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Revision 0

Light Water Reactor Sustainability Program

Computer-Based Procedures for Field Worker – Identified Benefits

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CONTENTS

FIGURES

ACRONYMS

CBP	computer-based procedures
CCV	correct component verification
DOE	Department of Energy
INL	Idaho National Laboratory
LWRS	light-water reactor sustainability
N/A	not applicable
OCR	optical character recognition
R&D	research and development

Computer-Based Procedures for Field Workers – Identified Benefits

1. INTRODUCTION

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

This report addresses the DOE Milestone – M4LW-14IN060309 – Report describing the benefits of computer based procedures.

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

It is important to distinguish between an electronic procedure and a CBP. In its simplest form an electronic procedure is an electronic copy of the paper procedure, i.e., a PDF or similar document that displays the procedure content in a manner that is very similar to the paper-version of the procedure. The more advanced electronic procedures uses for hyperlinks to provide additional information (photos, appendices, etc.), some user inputs (e.g., recorded values), and mark-up capability (e.g., writing notes and conduct traditional placekeeping in the PDF). Electronic procedures are currently offered by a variety of vendors. Also, it's important to note that a CBP and CBP system refers to slightly different things. The procedure system (CBP system) can contain many procedures (CBPs). In other words, the system is the technology or tool used to conduct the procedures.

In the context of the research effort a CBP is defined as a dynamic presentation of a procedure that guides the user seamlessly through the logical sequence of the procedure. In addition, the CBP system makes use of the inherent capabilities of the technology, such as incorporating computational aids, easy access to additional information and just-in-time training, and digital correct component verification. Technological advancements in the CBP system allow human performance improvement features to be even more integrated into both the procedure and the overall work process compared to the electronic procedures. For example, a CBP system offers a more dynamic means of presenting procedures to the user, displaying only the relevant steps based on operating mode, plant status, and task at hand. A dynamic presentation of the procedure guides the user down the path of relevant steps based on the current conditions. Current conditions and user input the CBP system determine which steps are applicable and which are not. This feature will reduce the user's workload and inherently reduce the risk of incorrectly marking a step as not applicable and the risk of incorrectly performing a step that should be marked as not applicable.

Context driven job aids, such as corrective action documentation, drawings, photos, just-in-time training, etc. 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 way 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, placekeeping, 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.

2. FUNCTIONALITY OF THE CBP SYSTEM

The reduction of operator workload using CBPs requires a balance between automation and decision support, operator engagement, and the procedure execution process. The high-level solution to the problem is to always provide a means to easily provide information to the operator about completed steps, steps marked not applicable, future steps, decisions made that influenced the path through the procedure, etc. The key functionality of the CBP system is described below.

Automatic placekeeping

The CBP system highlights the active step, i.e., the step to be conducted. All other steps are shown, but the operator can only take actions related to the active step. In the rare circumstance that the operator, with the approval of his supervisor, concludes that the CBP system is incorrect due to current conditions in the plant, the CBP system can be overridden. These functions make it easy for the operator to stay on the specified path. This built-in procedural adherence has proven to reduce the amount and severity of human errors. As seen in Figure 1 below, the active step is marked with a blue border. The future steps (below the active step) are grayed out. The field worker can read these steps, but no action can be taken on these steps at this point.

Simplified step logic

A conditional step in a procedure is a step that is based on plant condition or combination of conditions to be satisfied prior to the performance of an action. The CBP removes complexity from step descriptions by presenting IF/THEN, WHEN/THEN, AND, OR, etc. statements as simple questions. For example, conditional statements such as "IF starting pump A, THEN perform the following…" are presented as "What pump do you want to start; Pump A or Pump B?" Depending on the answer, the procedure will take the operator to either a step with the actions needed to start the Pump A or the step with the actions needed to start Pump B. Figure 1 shows an example of the simplified step logic. In this example, the CBP system asks a yes/no question instead of presenting an IF/THEN statement.

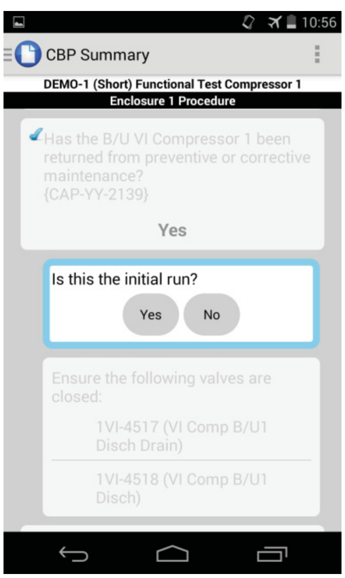

Figure 1. A screenshot from the CBP system, developed by the research team, showing an example of simplified step logic.

Correct Component Verification

Before taking an action on a component or piece of equipment, the operator is required to verify that it is the correct component. This is called correct component verification (CCV). Currently, this is done by looking at the procedure and reading the component identification out loud. Then, the operator will touch the component's label and read the component identification out loud. If there is a match, the operator is at the correct component. However, incidents where the operator manipulates the incorrect component still occur.

There are multiple ways CCV can be implemented and improved by utilizing technology. The researchers have explored CCV via barcodes, optical character recognition (OCR), and manual input. When using barcodes or OCR the system will match the input with a component database. If the correct component is verified the operator will be able to continue on with the step. If the correct component is not verified the operator will have to find the correct component before being able to proceed through the procedure. If the barcode or OCR fails or if the operator prefers to conduct component verification manually there is always an option to do so.

3. RESEARCH ACTIVITIES

The research team is exploring how best to design a CBP system that will deliver the intended benefits of increased efficiency and improved human performance. It is important to note that no "off-the-shelf" technology exists for the type of CBP system that is investigated and developed by the researchers. As more technology is integrated into the procedure process the importance of an appropriate and methodological approach to the design of the procedure system increases. Technological advancements offer great opportunities for efficiency and safety gains, however if the system is not designed correctly there is a large risk of unintentionally introducing new opportunities for human errors.

The research team is breaking new ground in the area of CBPs with the prototype they have developed. As mentioned earlier, current electronic procedure systems are most commonly electronic versions of the paper-based procedures with hyperlinks to other procedures, limited user input functionality, and the ability to mark steps completed. These systems do not fully exploit the advantages of digital technology. It is a part of the =researchers' role to develop and validate new CBP technologies that greatly increase the benefits of a CBP system to the nuclear industry.

The research team has developed a prototype CBP system, which has been evaluated both in laboratory settings and out in the real nuclear plant through an iterative process. The main functionality of the system and the research activities conducted to date are described in the following sections. The CBP research effort aims to provide the nuclear industry a better understanding of the benefits of transitioning to a CBP system by demonstrating proof-of-concepts and conducting activities where the actual end-users get to use the CBP system in their everyday work in a nuclear power plant.

A qualitative study was conducted first to investigate how procedures are currently used in the nuclear power industry. The study identified elements of the current use of procedures that should be retained when designing a CBP system—for example, providing an overview of the task at hand and keeping the operator focused on the task at hand. Areas for improvement were also identified, such as placekeeping, correct component verification, and seamless transition between procedures. Based on these findings, the researchers identified an initial set of design requirements, which was used to design the first version of the CBP prototype system. Each revision of the prototype was evaluated through empirical research conducted in laboratory settings at collaborating utilities. The results from the evaluations were used to revise both the design requirements and the CBP system. Figure 2 provides a summary of the activities conducted to date.

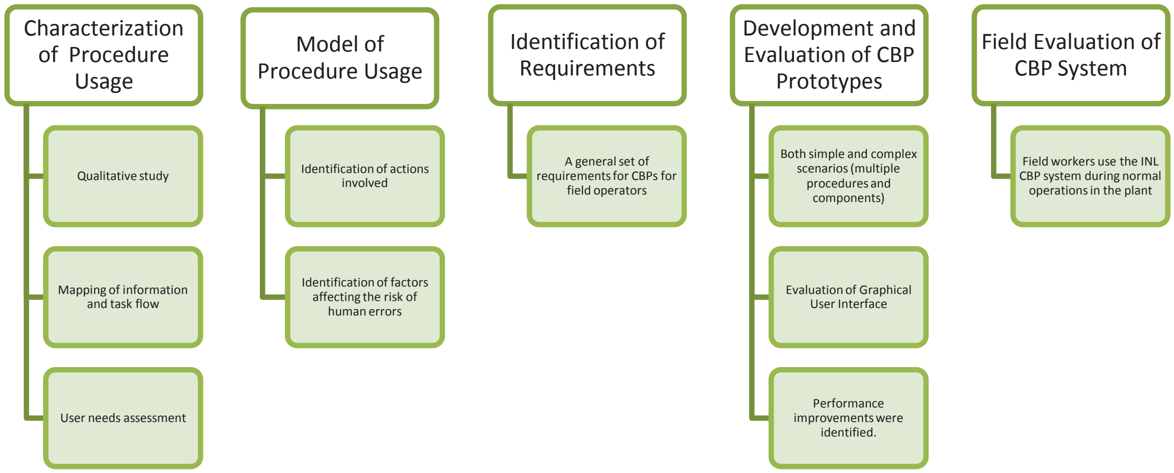

Figure 2. Research Activities Conducted To Date.

Industry acceptance of advanced technology and CBP systems is vital in order to move the industry closer to fleet-wide deployment of such systems. One of the most important tools to gain traction toward industry acceptance is to put a CBP system in the hands of field workers (e.g., auxiliary operators, maintenance technicians, etc.) and other end-users. Hence, engaging end users in early CBP system trials is a crucial step in enabling the field workers to work in a safer and more efficient manner with fewer mistakes.

Three laboratory studies were conducted to evaluate the CBP design from a human factors standpoint. Nuclear power plant operators and technicians participated in realistic work scenarios using both a paper-based procedure and a computer-based version of the same procedure. The researchers compared the participants' performance using both types of procedures. The evaluation studies focused on deviations from specified path, performance time, mental workload, and the general usability of device and interface. The evaluation studies were hosted by collaborating utilities and conducted in their training facilities (flow loop, electrical laboratory, and instrument and control laboratory). The main objective of the three evaluation studies was to collect feedback on the design of the user interface of the CBP as well as identify the appropriate functionality of the CBP. The researchers incorporated suggestions from the participants as well as insights gained from carefully observing the participants carry out the procedures using the CBP. In addition to gathering information about usability and functionality, the researchers aimed to evaluate the effect a CBP may have on performance and efficiency of the procedural task.

The results of the three laboratory evaluation studies indicate that well-designed CBPs will reduce errors. The procedure used in the first study was simple, and none of the participants made an error in executing the procedure, making it impossible to compare performance while using the CBP and paper-based version. The first study indicated that operators initially use more time to execute procedural tasks when they use a CBP system. The second evaluation study revealed that in a more complex procedure, using the CBP reduced the number of errors. Participants committed a total of 13 non-recovered errors when using the paper-based version of the procedure compared to a total of 1 non-recovered error using the CBP. Recovered deviations were defined as situations in which operators were not following the optimal path, but ultimately recovered. For example, when an operator walked to the wrong location or attempted to verify the wrong component (but ultimately found the right component or location), it was recorded as a recovered deviation. Non-recovered deviations were defined as deviations in which the operators failed to take an action specified in the procedure or took the wrong action. The researchers chose to classify the deviations separately because they wanted to capture deviations that indicate confusion or misunderstanding (especially with respect to the CBP prototype, but that would not typically be considered deviations in the procedure). The non-recovered deviations would have a greater impact on system performance and safety than the recovered ones. Again, in the second study the CBP appeared to increase the amount of time it took to execute the procedure. The third study showed the positive impact of computational aids. The procedure had a fairly simple calculation of how much water to add to a tank to reach a specific level. A large amount of the participants made calculation errors while conducting the task with the paper-based procedure. Due to the design of the CBP system, no calculation errors were made when the computer-based version of the procedure was used.

The third study also was the first of the ones conducted where there was no significant time difference between conducting the task with the paper-based procedures or CBPs. The researchers identified three main reasons for the potential time difference between using paper-based procedures and CBPs in the studies. First, the design concepts used in the CBP needed to be refined based on the input from the participants to adequately provide performance benefits. Secondly, the participants only received a brief training on the CBP system before they were asked to conduct the task using the CBP system. In the real world, the users would receive more extensive training. The reason for the brief training was to investigate how self-explanatory and user-friendly the design of the CBP system is. Lastly, even though the participants were instructed to save any comments about the CBP system until they had completed the task most of them were quite eager to share their impressions with the researchers while conducting the task. This phenomenon did not happen when they conducted the task with the traditional paper-based procedure. Figure 3 below depicts one of the participants in the evaluation study conducted in a flow loop facility in November 2013.

Figure 3. An Auxiliary Operator uses the CBP system as a part of the November 2013 Evaluation Study.

In summary, the laboratory research activities demonstrated:

- Automatic place-keeping and the ease of moving between and within procedures when having to transfer to other procedures and/or conducting continuous action steps increased both efficiency and human performance.
- Context-sensitivity and simplified step logic are highly desirable features. Context-sensitive cues (e.g., labels on buttons provides cues to what action needs to be taken) in the procedure increase the operators focus on the task at hand.
- Digital Correct Component Verification reduces the risk of manipulating an incorrect component. The use of barcodes to verify correct component is generally viewed as an effective implementation of the human performance tool.
- Photos of components included in procedure steps increased efficiency and reduced the risk of human error when locating specific components and equipment as well as when conducting component verification.
- Computational aids, such as performing calculations based on user inputs (e.g., recorded tank levels, temperature, and engine speed), have proved to reduce the risk of human errors.

The laboratory studies provided great insight to how to best design the dynamic presentation of the procedure and how to best incorporate human performance tools into the workflow. However, a crucial step to get the end users' (e.g., auxiliary operators, maintenance technicians, etc.) acceptance of such system is to put the system in their hands and let them use it as a part of their everyday work activities. This is achieved by field evaluation studies. Hence, the next type of activities to evaluate the CBP system will be conducted in an actual plant rather than in a training facility or laboratory setting. A pilot field evaluation study at a plant was conducted during April and May of 2014. A procedure for the weekly functional test of diesel-driven instrument air compressors, which is a task conducted by auxiliary operators, was used for the field test. Figure 4 shows two auxiliary operators using the CBP system to perform the functional test.

Feedback from plant staff (auxiliary operators, operation managers, procedure writers, trainers, etc.) was collected both during a plant visit the week leading up to the kick-off of the CBP field test activity and throughout the month the CBP system was used at the plant. Based on this feedback, the features of the CBP system that were most appreciated were:

- Photos of components included in procedure steps: The participants provided comments such as; “I wish I had this when I was new! Instead I spent a lot of time trying to locate components in the plant,” and “This would be very useful during outage or anytime you’re scheduled to do a job you only do once in a while.” The participants also stated that the photos are not only useful when locating the component, but also during the process of validating the correct component.
- Documents referred to in procedure steps are easily accessible: Additional information such as just-in-time training, drawings, etc. was linked to the steps, notes, or cautions in which they are referred.
- Automatic place-keeping: The computer-based procedure system automatically takes the user to the next applicable step. This step is the only one that is active and lets the user take action. Hence, the system effectively reduces the risk of unintentionally conducting steps out of order as well as the need to flip through pages to find the next applicable step. The participants liked the ease of moving between and within section of the procedure when having to transfer to other sections and/or conducting continuous action steps. Auxiliary Operators commented that the CBP system made the transitions much faster and smoother than when using the paper-based procedures.

- Digital Correct Component Verification: The use of barcodes to verify the correct component was generally viewed as effective. Some concerns regarding the time spent on barcode scanning were expressed. However, after using the CBP system most participants no longer had this concern.

Figure 4. Two Auxiliary Operators use the CBP System during the April 2014 Field Evaluation Study.

In order for CBP system to provide the highest value to the nuclear industry, it needs to encompass more than just procedures for auxiliary operators. The CBP system needs to be able to handle all types of instructions, checklists, procedures, work orders and other documents used in the plant. The vision is to have all the different organizations within the plant use the same system. To achieve the goal of one system the researchers have to make sure the system will be able to handle a broad variety of tasks and situations; therefore, collaborating with multiple utilities and multiple organizations with in the utility (e.g., Operations, Maintenance, and Chemistry) is essential. Hence, a series of field tests will be conducted at multiple utilities to ensure that the result from the current research effort is applicable both within individual plants and across the fleet of utilities.

A second field test will be hosted by another utility, starting in September 2014. This test will focus on a preventive maintenance work order for maintenance technicians, which is commonly conducted by multiple technicians over a couple of days. The functionality needed to handle this will be added to the revised version of the CBP system. This version also will take steps toward the vision of incorporating all elements needed in a work package. For example, the foreign material exclusion checklists (i.e., standard document in a work package used to report material not usually located at the work site) and previous logs (i.e., values recorder earlier) will be incorporated automatically in the system. In addition, the research team is currently in the planning stage, with at least two other utilities that have expressed interest in hosting field test activities. For each field test planned and conducted, the CBP system will be revised to include additional functionality needed to bring it closer to handle all aspects of a work package (i.e., the full process from initiating work request, planning, execution, and archiving).

4. Collaboration Efforts

4.1 Collaboration with vendors

Most utilities use software on handheld devices when making operator rounds in the plant, but very few utilities have similar systems for procedures. However, there is a general movement towards deploying electronic procedure systems. Most vendors offer electronic procedure systems, not CBP systems. The research focused on the benefits, for both the vendor and utilities, of using advanced systems to the overall safety and efficiency of the nuclear power plant.

Based on insights from the proof-of-principle, evaluation studies, and field tests, the CBP will assist the vendors in scoping and pursuing more advanced capabilities, ensuring that the end-products will meet the actual needs of the industry through adequate use of advanced technology. The CBP system and the results from the evaluation and field test activities are used to develop CBP system design guidance. The team also developed a standard structure for procedure content so that CBP systems can take full advantage of the technological advances, which is something that the vendor's existing systems do not have.

4.2 Collaboration with Nuclear Power Industry

The success of the CBP research effort is highly dependent on collaboration with the nuclear power industry. In order to develop design guidance for a CBP system the researchers need to understand the current work practices and processes, and they need to identify the applicable user needs. This is only achieved by close interaction and collaboration with the users (i.e., personnel at nuclear power plants). The goal is to develop a CBP design guidance that is applicable across the nuclear power industry and that encompass as many different types of procedures and instructions as possible. In order to minimize the risk of plant specific guidance the research team aim to collaborate with as many utilities as possible and to study a variety of field organizations.

In addition, most nuclear power plants do not have a wireless network in place throughout the whole plant. A wireless network is needed for certain functions of the CBP system to get the full benefit of the advanced technology, such as access to real time plant status, streamlined integration of multiple users of the same procedure, continuous access to additional information, etc. The prototype CBP system developed by the research team does not require major upgrades of infrastructure to demonstrate the benefits of the system. The researchers promote the use of docking stations and near-time plant status updates and communication. However, in collaboration with the utilities the research team aims to identify requirements for the infrastructure needed to support a CBP system.

The full cost of deploying a CBP system is not yet known. Due to procedures being such an integral part of how the utilities conduct business, the move from paper-based procedures to CBPs has larger cost impacts than the cost for the CBP system itself. Aside from the technology, there are costs associated with the training of all the operators and field workers, the infrastructure, and the change of work processes (e.g., how procedures are written, validated, and archived. Further work is needed to investigate the full range of benefits to the nuclear power plant to ensure that there is indeed a positive return on the investment in the CBP system and underlying infrastructure.

The results from the research activities – that is, the reduction of human errors and their potential consequences, time reduction when using CBPs compared to paper-based procedures, etc. – will be used to develop a business case. Further results and insights gained from the field evaluation studies will be used to provide further detail to the business case, consisting of a cost-benefit analysis conducted based on the results from both the evaluation studies and the plant validations. The goal for the business case is to encourage utilities to invest in infrastructure to support advanced nuclear power plant worker technologies such as CBP systems, but also to provide a rationale for obtaining a portion of the benefits by transitioning to CBPs even without having the entire infrastructure in place.

5. CONCLUSIONS

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

The research effort explores unknown territory by taking on the challenging task of designing CBPs for field workers. The majority of the previous CBP research has a strong focus on control room procedures and emergency procedures in particular. The research project has yielded valuable results supporting the hypothesis that a well-designed CBP system can improve efficiency, safety, and human performance. The research team supports the industry and vendors in moving towards CBP systems that encompass more advanced capabilities as well as providing the basis of a sound business case for transitioning to a CBP system.