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Light Water Reactor Sustainability Program

Computer-Based Procedures for Field Workers—Result and Insights from Three Usability and Interface Design Evaluations

September 2015

U.S. Department of Energy

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Computer-Based Procedures for Field Workers—Result and Insights from Three Usability and Interface Design Evaluations

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SUMMARY

As a part of the Department of Energy's Light Water Reactor Sustainability (LWRS) Program a research team at the Idaho National Laboratory, together with the nuclear industry, has developed a prototype computer based procedure (CBP) system for field workers. Although the CBP system has been evaluated through a series of laboratory studies it is crucial to get the field workers' acceptance. A step toward this is to put the system in their hands and let them use it as a part of their everyday work activities. A pilot field evaluation of the CBP system was conducted at a nuclear power plant early 2014, and a second field evaluation study was conducted at another nuclear plant in the fall the same year (Oxstrand, Le Blanc, and Bly, 2015). The results and lessons learned from these field evaluations were incorporated into a new revision of the CBP system. In collaboration with a third nuclear plant, the research team launched a field evaluation study in the spring 2015.

Even though the underlying design concepts used in the CBP system have been evaluated and proven successful in a number of studies over the years, the graphical user interface (GUI) has not been thoroughly evaluated. Therefore, two research activities (layout evaluation and GUI evaluation) dedicated to the GUI design and usability were conducted in addition to the field evaluation study.

The different types of studies (field evaluation, layout evaluation, and GUI evaluation) all address the usability, functionality, and visual design of the CBP system. Each of the studies provides unique perspective of these issues, and combined they provide an insight into the general user experience when conducting a task with the CBP system. The field evaluation study focuses on the operators experience while using the CBP system to conduct actual tasks in the control room and in the field. The layout evaluation study focuses on the visual appearance of the CBP system. The GUI evaluation study investigated the human factors aspects of the underlying design.

The main conclusion from all three studies is that the CBP system is easy to use, the underlying design concepts are sound, and the overall design in quite visually appealing. However, there are opportunities to further improve the user experience of the CBP system.

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ACRONYMS

AO	auxiliary operator
ASW	auxiliary salt water
CBP	computer-based procedures
CBWO	computer-based work order
CCV	correct component verification
CCW	Component Cooling Water
CNS	Catawba Nuclear Station
DCPP	Diablo Canyon Power Plant
DOE	Department of Energy
GUI	graphical user interface
HVAC	heating, venting, and air conditioning
I&C	instrumentation and controls
INL	Idaho National Laboratory
LWR	light-water reactor
LWRS	Light Water Reactor Sustainability
MCR	main control room
PBP	paper-based procedures
PVNGS	Palo Verde Nuclear Generating Station
R&D	research and development

CBP for Field Workers—Result and Insights from Three Usability and interface Design Evaluations

1. INTRODUCTION

Nearly all activities that involve human interaction with the systems in a nuclear power plant are guided by procedures. Even though the paper-based procedures (PBPs) currently used by industry have a demonstrated history of ensuring safety, improving procedure use could yield significant savings in increased efficiency as well as improved nuclear safety through human-performance gains. The nuclear industry is constantly trying to find ways to decrease the human error rate, especially human errors associated with procedure use. As a step toward the goal of improving procedure use and adherence, researchers in the Light-Water Reactor Sustainability (LWRS) Program, together with the nuclear industry, have been investigating the possibility and feasibility of replacing the current paper-based procedure process with a computer-based procedure (CBP) system.

The use of procedures has ensured safe operation of nuclear power plants for decades. Up until recently, the procedure process has been a strictly paper-based process. Even though these PBPs have a good safety track record they have some inherent limitations that prevent them from reaching their full human-performance and safety potential. For example, in order for a PBP to be applicable to the constantly changing environment in the plant, the procedure has to be written to encompass multiple different scenarios. This makes the PBP bulky and hard to navigate, which forces the worker to search through a large amount of irrelevant information to locate information applicable to the task at hand. This can take up valuable time the worker could have spent on task execution, and it can potentially lead to unintentional deviations and errors. 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 and Oxstrand, 2012).

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 light-water reactor (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 PBPs and replace them, where feasible, with CBPs.

In the context of the research effort, a CBP is defined as a dynamic presentation of a procedure that guides the worker seamlessly through the logical sequence of the procedure. In addition, the CBP system makes use of the inherent capabilities of the technology, such as incorporating computational aids, easy access to additional information, just-in-time training, and digital correct-component verification (CCV). A CBP system offers a more dynamic means of presenting procedures to the worker, displaying only the relevant steps based on operating mode, plant status, and task at hand. A dynamic presentation of the procedure guides the worker down the path of relevant steps based on current conditions. This feature will reduce the worker's workload and inherently reduce the risk of incorrectly marking a step as not applicable and the risk of incorrectly performing a step that should be marked as not applicable.

Context-driven job aids, such as corrective-action documentation, drawings, photos, and just-in-time training are accessible directly from the CBP system when needed. One obvious advantage is reducing the time spent tracking down the applicable documentation. The human-performance tools are embedded in the CBP system in such ways that they let the worker focus on the task at hand, rather than the human-performance tools. Some tools can be completely incorporated into the CBP system, such as pre-job briefs, place-keeping, correct component verification, and peer checks. Other tools can be partly integrated in a fashion that reduces the time and labor required, such as concurrent and independent verification.

The research team at the Idaho National Laboratory has developed a prototype CBP system for field workers, which has been evaluated through a series of laboratory studies. However, a crucial step to get the field workers' acceptance is to put the system in their hands and let them use it as a part of their everyday work activities. A pilot field evaluation of the CBP system was conducted at a nuclear power plant early 2014, and a second field evaluation study was conducted at another nuclear plant in the fall the same year (Oxstrand, Le Blanc, and Bly, 2015). The results and lessons learned from these field evaluations were incorporated into a new revision of the CBP system. In collaboration with a third nuclear plant, the research team launched a field evaluation study in the spring 2015. This third field evaluation study is described in detail in Section 2.

The underlying design concepts used in the CBP system have been evaluated and proven successful in a number of studies over the years (Oxstrand, Le Blanc, and Bly, 2014; Oxstrand, Le Blanc, and Bly, 2013, Oxstrand and Le Blanc, 2012; Le Blanc, Oxstrand, and Waicosky 2012). However, the graphical user interface (GUI) had not been thoroughly evaluated. Therefore, two research activities dedicated to the GUI design and usability were conducted in addition to the field evaluation study.

The different types of studies (field evaluation, layout evaluation, and GUI evaluation) all address the usability, functionality, and visual design of the CBP system. Each of the studies provides unique perspective of these issues, and combined they provide an insight into the general user experience when conducting a task with the CBP system, as illustrated in Figure 1. The field evaluation study focuses on the operators experience while using the CBP system to conduct actual tasks in the control room and in the field. The results from the study provide insights into the functionality that is most appreciated by the operators and, more importantly, functionality that should be added for the system to provide even better support to the operators. The layout evaluation study focuses on the visual appearance of the CBP system. The researchers investigated ways to improve the visual design of the system to make it more appealing to the users. In the GUI evaluation study, the underlying design concepts of the CBP system are evaluated by an external human-factors scientist. The goal is to ensure that no new error traps related to procedure usage are introduced in the transition from paper procedures to CBPs. The GUI evaluation activity is described in Section 4 and a study comparing different layout options is presented in Section 3.

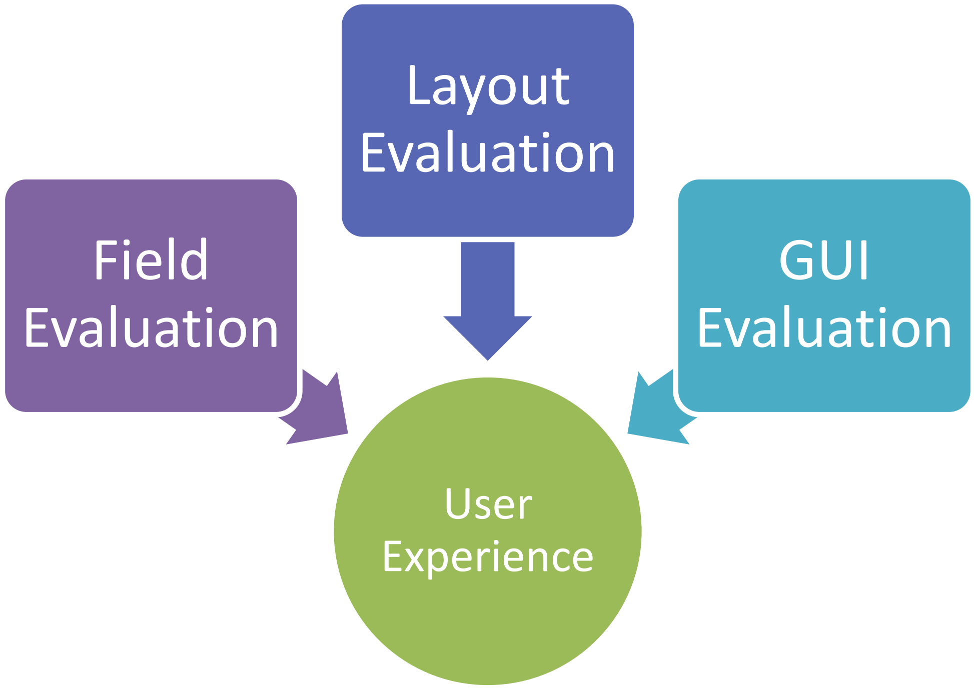

Figure 1. Relationship of the three studies.

This report address the DOE milestone M3LW-15IN0603094—Complete a report of the field evaluation of the added functionality and new design concepts of the prototype computer-based procedure system.

1.1 Previous Research Activities

Three evaluation studies were conducted in training facilities at collaborating nuclear power plants to evaluate the design concepts developed by the researchers. The first study was conducted in the electrical laboratory at Arizona Power Service's Palo Verde Nuclear Generating Station (PVNGS), the second study was conducted in the flow loop of Duke Energy's Catawba Nuclear Station's (CNS), and the third study was conducted in the instrumentation and control laboratory at PVNGS. In each of the studies the human performance using a PBP was compared to the performance conducting the same task using a computerized version of the same procedure. In addition, feedback on usability and form factor were collected as well. The laboratory evaluation studies are described Oxstrand, Le Blanc, and Bly (2014), Oxstrand, Le Blanc, and Bly (2013), Oxstrand and Le Blanc (2012),and in Le Blanc, Oxstrand, and Waicosky (2012).

Time savings is a common argument for transitioning from a paper process to a computer-based process. The results from the first two studies showed that conducting the task with the CBP took more time than it did using PBP, indicating that transitioning to CBP may not save time in procedure execution. However, in the third study it took the same amount of time to conduct the task with the CBP as with the PBP. The researchers concluded that the extra time it took to execute the procedure with the CBP in the first studies illustrates both the novelty effect and learning effect.

In the first study, the novelty of using the CBP caused participants to spend time commenting on the interface during the procedure execution. The participants were instructed to save comments, questions, and feedback until after they completed the task execution. However, the novelty of using a handheld device, scanning barcodes for correct component verification, and all other additional capabilities enabled by the technology enticed the participants to comment on the new functionalities as they were using the

CBP to execute the task. The participants use PBP on a daily bases, hence conducting the task with the PBP obviously was not influenced by the novelty effect.

Another reason for the longer times when using the CBP in the first two studies may be the effect of familiarity with the PBP. The operators use PBPs every day, but the study was the first time they had used the CBP. In the third study, the user interface was intuitive enough to overcome the familiarity effect of using PBPs. The CBP system was revised after each study based on feedback from the participants. The goal was to design a user interface and system intuitive enough that only minimal training was required before successfully completing a task using the system. The usability of the CBP system used in the third study was much improved compared to the version of the system used for the first system. Hence, the participants had an easier time understanding how to efficiently using the CBP, which reduced time to complete the task.

All three studies concluded that the CBP system reduced the risk of human errors and near misses. The integrated human-performance tools (e.g., automated placekeeping and digital CCV), automated calculations, and easy access to additional information, such as photos, operational experience, and reference documents, all contributed to the CBP's improvements to human performance.

The three laboratory evaluation studies were conducted in controlled settings, with the researchers observing as each participant conducted the task twice—once with the PBP and once with the CBP. This approach proved to be successful in evaluating the usability of the CBP system and its potential impact on human performance. However, there are also limitations with this type of study, such as the artificiality of conducting a task in a training facility while being observed, and the simplicity of the procedures used.

Moving forward, the researchers aimed to put the CBP system in the hands of field workers conducting actual tasks in the plant and to investigate whether the CBP system actually will have a positive impact on human performance. The researchers teamed up with CNS for the first evaluative field study. The following requirements were used to guide the selection of procedure and task for the study:

- The procedure does not use safety-related equipment,
- The procedure is not conducted in a radioactive area,
- The procedure includes branching between enclosures or sections, and
- The procedure is conducted at least once per week.

Based on the requirements, the procedure for the functional tests of backup air compressors, which is conducted weekly by auxiliary operators (AO), was selected for the study.

The CBP system was revised both to add new functionality needed for the selected procedure and to make the system rugged enough to be used in the plant for two months. This posed new requirements on the system, which previously only had been used for days at a time and under the researchers' supervision. The functionality added included:

- Handling of continuous action steps,
- Handling of contingencies,
- Ability to check revision of procedure before starting the activity,
- Creation of a printable copy of the procedure as executed for archiving purposes,
- Ability to review decisions and data input in previous steps,
- Improved ability to edit previous steps, and
- Improved data structure to handle the new functionality.

The results from the CNS study indicate that all of the AOs who used the CBP preferred it to the PBP. The AOs also reported that the CBP did not slow down the execution of the task. The AOs rated the CBP as highly usable at an average of 9.67 on a 10 point scale. They also indicated that there was no situation in which the CBP caused errors or error-likely situations. Instead, there was at least one instance in which the CBP may have increased efficiency compared to the PBP.

A second field evaluation study was hosted by PVNGS in 2015 (Oxstrand, Le Blanc, and Bly, 2015; Oxstrand, Al Rashdan, Le Blanc, Bly, and Agarwal, 2015). The plant selected a heating, ventilation, and air conditioning (HVAC) preventative maintenance work order to use for the field evaluation. The work order provides instructions for taking weekly readings from the plant's four HVAC chillers (and related equipment), and for handling out–of–range readings. In order to meet the needs of the HVAC technicians conducting the selected task, the research team modified the existing CBP system to include the following abilities:

- Store readings data for trending
- Import previous readings into current work order
- Export data to be used for trending
- Take notes while executing the work order
- Match readings data to acceptable ranges, alert users to out–of–range conditions, and provide a list of actions for out–of–range readings
- Enable sections of steps to be performed in any sequence as the task allows
- Execute the work order across multiple days and with multiple users
- Activate conditional steps based on multiple conditions
- Handle new functionality by utilizing an improved data structure.

The results from the PVNGS study indicate the importance of considering skill-of-the-craft knowledge required to execute the task. Procedures related to tasks that are heavily reliant on skill-of-the-craft knowledge do not translate well into a computerized version due to the difficulty of anticipating exactly how the procedure will be used. The researchers conclude that the utility moving towards a CBP system should consider what the adequate level of dynamic capabilities for procedures is sufficient for tasks that require skill of the craft. Lower levels of dynamic capability—with the lowest level being a PDF or similar—do not make use of all the capabilities of the technology, but enable higher autonomy to the field worker. Higher levels of dynamic capability allow for more automated decision support, which in turn restricts flexibility in how the worker conducts the task.

2. FIELD EVALUATION STUDY AT DIABLO CANYON

The research team is making a conscious effort to collaborate with as many LWR utilities as possible to ensure that CBP design concepts developed are applicable to the industry as a whole, rather than tailored to one specific utility and their procedures. The team also aims to cover as many different types of procedural steps as possible to make sure the final design guidance is as complete as possible. To achieve this, the researchers strive to collaborate with as many utilities as possible. Therefore, the team was pleased to add the Pacific Gas and Electric Company's Diablo Canyon Power Plant (DCPP) to the utilities and plants supporting the research effort. DCPP is hosting the third CBP field evaluation study.

The DCPP field evaluation study is currently ongoing, hence the results presented in this report are not yet finalized. The final results will be published in a 2016 milestone report.

2.1 Procedures

The approach for the third field evaluation study was to select one simple and straightforward task to be used to demonstrate most of the underlying CBP design concepts and one task to explore new functionality. In other words, the first type of task would successfully demonstrate that benefits can be gained even for simple tasks. The other type of task would both demonstrate benefits of using a computer-based process compared to a paper-based process and support further exploration and expansion of the CBP research.

In collaboration with DCPP, two tasks were identified to be used in the field evaluation: Swap of ventilation supply and exhaust fan sets and swap of auxiliary salt water (ASW) pumps. The fan set swap is a straightforward task, using one procedure, while the ASW pump swap is a task coordinated between the operators in the main control room (MCR) and the operators in the field. The task is conducted using two procedures; one used in the MCR to swap the ASW pumps and the second used in the field to swap chlorination trains to match the ASW pump swap.

2.2 Research Process

The research team conducted an initial visit to DCPP early in 2015. During the visit, the two tasks and three procedures were selected for the field evaluation study. One of the lessons learned from previous field evaluation studies is the value of walking through the tasks in the plant during the plant visit. This provides the researchers a greater understanding of any location limitations, what the tasks entail, and how the procedures are actually preformed, which becomes very important if skill-of-the-craft knowledge is involved in task execution. The walkthroughs also provide opportunity for the researchers to ask questions to better understand the flow of the task.

After the initial plant visit, the researchers mapped out the task flow for both tasks. The purpose of this activity is to identify all paths through the procedures that should be implemented in the CBP system. This is the first step in making the procedures dynamic. The result of the mapping exercise also becomes a visual representation of the task, which has proven a useful tool in conversation with the plant. Figure 2 and Figure 3 provide an example of this visual representation. In this example the original conditional statement in Step 6.2.1 (seen in Figure 2) has been rephrased to the question “Are the control switches for both the supply and exhaust fans in AUTO?” If both control switches are in AUTO, then the CBP system will automatically take the operator to Step 6.6.2, “Place the control switch from the supply fan in OFF,” as shown in Figure 3, automatically marking the steps in between as not applicable.

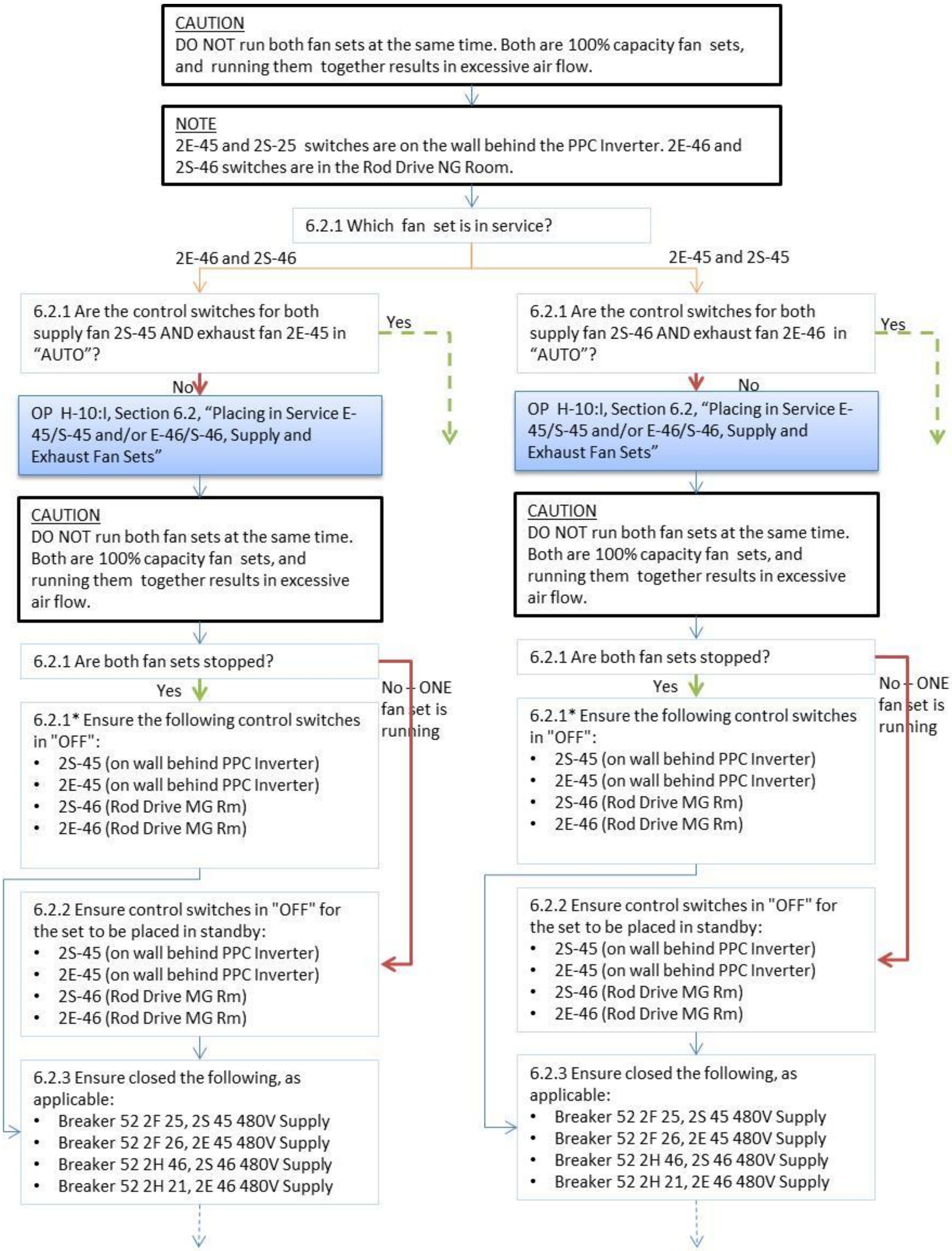

Figure 2. Example of visual representation of the task flow (1 of 2).

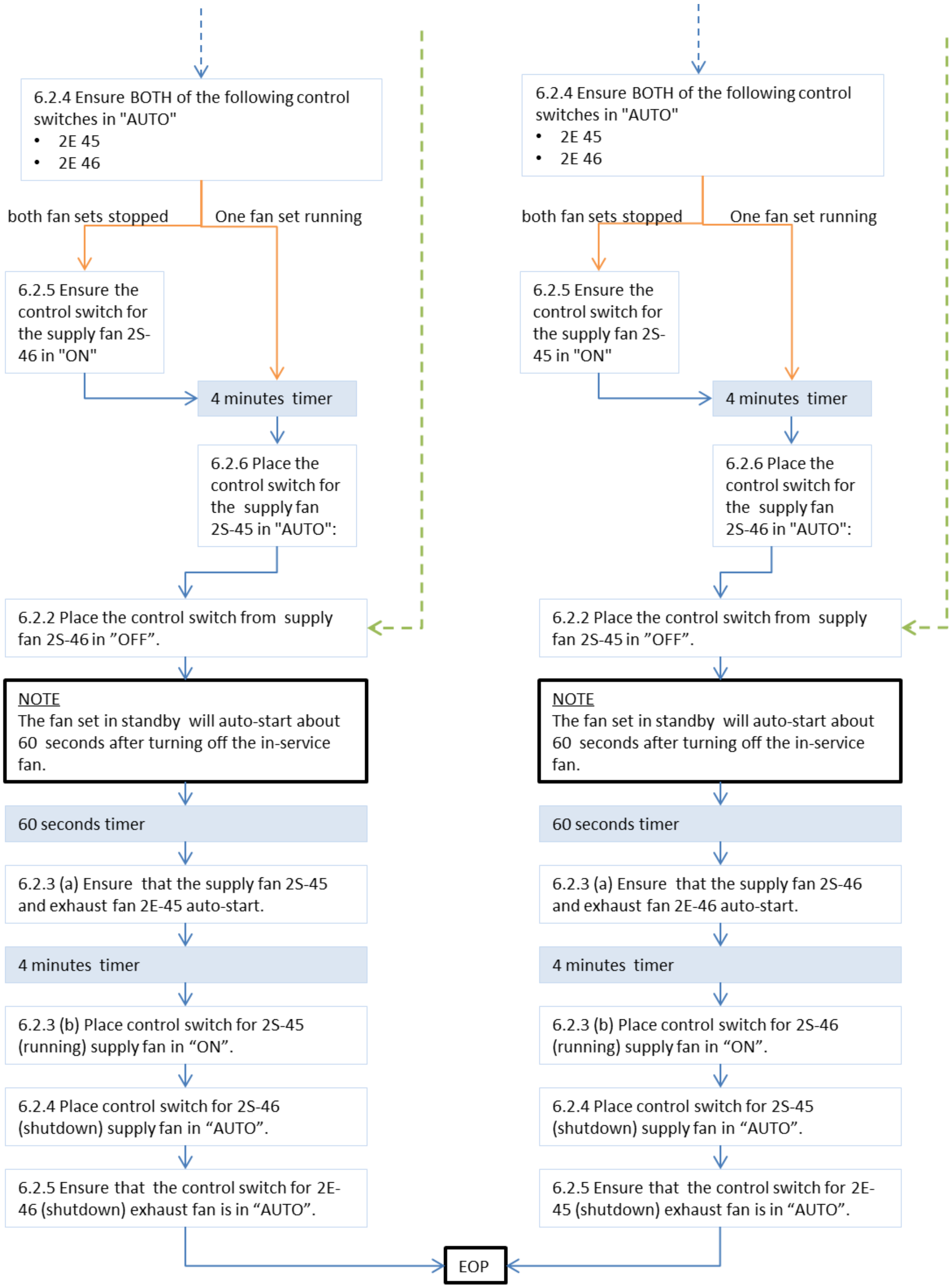

Figure 3. Example of visual representation of the task flow (2 of 2).

Procedure flows for the three procedures were validated through iterative discussions with experts at the plant. An important part of the process was to verify that the rephrased steps (e.g., the conditional steps) still met the intention of the original procedure and that the branching between steps and procedure sections were correct.

The research team then transferred the procedures into the CBP system, following the mapped flow. The previously developed version of the CBP system supported most of the functionality required by the selected procedures (Oxstrand, Le Blanc, and Bly, 2015). However, some new capabilities, which are described in the section below, were added to the system.

The research team conducted a second plant visit to DCPP in April 2015. The purpose of the visit was to provide training on the CBP system to both field and control-room operators and to validate the CBP version of the plant procedures. The team successfully trained operators, the procedures were validated, and technical issues identified were resolved onsite by the research team. Figure 4 depicts the researchers providing training to a control-room operator.

Figure 4. A control-room operator receives training on the CBP system.

The procedures were validated through direct comparison with the paper versions, talk-throughs, and walkthroughs in the field. In addition, the control-room procedure was validated by an operating crew in the control-room simulator, as seen in Figure 5.

Figure 5. A control-room operator and a field operator validate the CBP system.

The researchers handed over two seven-inch tablets (for field procedures) and one ten-inch tablet (for the control-room procedure) to DCPP. The seven-inch tablet is seen in Figure 4, and the ten-inch tablet is shown in Figure 5. The field evaluation officially kicked off Monday April 20th when the CBP system was successfully used for the task of swapping of auxiliary salt-water pumps. The field evaluation study will be ongoing until late 2015.

During the plant visit the research team had the opportunity to meet with the Ed Halpin, Senior Vice President and Chief Nuclear Officer, and Vice President of Nuclear Services Barry Allen and to demonstrate the CBP system to them. In communications after the visit, Mr. Halpin extended an invite for the INL to participate in DCPP’s Human Performance/Safety/Wellness EXPO in May. While the research team participated in the EXPO, they had the opportunity to gather additional feedback from operators using the CBP system.

2.3 New Functionality

The new functionalities added in the CBP system for the DCPP field evaluation study included an:

- Ability to mark place keeping in the summary section as well as notes, cautions, and warnings
- Inclusion of marked-up drawings and valve line-up photos
- Inclusion of timers.

Figure 6 below shows an example of how a caution is marked with place keeping within the procedure. The operator has to acknowledge that the caution is read before moving on to the next step. Another example of place keeping is illustrated in Figure 7, which depicts how the summary section place keeping is recorded. The operator can review the procedure (by clicking Review) before all steps in the summary section are adequately marked; however, the procedure cannot be started until all steps in the summary are marked. At that point, the option to start the procedure will appear below the Review button.

Figure 7 also shows the inclusion of valve line-up photos. These are photos that are marked up to give a clear visual representation of the desired outcome of the valve line-up. These images are both accessible directly from the step where they are relevant and from the summary page (as shown in Figure 7).

Other types of information accessible from both the summary page and directly from the steps where the information is relevant are shown in Figure 8. In this figure an example of an operation-experience document and an example of a marked-up drawing are depicted.

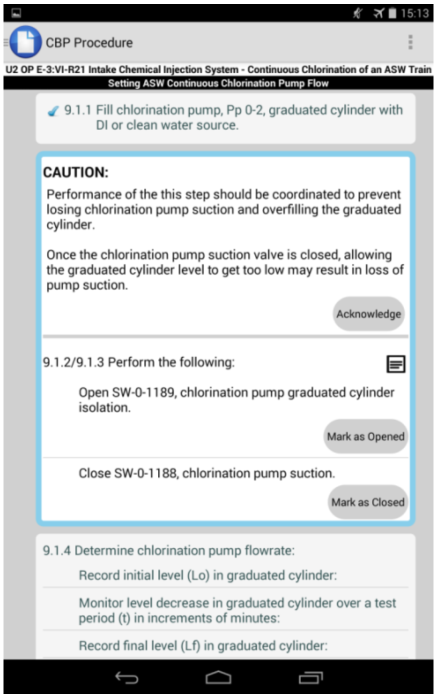

Figure 6. Example of place keeping of Caution..

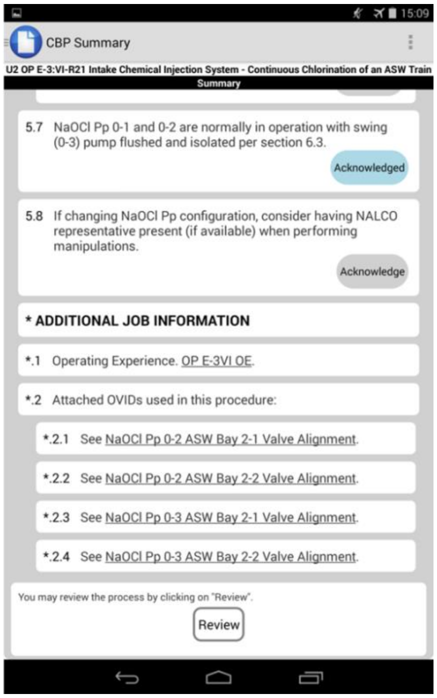

Figure 7. Example of valve line-up photo and example of placekeeping in the Summary section.

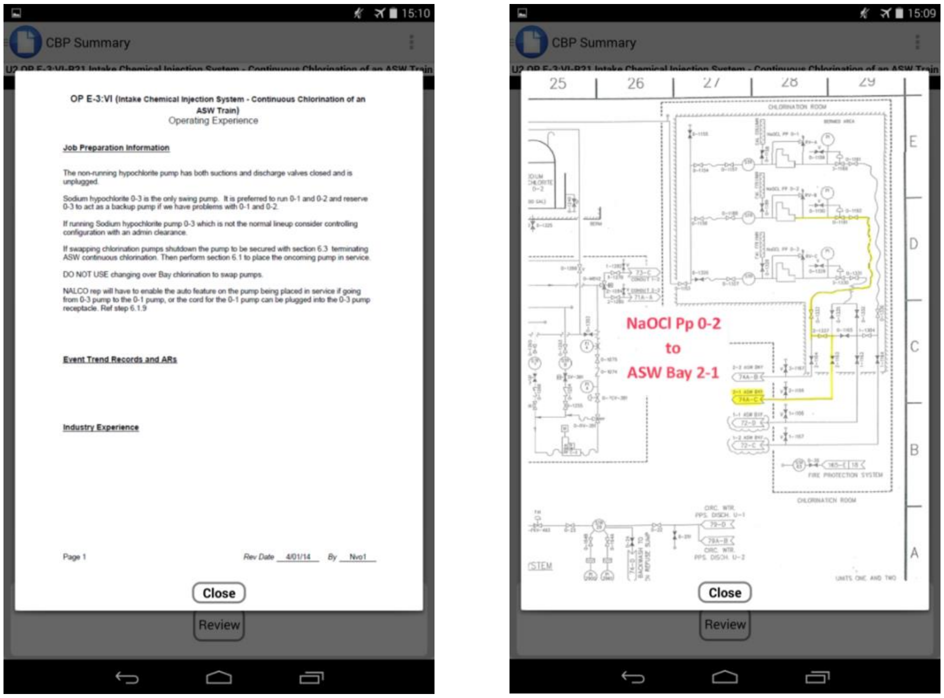

Figure 8. Example of operational experience and example of drawing.

Figure 9 shows a step with a timer. According to the step, the operator has to wait for at least three minutes before moving to the next step. Instead of relying on the operator to time the step, the CBP system automatically starts the timer when the step is activated (i.e., the previous step is completed). When the time is up, the system moves on to the next step.

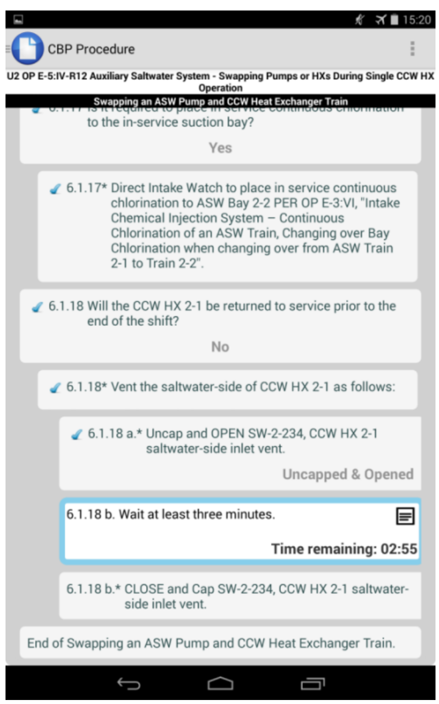

Figure 9. Example of a timer capability.

A functionality that is not new to the CBP system per se, but was used in a slightly different manner than before, is the use of conditional statements and automatic placekeeping to guide the operator through the procedure and, hence, automatically mark steps as not applicable (N/A'd) when appropriate. The DCPP's paper procedures used in the field evaluation study have a two- or three-column format. Each column represents a path through the procedure. Based on the specified conditions, the operator selects the correct path and column and stays in that column until told otherwise by another conditional statement. This column format was removed when the procedures were transferred to the CBP system.

Figure 10 illustrates how the same steps are presented in the original procedure (left image) and in the CBP system (right image). As seen in the left image, this procedure has two columns, one per configuration of the system. Based on the decision made in Step 6.1.1, the operator will stay in either the first or second column. In the example in Figure 10, the operator stayed in the first column, which shows place keeping accordingly. In the CBP version of the same procedure, Step 6.1.1 asks the operator "In what configuration is the system currently in? [sic]" Instead of using columns, the system recognizes the answer in Step 6.1.1 and will tailor the Step 6.1.2 accordingly. The second (irrelevant) column is marked as not applicable behind the scenes.

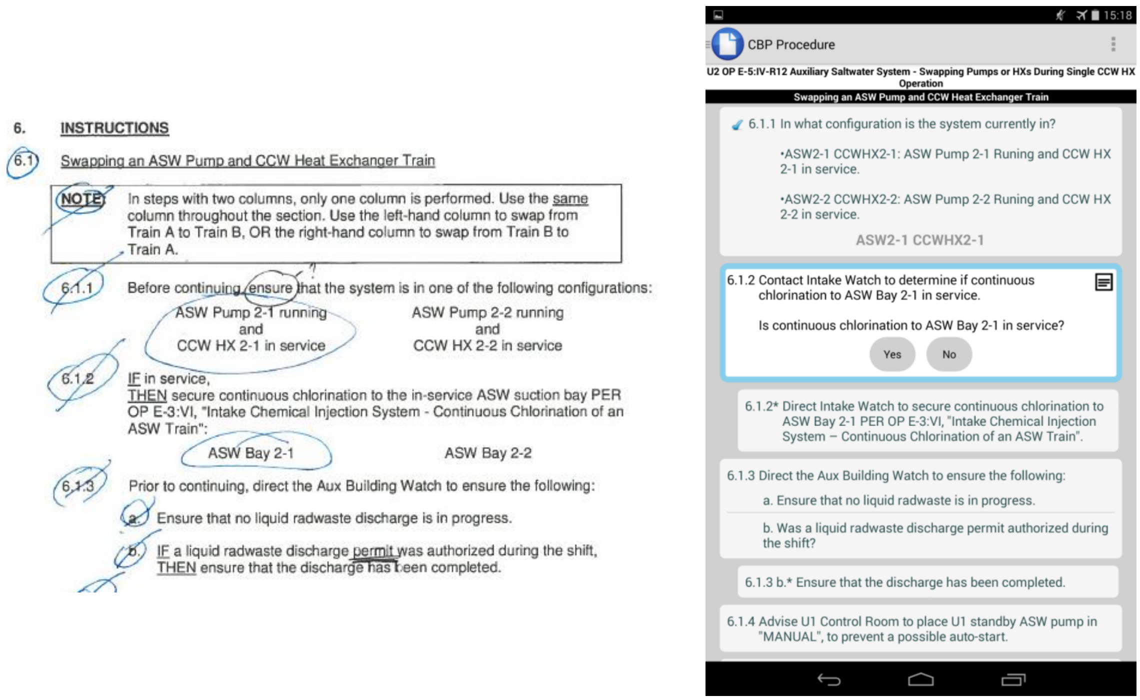

Figure 10. Example of a two-column format in PBP and CBP.

2.4 Method

The participants in the DCPP field evaluation study include the control-room operators and field operators tasked to conduct the AWS pump swap and the field operators tasked to conduct the ventilation fan swap throughout the duration of the study. A small set of operators were trained on the CBP system during the second plant visit. These operators were instructed to train their peers on the CBP system. A two-page summary of how to use the system was also provided (see Appendix A).

The DCPP study was launched April 20th, 2015, and is planned to end in November 2015.The participants were asked to fill out a brief web-based survey after completing the task using the CBP system. The questions targeted the experience of conducting the task with the CBP system as compared to the traditional paper-based process. The goal of the survey was to assess the usability of the CBP system and device. The survey was also developed to gain more detailed feedback on the design of the user interface and the overall experience using the CBP. The survey was designed to be short and simple so that it wouldn't add much additional burden to technicians, which would increase the likelihood that they would take time to respond. The wording of the survey questions was reviewed by plant personnel to ensure that operators would feel comfortable answering the questions candidly. The full survey is in Appendix B; additionally, some examples of questions are listed below.

- Did the CBP lead you down a path where you conducted a mistake, near-miss, or deviation?
- Did the CBP system prevent you from making a mistake, near-miss, or deviation?
- Did the CBP system cause any confusion or behave in a way that was unexpected while you executed the procedure?
- After executing the procedure with the CBP system, do you prefer using paper or the CBP?

2.5 Preliminary Results

As mentioned earlier, the DCPP field evaluation study is ongoing. Hence, the results presented in this section are preliminary. To date, eighteen control-room and eighteen field operators have participated in the study.

Out of the eighteen control-room operators who used the CBP system, 85% found the CBP system to be a positive change, while 15% were not in favor of using the system. All eighteen field operators using the CBP system indicate that they like the system. The general conclusion from the participants is that a CBP system would be a useful tool and that it should be explored for possible further development.

The feedback from the operators indicates that the most appreciated features of the CBP system are

- Automatic placekeeping (removal of columns)
- Digital CCV
- Photos and drawings
- Notifications
- Timers.

CBP handling of navigation through the procedure, which replaces the two-column format in the paper version, was noted to be a human-performance improvement. By only displaying the relevant steps for the current conditions, the risk of unintentionally conducting a step in the incorrect column was removed.

The digital CCV using barcode scanners was noted to help ensure the correct switches were used while conducting the ventilation-fan-set swap procedure. Some operators even intentionally scanned the incorrect barcode to test the CBP system. They were pleased with how the system stopped the task execution until the correct component was identified.

The notifications for incorrect component, transfers to different sections in the procedure, and for system updates (in which the path through procedure is revised based on manual input or decision point) were all appreciated.

The operators noted that the user experience was enhanced by easy access to additional information, such as photos and the marked-up drawings, as well as the added convenience of the embedded timers.

In general the CBP system was thought to be easy to navigate and intuitive to use; however, the operators did identify additional functionality that would further improve the system. The items identified were

- Adding valve location in the step

- Providing the option to switch between left and right handed use
- Enabling mark-up of the procedure (N/A steps and/or make notes) before going to the work site
- Communicating completion time to plant log
- Enabling pause or stop/restart within the procedure
- Enabling a flashlight (to find barcodes in dark spaces).

Future studies plan to investigate the first three items. The communication with plant computers is definitely possible, but unfortunately not feasible to demonstrate during a field evaluation study. The current version of the CBP system does not use a wireless network for any communication, and it does not communicate with databases or systems at the utilities. The two latter items already exist in the CBP system. For example, Figure 11 shows an operator using the flashlight to help scan a barcode at Catawba. However, feedback from the DCPP operators the researchers will improve the usability and accessibility of these functions.

Figure 11. Example of integrated flashlight.

2.6 Discussion

The preliminary results from the field evaluation study indicate that the new functionality added to the CBP system was appreciated by the operators. The marked-up drawings and valve lineup photos were especially appreciated, and the included timers were thought to add a level of convenience to conducting the task using the CBP system. Even though no feedback was specifically provided related to the ability to use place keeping in the summary, notes, cautions, and warnings, the operators did provide positive feedback on the system's automatic place keeping functionality and the human-performance improvements gained by removing the dual columns.

The field evaluation study at DCPP is currently ongoing and will close in November 2015. The researchers will conduct a final plant visit to debrief control-room and field operators and procedure writers. The goal is to gather any additional feedback the plant staff might have.

In addition to the debrief session, the researcher will demonstrate capabilities gained when utilizing a wireless network. The demonstration will take place in the DCCP control-room simulator. Using the ASW pump swap task, the researchers will demonstrate hand-offs between the control-room and field operator. In other words, the capability to easily share a task between multiple locations and organizations will be demonstrated.

Moving forward, the researchers will further improve the CBP system by incorporating additional functionality identified by the operators. The researchers will also explore ways to make already existing functionality, such as the flashlight, even more apparent and easy to use.

3. LAYOUT EVALUATION STUDY

The previously conducted activities in the CBP effort have proved the usability of the underlying design concepts (e.g., using questions instead of conditional statements, automatic place keeping, digital CCV, and computational aids). The next natural step is to evaluate the "touch and feel" of the system, i.e., the visual appeal of the CBP system.

The underlying design concepts focus on an intuitive way of guiding operators through procedures, maintaining place keeping for the operator, making the action steps stand out from information steps, alerting the operator on dependencies between steps, simplifying component verification for the operator, improving assessment of component conditions and of plant and equipment response, and improving communication (Oxstrand and Le Blanc, 2012). These design concepts have to be supported by the user interface. However, the researchers wanted to investigate how to improve the current layout design to make it even more visually appealing to the field workers. Two new layouts were designed to be compared to the original layout.

The purpose of the layout-evaluation study was to gain insights on how to improve the graphical design of the CBP system's user interface. Both quantitative and qualitative feedback were gathered on several specific topics regarding the CBP system's usability and functionality. The aim was to investigate whether the new layout designs provided an improved user experience compared to the original layout while maintaining the same functionality.

The study was designed to explore how members of the plant staff responded to the layouts and determine exactly what they liked and disliked about them, as well as their views on the usability of the different layouts. Input from the participants provided valuable information about interaction design, human-computer interaction, and general usability of the CBP system.

3.1 Original Layout

The original layout (Layout A) is the layout in the current version of the CBP system. The design can be seen in Figure 12. Layout A has a simple gray color scheme, with low contrast, and it only includes colors when necessary for alerts, confirmations, or identification of the active step. The font is the same between body and heading (headings are bolded), and the system uses very few icons, tending to rely more on text. The design of the system developed over multiple iterations through development. These iterations were based primarily on feedback given about the usability of the system, rather than visual design.

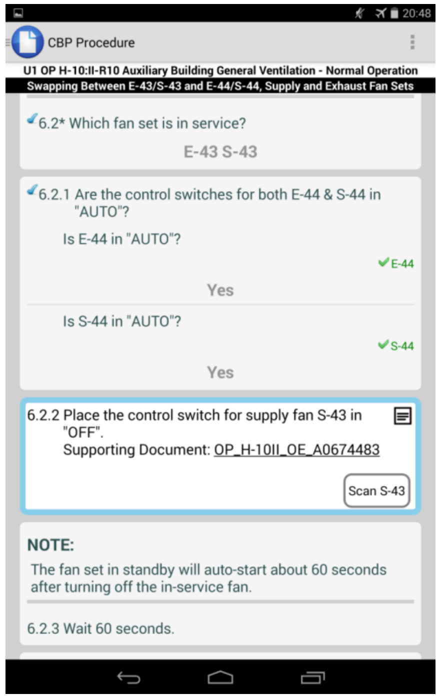

Figure 12. Layout A—original layout.

3.2 New Layout Designs

Two new layouts were designed for the evaluation study (Figure 13 and Figure 14). The two layouts follow the same general design concepts. Layout B is a portrait version (similar to Layout A) and Layout C is in a landscape format. The main changes in these new layouts compared to Layout A) are

- Additional blue color to improve the visual appeal of the interface.
- Higher contrast between all actions (using the blue colors), with greater emphasis on the active step of the procedure.
- A new font combination to increase readability and comprehension of overall actions, verbiage, headers and content, and content layout. Different fonts and weights help show the user differences between blocks of information.
- A new landscape orientation layout (for Layout C) that allows for simultaneous viewing of the active step and scrolling through the overview of the steps.
- Button placement was improved in Layout C (Figure 14).). Buttons were placed to allow for both thumbs to be placed on central starting point on each half of the tablet screen and to be easily reached from those points.

Figure 13. Layout B—portrait.

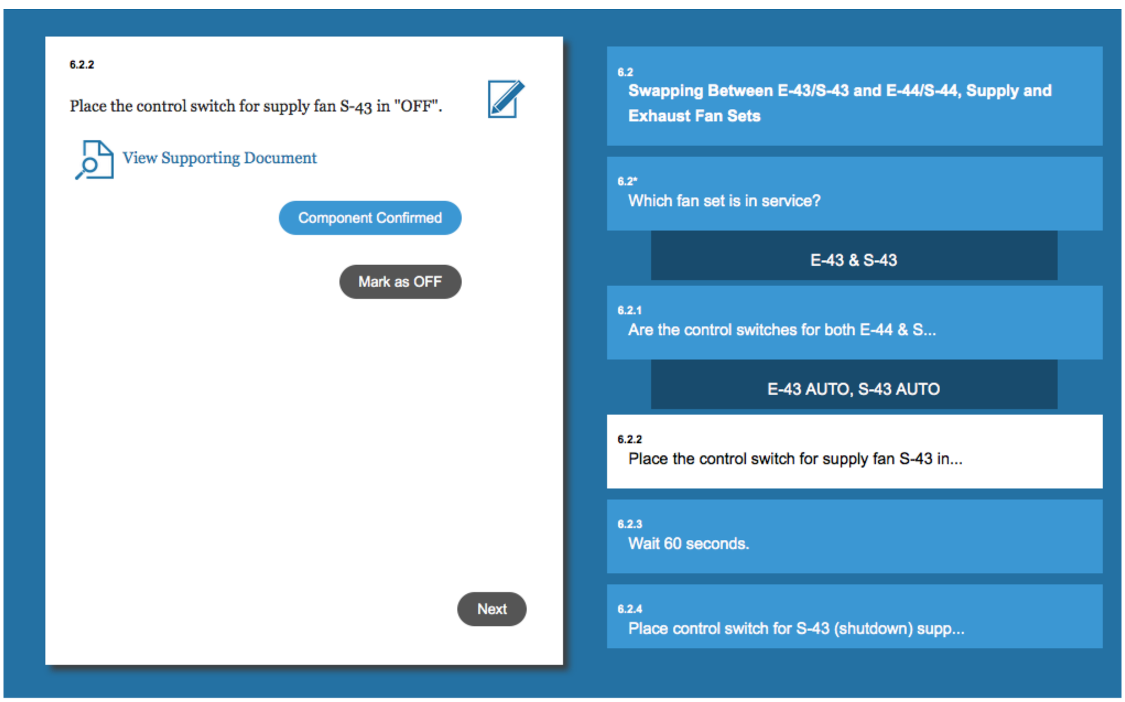

Figure 14. Layout C—landscape.

The new layouts focused on creating a higher contrast design and a more pleasing visual appearance. Layout B was designed to maintain the previous general framework of Layout A while introducing new aspects of color and contrast with minor design changes. Blue is commonly associated with feelings of trust and being calm; however, currently no significant empirical evidence reinforces a causal connection between color and emotion (Labrecque and Milne, 2011). Compared to Layout A, Layout B also took on more use of iconography, having a menu that is always visible with icons rather than text.

Aside from button placement in the system, button design was changed from using black text on a light gray background to white text on dark gray or blue (depending on whether the button had been pressed). This splits up the information based on contrast polarity and makes the information appear less crowded (Chung and Mansfield, 2009).

Layout C took a new approach to the design layout, changing to a landscape orientation and presenting a side-by-side view of the active step and an overview of the procedure, but it kept the same color and contrast aspects introduced in Layout B. Layout C, once implemented on a tablet, would reduce orientation shifting by the operator, as the component verification scanning requires that the tablet be in landscape orientation to use the barcode scanner. The split layout also allows the operator to view past and future actions, while staying aware of the requirements of the current step.

3.3 Method

3.3.1 Participants

Sixteen people from the nuclear-operations and procedure-writing organizations at different utilities were surveyed (four procedure writers, four utility managers, four vendor representatives, two other procedure professionals, and two others who did not fall into one of the previously given categories). All participants were male.

3.3.2 Protocol

Each participant tested a demo procedure of each layout. The demo for Layout A was used on a Nexus 7 tablet, while demos for Layout B and Layout C used a computer. After using the demos, participants completed a survey, via Survey Monkey, that asked questions regarding visual appearance, the task list overview, navigation, active step, and content of each layout. Each question (statement to be rated) was on a matrix scale of 1-8, with 1 being Strongly Disagree and 8 being Strongly Agree. They were also given a section to provide qualitative comments regarding each layout. The end of the survey asked which layout they preferred and requested comments on their preference. The demos were all conducted in the same order, Layout A then B then C. The evaluation was designed to be quick because it was performed during breaks at the Nuclear Procedure Professional Association 27th annual symposium.

The statements the participants were asked to rate were

1. This layout is visually appealing
2. The layout presents a good overview of the task
3. The active step is clearly marked and easy to find
4. Previous actions are easy to find and review
5. The navigation is intuitive and simple
6. The procedure content is presented clearly

An open-ended comments section for each layout allowed the participant to give comments about what was good or what improvements should be added to the design. It also prompted the participants for comments about improving the interface, adding functionality, and identifying system issues that needed to be addressed. The survey is considered the dependent variable, and the different layouts are considered the independent variables. Different interpretations of each layout affect the participant's answers to the survey questions.

3.4 Results

The researchers analyzed the results of the survey by comparing layout preference and ratings given each layout in the individual questions. Qualitative results were also collected and considered in the results for each survey question and overall preference. The responses to questions of which layout the participants preferred are shown in Figure 15. Layout C was the most preferred among those surveyed, with eight participants preferring Layout C (50%), five participants Layout A (31.25%), and three participants Layout B (18.75%).

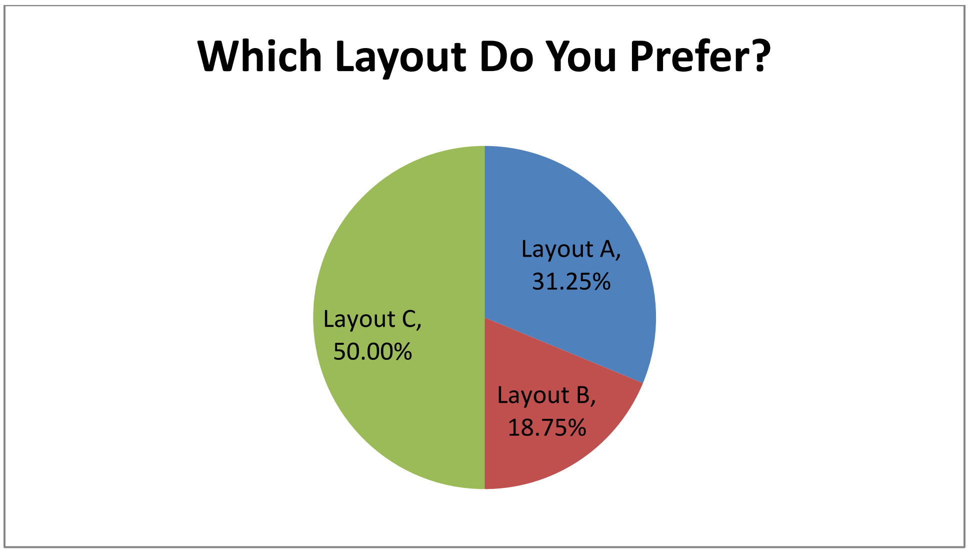

Figure 15. Percent of respondents who preferred each layout.

The responses to the individual questions for each layout were evaluated using an Analysis of Variance (ANOVA). As previously stated, the layout questions were scored on a scale of 1 to 8, with 1 being the lowest rating, and 8 being the highest. The grand mean of Layout A was 6.15, 5.85 for Layout B, and 6.91 for Layout C. A one-way ANOVA revealed a significant difference among the means of Layouts A, B, and C ($F(2,14)=22.52$, $p=0.000198$). A post hoc Tukey HSD revealed that there was no statistically significant difference between Layout A and Layout B, but there was a difference between Layout C to both Layout A and Layout B with $p<.05$.

To further investigate the differences between Layout A and C, dependent t-tests were run to test for significant difference of all the results from the individual questions for each layout using a 95% confidence and a p-value of 0.05. Full results of these can be seen in Table 1.

Table 1. Results of t-tests comparing Layout A and C.

Question		Mean	t-Value	p-Value	Standard Deviation[b]
Q1	The layout is visually appealing	$M_A = 5.81$, $M_C = 6.94$	$t = 2.1327$	$p = 0.0412$[a]	$\sigma_A = 1.87$ $\sigma_C = 1$
Q2	The layout presents a good	$M_A = 5.44$,	$t = 2.3048$	$p = 0.0283$[a]	$\sigma_A = 2.16$

	overview of the task	$M_C = 6.88$			$\sigma_C = 1.26$
Q3	The active step is clearly marked and easy to find	$M_A = 6.44$ $M_C = 7.25$	*t = 1.6630*	*p = 0.1067*	$\sigma_A = 1.71$ $\sigma_C = 0.93$
Q4	Previous actions are easy to find and review	$M_A = 6.44$ $M_C = 6.69$	*t = 0.4474*	*p = 0.6578*	$\sigma_A = 1.46$ $\sigma_C = 1.2$
Q5	The navigation is intuitive and simple	$M_A = 6.31$ $M_C = 6.56$	*t = 0.5205*	*p = 0.6066*	$\sigma_A = 1.66$ $\sigma_C = 0.96$
Q6	The procedure content is presented clearly	$M_A = 6.44$ $M_C = 7.13$	*t = 1.4074*	*p = 0.1696*	$\sigma_A = 1.79$ $\sigma_C = 0.81$
NOTE: *These results do not include information for Layout B. Results calculated are based on two-tailed t-tests with p<.05.* a. Significant difference b. σ = standard deviation					

Because of the small sample size, the data violate the assumption of normality; therefore non-parametric tests were run as alternatives to the ANOVA and t-tests to verify the validity of the results. Non-parametric tests do not assume normal distribution of data in their calculations; thus, they can serve as a more robust test to verify the validity of the results. A Kruskal-Wallis test revealed that there is still a significant difference between the different layouts (X2 =12.316, p = 0.0021). A Mann-Whitney U-test was run on each of the individual question results, and indicated a similar pattern of results for all the questions with the exception that the result for question 1 was marginally significant (U = 83, p = 0.093) at the 95% confidence level. Table 2 shows the associated data for the non-parametric tests.

Table 2. Test statistics, p-values, medians, and ranges of results.

Test	U-Test	p-Value	Median	Range
Q1. Layout A Q1. Layout C	*U = 83*	*p = 0.093*	Md = 6 Md = 7	R = 6 R = 3
Q2. Layout A Q2. Layout C	*U = 67*	*p = 0.023*	Md = 6 Md = 7	R = 6 R = 5
Q3. Layout A Q3. Layout C	*U = 89*	*p = 0.147*	Md = 7 Md = 7.5	R = 6 R = 3
Q4. Layout A Q4. Layout C	*U = 113.5*	*p = 0.596*	Md = 7 Md = 7	R = 6 R = 5
Q5. Layout A Q5. Layout C	*U = 126.5*	*p = 0.689*	Md = 7 Md = 7	R = 6 R = 3
Q6. Layout A Q6. Layout C	*U = 106*	*p = 0.418*	Md = 7 Md = 7	R = 6 R = 2

3.5 Discussion

It is interesting to note, that while only questions 1 and 2 (Question 1 - This layout is visually appealing, and Question 2 – The layout presents a good overview of the task.) had statistical significance in the t-tests between Layout A and Layout C; the standard deviation for each question of Layout A was larger and varied more widely than the standard deviation for Layout C. The difference is shown in Table 1. This implies that participants were more consistent in rating Layout C than Layout A.

Layout C had a higher score on Question 1 (This layout is visually appealing) than did Layout A; the blue may be a significant improvement in visual appeal compared to the gray scale. Another evaluation may be useful to determine user preference specifically between a blue and a gray background with no layout changes.

For Question 2 (The layout presents a good overview of the task), Layout C had a higher rating than Layout A; the split horizontal layout may be an improvement to the continuous scrolling for understanding the overview of the procedure. The ability to simultaneously view the active step and entire procedure may provide better cognitive mapping of the procedure for the user.

The researchers used the open-ended feedback to inform a revision to the design of Layout C. In Layout C (Figure 14), the information is split between the active step in the box on the left and the overview of the actions on the right. Several participants indicated that the overview of the procedure should be on the left rather than the right, and one participant preferred Layout B as his final choice, but stated in his comments that he would have chosen Layout C had the content frames been reversed. Two other participants who preferred Layout C also mentioned switching the content frames. In addition to the placement of the overview, participants also made comments about changing the design of the indication of a completed action. They felt that it was not noticeable enough and it diminished the ability of the operator to track the current place in the steps as well as previously chosen actions. The darker blue drop-down from each step in the overview frame represents the completed action in Layout C (Figure 14), and the same is true of all actions before the current one in Layout B (Figure 13).

One limitation of this study is that the layouts were presented to the participants in the same order. It is possible that there is some form of order effect that might have biased answers, but there is insufficient data to determine the effect of presenting the layout in a fixed order.

The evaluation was designed to be quick and informal. The results were intended for use as an exploratory element for future research and development of the CBPs graphical user interface. With this in mind, randomization of the order participants took the demo did not occur. The focus was on getting as many people to use the demos and fill out a survey as quickly as possible while at the symposium.

3.6 Revised Layout

The results indicate that a new iteration of the graphical user interface should be designed following the principles of Layout C, but with some significant changes. A preview of the next design iteration can be seen in Figure 16. Another evaluation study should be conducted to investigate if the active step should be on the left with the overview on the right or vice-versa. It is possible that this may need to be coded into the system as switchable based on personal preference or hand dominance. For example, if the operator is left-handed, the active step may need to stay on the left side to allow for easier access to the action buttons by the user’s dominant hand.

The overview section was also revised. Each item is now white with blue text, rather than each step having a blue background, and a white background indicating the active step. To indicate the active step in the revised design, the item is given an arrow design on the right side that visually directs the user to the detailed step area. This avoids the possibility of requiring the user to infer from the white background of the overview which step contains the same content in the active step area.

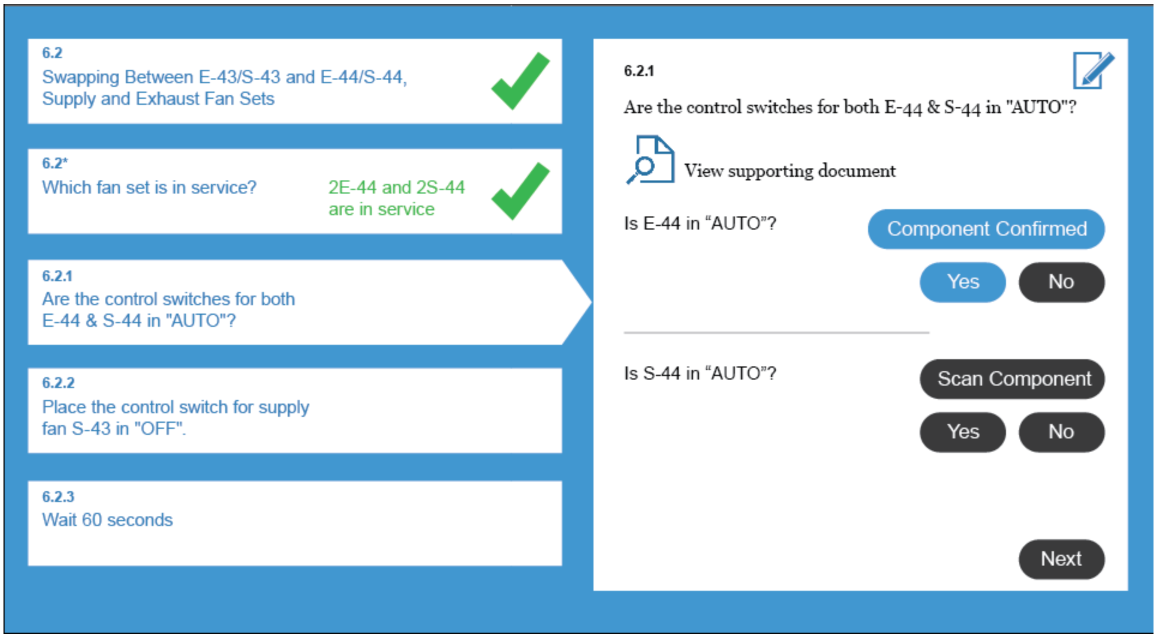

Figure 16. New design iteration.

The indications of a completed action were changed with the new design as well. Participants did not feel that the dark-blue drop-down was a good indicator of the completed steps of the task. Instead, a green checkmark and text was added to the overview box itself. The green provides easier recognition of the action, and placement within the step container creates better association with the step it applies to by proximity. Removing the drop-down box from the overview step reduces the loss of visibility of all steps seen when future steps were pushed out of frame by the drop-down in the old version.

3.7 Recommendations for Future Research

Future work will continue to improve the system's graphical design interface. Another evaluation study will need to be done to test the usability of the latest interface design. The design will need to incorporate and display system information and equipment status from the power plant during steps. Possibilities include displaying the information directly into the active step box, or including a separate pop-up style screen with the information. The demo procedures also did not include all of the possible actions operators may need to take. The next evaluation study should include new procedures that include conditional statements, continuously applicable steps, and real correct component verification.

4. GRAPHICAL USER INTERFACE EVALUATION STUDY

To confirm that no major issues were overlooked related to the underlying design concepts in the CBP system, the researchers asked a human-factors scientist to conduct an evaluation of the GUI design. Compared to the layout-evaluation study described above, the GUI-evaluation study was to focus on the human-factors aspects and usability of the design concepts, rather than the appeal of the visual presentation of the design. The human-factors scientist tasked to conduct the study had no prior involvement in the CBP research and was, therefore, not biased towards the current design of the interface. In fact, the scientist had never seen the CBP system before being tasked to conduct the evaluation. The researchers made the decision to have a novice user conduct the evaluation to test the claim that one does not have to be an expert user to understand how to execute a task using the system.

The objectives of the GUI evaluation were to analyze and evaluate the GUI using a recognized established human-factors evaluation tool, identify potential issues which may affect operator use of the GUI and, per analysis findings, provide recommendations for interface-design changes.

The human-factors scientist was instructed to use the three DCPP procedures when evaluating the GUI.

4.1 Heuristic Evaluation

Evaluation of a user interface carried out by a human factors scientist is commonly referred to as a heuristic evaluation. Often, an established evaluation tool is selected from the human-factors literature to utilize in the evaluation process. For this GUI evaluation, Jakob Nielsen's "Ten Usability Heuristics for User Interface Design," a widely known, heavily utilized tool in the field of human-factors engineering, was employed. Nielsen, a highly regarded expert in the area of usability research, originally developed the tool in 1990 (Molich and Nielsen, 1990; Nielsen and Molich, 1990). Later, he refined the initial factor analysis of 249 usability problems to a finely-honed list of ten to "derive a set of heuristics with maximum explanatory power" (Nielsen, 1994a). Nielsen referred to his usability principles as heuristics in that they serve as "broad rules of thumb," rather than strict usability guidelines (Nielsen, 1994b). These heuristics highlight common properties of usable interfaces. The Nielsen heuristics tool was selected as the evaluation tool for the CBP analysis due to its use of simple, clear and concise language as well as its universal application. These ten heuristics are presented in Table 3 below:

Table 3. Nielsen's usability heuristics.

Heuristic	**Range of Heuristic**
Visibility of system status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
Match between system and the real world	The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
User control and freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
Consistency and standard	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
Error prevention	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
Recognition rather than recall	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

Table 3. (continued).

Heuristic	**Range of Heuristic**
Flexibility and efficiency of use	Accelerators unseen by the novice user may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
Aesthetic and minimalist design	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility
Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

4.2 Usability Issues and Design Recommendations

The analysis of the user interface was carried out by applying each of Nielsen Heuristics to the CBP interface. The usability issues per corresponding heuristics were posed as questions. These, along with findings are identified below and are accompanied by screenshots highlighting the findings.

Usability Heuristic Question	**Applicable Nielsen Heuristic (No.)**
Does the interface present information in a natural and logical order?	N1 – Simple, critical information

Findings

For the most part, the interface does follow a natural and logical order:

- The procedure is provided in a natural list format.
- Completed procedure steps are marked with a prominent blue checkmark in the left corner of the procedure step (Figure 17).
- The active procedure step currently carried out is highlighted with a prominent blue border, stark white text box and large font (Figure 17).
- The interface Navigation menu can be accessed by clicking on the prominent application icon in the top left corner of the screen (Figure 18).

A “three-dot” icon is clearly displayed in the upper right corner of the interface, indicating a drop-down toolbar menu (Figure 18). The drop-down menu provides a number of user options for shifting verification modes, concurrent verification modes, and step number display alternatives. The options allow the user to personalize the process for carrying out the procedure.

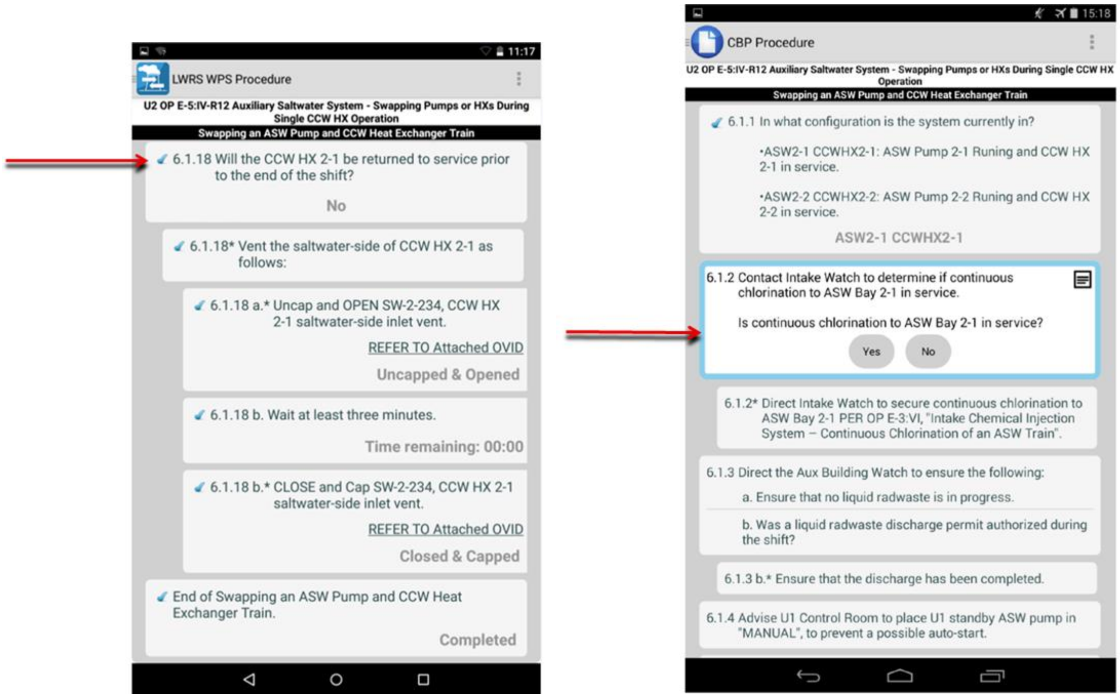

Figure 17. Blue checkmarks used to indicate completed steps. Active step highlighted with blue border.

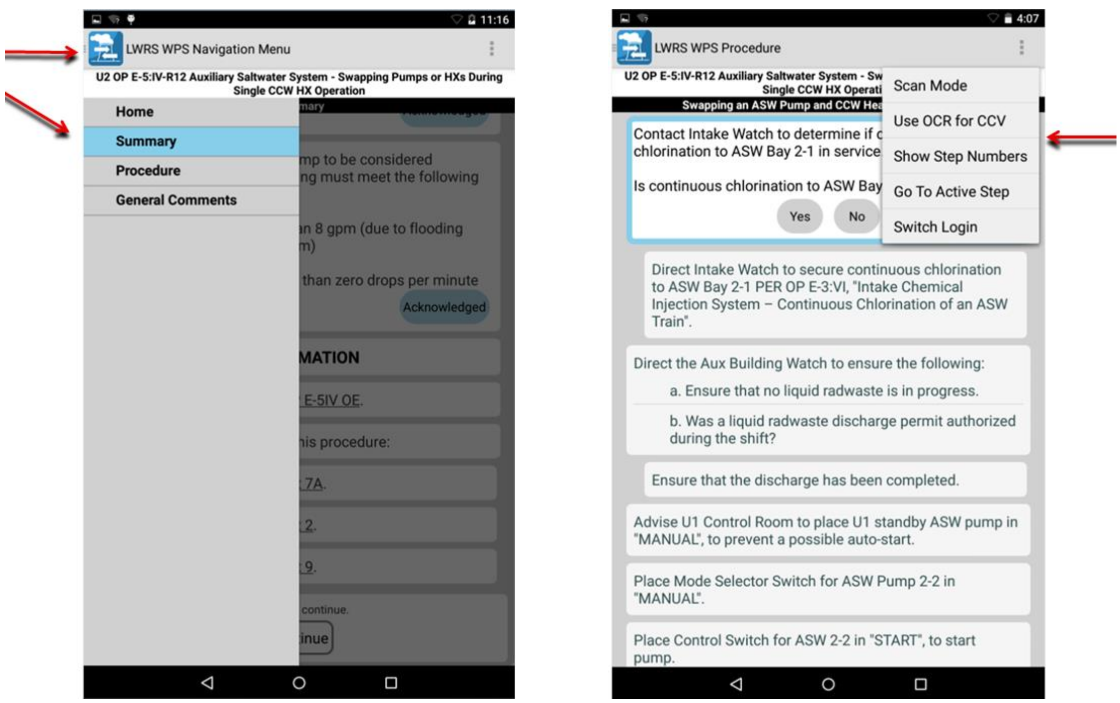

Figure 18. Application Icon and Navigation Menu and three-dot drop-down menu.

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface limit information presented to critical, necessary information, avoiding superfluous content?	N1—Simple, critical information
Findings The interface does indeed present the bare minimum needed to carry out the necessary tasks and does not overwhelm the user with excessive and inessential content. Necessary contents for carrying out procedure steps are easily accessed through both the Navigation and three-dot drop-down menus. Drop-down menus are a means of conserving screen space; therefore, the interface is designed to carefully maximize screen space without sacrificing efficiency.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface express dialogue clearly in "words, phrases and concepts familiar to the user" rather than utilizing terms oriented to the system?	N2—Users language
Findings The interface utilizes terminology familiar to those in the nuclear field. Language is clear and precise.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface present readily available instructions, either visible or easily retrievable?	N3—Minimization of user's memory load
Findings • The interface provides readily available instructions for carrying out each step of the presented procedures. These instructions are easily retrievable by logging into the system via the Log-in Page and selecting the desired procedure, the desired date and, in some cases, a particular option per single procedure such as changing over from ASW Train 2-1 to Train 2-2 or vice versa (Figure 19). • Within the PROCEDURE section of the Navigation Menu, information is provided in the form of textboxes highlighted as "NOTE:" and "CAUTION:" providing clarification to the instruction (Figure 19). • Within the SUMMARY section of the Navigation Menu (Figure 20), the interface provides additional instruction for carrying out the procedures including: - Scope of Work - Discussion - Responsibilities - Prerequisites - Precautions and Limitations - Additional Job Information/Diagrams While the interface provides information for carrying out the procedure steps, there are currently no instructions provided for questions related to the use of the device or interface. Paper-based documentation regarding the use of the device is identified as a "one-pager" and is available as a resource to the plant operators.	

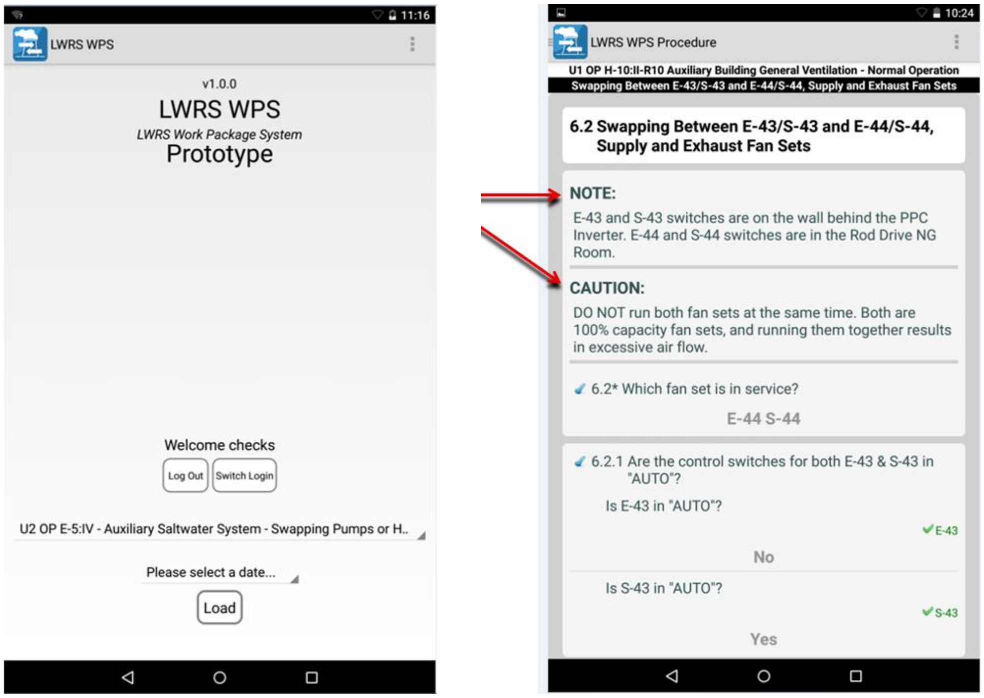

Figure 19. Application’s home login page and example of Note and Caution in the step.

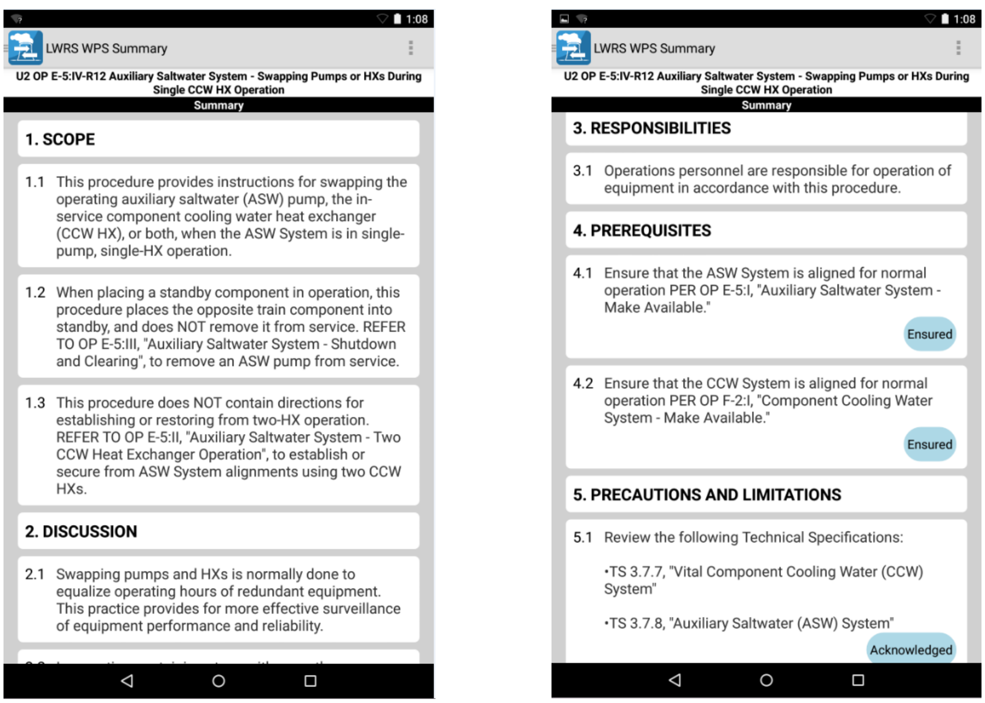

Figure 20. Information provided within the Summary section of the Navigation menu.

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface consistently present information such that a user is confident that words, situations or actions mean the same thing?	N4-Consistency

Findings

For the most part, the interface presents information consistently, relying upon the same terms and concepts throughout with corresponding consistency in the situations and actions encountered by the user. There are two notable exceptions to this:

- The inconsistent use and general overuse of asterisks before and after procedure steps creates confusion. As asterisks are generally used to highlight or call attention, there is question as to why they are used indiscriminately (Figure 21). For example, in Procedure E-5, there are two separate steps labelled "6.1.15 *" and further into the procedure there are steps:

  The asterisk is used again in E-5 between steps 6.1.11 and 6.1.12 to display this statement, "*Verify Intake Watch has secured continuous chlorination..."

The use of the blue checkmark (shown earlier in Figure 17, located to the left of each procedure step) is a clear indicator that the step has been completed. However, within the interface this same checkmark is also used to edit a procedure step. This concept seems unusual with nothing about the icon suggesting that it may be used to edit—that is, undo/redo a procedure step.

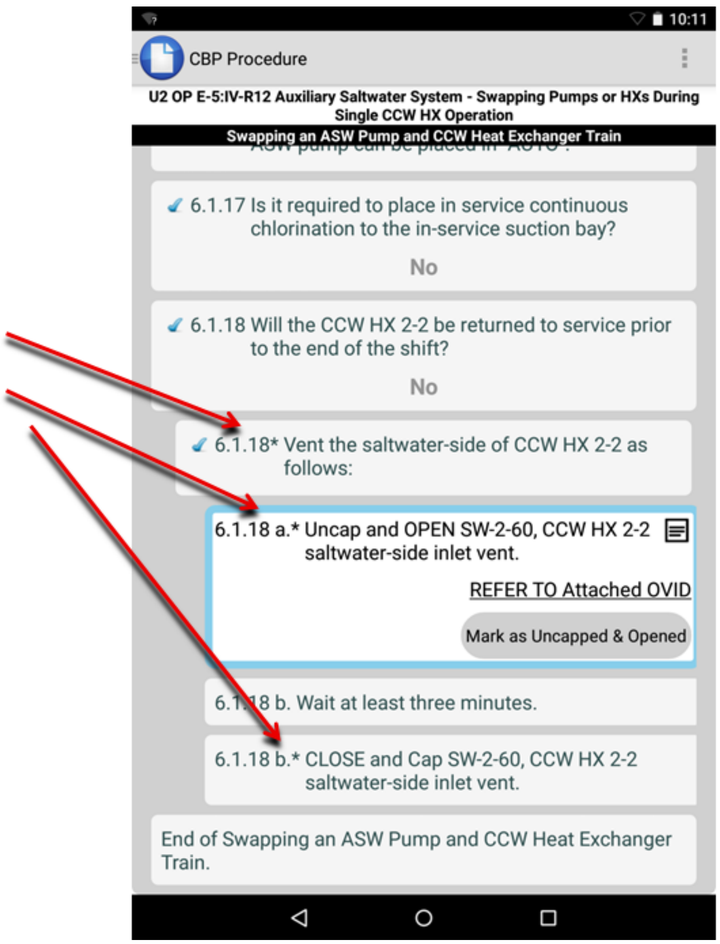

Figure 21. Excessive use of asterisks compromises clarity within the Procedure steps.

Usability Heuristic Question	Applicable Nielsen Heuristic (#)
Does the interface afford awareness, keeping user informed as to "what is going on?"	N5—Feedback

Findings

The interface does a fine job of displaying information to afford user awareness. For example:

- As displayed earlier (Figure 17) the active step—that is, the procedure step currently being carried out—is displayed as a stark (in that it is very white against a subtle gray background) text box, with large font and a thick blue border. This highlights and draws the user's eye to the step.
- The interface provides a timer as part of procedure steps such as 6.1.18 b. (Figure 22), which instructs, "Wait at least three minutes".
- Verification steps turns blue (Figure 22) when confirmed such as "Acknowledged or Mark as Obtained/ Obtained"

Additionally, users are presented with extensive updates as they proceed through the interface steps.

- When asked a question, responses are recorded in bold font below the question, quickly followed by two immediate messages, "Updating flow based on decision" (Figure 23) and "Updating flow based on data changes" (Figure 23).
- Feedback is clearly provided to user when the last step in the procedure has been completed with the interface displaying the message "Procedure Complete" (Figure 24).

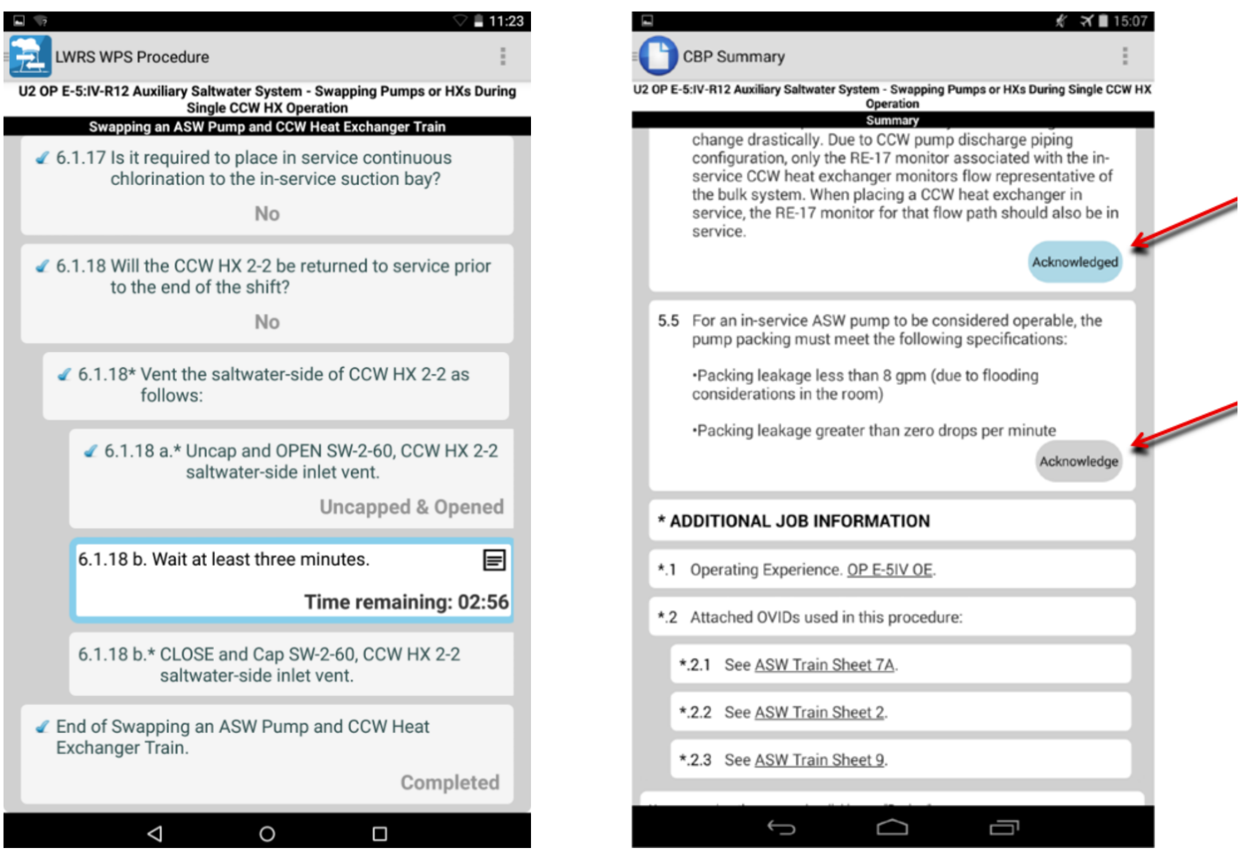

Figure 22. The embedded timer and visual cues when placekeeping summary.

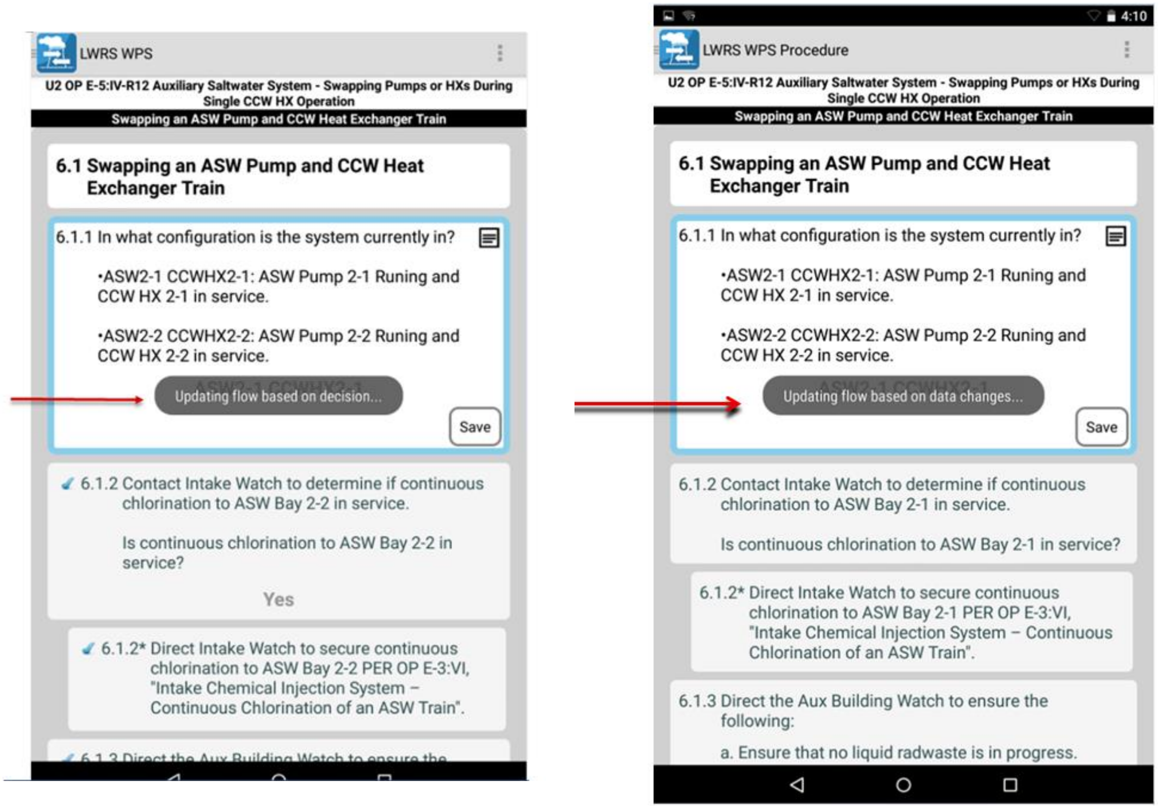

Figure 23. Feedback provided to user when procedure step has been edited.

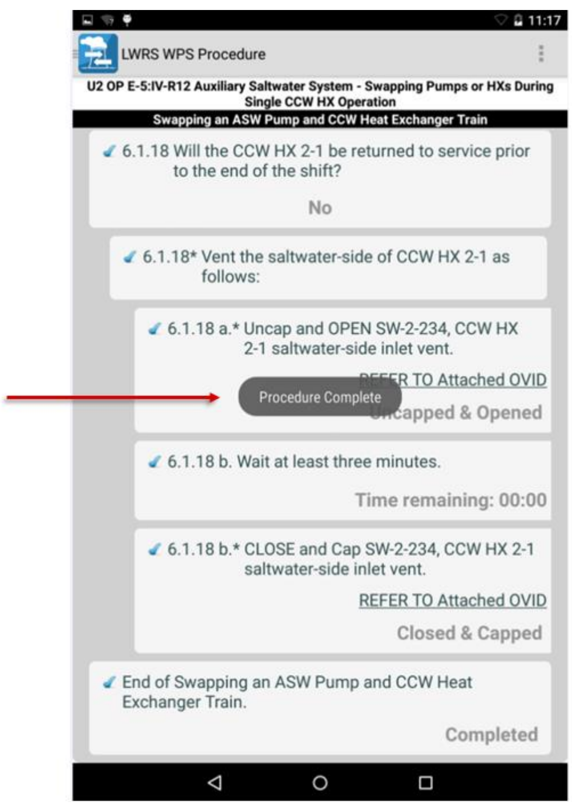

Figure 24. Feedback is provided to the user when the procedure has been completed.

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface provide feedback within a reasonable amount of time?	N5—Feedback
Findings Yes. As a whole, the interface provides feedback quickly. Buttons instantly turn blue when selected, and messages are consistently displayed within a few seconds.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface provide clearly marked “emergency exits” to quickly and easily undo/redo an action and return to the pre-action site?	N6—Clearly marked exits
Findings • The back arrow located at the bottom left of the device screen quickly returns to the previous section(s) of the navigation menu. For example, clicking on the back arrow while in the Procedures section of the interface returns the user to the Summary page. Clicking on the back arrow a second time returns the user to the Home Page. • As previously mentioned (N4—Consistency) the interface provides a small blue checkmark in the left corner of the procedure step. If the user clicks on this checkmark, it allows the user to “edit” the step. That is, it provides an opportunity for the user to return to the step and select a different option at the prompt to undo an outcome. • Nothing about the icon or indicator of a checkmark intuitively suggests recovery action. • Clicking on blue checkmark gives you the message, “Are you sure you want to edit the step?” Using the term “editing a step” to undo/redo a procedure step may lead to confusion for the user.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface afford accelerators or shortcuts to the experienced user such that it can be used easily by both novice and experienced users.	N6—Flexibility and efficiency of use
Findings Upon examination, there do not appear to be specific tools within the interface geared for either the novel or the experienced user. Support of both novice and expert operators is effective for the intended tasks.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Is the interface designed to communicate error messages in plain, yet precise language when a problem is encountered?	N8 - Minimalist design
Findings The error messages displayed within the interface are clear and concise.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Is the interface designed such that error messages presented to the user provide constructive solutions to the issue(s) encountered?	N8—Minimalist design
Findings The error messages displayed within the interface immediately identify issues encountered and provide guidance to the user.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Is the interface carefully designed such that all actions have been thoroughly tested to mitigate the rate of errors?	N9—Error recognition and diagnosis
Findings The interface has been designed to mitigate the possibility for error. Errors encountered are limited to those situations where the user attempts to carry out a procedure before completing all preliminary steps in the Summary menu or inadvertently begins work on the wrong component.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
If and when necessary, does the interface provide help and critical documentation to the user?	N10—Help and documentation
Findings The Summary and Procedure sections of the interface provide complete and readily available instructions for carrying out each step of the plant procedures. While the interface provides information for carrying out the procedure steps, there are no instructions related to the use of the device or interface. Paper-based documentation regarding the use of the device is identified as a "one-pager" and is available as a resource to the plant operators.	

Usability Heuristic Question	Applicable Nielsen Heuristic (No.)
Does the interface provide help and documentation presented such that the information is: a) Easy to search b) Focused on the user's task c) Compiled in a list of concrete steps to be carried out d) Adequate, but not overwhelming in size.	N10—Help and documentation
Findings a) For this application, the instructions for carrying out plant procedures are not set up so that they may be accessed via search, yet they are readily available via the interface Home page. Users familiar with carrying out plant procedures, will intuitively look for information in the Summary and Procedure sections. b) Information presented is focused on the user's task. c) The procedures are broken down into a series of concrete steps. d) Procedures are complete but not overwhelming in presentation.	

4.3 Identified Issues and Recommendations

The GUI evaluation identified a small number of potential usability issues. The human-factors scientist conducting the evaluation made the following design recommendations to improve the ease of use for the interface for each of the identified issues. The recommendations are

1. Add a “Help” option to the Navigation Menu.
2. Darken the three dots in the three-dot drop-down menu.
3. Add a recovery action icon for recovery actions (undo/redo).
4. Use “correct or change procedure step,” instead of “edit.”
5. Omit asterisks.

Adding a Help option at the bottom of the Navigation Menu will provide a means for clear, simple instructions for using both the interface and the device (Figure 25), and darkening the three dots in the drop-down menu will increase the visibility of the menu (Figure 26).

The third recommendation is to add a prominently displayed recovery-action icon to the left and directly below the checkmark rather than using the checkmark icon to imply both that a task has been completed and that the checkmark can be used to initiate recovery actions (undo/redo). While the checkmark conveys completion, from a usability standpoint it is an ineffective symbol to convey editing/undo/redo functions to the user (Figure 27).

Related to this process, it is suggested that a different term be used, rather than edit, within the procedure step for providing the user the option of returning to a step for recovery action. For example, substituting “correct or change procedure step” may reduce or eliminate confusion for the user.

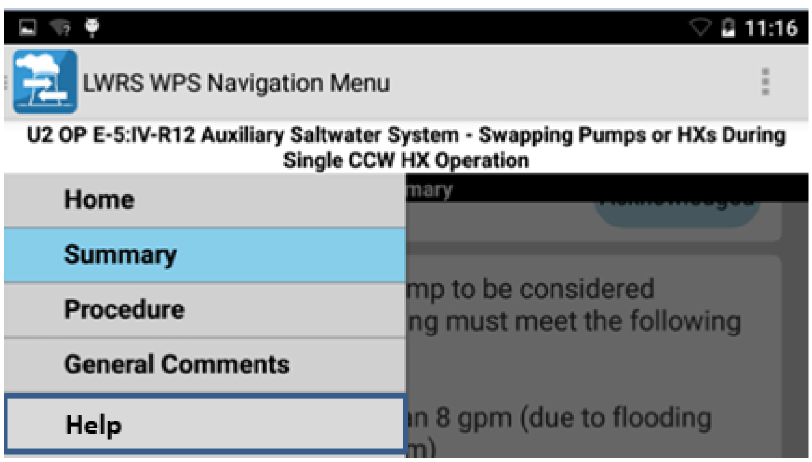

Figure 25. Suggested Help option.

Figure 26. Suggestion made to darken dots for the three-dot drop-down menu.

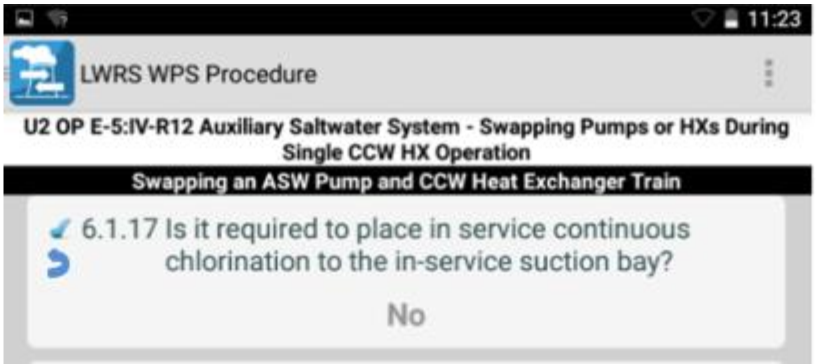

Figure 27. Insertion of recovery arrow function to change or correct procedure step.

Finally, the evaluator recommended that the use of asterisks within the Procedure steps be omitted as they fail to provide critical information to the process, but create visual clutter in the interface. However, the asterisks does provide essential information and may be the most straightforward way to indicate that a specific procedure step in the CBP version is simply part of a step in the PBP is broken into multiple steps in the CBP. The asterisks are necessary to preserve a one-to-one mapping between the original paper procedure and CBP version. As long as the utilities have PBPs in parallel with the CBP system it will be necessary to provide the direct mapping between the two versions.

5. SUMMARY AND PATH FORWARD

The researchers conducted three different types of studies to address the usability, functionality, and visual design of the CBP system. The result from the field evaluation study concluded that the operators liked the new functionality added to the CBP system and found the system easy to use. Additional functionality to further improve the system was identified. The layout-evaluation study focused on the visual appearance of the CBP system. The main finding from the layout-evaluation study is the need to develop a landscape layout that combines an overview of the task and detailed action information. The underlying design concepts of the CBP system were evaluated in the GUI evaluation study. The GUI evaluation concluded that the design of the CBP system for the most part is in alignment with common human-factors heuristics.

The main conclusion from all three studies is that the CBP system is easy to use, the underlying design concepts are sound, and the overall design in quite visually appealing. However, there are opportunities to further improve the user experience of the CBP system.

Moving forward, the researchers will address and evaluate the recommended improvements in two different ways. First, the added capability gained from communicating over a wireless network will be demonstrated to show the streamlined handling of shared tasks. The researchers will also demonstrate the capability to communicate with plant systems, such as the planning and scheduling systems.

Next, to further ensure that the transition from paper to a computerized process does not add new, unexpected error traps or performance inefficiencies, the researchers will evaluate the CBP performance using a performance-modelling tool, such as Integrated Performance Modelling Environment (IPME). The tool will be used to model human processes and human interactions with technology. The activity will:

- Identify human-performance issues with the task (results that applies to both the PBP and CBP version)
- Simulate options to improve the task execution, provide suggestions of how to best implement these improvements in the CBP system and evaluate these improvements
- Ensure that the CBP design in fact does not introduce any new error traps or other inefficiencies

- Investigate which of the underlying CBP design concepts provides the most benefits compared to the PBP (and at the same time see if there is any feature that doesn't make a difference at all)
- Provide validity and a scientific basis to the argument that transitioning to computerized systems in fact will result in time/resource savings.

As a part of the conscious effort to collaborate with as many LWR utilities as possible to ensure the CBP design concepts developed are applicable to the industry as a whole, rather than tailored to one specific utility and their procedures, the researchers will conduct additional field evaluation studies with new collaborating utilities. The goal is to cover many different organizations, tasks, and procedures to make sure the final design guidance is as complete as possible. The field evaluation studies will evaluate the added functionality and revised layout as well as identify additional functionality the field workers would like in the system. In addition, a smaller study will be conducted to evaluate the new layout design. The goal is to ensure the new layout is more visual appealing than the current layout.

As described in the reports by Bly, Oxstrand, and Le Blanc (2015) and Oxstrand, Le Blanc, and Bly (2015), in order to gain full advantage of the technological advancements inherent in computer-based procedures, there must be a translation layer between the person composing the procedure and the data structure, i.e., a procedure-authoring and editing tool. Extensible Markup Language (XML) can be used to represent the procedure in the structure that the Computer-Based Procedure System (CBPS) can interpret. To compose an XML document, the author has to be both familiar with the specific XML syntax and be prepared to compose a document that might be lengthier than one produced using a traditional word processing application such as Microsoft Word. In addition, even an experienced XML user can make mistakes, such as adding sequences out of order or typographical errors, which create a need for testing and debugging of each XML document. All of this makes the process of writing procedures in XML more time-consuming and requires new skills than the currently used procedure-writing process.

The authoring and editing tool should be designed to be used by individuals that have no prior XML knowledge or skills. The user interface should be easy to use, and linkage to the underlying data structure should happen in the background. The vision is a tool where the user easily can create a procedure for a specific task by selecting the components and actions required. The tool will ensure that relevant steps are identified and sequenced in their proper order. The CBPS authoring and editing tool must be able to handle relationships between steps (e.g., decision points, input fields, and marking steps not applicable).

Most computer users are familiar with the concept of drop-down boxes, input boxes, lists, and options. Using these elements in a tool to create an XML document will mitigate errors that might otherwise be introduced into the document. It will also allow a user to create a document in less time, without the need to verify the syntax is correct and the sequence is in order.

As steps are created they can be stored and reused. An authoring and editing tool can allow the user to view a library of steps and select ones that fit into a procedure. This will decrease the time needed to revise and author procedures.

No known authoring tool is available from the market today that is both user-friendly and able to output the structure needed for complex procedures that a CBPS system needs to run the procedure. A prototype tool must be created in order to show the utilities and vendors what is possible and what is needed.

The process of designing and creating the authoring tool will be used to develop guidelines that the vendors and utilities can use in order to develop authoring tools of their own. Feedback will be sought through the working groups already established to fine-tune the authoring tool capabilities.

The final outcome or product of the research project is CBP design guidance. The design guidance will provide a detail description of the underlying design concepts and their technical bases. It will also provide guidance on how to design the task-execution process, how to seamlessly integrate human-performance tools, and how to design the user interface to make it user-friendly and visually appealing. The researchers will develop two versions of the design guidance: a written document and an interactive web-based tool. The document and the tool are meant to be used together where the document provides detailed information and the tool provides a visual representation of the design concepts. The interactive web-based tool will simulate a procedure being used in a CBP system. The user will be able to walk through the procedure and hence explore all the different capabilities covered in the research effort. The goal of the interactive tool is to communicate the insights from the research in a format that is easy accessible and digestible to the nuclear industry.

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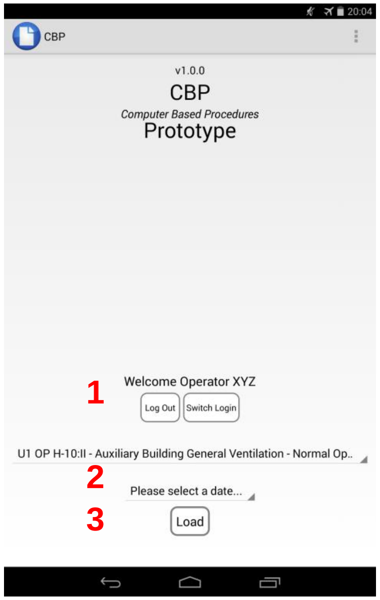
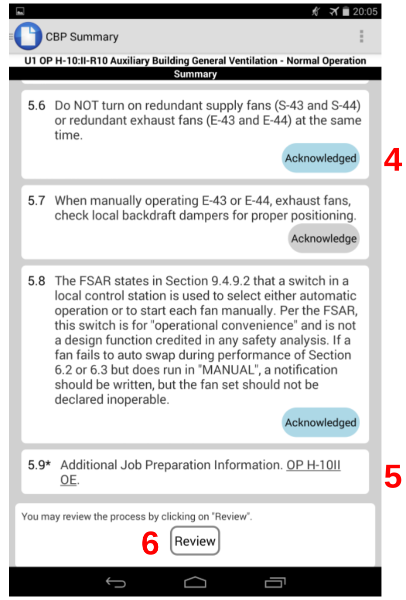
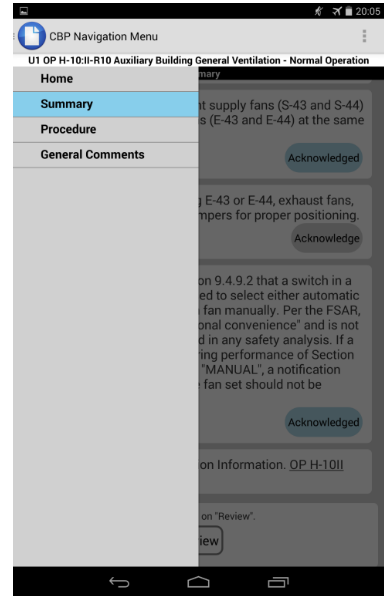
Appendix A

CBP Job Aid

Appendix A
CBP Job Aid







<u>Home Screen</u>

1. Log in by typing your User ID.
2. Select procedure to perform and Select today's date using the dropdown menus.
3. Load the selected procedure.

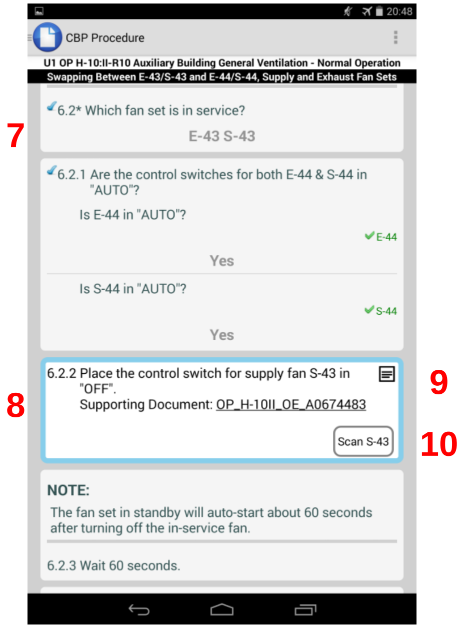
<u>Summary Screen</u>

4. Placekeep steps in Sections 1-5 by Acknowledged you read the step. If needed, these steps can be conducted out of sequence.
5. Access additional information by clicking on links.
6. If needed, review the procedure before completing Sections 1-5.

<u>Navigation Menu</u>

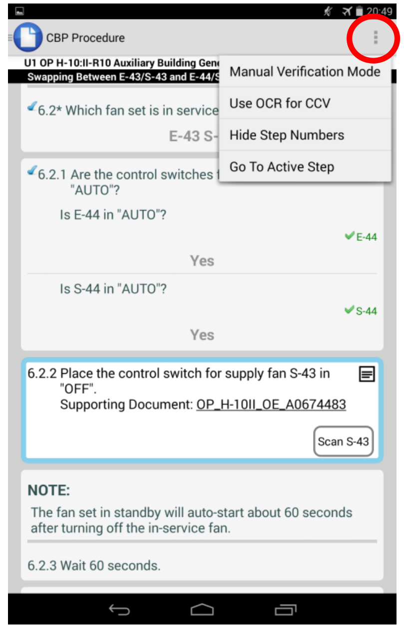
Swipe your finger left to right from the left side of the screen OR click the document icon in the top left corner.
Home – User and procedure selection.
Summary – Sections 1-5.
Procedure – Section 6.
General Comments – Allows you to add comments while conducting the task.

(1)



Procedure Screen

7. Conducted steps are marked with a checkmark and decision/input/action taken is displayed.
8. Active step has blue border.
9. Notes can be added to any step.
10. For H-10:II, component barcodes can be used for correct component verification.



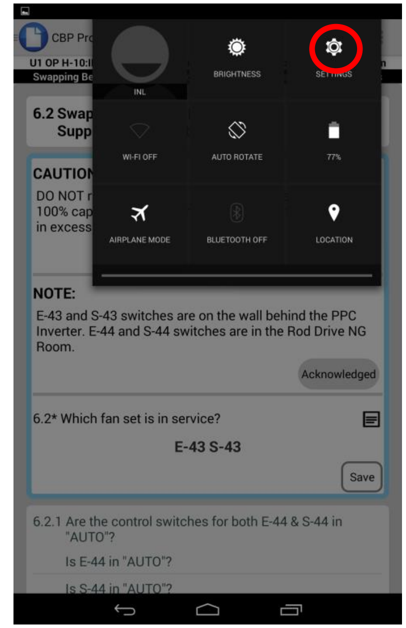
Dropdown Menu

Manual Verification Mode/Scan Mode – Switch between manual correct component verification (CCV) and using Barcodes for CCV.

Use OCR for CCV –
Switch to Optical Character Recognition for CCV. [Beta version]

Hide/Show Step Numbers –
Option to hide or show numbers.

Go To Active Step –
Go back to the step to be performed (the currently active step).



Settings Menu

To increase/decrease font size slide finger downwards from the top of the screen to access the Settings menu.

Hit return button on the bottom of the screen to return to the procedure.

(2)

Appendix B

DCPP Post Task Web Survey

Appendix B
DCPP Post Task Web Survey

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

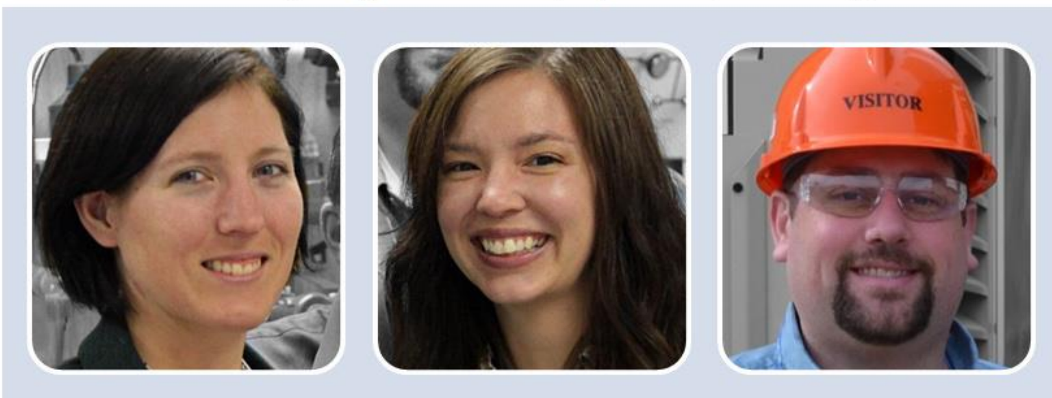
Welcome to the Post Task Survey!

Thank you for participating in our field test of the Computer-Based Procedure (CBP) system. We now need your help to understand what worked well, what you liked, and things that need additional improvement.

Your feedback plays an important part in advancing the field of Computer-Based Procedures!

Thank you,
The INL team

The Idaho National Laboratory team (Johanna Oxstrand, Katya Le Blanc, and Aaron Bly)



8%

Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

INL Computer-Based Procedure (CBP) Post Task Survey

Please answer the following questions based on your experience using the Computer-Based Procedure (CBP) system.

*** 1. Please enter the following information:**

Your User ID*

*** 2. Which procedure did you use?**

- ◯ OP E-5:IV – Auxiliary Saltwater System - Swapping Pumps or HXs During Single CCW HX Operation
- ◯ OP E-3:VI – Intake Chemical Injection System - Continuous Chlorination of an ASW Train
- ◯ OP H-10:II – Auxiliary Building General Ventilation - Normal Operation

(*) The User ID will only be used by the INL team to compare potential changes over time, i.e., if you use the CBP system multiple times (and therefore provide multiple survey responses) how - if at all - does your feedback change. The INL team does not have knowledge of which individual is linked to a specific User ID, hence your feedback is still anonymous. The survey results will be aggregated before shared outside the team and will at that point no longer be associated to the User IDs.

17%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 3. Did the CBP lead you down a path where you conducted a mistake, near-miss, or deviation?**

- ◯ Yes
- ◯ No

25%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the Computer-Based Procedure (CBP) system.

*** 4. Briefly describe the situation in which the CBP lead you down a path where you conducted a mistake, near-miss, or deviation.**

33%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 5. Did the CBP system prevent you from making a mistake, near-miss, or deviation?**

- Yes
- No

42%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 6. Briefly describe the situation in which the CBP system stopped you from making a mistake, near-miss, or deviation.**

50%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 7. Did the CBP system cause any confusion or behave in a way that was unexpected while you executed the procedure?**

- Yes
- No

58%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 8. Briefly describe the situation in which the CBP system caused confusion or behaved in a way that was unexpected while you executed the procedure.**

67%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 9. After executing the procedure with the CBP system, do you prefer using paper or the CBP?**

- I prefer the CBP system.
- I prefer paper procedures.

75%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 10. Describe what you liked and what could be improved in the CBP system.**

For example, suggestions for improving the interface, additional functionality you would like, or issues that need to be addressed before a system like this could be implemented.

83%

Prev Next

INL Computer-Based Procedure (CBP) Post Task Survey - DCPP

Please answer the following questions based on your experience using the CBP system.

*** 11. Please Rate the usability of the CBP system.**

Consider how easy it was to navigate, how easy it was to learn, and how easy it was to use.

1. **Poor**	2	3	4	5	6	7	8	9	10. **Excellent**
○	○	○	○	○	○	○	○	○	○

12. Do you have anything you want to add?

Thank you for your input!

Have ve a great day!
-- INL Team

100%

Prev Done