A conceptual application for computer-based procedures for handheld devices

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Abstract: This paper describes the concepts and proposed design principles for an application for computer-based procedures (CBPs) for field operators in the nuclear domain (so-called handheld procedures). The concept is focused on the field operators’ work with procedures and the communication and coordination between field operators and control room operators. The goal is to overcome challenges with shared situation awareness (SA) in a distributed team by providing effective and usable information design. An iterative design method and user-centred design is used for tailoring the concept to the context of field operations. The resulting concept supports the execution of procedures where close collaboration is needed between control room and field operations, e.g. where particular procedure steps are executed from remote control points and others from the control room. The resulting conceptual application for CBPs on handheld devices is developed for mitigating the SA challenges and designing for usability and ease of use.

Keyword: Computer-based procedures, field operators, user-centred design, shared situation awareness, Gestalt principles.

1 Introduction

Technical solutions supporting the execution of procedures where close collaboration is needed with field operations, e.g. where particular procedure steps are executed from remote control points is a relatively unexplored field. Nuclear Power Plant (NPP) operators perform many tasks that are supported by different types of procedures. These procedures are so far mainly paper-based (PBPs – Paper Based Procedures). Different studies have concluded that the operators can benefit from using computer-based procedures (CBPs) [1][2]. CBPs can provide functionality that is not possible with static PBPs. For instance, a CBP can feature automatic place-keeping, tell the operator which procedure step to work with and which is next, present process information relevant to the task, assist in monitoring plant parameters, and automatically execute a procedure. The studies and guidelines that have been made for PBPs and CBPs have so far mainly focused on the tasks of the control room operators, using desktop workstations. This paper describes a concept application for CBPs for a handheld device used by field operators.

An application with CBP for a handheld device used by field operators is an area of great potential. Giving field operators access to well-designed handheld procedures, in interaction with the control room, can make fieldwork more efficient and safe. A handheld device (smartphone) will give them a powerful tool. They are easy to bring, usually connected and directly addressable, they have sensors that can detect location and environmental conditions, and they can have access to a wide range of information.

Handheld procedures with relevant features supporting task performance, integrated with the control room CBP system, can enable field operators to be more involved in the process and more independent of the control room operators. This is supported by a study of O’Hara et.al.[3]. Also, when providing handheld procedures to field operators, the control room operators can continuously be updated on actions in the field. Based on this, the situation awareness (SA) of plant state rises and the basis for reasoning and taking actions can be improved.

Handheld or portable devices are starting to be a part of different types of work for on-site operation, e.g. in health care and the oil
industry\textsuperscript{4}\textsuperscript{5}. Also research institutes in the nuclear field are starting to investigate the use of portables for field operators. There is some research and products existing concerning field operator support systems, using wearable or portable technology. However, there is little literature concerning CBPs for field operators. The articles\textsuperscript{6}\textsuperscript{7}\textsuperscript{8}\textsuperscript{9}\textsuperscript{9} found describe prototypes, where the technology or requirements and information needed are the main focus. The design of the prototypes, concerning how to organize and visualize the information and what interaction methods to use tailored to the context of work, is so far not the main focus. A successful design embraces not only needed functionality, but also user-friendliness and the more qualitative feeling of ease of use.

The present author has made the conceptual application for CBPs on handheld devices as described in this paper. The application for handheld procedures for field workers enables remote, synchronous and asynchronous communication and real-time updates on procedure work between control room and field operators. The object is to increase shared situation awareness in the distributed team; the field operators and control room operators. The immediate access to this information can increase shared SA of plant state and improve continuity in procedure work. According to Endsley & Jones\textsuperscript{10}, a common picture of the situation, where information that is compatible with the users needs, can support team operations. The resulting application for CBPs on handheld devices is an attempt to address the SA challenges and to design for usability and ease of use.

2 Motivations

This study is focusing on the field operators’ work with procedures and the communication and coordination between field operators and control room operators during this work, trying to overcome challenges with shared SA in a distributed team as well as providing an effective and usable information design.

One of the main challenges in fieldwork is distributing real-time information about work and process status, and plant configuration. Combining CBPs with relevant information and collaboration features may help meet this challenge. When replacing PBPs with CBPs for field operators, the application should be an improvement of the PBPs. The CBPs for field operators should include solutions to the challenges that operators experience with the current PBPs. Features needed for better performance when executing the procedures is one issue to consider. Another issue is how to visualize and organize the information, resulting in an effective and usable information design that brings clarity and comprehensibility to the visual material.

Shared situation awareness is important for performing tasks where operators are dependant on each other’s performance, such as field operators and control room operators. The distributed nature of the team makes it difficult to assess where people are in the procedure when using PBPs. The shared SA in the distributed team can be improved by keeping each other in the loop by interacting with a CBP system and giving immediate information on what actions are taken.

“(…) shared SA also often encompasses a consideration of the status of other team members’ tasks and their impact on one’s own tasks and goals\textsuperscript{10}.”

During the development phase of this application, field operators described some SA challenges related to this distributed team. They have also described challenges related to the execution of procedures tasks. Field operators are responsible for the operational activities outside the control room. These activities should be carried out under the general direction of the control room operators and in accordance with relevant operating instructions and procedures. The field workers working area is spread across the plant, at different heights, sometimes holding on to a
ladder while typing information on a crunched-up bunch of printed PBPs, after having it stashed in the breast pocket. In their execution of tasks, field operators talk with the control room operators on the phone, they go back and forth to the control room to get approval of new procedures to perform, reprioritize tasks, get confirmation on equipment to work on or request data values. Operators describe the process of getting the performed procedures signed by the different participants as a long and cumbersome process. The same sheet of paper needs to be signed by all participants for each step they have finished. Sometimes the field operators call each other for plant-relevant questions, leaving the control room operators out of the loop, which might result in poor SA in the distributed team. Statements from operators from power plants\cite{11} illustrate current challenges as well as the potential for utilizing handheld units with an application for CBPs, supporting shared situation awareness and providing needed information:

“Now control room operators can be far less experienced than before. This may mean that the field operators choose to call each other rather than to contact the control room when they are stuck. They can thus call back and forth between themselves without the control room knowing what is going on out in the plant.”

“There is much to be done for the least little thing (…): Printing an instruction of 20-30 pages and verify the latest version. Getting the necessary equipment in the control room: documentation, tools, instruments, and keys. Waiting for other departments.”

In studies, made by Jokstad\cite{6} and Kaarstad et al.\cite{12}, they found many potential benefits by providing operators access to real-time process information and communication tools on a handheld device. This papers’ concept builds on the hypothesis that providing field operators a CBP system in a handheld device will be a positive contribution to the fieldwork as well as to the control room work.

3 Method

This paper describes the initial process of the work with computerised procedures tailored to field operations. The design process is driven by an iterative design process\cite{13} (see Fig.1) and user-centred evaluations\cite{14}, where groups of operators from the nuclear domain have contributed as sources of relevant data and by evaluating different iterations of proposed solutions of the handheld procedure application. The work is based on a combined basic research and applied research approach, aimed at finding solutions for field operators.

The conceptual design presented here, of an application for computerised procedures, visualised in a handheld device, is mainly a result of observations in a nuclear power plant, semi-structured interviews with field operators from different nuclear power plants, and feedback from operators on several mock-ups during the iterative design process. The main focus for the design is the operators’ input on what information they need, how they work and how they use the procedures. Guidelines on CBP\cite{1}\cite{2} have also been used as a source for representation of procedures. Human Factor experts and HSI designers have contributed in evaluating the mock-ups.

The key concepts for a procedure application are conceptualised in a mock-up, using Microsoft PowerPoint for exploring promising directions, testing user interaction methods and evaluating the storyboard for the application. The mock-up has been further explored in the process of making a prototype for more realistic testing, implementing a prototype application for an Android smart-phone.
4 Objectives for design
Feedback from operators during the iterative design phase gave objectives for design. This chapter describes the main purposes of the CBPs for a handheld device and the concept for the handheld procedures.

4.1 Main purposes of CBPs for handheld device
The application for computerised procedures for field operators should be provided mainly to:

- Improve communication and shared situation awareness [10].
- Make fieldwork more efficient and safe by providing immediate information on procedure work and plant and equipment status, guiding through procedure steps and validating actions.
- Reduce cognitive workload, as a result of for instance integrated information, automation of certain processes, place keeping and icon recognition, resulting in fewer interruptions, information searching and need for reading.
- Reduce workload, as a result of minimizing the need for printing procedures, walking back and forth to the control room to receive new tasks/procedures, and shorten the time spent on signing steps in the procedures.

4.2 Key concepts
The key concepts of the prototype are based on operators’ descriptions of their work and needs. The operators’ working culture, concerning for example use of procedures, distribution of tasks and view on new technology, have an impact on their descriptions and thus also the proposed solution for the handheld procedures. Their activities involve climbing, walking, logging, operating components, talking, and navigating in the plant, which also must be considered in the concept. The operators described tasks that are important when working with procedures. Table 1 shows the solutions for performing these tasks with the handheld procedure application:

Table 1 Procedure tasks and solutions in the concept

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Solutions in the concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Find procedure</td>
<td>• Relevant procedures for “today” are in one list.</td>
</tr>
<tr>
<td></td>
<td>• Search function</td>
</tr>
<tr>
<td></td>
<td>• SMS from control room with link to procedure</td>
</tr>
<tr>
<td>Version control</td>
<td>Automatic version control</td>
</tr>
<tr>
<td>Find location</td>
<td>Buttons for maps for each procedure and procedure step</td>
</tr>
<tr>
<td>Verify component</td>
<td>Scanning tags with feedback on verified or not</td>
</tr>
<tr>
<td>Check documents, P&amp;IDs, process information</td>
<td>Include piping and instrumentation diagrams (P&amp;IDs) and real-time process information</td>
</tr>
<tr>
<td>Log measurements</td>
<td>Logging features for measurements</td>
</tr>
<tr>
<td>Log deviations</td>
<td>Features for field notes</td>
</tr>
<tr>
<td>Coordinate work</td>
<td>• Information on status is sent between the CBP for handheld device and the control room CBP system</td>
</tr>
<tr>
<td></td>
<td>• SMS (when synchronous communication is not needed)</td>
</tr>
<tr>
<td></td>
<td>• Video call</td>
</tr>
<tr>
<td>Start, postpone and end procedure steps</td>
<td>Features for changing status of procedures and steps.</td>
</tr>
<tr>
<td>Sign procedure/-steps</td>
<td>• Steps are automatically signed when finished</td>
</tr>
<tr>
<td></td>
<td>• Procedures are signed for certain combinations of procedure step statuses</td>
</tr>
</tbody>
</table>

5 User-centred design
The application graphics is based on user-centred design. To achieve a user-centred design, considering both the operator’s SA and shared SA in distributed teams seems important. Endsly & Jones [10] state that SA is the key to achieving user-centred design. They define SA as “the perception of the elements in the environment within a volume of time and space, comprehension of their meaning, and the projection of their status in the near future”.

Endsley & Jones describe a key principle for achieving a user-centred design: Organize technology around the user’s goals, tasks and abilities [10]. For organizing the procedure application around the user’s abilities, the Gestalt principles of perception [16] are applied. Gestalt theory provides rational explanations for why changes in configuration can have a profound effect on the meaning of the presented
information. The Gestalt principles have inspired the total layout, the use of colours, the elements and symbols and organisation of information. An application of Gestalt theory can result in stronger compositions that facilitate communication. In the following, the design is described in the context of SA and Gestalt principles.

5.1 Perception of the elements in the environment
The first of the principles of achieving SA is to “perceive the status, attributes and dynamics of relevant elements in the environment”\[10\]. This also includes perceiving the important elements. In relation to this principle, it seems relevant to include the two Gestalt principles, Prägnanz and figure/ground.

The principle of Prägnanz describes how we tend to simplify what we see, which can be cognitively demanding\[16\]. The visual appearance of the design is simplified by avoiding visual clutter and data overload. Also, the use of colours is limited and only relevant information shall be displayed. The concept pictures are simplified by only showing what is needed, when it is needed. This principle is used for the total set-up of the application, trying to match the users’ immediate need for information related to the progress of tasks. There are three levels of information in the application (see Fig.3). The first is the overview of all relevant procedures to be used “today”, allocated to one specific operator. The second level is an overview of all procedure steps in the chosen procedure. The third level is information needed for performing one single procedure step. Information and features are prioritized relative to their importance for performing the tasks and how often they are needed. Frequently used information and features are displayed contextually in the main pictures. Less important or less used information and features are available from a dropdown menu.

The principle of figure/ground describes how we separate objects (figures) from their surrounding background (ground) when perceiving a visual field\[16\]. This law of perception is dependent upon contrast. If the two visual fields are similar, it will be difficult to perceive the figure. Images and text must be visible. Varying degrees of contrast can detract or enhance legibility. Therefore, layering of information by using the figure/ground principle is used for optimizing the perception of important information. The most relevant information for the field operator is most salient. High contrast on important information is used to optimize visibility also in bad lighting and to attract the user’s attention. More or less dull grey colours are used on other information, according to their importance.

Fig.2: Layering of information

Fig.2 is an example where contrast and use of colours are used for visually layering information. The text in field operator steps is both larger and more salient than steps for control room operators. A blue icon is also supporting the field operators in quickly perceiving their steps. Information concerning the status of steps (finished and postponed) is also made more salient.

5.2 Comprehension of the current situation
The second of the principles of achieving SA is “understanding what the data and cues perceived mean in relation to relevant goals and objectives”\[10\]. This is interpreted as putting elements, status and attributes, in the right context. The Gestalt principles of proximity and similarity seem relevant in this context.

The principle of proximity implies that when we perceive a collection of objects, we will see objects close to each other as forming a group\[16\]. Contextual chunking of information is used to group information belonging to the same context,
or information aimed at the same objectives. For instance, one procedure step is one group. Within this group, there are smaller groups, separating the different information belonging to this group: the step number, descriptive text for the step, map button, and status icons (see Fig. 2).

The principle of similarity captures the idea that elements will be grouped perceptually if they are similar to each other\textsuperscript{16}. Text and icons with the same meaning or feature are arranged at the same place within the groups. Also, icons with the same function are designed alike. Consistency is applied to the design. For instance, all active procedures and steps are white, making it easy for the user to understand what procedure is currently worked on and what step to perform next. Another example is that all status icons are placed at the left side of the picture, helping the user to quickly perceive the current situation for each step by scanning the left side of the picture (see Fig. 2).

In some instances, the principle of similarity is deliberately broken to draw attention to certain elements. The active procedures and procedure steps are white, while the other steps are grey. Because there should be only one or few active procedure steps at once, these will pop out and draw attention. This is a place-keeping function that helps the users in keeping track of where they are in accomplishing the sequence of steps in the procedure. Another example is that icons for switching between three different lists of procedures, My List, All and Postponed (see Fig. 3, level 1), all have the same shape and colour. However, the chosen list breaks the pattern of similarity because of a lighter fill colour. This is for the users to have a clear perception and understanding on which procedures they are looking at.

The principle of similarity is used also for interaction methods and gestures. The gestures selected are an attempt to make the interaction easy, both concerning one-hand operation, familiarity and intuitiveness. Patterns for touchscreens gestures are used. The same gesture will give the same result. Tapping an icon will open new information. Tapping the map button will open a map and tapping a procedure step will open a view mode of the procedure. For changing status on procedure steps, the user must confirm that procedure steps shall be activated by sliding the step, and confirm that the step is finished or postponed by dragging a slider. The sliding function is for making input on procedure status slower to ensure correct input.

To make sure that the user understands the system actions that follow the operators’ interaction with the application, feedback on user actions is provided. Every user action is followed by a visible change. For instance, when tapping a button, the button will, for a split second, be lit up by a brighter colour and accordingly the information related to the button appears.

The main organizing principle of the concept is related to what information the operators need in different contexts. The application includes three main levels of information, reducing the number of steps for achieving the goals. The operator can go from an overview level to a detailed level in two taps, providing current status information. The three main levels are illustrated in Fig. 3. Each information level reveals more information, related to the procedure work progress. Overall descriptions of procedures and their status are at level 1 (the Task list), only showing the needed information for the goal of getting an overview. The task list is a collection of all procedures planned for the shift. Level 2 includes all steps for the selected procedure. The operator can see steps involving both their own and others’ roles, and the status for each step (active or not, completed or postponed). Information on where to perform each step is included in the context of the step. Level 3 includes all information needed to perform the step: features for changing status of the procedure step, registering levels, component verification by scanning tags, piping and instrumentation diagrams, real-time process information, video material, pictures of
equipment, and a feature for writing notes to the procedure step. The feature for changing status is on the top, for the user to easily find this feature. This feature is also visible, staying at the same place on top, when scrolling in the picture.

When doing changes on equipment or measuring levels, it is important that the operator is really working on the right component. An easy way of confirming this will make operations safer. In the procedure application, a feature for component verification by scanning tags is included. The scanning will compare the tag on the component and the tag in the procedure. The operator will get feedback on whether the tag is correct or not.

5.3 Projection of future status
The third principle for achieving SA is projection of future status\(^{10}\). When understanding the meaning of the elements covered by the first and second SA principle, the user can predict their future status. For instance, when understanding that the procedure steps will change from grey to white when it turns active, the user will understand what step to work on next. Real-time process information and trends can help the operators in predicting future status. These features enable the user to be proactive in finding out what actions should be taken next. There is a timeline at the top of level 2 and level 3 pictures, showing the progress of the procedure work. A white stripe on grey background will be stretched depending on the procedure progression (see Fig.3, level 2 and 3).

6 Result, the handheld procedures
The main concept pictures of the handheld procedures are in Fig.3. The conceptual application is the result of mitigating the needs and resolves the challenges that operators have described. It includes solutions for all the features and information needs described in this chapter. The findings from the interviews and feedback from operators indicated that making a concept for an application only including procedures is not sufficient for the purpose of making the application usable for the operators, and for improving the work efficiency and communication between field operators and control room operators. The procedures are seldom used as the only information source when performing tasks. Based on operators’ statements on their challenges and needs, they would benefit from integrating the procedures with other information sources and communication features needed in the different contexts of work.

Fig.3: The three main levels of procedural information.
The resulting concept for mobile phones is different from the control room desktop CBP system. The interface and interaction methods are designed to fit a phone-sized device, a smartphone, which can be carried in the pocket and supports one-hand operation. This is for making it more user-friendly for different working positions (e.g. on a ladder) and for making it easy to bring along. The size of the screen and the absence of a mouse and keyboard require a different mind-set and principles of how to display the information and what interaction methods to use. Also, the size of the device requires a strict prioritization of what information to display and how to display the information. Procedure structure must be simplified and standardized to meet the capabilities of the technology.

A criterion for exploiting the benefits of computerized handheld procedures is to synchronize the information from the handheld device, used in the field, and the CBP system in the control room. The Institute for Energy Technology / OECD Halden Reactor Project has developed a CBP system integrated with process information for a nuclear control room that has received high usability scores in initial user tests[15]. The CBP system integrates procedural information with process displays. Some design choices in the handheld procedures are made for consistency between the two procedure tools. The design principles that are used for indicating, for example, active, completed and postponed (rest-marked) procedure steps are harmonized with the design of the CBP in the control room.

7 Discussion and further work

The design activity, working with a concept for CPBs in a handheld device, has identified a whole collection of features and resulted in a design concept that might supports task performance, communication, coordination and SA in distributed teams.

The work with making a usable application prototype for CBPs for field operation, visualizing procedures on a full-screen mobile phone with touch-screen, has started. The implementation includes implementing a connection between the application for the field operators and the CBPs in the control room in HAMMLAB (Halden Man Machine Laboratory). The application will be used for human factors studies in HAMMLAB. A planned activity is to perform a usability test of the application in a full-scale test environment in HAMMLAB. For future work, it would be interesting to also test whether this tool for real-time update of work status related to procedure work can improve task performance, communication and shared situation awareness between the control room and field operators.

For making this application successful, both concerning team performance and field operator performance, the technology needs to be embraced totally. The handheld procedures need to interact with the CBPs in the control room. Shift meetings should include prioritising tasks, approving procedures to be performed and planning of today’s activities. Also, updating procedures regularly in the system is necessary. To benefit from the advantages of the technology it is essential to take a full step into the digital working method. Using both PBPs and CBPs will only result in more workload on operators and uncertainty as to whether the digital procedures are updated or not. Implementing this application in a nuclear power plant can therefor be challenging.

There are more factors that can be challenging with this application. One is the technology challenge, concerning battery capacity, wireless connectivity at the plant and the fact that an off-the-shelf smartphone is not a rugged device. It might be necessary to consider how to handle these challenges to reduce the risk of loss of information. Also, the smartphone has a small screen, which might not be suitable for all types of work. The possibility to get a larger overview, e.g. to scan through the procedure to get an overview of the next instructions to be performed,
is limited. Methods for avoiding keyhole effects and navigation problems are essential for a satisfactory usability. One solution for these challenges is to establish workstations around in the plant, with access to larger screens, to load and unload information, to charge the battery, and for displaying larger overview pictures. Before developing such solutions, a fundamental question to investigate is: How much information do field operators need for the on-site tasks?

There might also be challenges related to the representation of the procedure structure on this small device. The device requires a strict prioritization of what and how to display, and which interaction methods to use. In the concept described in this paper, procedure structure has been simplified and standardized to meet the capabilities of the technology. For instance, the concept as it is now, does not involve representation of procedure branches as described as important in NUREG-0700: “Nuclear plant procedures are not like simple checklists in which a user starts at the top and linearly proceeds step-by-step to the end. Based on plant conditions, the operator may be required to branch from one part of a procedure to another or from one procedure to another”[2].

A CBP system can offer context-sensitive branching recommendations. However, how this can be represented in such a small device, and still keep the operator in the loop of automation actions, is so far an unresolved issue.

The expected outcome of testing the handheld procedures will be increased knowledge regarding whether the proposed solution for a handheld device is feasible and will give valuable support for the cooperation between field operators and control room personnel. This concept can also provide input to new ideas that will be important to take into consideration for near-term applications. It can provide input to designers, vendors and regulators in their work with designing and evaluating control room solutions, also in the context of an outage control centre, where coordination and communication in a distributed team is important for performance and efficiency.

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