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STANDARDIZED PROCEDURE CONTENT AND DATA STRUCTURE BASED ON HUMAN FACTORS REQUIREMENTS FOR COMPUTER-BASED PROCEDURES

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ABSTRACT

Most activities that involve human interaction with systems in a nuclear power plant are guided by procedures. Advances in digital technology make computer-based procedures (CBPs) a valid option to the current use of paper-based procedures (PBPs) that provides further enhancement of safety by improving human performance. The transition from PBPs to CBPs creates a need for a computer-based procedure system (CBPS). A CBPS needs to have the ability to perform logical operations in order to adjust to the inputs received from either users or real time data from plant status databases. Without the ability for logical operations the procedure is just an electronic copy of the paper-based procedure.

To provide the CBPS with the necessary information to display the procedure steps to the user, special care is needed in the format used to deliver all data and instructions to create the steps. The procedure should be broken down into basic elements and formatted in a standard method for the CBPS. The CBPS will provide the context for the step to deliver referential information, request a decision, or accept input from the user. The data structure will provide all data necessary for the system to accurately perform each step without the need for the procedure writer to reprogram the CBPS.

The researchers at the Idaho National Laboratory have developed a prototype CBPS for field workers as well as the underlying data structure. This paper will describe the insights gained from the research activities conducted to date.

Key words: computer-based procedures, data structure, field workers, human performance improvement.

1 INTRODUCTION

Nuclear Power Plants (NPPs) are constantly seeking ways to improve upon the existing paper-based process of procedure-guided work activities. Advances in digital technology make computer-based procedures (CBPs) a viable option to further enhance the safety at NPPs by enhancing procedure performance. Static paper-based procedures (PBPs) do not match the dynamic nature of plant systems. Because the PBPs have to accommodate many different conditions, the field worker sometimes has to search through a large amount of irrelevant information to address the task and situation at hand. Other challenges related to PBPs are the management of multiple procedures, place-keeping, and finding the correct procedure [1]. All of these challenges can easily be addressed by the capabilities provided by digital technology. A CBP system (CBPS) can enforce procedure adherence expectations, make sure that relevant information is available to the field worker when needed, automatically conduct place-keeping, and automatically decide which steps are relevant based on plant status, user inputs, and previous decision points.

There are different types of electronic procedures ranging from a simple presentation of a procedure document in a Portable Document Format (PDF) displayed on the computer screen to a dynamic and context-sensitive representation of the procedure. The latter is the definition of a CBP used by the researchers. Also note that CBP and CBPS refer to slightly different things. The procedure system (CBPS) can contain many procedures (CBPs), and a CBP refers to one procedure.

In the case of a simple electronic procedure where a PDF is displayed on the screen, the advantages that digital technology can provide are not utilized. A more advanced electronic procedure might use hyperlinks to provide additional information (e.g., photos and appendices), provides the option for limited user inputs, links between procedures, and mark-up capability (e.g., writing notes and conduct traditional place-keeping in the PDF). These types of electronic procedures are currently offered by a variety of vendors. Unfortunately, these electronic procedures simply eliminate paper while replicating the current process, and do not provide much opportunity to improve performance. In order to take advantage of the capabilities of digital technology the procedure needs to be presented to the field worker through a system that can provide an environment that has the ability to perform logical operations and adjust to the inputs received by the user or other incoming data. This functionality can transform a simply inert electronic procedure into an intelligent and dynamic procedure – a CBP.

The objective of the research effort is to develop guidance for the nuclear power industry, which the utilities can use in their discussions with potential CBPS vendors. The guidance will cover the design of the graphical user interface. However, in order to realize a CBPS there is a need for an underlying data structure or architecture to support the dynamic functionality. The researchers are developing a data structure as part of the effort, which will be described in detail in the design guidance. The goal is to use the data structure as a basis for an industry-wide standard. This paper discusses the high-level design concepts and the supporting underlying data structure for the CBPS.

2 COMPUTER-BASED PROCEDURE SYSTEM

The technological advancements in the CBPS allows human performance improvement features to be integrated into both the procedure and the overall work process, e.g., a CBPS offers a dynamic way 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. 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. Furthermore, human performance tools are embedded in the CBPS 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 CBPS, 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.

It is deceivingly easy to believe in an automatic reduction of workload and human errors as well as increase efficiency when replacing a paper process with a computerized system. Though computerized or automated systems certainly can have a positive impact on overall performance there is also a risk of introducing new opportunities for inefficiencies and errors. This is especially the case if the current workflow or process is changed as a part of the transition to a computerized system. For example, automation decision support and automated aids may lead to reduced workload and increased efficiency, but could also result in reduced field worker engagement. Reduced engagement can lead to a reduction of human performance. Therefore, the researchers' goal is to find the ideal balance between automated decision support and aids while keeping the field workers engaged in the process.

2.1 Standardized Procedure Content

As an initial step the researchers studied the use of paper-based procedures. They observed field workers executing tasks using procedures, interviewed field workers, and facilitated focus group discussions. All with the purpose to identify all physical and cognitive actions the field worker has to conduct to execute one single procedure step and to identify issues with the current workflow that should be improved as well as identify parts that work well and should be kept when transitioning to a CBPS [2]. Based on the insights gained, the researchers identified several high-level design concepts that should be in place in order for a CBPS to become a valuable replacement to the paper process.

Examples of design concepts are; dynamic context sensitivity, automatic place-keeping, simplified step logic, component verification, automatic calculations, and availability and accessibility of relevant supplemental information. By the nature of PBPs the information presented in these procedures are static, i.e., the printed copy will not change. The field worker will manually have to keep track of things such as the conducted steps, the step to be conducted, what steps are not applicable, the current plant status and operating conditions, and other active procedures that might influence the task to be conducted. Digital technology is inherently dynamic; hence, the procedure can be presented in a manner that reflects the current plant status and operating mode.

Based on information such as user input and actions taken in previous steps the CBPS can dynamically control the content of the procedure and keep the displayed content pertinent to what the field worker needs and guide the field worker thought the correct path in the procedure. Hence, the CBP system eliminates the need for the field worker to search for the next step in a procedure or find the next section within the procedure to branch to. This is a major advantage compared to both a PBP and an electronic procedure. The CBPS can hide or show the steps needed based on inputs received and can merge sections and procedures together in a seamless manner.

The CBPS can provide visual indicators to the user in order to help in keeping track of the current step and controlling the options for user interaction with the procedure at the time. Thus, helping the field worker stay on task and coordinating the order of the tasks in a correct manner. Steps that are not applicable to the path will automatically be marked as such and the field worker will be taken to the next relevant step in the procedure. In other words, the system will automatically take care of the place-keeping. The automatic place-keeping makes it easy for the field worker to stay on the specified path. This built-in procedural adherence has shown potential to reduce the amount and severity of human errors.

Another benefit of digital technology is the ability to provide easy access to supplemental information relevant to a particular procedure step, such as photos of the component, drawings, and just-in-time training. The system can also conduct calculations when required, which has been proven to have a large positive impact on human performance and human error reduction [3].

A common type of procedure step is one that is based on plant conditions or a combination of conditions to be satisfied prior to the performance of an action. Conditional statements can become hard to understand if complexity is added by nested statements. To reduce the mental workload associated with complex conditional statements, the researchers introduced the concept of simplified step logic, which removes complexity from step descriptions by presenting conditional statements as simple questions, paired with condition-specific instructions. For example, 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 field worker to either a step with the actions needed to start Pump A or the step with the actions needed to start Pump B.

Another way technology can support increased human performance and overall efficiency is to reduce the risk of the field worker conducting actions on incorrect components. The field workers are required to conduct correct component verification (CCV) before they take any actions. Currently, this is conducted by the field worker reading the component’s name, identification tag, and location as it is written in the procedure. Then the field worker matches this information with the information located on the component’s identification label. It is a straight forward process that prevents most cases of potential actions on incorrect components; however, these incidents do occur and they can be very costly to the plant.

The CBPS can provide the means to verify the user is working on the correct equipment or component by utilizing the technology to match the component information in the procedure step with the information on the physical component. This digital CCV can be done in a variety of ways. For example, the CBPS can support the identification by displaying photos or videos of the component. The system can also utilize the built-in camera that most devices have to allow the field worker to scan a barcode on the equipment. In addition, radio frequency identification devices (RFIDs) and optical character recognition (OCR) can also be used for digital CCV. To date, the researchers have investigated OCR and barcodes. Most nuclear power plants do not have a formatting standard for the labels used in the plants; hence, there is variability in color, font, and font size across the plant. The optical character recognition technology proved to not yet be mature enough to sufficiently handle this variability. Therefore, the researchers have focused on barcodes to prove the concept of digital CCV. When a barcode is scanned the system will match the input with a component database. If the correct component is verified, the field worker will be able to continue on with the step. If the correct component is not verified, the field worker will have to find the correct component before being able to proceed through the procedure. There is always the option to conduct component verification manually.

All these enhanced capabilities that a CBPS can provide to the field worker can reduce human errors by incorporating human performance into the procedure logic and allows the user to focus more on the actual task being performed. To enable the design concepts mentioned above, an underlying data structure or architecture needs to be developed, which breaks down the procedure into basic elements which will be formatted in a standard method for the CBPS. The structure will provide a standard format used to deliver data and instructions needed to create steps in the CBPS.

As stated earlier, almost all activities in the nuclear power industry are guided by procedures. The procedures come in different formats depending on a variety of factors, such as organization, type of task, and the classification of the system. The format can be anything from simple checklists, taking readings, or sets of instructions that require branching back and forth between multiple sections, to an instruction that is executed by multiple field workers over multiple days. The CBPS needs to be able to handle all these different types of procedures and instructions. This requires the CBPS to be flexible and to have a method to easily add new procedures. Since the CBPS will be able to run on a variety of hardware as well as on different operating systems, the code for the CBPS will have to slightly vary between platforms. Most procedure writers are not software developers; hence, there has to be a way to easily export the procedures into a common standardized format. In addition, there needs to be a common method of receiving the procedure data in order for the CBPS to determine how to display the instructions to the field worker. The next section describes one approach to defining the data structure.

3 DATA STRUCTURE

As stated earlier, the research effort's goal is to develop design guidance for the data structure for CBPs. The guidance will suggest a template for a standard data structure. A standard data structure will provide the means of converting all procedures into the format a CBPS can understand and process. Also it can provide a method to be able to transfer the procedure to any CBPS that uses the same structure.

The standard data structure allows a CBP to be used between any given CBPS on any device and let the CBPS display the step how it is programmed to as long as the data contains all the information needed. This allows the utilities to not be limited to any one particular vendor. It also provides the ability to share procedures, if appropriate, across nuclear power utilities and even if they are employing a different CBPS, the procedure will work in their system.

The CBPS should be designed to understand how to display the information based on the data given. The structure does not tell the CBPS how to display the data, just what information needs to be displayed. This allows the data structure to be condensed into only needing to instruct the CBPS what the procedure needs to perform and not how to display it. This separation allows a standard data structure to be used between any given CBPS and let the CBPS display the procedure how it is programmed to as long as it contains all the information the structure dictates.

There are a couple of methods that can be used to supply the procedure data to the CBPS. For example, a database could be used to store the procedure structure or the structure could be an extensible markup language (XML) schema to deliver the information to the system. In the current research effort the XML schema method was used. XML is a language that provides a document in a format that can be read easily by both human and machine.

The XML document is organized into a data structure that includes elements to provide a type for the data being presented. The elements can contain attributes that provide more detail on the element. Figure 1 shows a simple basic XML document that contains elements with supporting attributes that is used to describe a procedure to the CBPS.

```
<Procedure title="Shut Off Water Flow">
   <Step stepText="Close Valve A."/>
</Procedure>
```

Figure 1. Sample XML data structure

The sample procedure shown in Figure 1 has a title and contains one step. The step itself contains text stating the action to be performed. The example illustrates a need to break down procedures into basic elements so that they can be structured. The actions in a procedure are commonly referred to as steps and, as they are already separated in procedures, become the best choice to be a building block in the structure of a procedure. Attributes are added to the step element in order to provide more detail on what type of interaction the user should have with the procedure. Once broken down the steps themselves become autonomous and reusable. They can be stored and added to any procedure that might require that same step to be performed. This reusability promotes more standardized structure that can be used in other procedures.

The step block needs the attribute details in order to supply the instructions to the CBPS on how to direct the flow and update the CBP. Without the additional information attributes the CBPS would only be able to recreate the PBP in an electronic form. There would be no dynamic content as the CBPS would not know what action the step was asking the user to do.

The attributes added to the step block can give the step more depth and ability to be interactive. It directs the intelligence inherent in a CBPS and makes the difference of a plain electronic procedure into a smart CBP. There are several types of actions that a step can perform. A few examples can be seen in Table 1.

Table 1. Step action types

Action Type	**Details**
Scan	Instructs the CBPS of the need to perform CCV.
Input	Request input from the user. Request information from other systems on status or input from a previous procedure.
Decision	Ask a binary type question. Further steps can be shown or hidden based on outcome from decision. This controls the context and flow of the procedure. As mentioned earlier this provides a more intuitive interaction then trying to determine and IF-THEN statement.
Calculation	Perform arithmetic functions based on inputs.
Multi-Input	A grouping of similar inputs, decisions or calculations
Information	Provide access to reference materials. (Photos, Documents, etc.)

The actions can be combined in a single step, creating a very dynamic information rich experience for the user. The CBPS should be programmed to handle each action the standard data structure should expect it to handle. As mentioned, the data structure does not know how the CBPS will handle the specific action; the CBPS simply expects the results or information to be available in further steps if needed. The few examples shown in Table 1 provide a subset of actions that have been needed during the pilot studies performed with the prototype. The action types and the attributes used in the data structure to describe them provide the information needed by the CBPS to accurately perform the actions. They are based on the needs found in converting the procedures used in the research and the feedback from the users of the prototype.

An example of a common action in a procedure was the need to mark steps that have become irrelevant based on conditional logic in the procedure as Not Applicable (N/A). In order to provide the user with the context needed and to simplify the procedure for the user a Decision action was developed. This presents a user with a simple question which can change the rest of the procedure based on the answer. The procedure may ask something like “If motor speed is between 1100 rpms and 1500 rpms, then perform the following… .” If the condition is not satisfied then the step or next set of steps can be N/A’d. This logic can become confusing if there are several conditions to have to compare to. The Decision action simplifies this by restating the statement as a question like “Is the motor speed between 1100 rpms and 1500 rpms?” The user answers the question and based on the answer the CBPS can N/A the steps that are no longer applicable. In order to only present the right information at the right time to the user, the prototype hides the steps that are no longer needed. This removes them from the users and keeps only the necessary steps present. In order to know what steps are affected by the decision, the structure provides attributes to the steps that tie back to the decision steps answer.

The other actions stated above provide the necessary functions needed in order to collect and provide the information needed by the user. Scan indicates a need to perform a CCV in order to make sure the user is on the correct component before performing the other action that the step states. Inputs can collect data that is needed by the procedure to continue and provide further information to the user. This can be collected from the user or retrieved from external sources from the CBPS, e.g. plant status or actions being performed simultaneously by other procedures that affect what the user needs to do in the current procedure. Information attributes provide the location of supplemental data that the user may need in order to perform the steps. This data could be pictures, videos or documents describing lessons learned from other users that have performed the procedure before.

The data structure needs to provide the information or instruct the CBPS where the information can be retrieved. The information could be anything that the CBP might need in order to present the data to the user. In the future this data can reside anywhere in the plant and could be accessed real time through a Wi-Fi connection. During the research the prototype used had to include all the data that might be needed in the procedure on the device itself as the plants used in the study did not have the infrastructure available yet to support external connections to the device.

With connection to Wi-Fi, real time updates to the CBP could be provided by a trusted source. Wi-Fi hot-spots could be set up to provide near real time updates. The updates could be additional steps or instructions sent by a supervisor to help the user handle situations that may have arisen. The procedure progress could be monitored from a central location and authorization can be obtained through the CBPS to perform actions that needed approval.

Step numbers were designated as optional in the data structure developed so far by the research team. Since the steps are autonomous the CBPS can be updated with new steps as conditions change. The removal of step numbers allows the user to focus on the task and rely on the CBPS to direct the correct dynamic flow of the procedure.

The following figures give an illustration of what a CBPS, in this case the prototype developed by the research team, could present to the user based on the information given to accept an input and provide a calculation based on the input. On the left is the XML and on the right is the CBPS generated output.

```
<Step
   stepText=”Record current &quot;FUEL LEVEL&quot; (inches):"
   hasInput=”true”
   inputSaveAs=”FuelLevel”
   inputNumberOnly=”true”
/>
```

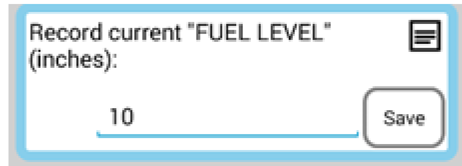

Figure 2. Step element requesting user input

To gather input from the user the step would be structured as shown in Figure 2. This step instructs the CBPS to display an input box so the user can record the fuel level. The attribute inputNumberOnly=”true” further instructs the CBPS to accept numeral input only from the user.

Figure 3 provides a calculation based on the previous input given for the fuel level. It is able to request the number that was input previously by accessing the variable that was used to save the input step. This step updates the text based on the result of the calculation. It also shows the user the equation used so that verification can be performed.

```
<Step
   hasCalculationView=”true”
   stepText=”Notify Garage Personnel _XX_ gallons of
fuel needs to be added to restore level.”
   calculationStepTextReplace=”_XX_”
   inputVariable=”FuelLevel”
   unitOfMeasure=”gallons”
   equation=”( X - 5 ) * 0.205”
   equationConfirmText=”( X in - 5 in ) * 0.205 gal/in
= Y gal”
   placeholderVariable=”X”
   rounding=”1”
/>
```

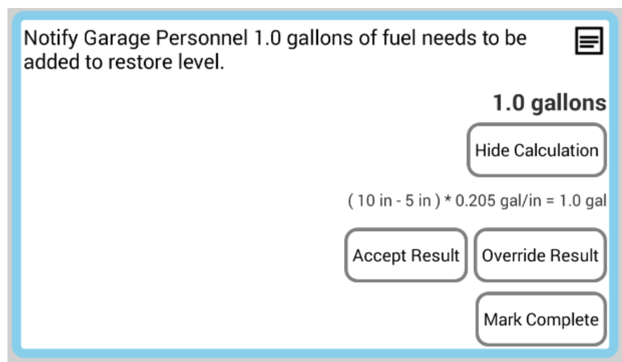

Figure 3. Step element performing calculation

Since the data structure could become complex in order to provide all the correct attributes needed to make the CBPS function, a tool needs to be developed in order to assist the procedure writers. The tool should be able to provide an easy interface to the writers and translate their inputs into the standard data structure relieving them from the need to have to write the XML themselves. The next section describes in a little more detail some suggestions of what such a tool would do.

4 AUTHORING AND EDITING TOOL

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 when using a traditional word processor, such as Microsoft Word. In addition, even an experienced XML user can make mistakes, such as adding sequences out of order and make typos, which create a need for testing and debugging of each

XML document. All of which makes the process of writing procedures in XML more time consuming and requires new skills than the currently used procedure writing process.

In order to gain full advantage of the technology advancements there has to be a translation layer between the person composing the procedure and the data structure, i.e., a procedure authoring and editing tool. 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 the linkage to the underlying data structure should happen behind the scene. 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.

An example of a tool that is commonly used to create a behind the scenes XML document is Microsoft Word. However, Word documents are nothing more than compressed XML files. Hence, the XML schema for Word files are designed for a different purpose then the XML schema needed for CBPs. The CBPS authoring and editing tool could not be as simple as a word processor without burdening the author with other syntactic requirements, which would defeat the purpose of trying to remove the author from the XML document. 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 their procedure. This will decrease the time needed to revise and author procedures.

5 CONCLUSIONS

The current research effort investigates the use of CBPs in the nuclear power industry. The researchers have shown that allowing the CBPS to perform the task of controlling the procedure flow, correct component verification, and verification of user inputs while the user focus on the actual task can result in a reduction of both the amount and the severity of human errors.

It has been shown that an advanced data structure is needed in order to create a CBP with the functionality needed to have a positive impact on human performance. The data structure needs to contain the data and flags necessary to correctly instruct the CBPS on how the procedure is to be displayed to the user and how the user can interact with the data presented. Without the advanced elements the procedure would just be an electronic version with no dynamic context being utilized.

Creating a standard data structure allows for the reuse of the structure across different CBPS. This allows the users the ability to be flexible with which CBPS they may choose to use.

In order to gain the greatest advantage from a CBP, real-time updates of plant status based on procedure data and real-time updates of the procedure based on plant conditions should be incorporated. One unresolved issue is that availability of access to external data limits the ability of the CBP's real-time updates. Infrastructure needs to be implemented in order to achieve the level of real-time data desired for the CBP. Users need to consider the benefits of allowing the CBP access to the data, whether by Wi-Fi or docking stations. The more access the CBPS has the more dynamic and intelligent the CBP can become.

Another important aspect of transitioning industry to CBPs is the need of a procedure authoring and editing tool to be able to create and maintain CBPs. The tool needs to be able to create the standard data structure that the CBPS understands while presenting an easy interface to the procedure writer.

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