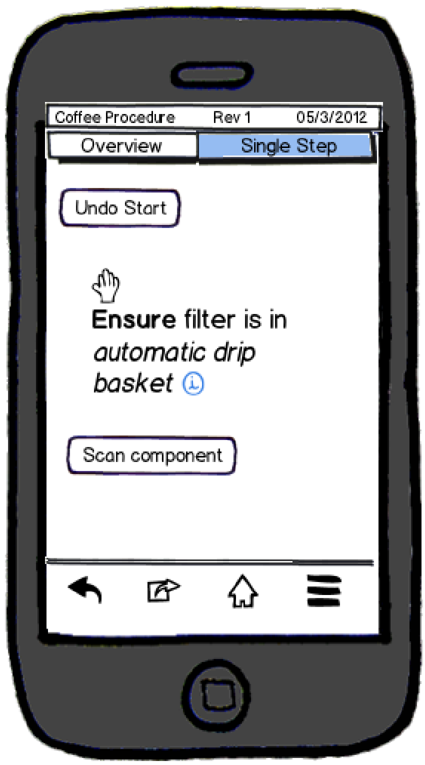


Figure 5. Example Screen From The Mock-Up

The research team elicited feedback from the collaboration partners as well as other human factors researchers at the Idaho National Laboratory (INL). The mock-up development was an iterative process in which feedback was continuously incorporated into subsequent versions of the mock-up. One of the main purposes of the mock-up was to serve as a visual specification to be used in the development of the prototype. Therefore, it was important to address any issues or concerns identified by collaboration partners or human factors experts. Addressing these issues and concerns in the mock-up phase rather than in the prototype phase ensured that many of the potential usability issues and concerns were resolved before the prototype was used in the evaluation study.

2.3 Prototype Development

The research team utilized the mock-up and the feedback from the collaboration partners as the reference for the prototype. The prototype development consisted of two main parts; develop a database generic data structure to encode the procedures and, develop the graphical user interface for the CBP.

2.3.1 Encoding of Procedures

In order for procedures to be imported to a CBP system, they first need to be converted into structured data (also known as encoding). Ideally, the data would be structured according to a standard that would allow the data to be used by any system so that the plant would not be tied to any particular solution. Thus, researchers chose to encode the procedures in the Extensible Markup Language (XML).

XML is used to define a set of rules for encoding documents. XML is used in the current research effort as a tool to create a standard that, when followed, adds power and flexibility to document processing. Requiring documents to conform to the XML defined standard has the added benefit of promoting uniformity among documents that may help document writers to produce higher quality procedures. These documents may then be quickly processed for myriad purposes including both PBP printing and CBP displays.

To convert a standard procedure to an XML document first requires identifying the structures and patterns within the procedure. Once identified structures such as lists, tables, or branching paths can be defined using XML tags. Every XML entry begins and ends with a tag. The opening tag has the form <tag_name> while the closing tag is written </tag_name> where tag_name is a predefined word that represents the structure or pattern enclosed between the two tags. A computer program can then parse out the elements of the XML document using tag names to identify how to proceed in processing the text.

The research team uses XML tags to compile the text into a proper form and define the relationship between the various steps within a procedure. These steps can then be displayed on any device that has the proper software installed. The information in the PBP is converted into XML using a schema, i.e., XML encoding of the PBP. The process results in a XML document. The software running the CBP prototype uses the XML document to compile the information in the XML document to a format it can use, i.e. binary code. The binary code is then used to present the procedure on the screen of the handheld device. Figure 6 graphically represents the logic behind this process.

Figure 6. The Encoding Process

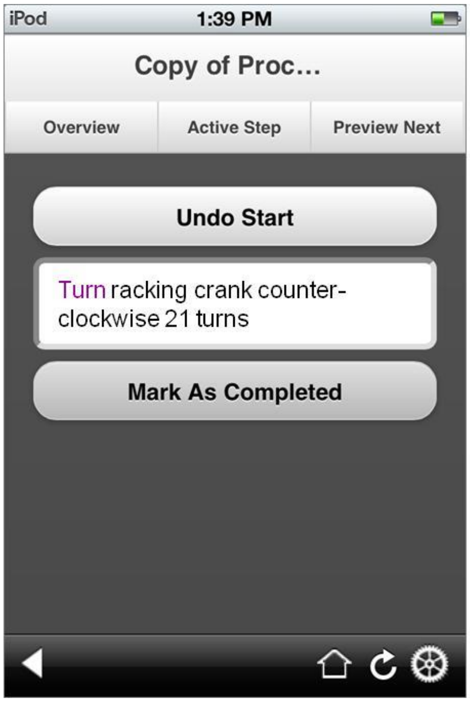
The challenge of creating a good XML document is creating a good schema. If XML is the rule base that a procedure must follow, the schema is the rule base that XML must follow. The XML schema must be created such that it allows for the encoding of any class of procedures. This means that the structure and patterns of every possible procedure document must be accounted for. In the general case where every conceivable structure and pattern, current or future, cannot be accounted for, the schema must be developed with enough flexibility to allow for new and unforeseen document elements. Time is the only test that can prove whether a schema is sufficient. However, designing the schema to allow for general pattern and structure types increases the flexibility of an XML document and mitigates against the chance that the schema will need to change in the future. Having a solid schema and XML structure allows any properly converted procedure to be quickly deployed as a CBP.

2.3.2 Development of the Graphical User Interface

The development of a CBP prototype interface was an iterative process. Based on the model of procedure usage and the two sets of requirements identified earlier in the research effort, the team selected functionalities to implement and which requirements to address in this first iteration of the prototype (described in detail in section 2.2: mock-up development). As stated above, the main features are context sensitivity, simplified step logic, place-keeping, and correct component verification.

The functionality specified in the mock-up was implemented in the prototype software. The following is a description and illustration of how the functionality was implemented in the first phase of the prototype. The screen shots presented are utilizing a simplified plant procedure that was encoded in XML, imported into the procedure system, and rendered on the CBP. The procedure is a simple procedure for racking a breaker. The procedure is the one that was used in the evaluation study and the details of the selection of this procedure are presented in section 3.1.2.1.

Figure 7 shows an example of how the CBP guides the field worker through the procedure based on the field worker's input. Figure 7 illustrates a step in the procedure where the CBP presents the step to be taken, i.e. turn the crank 21 turns. Based on user input earlier in the procedure, the CBP system knows the appropriate amounts of turns that should be conducted. The manner the same step would be presented in a PBP is shown to the right in Figure 7. The field worker needs to remember both the current position and the desired position in order to find the desired number to turn the crank. Reading a table also takes more effort and is subject to interpretation errors compared to reading the sentence presented in the CBP version of the step.



___ 4.2.7 Turn the racking crank counterclockwise to the Desired Breaker Position per the table below:

✔	Desired Breaker Position	APPROXIMATE Number of Turns from CONNECTED Position	APPROXIMATE Number of Turns from TEST Position
	CONNECTED		
	TEST	14	
	DISCONNECTED	21	7
	WITHDRAW	26	12

Figure 7. Context Sensitivity Reduce the Need for Tables

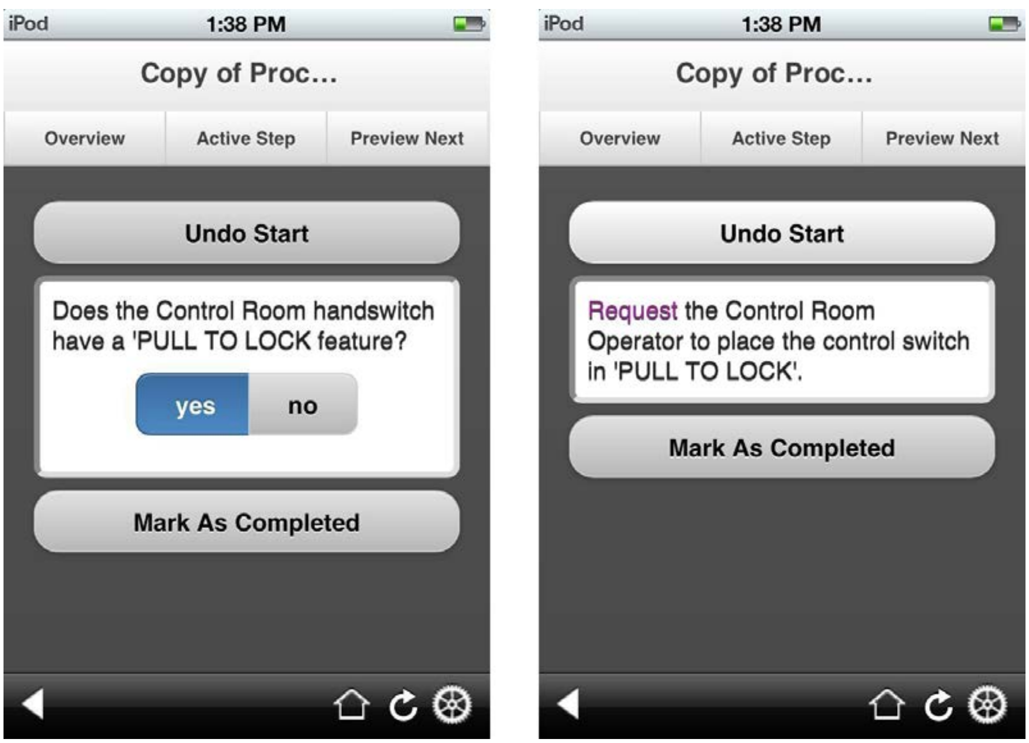


Figure 8. Example Simplified Step Logic

Figure 8 illustrates an example of how the complexity of the step logic has been reduced. Instead of giving the field worker an IF/THEN statement, a simple Yes/No question is asked. In this case, the procedure asks the field worker if the control room has a specific feature. If the answer is 'Yes,' the step to request the control room to take action will be the next step. If the answer is 'No', then the "request the control room…" step is omitted and the next relevant procedure step is displayed instead.

Figure 7, Figure 8, and Figure 9 all show the single step view of the procedure. The current step is the only step that is not marked as disabled (by being "grayed out"). The figures also show how the operator can easily navigate to the currently active step from anywhere in the procedure.

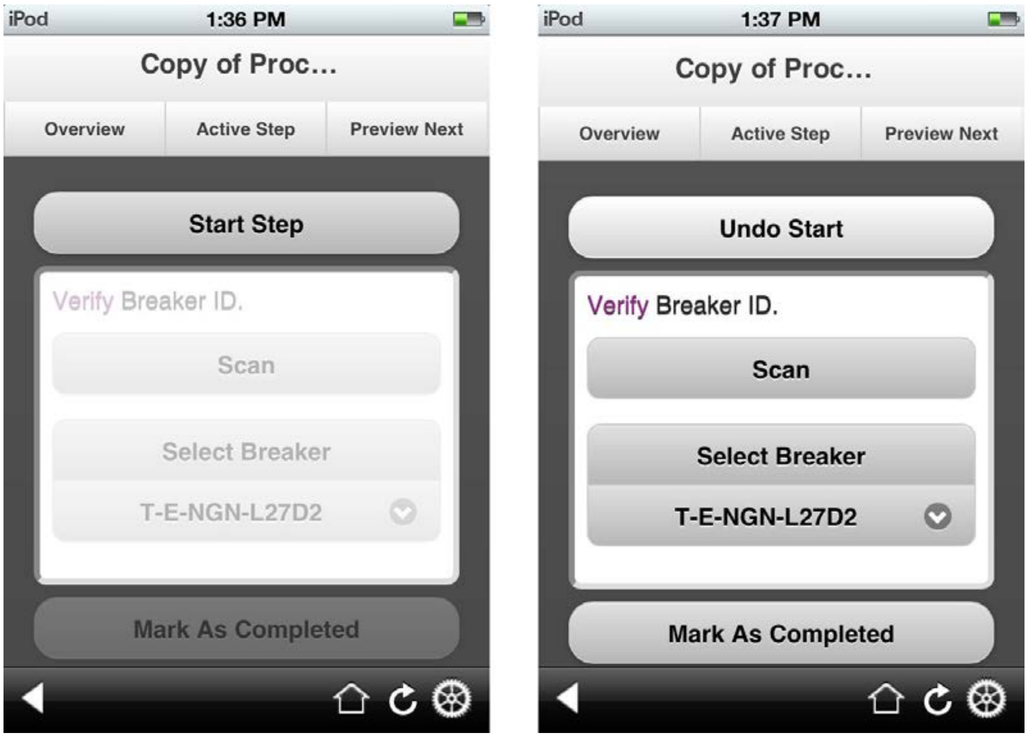


Figure 9. Preview Step and Active Step

The field worker is required to review the procedure step before conducting it. The step is grayed out and no actions can be taken as long as the field worker reviews the step, as shown inFigure 9. In order to take action the field worker must select "Start Step." In the case of unintentionally starting the step, the field worker always has the option to go back via the "Undo Start" option. The field worker is not able to start any other steps until the active step is completed, i.e., "Mark as Completed" is selected. This will automatically take the field worker to the next relevant step in the procedure.

The prototype supports two different ways to move to the next step. From the single step view, the field worker can navigate to the next step by selecting "Preview Next." The field worker can step forward as many procedure steps as he/she would like. The steps are grayed out to indicate that the field worker can only review them at this time. The current or active step is always only one click away. The option "Active Step" will take the field worker back to the step that is to be performed.

From the single step view, the field worker can also navigate to the overview page. This displays all the steps in the procedure. The previous and the future steps are grayed out, and the steps performed have a checkmark next to them. Due to the context sensitivity, only the relevant steps will be performed. The current step is indicated by a blue frame and is highlighted. It is important that the current step is easy to find in order to support a high level of situation awareness. Figure 10 shows an example of the overview page.

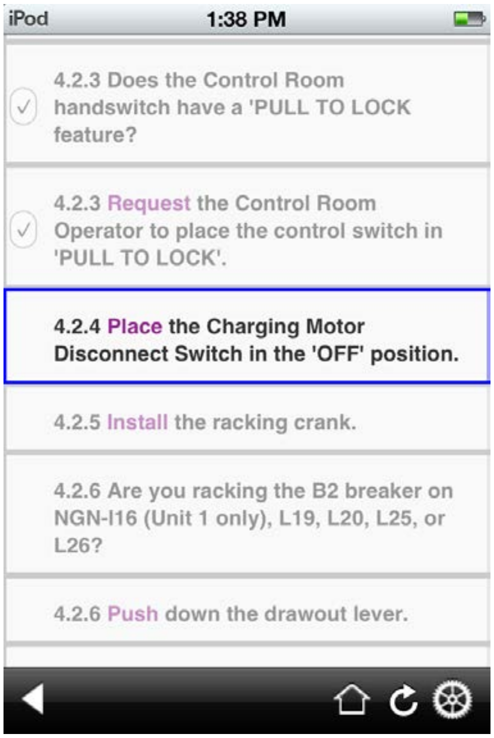


Figure 10. The Overview Page

The last functionality that the research team focused on is correct component verification (CCV). The CBP should ease the burden of CCV for the field worker. In order to meet this requirement, the CBPs should employ some method to automate CCV (e.g., include barcode scanning or text recognition functionality). Due to the immaturity of optical text recognition technology, the research team decided to use barcodes for CCV in the current version of the prototype. Figure 9 shows an example of a procedure step where the field worker is required to conduct a CCV. The field worker has the option to scan the equipment barcode. The CBP system will verify that the barcode information is a match to the required equipment. If the barcode is not available or readable, the field worker can select the equipment identification number from a list and perform the CCV in the same way as when using a PBP.

3. Evaluation Study

The evaluation study was conducted in an electrical training lab on-site at Palo Verde Nuclear Generating Station (PVNGS). The evaluation study was designed to be an objective assessment of the initial CBP prototype. The main objectives of the study were to demonstrate to potential users and decision makers how a CBP system might improve performance and to gain input on how to improve the functionality and user interface of the CBP prototype. Results will be incorporated into a second phase of prototype development. Another goal was an initial test of whether the CBP prototype offered any performance improvements over its paper-based counter-parts by directly comparing performance using the CBP and the PBP.

The evaluation study was focused on obtaining input on several specific aspects of the CBP interface that might have unintended consequences when actually used. For example, to make the procedure readable on a device as small as an iPod the prototype presents one procedure step per page. The researchers were concerned that this might affect the procedure performer’s awareness of where they are in the overall context of the procedure. The materials used in this study were designed to elicit specific feedback on this issue and for the issues listed below:

- Managing a computerized interface may lead to additional tasks that are not present in PBPs which may take focus away from the task.
- Presenting the procedure in a context-sensitive manner is different from what procedure performers are used to. They may be disoriented or confused when irrelevant steps are not presented.
- Presenting conditional steps as a question inquiring about the conditions, and then as condition-relevant instructions may be confusing to the operators. They may also find it annoying to have to answer questions rather than simply N/A-ing a step.

Focused feedback on these concerns as well as input regarding more general usability issues will help the researchers to develop the second-phase prototype, and will make the eventual deployment of a CBP system more usable and more readily accepted by users.

3.1 Method

Researchers compared performance between the CBP prototype and the traditional PBP using the same scenario. Performance was compared using both objective measures (deviations from optimal procedure path and time to complete the scenario) as well as a subjective workload assessment. Additionally, researchers elicited feedback regarding the usability of the CBP interface.

3.1.1 Participants

The participants in the evaluation study included 13 technicians at PVNGS. The technicians came from varied disciplines within the plant including two electricians, two mechanics, three I&C technicians, one chemistry technician, two procedure writers, one IT expert and two others. All of the participants were male. The average age of participants was 48 years (*SD* = 12.95 years). Eleven of the participants reported that they use paper procedures as part of their daily job duties in their current role, and all 13 reported that they used paper procedures as part of their the daily job duties in previous roles. Six of the participants were qualified electricians and had executed tasks similar to the task in the selected procedure. The remaining seven had never racked out a breaker before, so the task was unfamiliar.

3.1.2 Materials

3.1.2.1 Procedure selection

Researchers worked with plant personnel to identify a procedure that would ensure that the functionality of the prototype could be demonstrated during the evaluation scenario. Personnel selected a procedure that met the following criteria.

- The procedure needed to have at least one conditional step
- The procedure needed to have supplemental information associated with it
- The procedure should be applicable to a scenario that could be run in a training facility, which allows for the operators to manipulate simulated equipment
- The procedure should branch to other sections (or procedures) based on plant conditions or operator input
- The scenario should take about 15-20 minutes to conduct from start to finish

The procedure selected was a plant procedure for “racking out a breaker” adapted for use in Palo Verde’s electrical training lab. The use of a training lab in the evaluation study allowed for a realistic setting, in which technicians could take actions on the equipment without affecting the plant.

The procedure is presented in Appendix B, “Procedure Used In Evaluation Study”. Researchers prepared a paper-based version of the procedure that conformed to the PVNGS procedure-writing guide, and a computer-based version using the prototype CBP software. The computer-based version was presented on an apple iPod.

3.1.2.2 Surveys

Computerized interfaces are typically intended to ease workload for the user; however, interface management tasks can actually increase workload rather than decrease it (O’Hara, 2002). The researchers developed the CBP prototype based on previous research in order to maximize the degree to which the CBP supports procedure execution and to minimize the overall workload associated with using the interface. However, it is important to evaluate workload so the CBP prototype can be constantly improved, resulting in a final prototype that supports performance without adding additional workload. To assess the workload associated with using the CBP prototype compared with the traditional PBPs, researchers used the NASA Task Load Index (TLX) (Hart & Staveland, 1988). The NASA TLX was administered using paper and pencil, and is included in Appendix C.

Researchers developed their own usability survey to assess the interface of the CBP prototype. The 8-item survey targeted the availability of information, ease of navigation, and ease of use of the CBP interface. Researchers also developed a 6-item usability survey to assess the usability of the device (in this case, the iPod).

Researchers also developed a debrief questionnaire to gain more detailed feedback on the design of the user interface and the overall experience using the CBP. The questions on this survey were open-ended. The 8-item usability survey, the 6-item usability survey, and the debrief questionnaire are included in Appendix D and E.

3.1.3 Design

The researchers used a 2-factor within-subjects design. The independent variable was procedure presentation type (i.e., CBP or PBP). Participants were assigned to either PBP-first or CBP-first order. The order was counterbalanced across participants.

Researchers measured the completion time of each scenario and the number of deviations from the optimal procedure path in addition to the surveys and questionnaires mentioned above.

3.1.4 Experimental Protocol

When participants arrived, they filled out an informed consent form. They then completed a pre-job brief that included a review of the procedure, a discussion of the conditions that would be encountered in the scenario, as well as a discussion of the potential safety issues associated with the scenario. This pre-job brief served as the pre-job brief for both conditions (PBP and CBP) and was executed with the PBP. If the assigned order was PBP-first, the participant completed a two-minute drill using the paper-based procedure; the two-minute drill occurred at the "job-site" and included a brief overview of the expected initial conditions and the potential safety hazards. If the assigned order was CBP-first, the participant completed the drill using the computer-based procedure. Participants were instructed to complete the procedure scenario to the best of their ability and at their own pace.

A researcher and a qualified electrician observed each scenario. Researchers were trained to recognize deviations from the optimal procedure path. They followed the scenario closely and recorded any deviations. Additionally, the qualified electrician observed the scenario and was instructed to note any deviations and share them with the researchers after each participant completed the scenario. The researcher started a stopwatch at the initiation of the first step and stopped the stopwatch once the final step was completed. When the scenario was complete, the participant was given the first NASA TLX and then he completed the scenario with the CBP.

Figure 11. A Researcher Provides Training on the CBP to a Participant

Before the CBP scenario, the participant was given a 5-minute training session on how to use the CBP interface. Figure 11 depicts the researcher training a participant on how to use the CBP interface. The training provided was minimal, but was expected to be sufficient to allow the participants execute the procedure. The rest of the scenario occurred exactly as the PBP scenario, except that the procedure was executed using the CBP prototype. Figure 12 shows the use of the CBP prototype during the study. Once the scenario was completed, the participant was given another NASA TLX form and the usability survey.

Once both scenarios were complete, the participant was given the debrief questionnaire.

Figure 12. The CBP Prototype in Action

3.2 Results and Discussion

The participants were able to successfully execute the procedure with both the PBP and the CBP. The CBP was a new interface that they had not used previously on the job, yet participants were able to use the CBP effectively with minimal training. The specific results related to performance and usability are summarized below.

3.2.1 Objective Performance

Researchers used two measures to compare performance between the CBP and the PBP: deviations from the optimal procedure path and completion time.

3.2.1.1 Deviation from optimal procedure path

Researchers recorded only one deviation from the optimal procedure path across all participants and all conditions. The deviation occurred when a participant was counting the number of turns of the racking crank. The participant stopped at 20 turns (instead of the prescribed 21). However, the participant indicated immediately that he had counted the first turn twice (i.e., 1, 1, 2…), and thus he had in fact turned the crank 21 times. The qualified electrician who was observing the scenario verified that the crank had been turned 21 times. Thus, this possible deviation, which occurred during the PBP condition, was not recorded as an actual deviation.

Because there were no verified deviations in the study, a comparison of performance between the paper and computer-based versions of the procedures was not possible for this measure. The lack of deviations is likely due to the fact that the procedure and the scenario were relatively simple to execute. To evaluate performance via deviations in the optimal procedure path in future studies, a more complex and difficult procedure should be selected.

3.2.1.2 Completion time

The completion time was defined as the time elapsed between the start of the first step of the procedure and the successful execution of the last step in the procedure. Researchers used a stopwatch to measure the time in seconds.

The completion time was compared between the CBP and PBP conditions, also taking into account the order in which the scenarios were executed. The completion time data was subjected to a 2 X 2 mixed analysis of variance. The within-subjects factor was procedure style (CBP or PBP) and the betweensubjects factor was order (PBP-first or CBP-first). The results indicated that it took longer to execute the scenario with the CBP (*M* =447, *SD* = 103) than with the PBP (*M* = 332, *SD* = 111), the main effect of presentation style was significant $F(1, 11) = 37.595$, $p < .001$. Figure 13 highlights the difference between completion times based on procedure style and order.

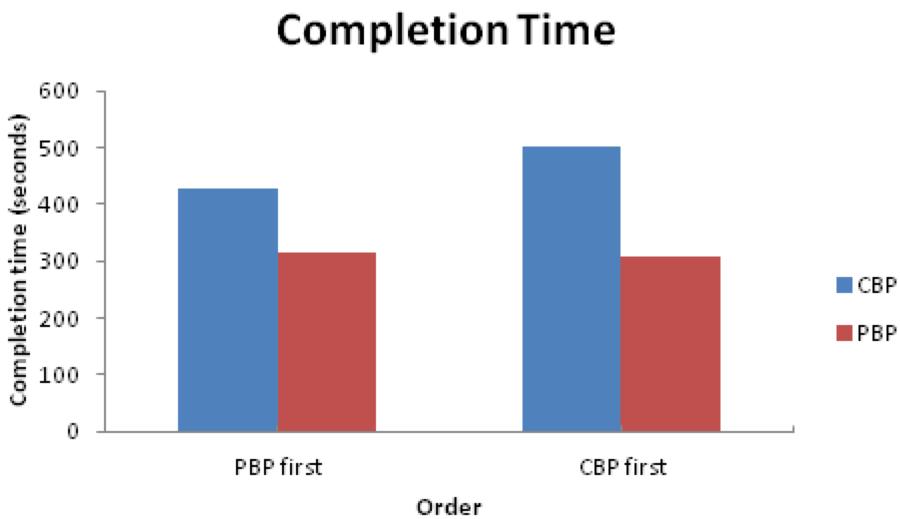


Figure 13. Comparison of Completion Time

There was a significant interaction between procedure style and order $F(1,11) = 14.087$, $p < .01$; if the CBP scenario was completed first, then the difference between CBP and PBP was greater than if the PBP was completed first. Essentially, the effect of practicing the actual procedure had a greater effect on the CBP than the PBP. There was not a significant main effect of order.

There are several possible explanations for why it took longer to execute the scenario with the CBP than with the PBP. The first is that the participants were using the CBP for the very first time with minimal training, while most the participants were used to using the PBPs on a daily basis. Another potential explanation is that the participants would often stop and comment on aspects of the CBP during the scenario execution even though they were instructed not to, increasing the overall completion time of the scenario.

3.2.2 Subjective Workload

Subjective workload, as measured by the NASA TLX scores, was compared between the scenario execution with the CBP and scenario execution with the PBP. The mean overall workload score[b] was computed for each participant and compared between procedure styles. A paired samples t-test revealed that there was not a significant difference between subjective workload scores for the CBP (*M* = 2.23, *SD* = 2.04) and the PBP (*M* = 1.73, *SD* = 1.63).

The workload scores were relatively low across conditions, indicating that participants found the scenario to be relatively easy to execute. A more difficult task may have yielded larger differences in workload.

Importantly, the workload was similar for both the procedure execution with the CBP and the PBP. This indicates that managing the CBP interface did not add significant workload for the participants. In a

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[b] The NASA TLX scores are typically computed using weighted averages, however computing the overall average without the weights is a common practice and provides comparably valid scores (Hart, 2006), so the simple averages (or raw TLX scores) were used in this case.

task in which the overall workload is higher, it might be possible to detect an advantage in workload for CBPs.

3.2.3 Usability Survey

The usability survey was designed to assess the overall usability of CBP interface by inquiring about the ease of navigation, the availability of information, and other common usability dimensions (see Appendix D for the full survey). The overall usability score was computed by averaging the scores across all of the questions. Participants rated the CBP interface as moderately usable; the mean overall usability score was 3.5 on a 6-point scale. The lowest scores were reported for items related to the navigation of the user interface.

Age and familiarity with technology are potentially important factors for acceptance of new technology, so the researchers investigated the role of those factors in the usability scores.

There was a trend toward a positive correlation (r = .439, p = .15) between self-reported experience using technology and the usability score, indicating that participants with more experience using technology tended to find the interface to be more usable.

Though not statistically significant, there was small negative correlation (r = -.261, n.s.) between the participants' age and the usability score. This suggests a trend that younger participants showed a tendency to find the interface to be more usable than older participants. The fact that this trend was not statistically significant is possibly due to the small sample size.

Researchers observed that some of the older participants appeared to have a negative attitude towards the technology and some of the older adults were enthusiastically positive regarding the technology, while younger participants seemed to have a more unanimous acceptance of the new technology. The researchers conducted post-hoc analysis to investigate whether younger adults rated the usability scores as higher than older adults. The participants were divided into to two age groups; older adults (>40 years) and younger adults (<40 years). An independent sample t-test revealed a marginally significant difference $t(10) = 2.46$, $p = .052$ between usability ratings of the older adults (M = 3.28, SD = .75) and younger adults (M = 4.25, SD = .50), indicating that younger adults rated the CBP higher than older adults.

3.2.4 Debrief Questionnaire

Before scoring the debrief questionnaire, researchers developed a coding scheme for the open-ended responses. Any responses that did not fit into the *a priori* coding scheme were marked as "other" during coding. The results are presented on a question-by-question basis below.

3.2.4.1 Procedure style preference

More participants preferred the CBP to the PBP. Seven participants indicated that they preferred the CBP; two said they preferred the PBP, and four indicated that they had no preference (See Figure 14below)

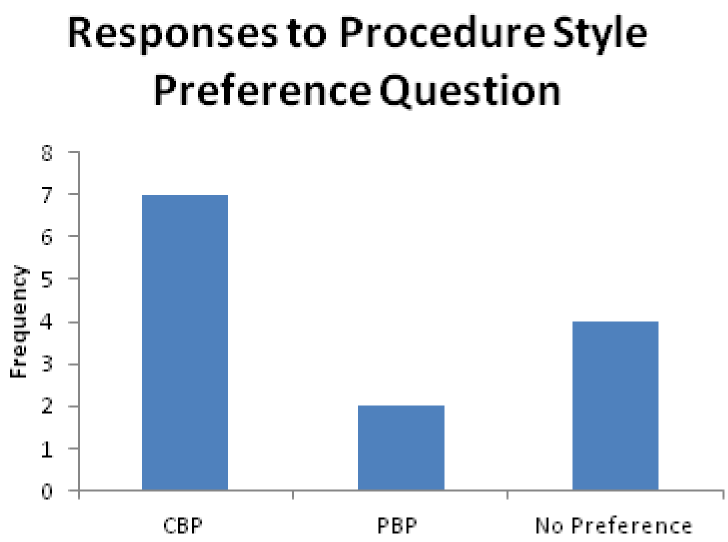

Figure 14. Responses to Procedure Style Preference Questions

The most common reason for favoring the PBP (or having no preference) was that the CBP provided no way of looking ahead. This is an interesting result, because the CBP prototype had multiple ways of looking ahead, including the overview and the ability to preview the next steps. These features were pointed out during training. This indicates that either the participants were not trained extensively enough on these features, that they did not remember about the look-ahead functions, or that they did not find them useful. Other reasons for preferring the PBP (or having no preference) were the fact that the procedure pages took too long to load, and that the iPod was too small. The most common reason for preferring the CBP was that it reduced the opportunity for errors compared with PBP.

Researchers investigated the relationship between age and procedure style preference, to understand whether younger participants might more readily accept new technology. There was a trend toward a negative correlation between age and procedure style preference ($r = -.417$, $p = .156$), indicating that younger participants may be more likely to prefer the CBP than older participants.

3.2.4.2 Single-step view

Most of the participants (92 %) responded that they felt that single-step presentation of the procedure on the iPod had some impact on their awareness of where they were in the overall procedure. Even though the prototype allowed the participants to look ahead at future steps, and provided an overview with all the steps and the current progress indicated, participants felt that they were locked into viewing the current step. This result may indicate that even though it might be ideal for some reasons (e.g., it can easily fit into a pocket); the iPod may be too small to effectively present a procedure.

Another interpretation is that the participants need to be trained more extensively on the functions of the user interface, so they are more aware of the flexibility of their viewing options during the execution of the procedure. Responses to another question on the debrief questionnaire ("did you use the overview when executing the procedure with the CBP?") provides some evidence to support this interpretation. Only one participant reported that he used the overview during the execution of the scenario, he also reported that he thought that it helped his awareness of where he was in the procedure. Several of the participants who reported that they did not use the overview noted that it probably would have helped their overall awareness of where they were in the procedure.

3.2.4.3 Context-sensitivity

All participants reported that only seeing the relevant steps in the CBP was an improvement over the paper-based procedure. This result indicates that participants did not find it confusing that irrelevant steps were not presented. Additionally, participants unanimously preferred the simplified step logic of the conditional statements. This indicates that context-sensitivity is a highly desirable feature of CBPs. It is important to clarify that the context-sensitivity is not related to the "single-step" view. The single-step view refers to the decision to present only one step per screen in order to maximize readability of the steps on the iPod (a device with limited screen real-estate). Context-sensitivity refers to eliminating the presentation of steps that are not relevant under the current conditions. The ability to present steps in a context-sensitive manner is independent of the decision to present the steps "one-at-a-time." This is an important distinction, because the results indicate that context sensitivity is beneficial, while the single-step view may not be.

3.2.4.4 Technology as a distraction

More than half of the participants (58%) reported that using the CBP did not distract them from their primary task (executing the procedure). The majority of others reported that being unfamiliar with the technology and the interface may have distracted them slightly, but that the distraction would likely disappear once they had used the system for a while.

3.2.4.5 Specific usability suggestions

The final question on the debrief questionnaire gave the participants an opportunity to offer any suggestions on how to improve the CBP interface. These suggestions will be incorporated into the second phase prototype of the CBP. The specific suggestions are:

- The CBP should indicate when there is additional text that the user needs to scroll down to read.
- The buttons on the CBP interface should be separated slightly to prevent users form accidently pressing the wrong one.
- The CBP should not require the user to start each step; the default behavior should be that the step is automatically activated when the previous step is marked as complete. If there is a need to know precisely when a critical step is started, then that step can require the user to start, but most steps should start automatically.
- If a user scrolls down to read text, there should be a navigation button below that text so the user does not have to scroll back up to move forward in the procedure.
- The user should be able to execute the procedure from the overview mode.
- The user should have the ability to "pause" the procedure to indicate that he is no longer actively working on it.
- The CBP should always indicate what decision led them down a particular path; it should not be an option to view that information. For example, if an answer to a question inquiring about a particular condition leads the user to branch to another section in that procedure, the user will be presented with a brief explanation of how they ended up in that section. This may prevent an operator from going down the wrong path in the event that he made an erroneous choice in a previous step.

4. DISCUSSION AND CONCLUSION

The most important finding in this evaluation study is that technicians were able to successfully execute a procedure with the CBP prototype. Additionally, successful execution of the procedure with the CBP occurred with minimal training, indicating that the CBP interface is easily learned and relatively intuitive to use.

The objective performance measures did not necessarily show a performance advantage using the CBP in this study (and in some cases, appeared to favor the PBP), but this is likely a consequence of the simplicity of the procedure and scenario selected for the evaluation study. In order to facilitate the gathering of feedback from a large and diverse group of technicians, the procedure that was selected only took 5-10 minutes to complete. This allowed the researchers to directly compare performance using the CBP and the PBP. However, the procedure was not complex enough to highlight the advantages of a context-sensitive procedure system. There were only a couple of opportunities to demonstrate context sensitivity in the procedure, and as such, there was minimal opportunity to measure performance advantages (in both timing and deviations from the optimal path). The researchers plan to use more complex procedures in future efforts, and expect to see clear performances advantages when using the CBP.

Additionally, the operators did not have extensive enough training with the device and the interface in this study to eliminate the effects of using the unfamiliar technology. This is likely the main reason that it took longer to execute the procedure with the CBP in this particular study. There was also a tendency among the participants to stop and comment on the CBP prototype, which added some time to the overall execution of the scenario. One way to mitigate from this in the future is to give the participants a trial run using a simple procedure before conducting the actual and more complex task. This way the participants may ask and comment as much as they like while using the simple procedure and then focus on completing the task without talking to the researchers. Because the main purpose was to get feedback on the CBP interface from as many people as possible, the researchers prioritized running more participants over spending a large amount of time on training. The important thing to note is that five minutes of training on the device was sufficient for the operators to actually use the prototype for the intended task, even though it was not sufficient to eliminate learning effects. There may be great advantages to a system that can be learned after only five minutes of training.

In future studies, researchers will develop more extensive training on how to use the device and what features are available, particularly the overview and look-ahead functions. Once the effects of using an unfamiliar interface are reduced, researchers expect to see a performance advantage when using the CBP.

In the past, researchers have argued that older adults may be less likely to accept new technology (Morris and Venkatesh, 2000). This is an important issue because the much of the workforce in current nuclear power plants will reach retirement soon, and will be replaced by much younger workers. However, any CBP solution is going to have to appeal to all demographics. Therefore, it is important to understand how age and experience may affect the overall acceptance of a CBP system. According to the results of this study, there were several moderate trends indicating that the younger workers may more readily accept new technology than the older workers. However, the relationship between age and usability ratings was more complex than initially hypothesized. The results point to the fact that while younger workers preferred the CBP and rated the CBP as more usable, older workers tended to have more mixed opinions. This indicates that even though the older generation of field workers might not be as eager to learn how to use new technologies as the younger generations, there is still a good chance they will accept a CBP system as long as they are used to working with technology. It is important to note that the results based on age were not statistically significant, and that the general trends should be interpreted with caution in this case. The sample size of 13 participants was relatively small to fully explore the effects of age, especially if the overall effects are small. For future efforts, the researchers plan to collect data from larger and more diverse age groups to thoroughly investigate the effect of age on acceptance of a CBP system.

Another important finding is that the main feature of the prototype (i.e., context-sensitivity) was well received by the participants and utility partners. All the participants preferred the context-sensitive procedure to the current presentation of PBPs. Additionally participants did not find confusing to essentially skip steps in the procedure that are not relevant to the current procedure. Though it was not demonstrated in the evaluation study scenario, the context-sensitive CBP prototype is designed such that it provides a single seamless procedure with only the relevant step presented. This feature will eliminate the difficulty of managing multiple procedures, because the referenced procedure will be incorporated into the overall procedure. The context-sensitivity is an important innovation of this research effort, and is therefore a topic that the research team will continue to refine and improve.

The evaluation study highlighted the benefits of gathering specific feedback on how to improve the user interface. Even though the research team based the design of the user interface on general human factors principles and feedback gathered from the industry, a large amount of specific feedback was captured as the participants attempted to use the CBP. This additional feedback would have been hard to obtain without hands-on experience with the CBP system.

4.1 Path Forward

Moving forward, the research effort will conduct two additional major studies in collaboration with two different utility partners within the first half of FY13. These studies are planned based on the results and findings from the activities conducted and described in this report as well as the *Computer-Based Procedures for Field Workers in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements* (Oxstrand and Le Blanc, 2012). One of the overarching objectives for both of the planned studies is to continue exploring the concept of context-sensitive procedures. At this point in the research effort, the focus will be on context-sensitivity based on user input, either from the field worker while executing the procedure or on information collected at the planning stage. The long-term objective is to look at context sensitivity based on real-time plant status information.

The first study, which will be conducted in the fall of 2012, aims to use a more complex scenario and procedure than what was used in the previous study. The objective is to determine whether there are efficiencies to be gained by using the CBP instead of the PBP. The CBP prototype will be revised to incorporate improvements based on the result from the evaluation study. Another objective is to explore the single step usage in more detail. Based on the results from the evaluation study, the single step view could potentially reduce the field worker’s awareness of where he/she is in the procedure. The research team wants to explore whether this is due to the design of the prototype at the time of the evaluation study, or if presenting one procedure step at the time generally will have a negative impact on the field worker’s situational awareness. The participants will also be given a longer familiarization period with the prototype before conducting the actual scenario.

The second study is planned for early spring of 2013. In the second study, a new revision of the CBP prototype will be used, which incorporates improvements based on the results from the fall study. The revised prototype will also be developed in a manner which supports both screen sizes, i.e. the iPod Touch and the iPad. This will allow for a comparison between the devices to investigate is there is a particular screen size that is preferred by the participants. Also, additional and/or improved functionality that already has been identified will be incorporated into the prototype in time for this study. This functionality includes the ability to:

- Present relevant supplemental information at the appropriate step to support situation assessment on demand
- Communicate to supervisor via text message, voice message, or photo/video capture

- Conduct correct component verification via barcode scanning and/or optical character recognition
- Cue the field worker when he or she needs to address continuously applicable steps

The research team together with the utility collaboration partners will define additional short-term goals and objectives based on the result from both studies. Future research activities to address these goals and objectives will be identified, planed, and conducted.

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Appendix A

Functionality and its requirements for the computer-based procedure prototype

Functionality	Example	Hardware requirements	Software requirements	Notes
Check worker credentials through badge scan	Does the operator have the necessary qualifications and training to conduct the activity/procedure?	Ability to scan barcode on badge (or enter badge number)	Access to database of operator training and qualifications, and access to data base that stores qualifications for the specific procedure about to be executed. Ability to compare the two.	
Update procedure based on Current conditions	Plant is in Mode A (e.g., 100% power), so a certain set of global conditions apply. Some equipment is also unavailable, so those temporary conditions apply as they are relevant to the specific procedure.	Ability to communicate to a database that stores plant status information including information about component position (open or closed)	Access to plant status database. Ability for procedural database to compare information to plant status database and select appropriate steps to present to operator)	
Update plant status database based on procedural actions taken	An operator has just completed a procedure step that instructed him to open a valve, once that step is marked as completed it updates a database with the information that the valve is open	Ability to communicate to database that stores plant status information		

Functionality	Example	Hardware requirements	Software requirements	Notes
Update procedure based on operator actions	The operator chooses a path through the procedure, only the steps that are relevant on that path are presented	Ability to update procedure steps "on the fly" based on decisions made while working through the steps		Some procedure steps currently present an option to the Operator, such as Conduct action on component X or Y. Later on in the procedure there can be steps saying: If conducted action on X earlier, then do this step, else do something different. The CBP should only display steps valid based on the component (W or Y) the operator decides to take action on.
Correct component verification via barcode scanning and/or character recognition	An operator must scan the equipment barcode to verify he is on the right component before he takes a procedural action.	Camera or barcode scanner (or both)	Access to database of components and ability to compare scanned code with one in procedure	
Track progress and time as procedure is executed			Ability to time-stamp start and stop of procedure and procedure steps.	This information should maybe not be displayed in the procedure itself, i.e. not displayed to the operator. However the information might be useful to the supervisor or for future planning purposes

Functionality	Example	Hardware requirements	Software requirements	Notes
Ability to merge multiple procedures and present it as a single seamless procedure	If a procedure specifies, based on conditions, that the operator needs to transition to another procedure, the relevant steps will be extracted from the database and presented as part of the procedure.		Access to procedure database and ability to identify relevant steps to present to the operator	
Ability to capture and annotate still photos and video and connect them with particular steps	If an operator encounters a problem with equipment he is working on, he can capture photos to send to his supervisor	Camera	Ability to attach procedure information to photo automatically (i.e., as metadata) and ability to annotate photo and video	
Ability to keep track of where the operator is in the procedure (i.e., place-keeping)	Highlight current step and have some indication of start/and finish of step.		No specific software requirements are necessary	
Ability to cue the operator when he needs to address continuously applicable steps	An operator needs to take some action when a certain condition is met, however he needs to continue with the procedure in the mean-time		No specific software requirements are necessary	This can only be done automatically of the relevant device is instrumented. In other cases there should be a continuously present cue that lets the operator know that he has a continuously applicable step that is not completed)

Functionality	Example	Hardware requirements	Software requirements	Notes
Ability for operator to look ahead and read future steps			No specific software requirements are necessary	
Ability for operator to override	If an unexpected event occurs, the operator needs to be able to put the plant in a safe state even if this means deviating from the current procedure.		No specific software requirements are necessary	There should be two conditions for this 1) Operator override with supervisor approval and operator override in case of an emergency that needs to be addressed immediately in order to put the plant in a safe state (i.e., there is not time for supervisor approval)
Ability to present procedure step logic in a more understandable manner	An if/then step would be broken into two pieces, 1) what is the current condition? (requires operator response), and 2) present action to be taken based on operator response		No specific software requirements are necessary	
Apply some code (e.g., color) to highlight steps where actions must be taken versus simply checking a state.	The operator gets a visual cue from the CBP which reminds him that the current step requires an action and not only a verification of current state		No specific software requirements are necessary	

Functionality	Example	Hardware requirements	Software requirements	Notes
Ability to present relevant supplemental information at the appropriate step	Just-in-Time training, i.e. if errors repeatedly occur at a particular step there should be an embedded video linked to the step that illustrates how to avoid the error.		No specific software requirements are necessary	
Ability to communicate to supervisor via text message		Access to a network and capability to send and receive information		
Ability for operator to access drawings and other supplemental information to support situation assessment on demand.			A database of information/documents that might be relevant to view while conducting the procedure	

Appendix B

Procedure Used In Evaluation Study

___ 4.0 **INSTRUCTIONS**

___ **4.1** **Verify that you are at breaker T-E-NGN-L27D2 and it is in the prerequisite condition per section 3.3 of this Work Order.**

___ **4.2** **Racking Out Breakers**

___ 4.2.1 Obtain the proper personal protective equipment (PPE) per section 3.2 of this Work Order.

___ 4.2.2 Ensure the breaker T-E-NGN-L27D2 is open.

___ 4.2.3 **IF** the Control Room handswitch has a PULL TO LOCK feature,
THEN request the Control room Operator to place the control switch in PULL TO LOCK.

___ 4.2.4 Place the Charging Motor Disconnect Switch in the "OFF" position.

___ 4.2.5 Install the racking crank.

___ 4.2.6 **IF** racking the B2 breaker on NGN-L16 (Unit 1 only), L19, L20, L25, or L26,
THEN push down the drawout lever.

___ **NOTE**

Breakers shall not be left in the WITHDRAWN position unless the breaker is being removed immediately.

___ 4.2.7 Turn the racking crank counterclockwise to the Desired Breaker Position per the table below:

✔	Desired Breaker Position	APPROXIMATE Number of Turns from CONNECTED Position	APPROXIMATE Number of Turns from TEST Position
	CONNECTED		
	TEST	14	
	DISCONNECTED	21	7
	WITHDRAW	26	12

Figure No: 4.2.8

___ 4.2.8 Remove the racking crank and check the shutter closes.

___ 4.2.9 **IF** the shutter does not close,
THEN move the breaker slightly, either in or out, with the racking crank until the shutter closes.

___ 4.2.10 Verify that the Breaker is in the Disconnected Position by measuring the distance that the Breaker is protruding from the housing. The distance for Disconnected is 3.5 inches.

Figure No: 4.2.11 Disconnected Position

4.2.11

Appendix C

NASA TLX

Computer-Based Procedure Project – NASA TLX

To be administered after each task

For each of the categories below, please draw a line indicating where on the scale you think the task falls. For example if you thought mental demand on this task was medium, you would draw a line as close to the center as you could. When evaluating each category, compare the task to driving a car in no traffic versus driving a car in heavy traffic.

Mental Demand -- *How much mental activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?*

|____|

Low High

Physical Demand – *How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.) Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?*

|____|

Low High

Temporal Demand – *How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?*

|____|

Low High

Performance – *How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?*

|____|

Good Poor

(More on reverse)

Effort – *How hard did you have to work (mentally and physically) to accomplish your level of performance?*

|____|
Low High

Frustration Level – *How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?*

|____|
Low High

Appendix D

Usability Survey

Computer-Based Procedures: Usability Survey

To be administered only after the CBP task

Device

Please rate the suitability of the device (i.e., the iPod) for the task you did today based on the following factors. Circle the number that best applies.

1. Size

   0 1 2 3 4 5 6
   Inadequate Adequate

2. Weight

   0 1 2 3 4 5 6
   Inadequate Adequate

3. Screen Size

   0 1 2 3 4 5 6
   Inadequate Adequate

4. Display Brightness

   0 1 2 3 4 5 6
   Inadequate Adequate

5. Ruggedness

   0 1 2 3 4 5 6
   Inadequate Adequate

6. Would any of the responses to the above be different for the tasks you do in your normal job duties (as opposed to the task you did today)? Please explain.

Interface

Please rate the computer-based procedure software based on the following. Circle the number that best applies.

1. It was easy to navigate to the screen that I needed.

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

2. I understood how to use the software to complete the task.

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

3. I was able to find the information I needed easily.

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

4. I sometimes got lost, and could not find the screen I needed. *(reverse scored)*

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

5. The interface behaved exactly as I expected it to.

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

6. I was sometimes confused about where I was in the procedure. *(reverse scored)*

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

7. It was easy to undo something if I made a mistake.

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

8. I was sometimes surprised by how the computer-based procedure system responded. *(reverse scored)*

   0 1 2 3 4 5 6
   Strongly Disagree Strongly Agree

Appendix E

Debriefing Questionnaire

Computer-Based Procedures: Debrief Questionnaire

1. Now that you have executed the procedure using both the paper-based procedure and the computer-based procedure, which did you prefer?

   Why?

2. In the computer-based procedure system, the procedure steps were presented one step at the time; do you think that this affected your awareness of the procedure and your progress within the procedure? Please explain.

3. The computer-based procedure presented only the steps that were relevant under the current conditions; did you find it confusing to not see the irrelevant steps?

4. Did you use the “overview” display mode? Did it help with your understanding of where you are in the procedure?

5. Do you feel that using the technology distracted you from your primary task (i.e., executing the procedure)?

6. Do you have any suggestions for how to improve the user interface?

7. Is there anything you would like to add?