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Abstract. Although computer-based procedures (CBPs) have been investigated as a way to enhance operator performance on procedural tasks in the nuclear industry for almost thirty years, they are not currently widely deployed at United States utilities. One of the barriers to the wide scale deployment of CBPs is the lack of operational experience with CBPs that could serve as a sound basis for justifying the use of CBPs for nuclear utilities. Utilities are hesitant to adopt CBPs because of concern over potential costs of implementation, and concern over regulatory approval. Regulators require a sound technical basis for the use of any procedure at the utilities; without operating experience to support the use CBPs, it is difficult to establish such a technical basis. In an effort to begin the process of developing a technical basis for CBPs, researchers at Idaho National Laboratory are partnering with industry to explore CBPs with the objective of defining requirements for CBPs and developing an industry-wide vision and path forward for the use of CBPs. This paper describes the results from a qualitative study aimed at defining requirements for CBPs to be used by field operators and maintenance technicians.

1. Introduction

In complex work environments, such as the nuclear power industry, written procedures are used to guide human operators in a variety of tasks. Currently, most United States nuclear power plants present procedures on paper. Paper based procedures (PBPs) are an important tool for ensuring that operators take the appropriate actions on a system; however many challenges have been identified with PBPs, including:

- Nuclear power plants are dynamic systems, and PBPs have to be written so that they can account for a large variety of possible conditions. Therefore, portions of the procedure may not apply in the current conditions, which could potentially confuse the operator. [1]
- Operators often need to execute more than one procedure at a time, and it can be challenging to manage multiple procedures. [2]
- With PBPs, place-keeping must be done manually, which may increase operator workload and increase the likelihood of errors. [1]

The potential to mitigate some of these challenges by presenting procedures on electronic devices was recognized in the mid 1980's. Several groups designed early computer-based procedure (CBP) systems for example, COMPRO (developed by Westinghouse Electric Corporation), COPMA (developed by The Halden Reactor Project), and the computerized procedures for the French N4 design. CBPs are currently in use or planned to be used in several international nuclear power plants [1]. However, despite the fact that CBPs have been investigated for almost thirty years, they have not yet been deployed in US utilities. One of the reasons for the delay in implementing CBPs may be the fact that there is insufficient information available regarding the effect of CBPs on human performance of procedural tasks. This makes it difficult for both utilities and regulators to assess the overall impact that CBPs may have on plant safety and plant performance. A few experimental studies have investigated the effect that CBPs have on operator performance in simulated scenarios [3-8], but the data gathered in these studies does not provide strong evidence that CBP systems will improve operator performance. Thus, it is difficult for utilities to justify the cost of developing, implementing and licensing a CBP system for existing plants.

Despite the lack of operational experience, many utilities are considering CBPs as part of digital upgrades to existing equipment. For existing plants, CBPs may be an important opportunity to increase efficiency by simplifying work processes and the management of procedures. CBPs may also offer an opportunity to enhance human performance and plant safety by providing context-sensitive information and real-time plant status information. However, as with most new technology, it is important to fully understand the impact of the system before implementing it. Most efforts related to CBPs have focused on CBPs for main control room procedures. However, field operators face the same challenges associated with PBPs and may benefit from a switch to CBPs. By proving the potential of CBPs in less risky field operations, it may be possible to justify the next step of adopting CBPs in the main control room, thus forging the path forward for wide-scale CBPs deployment.

Researchers from Idaho National Laboratory, along with participants from the nuclear industry, are working on a research project aimed at identifying a path forward for implementing CBPs, starting with CBPs for field operators. The specific objectives for this project are:

(1) Evaluate utility interest in CBPs.
(2) Determine the challenges utilities are having with current PBP systems.
(3) Identify requirements for CBPs for field procedures to address those challenges.
(4) Develop a prototype CBP system based on the requirements identified.
(5) Define an industry-wide vision and path forward for CBP deployment.

As part of meeting the first three objectives, researchers at INL conducted a qualitative study during plant visits at two utilities. The purpose of the study was to identify how PBPs are used by field operators and develop requirements for CBPs.

2. Method

The research conducted in this study consisted of four parts:

(1) A needs assessment to ensure that the research conducted will meet the needs of utilities who wish to implement CBPs
(2) A qualitative study conducted at a nuclear power plant
(3) The development of a model of procedure usage
(4) The development of requirements for CBP systems used by field operators

2.1. Needs assessment

The research team conducted the needs assessment in two parts. The first portion of the needs assessment occurred during the first plant visit. The team collected data during focus group discussions. The second portion of the needs assessment included a survey distributed at a meeting during another plant visit.

2.1.1. Focus Groups

Researchers conducted several focus group discussions that were aimed at identifying how technology can be used to enhance human performance, and specifically how CBPs might improve performance over PBPs. Four utilities participated in the focus group discussions.

2.1.2. Survey

As a follow-up to the focus group discussions, researchers distributed a short survey to identify utilities' current plans for implementing CBPs, current infrastructure in place to support enhanced functionality, such as real-time plant status updates, perceived barriers to implementing CBPs, and the information and support a utility would need in order to overcome those barriers. This survey was distributed to fifteen individuals representing six utilities.

2.2 Qualitative study

In order to build a model of procedure usage, researchers conducted a qualitative study at a nuclear power plant. Researchers gathered data for the qualitative study during on-the-job-observations and structured interviews during a plant visit.

2.2.1. Observations

Researchers observed two nuclear power plant equipment operators on-the-job. The researchers used a checklist of items to conduct the observations. The following information was captured in the on-the-job observations:

(1) A timeline of the tasks the operator executed
(2) Answers to the following questions about information flow
  (a) What information is needed in the field?
  (b) When is it needed?
  (c) How is it presented? Is it committed to memory?
  (d) Who needs it?
  (e) How is information communicated?
  (f) What information is needed in parallel?

2.2.2. Interviews

Researchers conducted semi-structured interviews with both field operators and maintenance technicians. Five maintenance technicians and ten field operators were interviewed. The following questions were asked in the interviews:

(1) What are the most common reasons for deviating from a procedure?
(2) During a typical procedural task, do you have the overall goal of the procedure in mind, or are you focused on executing the current step?
(3) When executing a procedural action, do you feel you understand the consequences of that action on the plant?
(4) What kind of things would cause you to stop and question whether you can complete a procedure as expected/written?
(5) Can you walk me through the process of following a procedure step? What are the subtasks of following a procedure step?
(6) On a typical day, how often do you consider stopping the procedure because you are unsure, but ultimately decide not to and go ahead with the procedure? What are your reasons?
(7) What kind of information/criteria do you use to decide whether you need to stop and contact a supervisor?

In addition to the predefined questions, researchers asked *ad hoc* follow-up questions as needed to better understand how operators interact with the current PBPs.

2.3. Development of model

The data gathered in the qualitative study was used to construct a model of procedure usage that contains the following elements:

(1) A detailed task flow illustrating the individual elements in the process of executing a single procedure step. This was constructed using the operators' descriptions of exactly what they do when they are attempting to execute a single procedure step.

(2) A description of the techniques used to make decisions outlined in the task flow. This was constructed using the operators' descriptions of exactly how they decide whether they can execute a procedure step as written.
(3) A description of the factors that affect the likelihood of errors for each element in the task flow. This was constructed by both: 1) considering operators' descriptions of situations in which they have made errors (or could have made errors), and 2) evaluation of the decision techniques from a psychological and human factors perspective.
(4) A description of the cognitive factors that influence the error likelihood for each element. This was constructed by reviewing the current psychological literature for research that is relevant to the errors.

2.4. Development of Requirements

The researchers used the insights gained from the model of procedure usage to develop a set of general requirements for CBPs for field operators. Those requirements were based on an analysis of the model of procedure usage. Researchers considered the factors that affect the likelihood of errors that were identified in the model and evaluated whether they could be mitigated with CBPs. Researchers also reviewed basic psychological and human factors literature to determine if the potential CBP solution may produce unintended consequences (e.g., exacerbating problems by introducing additional interface management tasks). Where there were clear, attainable solutions for the potential errors identified in the model of procedure usage and minimal negative consequences identified, the researchers developed a requirement for CBPs.

In addition to the general set of requirements, the authors also produced a list of specific requirements for CBPs for field operators based on a review of the existing guidance for CBPs. The authors reviewed three documents to produce these requirements: Section 8 of NUREG-0700 [9], the IEEE standard 1786 [10] and an in press NUREG/CR [11]. The requirements were selected and adapted from the list of human performance issues identified in [11] Researchers selected only the issues that were relevant to field operating procedures based on the assumption that field operating procedures are unlikely to have procedure-based automation, as most of the equipment is operated locally (thus issues with procedure-based automation were excluded from the requirements). Similarly, it is unlikely that field CBPs will include soft controls, so issues related to the use of soft controls were also excluded.

3. Results

3.1. Needs Assessment

The results from the focus group discussions and the survey were analyzed separately.

3.1.1. Focus Groups

The focus group discussions revealed the following insights:

- Utilities need a set of requirements and standards for CBPs in order to implement a CBP project
- CBPs must be designed to enhance human performance compared to PBPs; a CBP system that simply mimics PBPs and displays them on an electronic device would not be enough of an improvement to justify a migration to CBPs
- Due to regulatory requirements, utilities do not wish to take the risk of implementing CBPs alone; they would prefer to move together with CBPs as a whole industry

3.1.2. Survey

The researchers calculated the proportion of "yes" responses to forced-choice yes/no survey questions. 100% of the utilities surveyed reported that CBPs for field operators were part of their long-term vision. 66% reported that CBPs for control room operators were in the long-term vision.

The researchers coded responses to open ended survey questions according to a list of categories developed after the data was collected. The categories that were developed for these questions are presented below in table 1 along with the proportion of responses that fit into that category.

Table I. Proportion of responses to needs assessment survey questions organized by category.

Question	Categories and Proportion of Responses
What are your reasons for considering CBPs?	Configuration and control of procedures – 30% Context sensitivity of procedures – 20% Procedure tracking – 20 % Human performance improvement – 20%
What functionality would you like to see in CBPs	Context Sensitivity – 55% Specific interface issues – 28% Ability to update plant status based on procedural actions – 17%
What would your utility/plant need in order to move forward with a CBP project?	Successful implementation at another utility – 25% Infrastructure improvements – 25% Proof of concept – 16% Requirements and standards across industry – 16% Other – 18%

3.2 Model of Procedure Usage

The researchers developed a model of procedure usage based on the observations and interviews. A detailed description of the development of the model and a detailed presentation of the model can be found in [12]. The model of procedure usage was used to develop an initial list of requirements for CBPs presented in the next section.

3.3. Requirements

In order to address the specific challenges identified in the qualitative study, CBPs need to meet the following general requirements. It is important to note that this is not a complete set of requirements for CBPs. These requirements are based on the specific issues that were identified in the qualitative study. The requirements presented here should be viewed as a minimum set of requirements for CBPs intended to address some of the challenges that field operators have identified associated with their current use of paper-based procedures.

(1) *CBPs should guide operators through the logical sequence of the procedure*. The CBPs should be designed so that they automatically take the operators through the specified procedure path based on initial conditions and operator input.
(2) *CBPs should ease the burden of place-keeping for the operator.* CBPs should keep track of where the operator is in the procedure, should mark steps as completed, and should highlight the current step.
(3) *CBPs should make the action steps more distinguishable from information gathering steps*.

CBPs should use some method to differentiate steps for which an operator must actually manipulate the plant versus when he must simply check a condition or value.

(4) *CBPs should alert the operator to dependencies in steps more visibly.* Typically, the operator has to rely on previous experience or on a caution or warning in order to identify the situations in which he needs to read ahead in the steps. CBPs should alert the operator when he reaches a step with dependencies, rather than relying on him to read ahead (or remember from previous experience) to detect the dependency. Additionally, if a CBP system has access to real-time plant data the system should alert the operator when plant status changes in a manner that affects the operator's task.

(5) *CBPs should ease the burden of correct component verification (CCV) for the operator.* CBPs should employ some method to automate CCV (e.g., include barcode scanning or text recognition functionality).

(6) *CBPs should ease the identification and support assessment of the expected initial conditions.* Some method of illustrating the expected initial conditions in a simple and easy to understand manner should be available to the operator through the CBPs. For example a schematic or piping and instrument diagram of the relevant equipment could be available on-demand.

(7) *CBPs should ease the identification and support assessment of the expected plant and equipment response.* Some method of illustrating the expected equipment and plant response in a simple and easy to understand manner should be available to the operator through the CBPs. For example a schematic or piping and instrument diagram of the relevant equipment could be available on-demand.

(8) *CBPs should include functionality that improves communication.* In the event that an operator encounters a situation that he needs to contact a supervisor to resolve, he needs to be able to efficiently and accurately describe the problem. Tools such as texting, capturing photographs and streaming video have all been identified as highly desirable to have built into any device that display CBPs.

Additionally, CBPs must also be designed so that they are consistent with existing guidance and human factors engineering principles. Thus CBPs for field operators must also meet the following specific requirements identified by the review of guidance documents:

- CBPs should be designed so that the operator controls the procedure pace.
- CBPs should make calculations when the necessary information is available.
- The CBP system should alert users when procedure steps or conditions have been violated.
- The CBP system should alert users when conditions require transitioning to another procedure.
- When the necessary information is available to the CBP, the procedure system should evaluate step logic.
- The CBP system should be designed so that it is easy for the user to "undo" an unintended or incorrect action (an error of commission).
- The CBP should provide dynamic, context-sensitive information.
- The CBP system should automatically monitor users.
- The CBP system should allow the operator to look ahead and back in the procedure.
- The CBP system should provide seamless navigational transitions to other active procedure(s), to branches and transitions in the same procedures, and to supplemental information required by the procedure.
- The CBP system should indicate when there are multiple active procedures.
- The CBP system should provide flexibility in the amount of information/level of detail where appropriate.
- The CBPs should provide identification of active procedure information (title, revision number, etc.).
- The CBP should provide high-level information related to procedure goals.

- The CBP system should provide identification of procedure system status.
- The CBP should provide indication of user input requirements.
- The CBP system should provide user support (e.g., a help function).

4. Conclusions

CBPs have been identified as a way to contribute to efficiency and safety of the current US nuclear fleet by reducing human error. However, most existing nuclear power plants in the US are still using PBPs to guide procedural activities. The researchers have established that there is substantial interest in the US nuclear power industry to migrate to CBPs in the near future. In order for deployment of CBPs in the existing nuclear fleet to occur, the industry needs a set of standards or requirements for CBPs and an example of success. The researchers have taken the first step in developing a set of requirements and standards for field procedures by identifying the how operators use PBPs, and how they may contribute to errors. The researchers have also identified a preliminary set of requirements that CBPs must employ in order to mitigate those potential errors. The researchers also reviewed the existing guidance on CBPS and selected requirements for field CBPs based on that guidance. Together, these requirements will serve as a starting point to develop an initial CBPs prototype for field procedures. The next step in this research effort is to design a CBP prototype based on these initial requirements, evaluate that prototype in a realistic setting, and update the requirements based on the findings.

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