THANKS FOR THE MEMORIES: A PRIMER ON CAPTURING AND MANAGING UNDOCUMENTED EXPERT KNOWLEDGE

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ABSTRACT

Many highly knowledgeable workers in the energy industry and various economic sectors with up to three decades of experience are departing as a result of retirement, job transfers, downsizing, and other reasons. The loss or departure of this valuable knowledge, specifically tacit (or undocumented) knowledge, can have negative operational, environmental, safety, and economic consequences, especially with complex systems that have been in place for many years. This paper provides important elements that companies should consider when implementing a new program or expanding an existing program to capture and manage undocumented expert knowledge from departing or other potentially unavailable workers. Various approaches are provided for selecting and applying methods, techniques, and tools for eliciting, storing, retrieving, and presenting valuable knowledge to other personnel, such as: 1) using existing resources, 2) identifying subject matter experts (SMEs), and/or 3) selecting one of the following elicitation methods: a) Critical Decision Method, b) simulations and scenarios, and c) concept mapping. Since SMEs rely heavily on perceptual skill and recognition, but may have difficulty articulating their knowledge of procedures and perceptions, i.e., tacit knowledge, the Critical Decision Method process is a key component to facilitate this effort successfully. Knowledge elicitation methods that involve probe questions yield better information about perceptually-based assessments (e.g., diagnostic cues, discriminators) than when SMEs are provided little structure or guidance during the elicitation task, even though they are explicitly asked to describe their perceptions. It is important for organizations to determine early whether potentially valuable undocumented knowledge will be lost with the unavailability of experienced personnel. If this knowledge is worth capturing, these methods can be used to elicit, store, retrieve, and present this knowledge when needed.

INTRODUCTION

Many highly knowledgeable workers in the energy industry and various economic sectors with up to three decades of experience are departing as a result of retirement, job transfers, downsizing, and other reasons. Table I summarizes how the loss or departure of this valuable knowledge, specifically tacit (or undocumented) knowledge, can have negative operational, environmental, safety, and economic consequences, especially with complex systems that have been in place for many years.

Table I. What Do You Have to Lose?

• Historical knowledge of equipment and systems, including the plant and systems as built and as modified
• System engineering knowledge
• Troubleshooting skills
• Decision-making and problem-solving abilities, which may include detection, diagnosis, solution selection and implementation
• The big picture – the ability to create an accurate mental model of a process, situation, or task and to put a problem in perspective
• Corporate history including lessons learned
• Knowledge of the correct people to contact for information and where needed information is stored

Often, this type of knowledge is unique, known to one or a very few individuals or teams, and is not always available to others through procedures or normal training. However, younger incoming staffs are unlikely to have had education, training, or experience that is directly applicable to these older technical systems.

An Electric Power Research Institute (EPRI) Strategic Human Performance Program survey was conducted of management and supervisory utility staff and yielded a startling discovery. Nearly 92% of all respondents believed that a loss of unique, valuable expertise would pose a problem within the next five years, but only 30% indicated a planning effort was in place to retain knowledge from experienced personnel and make it accessible and usable by new or replacement workers. Of the electric utilities that have efforts in place to capture and store valuable knowledge, the processes typically involve capturing information in procedures, training programs, or job rotation. Mentoring, another common industry approach, has been reduced by the pressure to minimize the number of employees. Methods frequently used for dealing with departing personnel include hiring outside contractors or consultants, searching for suitable replacements, using raises, promotions, or other incentives to induce departing workers to remain, and hiring employees back as independent subcontractors after they retire. Nevertheless, about 26,000 new employees will be required over the next 10 years to replace workers expected to depart from nuclear power generation facilities, and qualified replacements are becoming increasingly difficult to find and retain (1-4).

Purpose

This paper provides important elements that companies should consider when implementing a new program or expanding an existing program to capture and manage undocumented expert knowledge from departing or other potentially unavailable workers. Various approaches are provided for selecting and applying methods, techniques, and tools for eliciting, storing, retrieving, and presenting valuable knowledge to other personnel, when needed, as follows:

- Using existing resources
- Identifying subject matter experts (SMEs)
- Knowledge elicitor should be familiar with the domain
- Selecting elicitation methods
  a) Critical Decision Method
  b) simulations and scenarios
  c) concept mapping
- Transcription bottlenecks
- No right or wrong methods
- Knowledge modules – the end product

In addition to industry settings, this process encompasses areas of knowledge management, cognitive psychology, applied psychology, and artificial intelligence/expert systems.

Using Existing Resources

To the extent feasible, existing resources, programs and infrastructure should be used to collect and disseminate valuable undocumented knowledge. Thus, time and costs to initiate a new program may be minimized. In many organizations, an existing department, group, or individual will be assigned the responsibility for capturing undocumented knowledge. For example, training groups and programs (e.g., databases), procedure groups, human resource organizations, etc., are used routinely to identify, collect, and disseminate important information. In addition, some companies have effective mentoring, apprentice, job rotation, and cross-training programs.

WESKEM, LLC's Environmental, Safety and Health (ES&H) Department, for example, previously assessed that a lack of consistency, poor communication and use of antiquated communication tools could contribute to the failure of capturing and disseminating undocumented knowledge. To address these issues, the ES&H Department has established an Activity Hazard Review (AHR)/Activity Hazard Analysis (AHA) process for systematically identifying, assessing, and controlling hazards associated with project work activities during work planning and execution. Depending on the scope of a project, information from field walkdowns and table-top meetings are collected on an AHR form. The AHA then documents the potential failure and consequence scenarios for a particular hazard. Also, the AHA recommends whether the type of mitigation appears appropriate or whether additional controls should be implemented. Since the application is web based, the information, including undocumented knowledge, is captured into a single system and organized according to the >200 work activities already recorded in the database. Using the streamlined AHA method improves cycle time from over four hours to an average of one hour, allowing more time to capture undocumented knowledge, analyze unique hazards and develop appropriate controls. Also, the enhanced configuration control creates a readily available AHA library to research and utilize along with standardizing hazard analysis and control selection across four separate work sites located in Kentucky and Tennessee (Figure 1). The AHR/AHA system provides an applied example of how the ISM concept has evolved into a standardized field-deployed tool yielding considerable efficiency gains in project planning, resource utilization, and capturing undocumented knowledge (5).

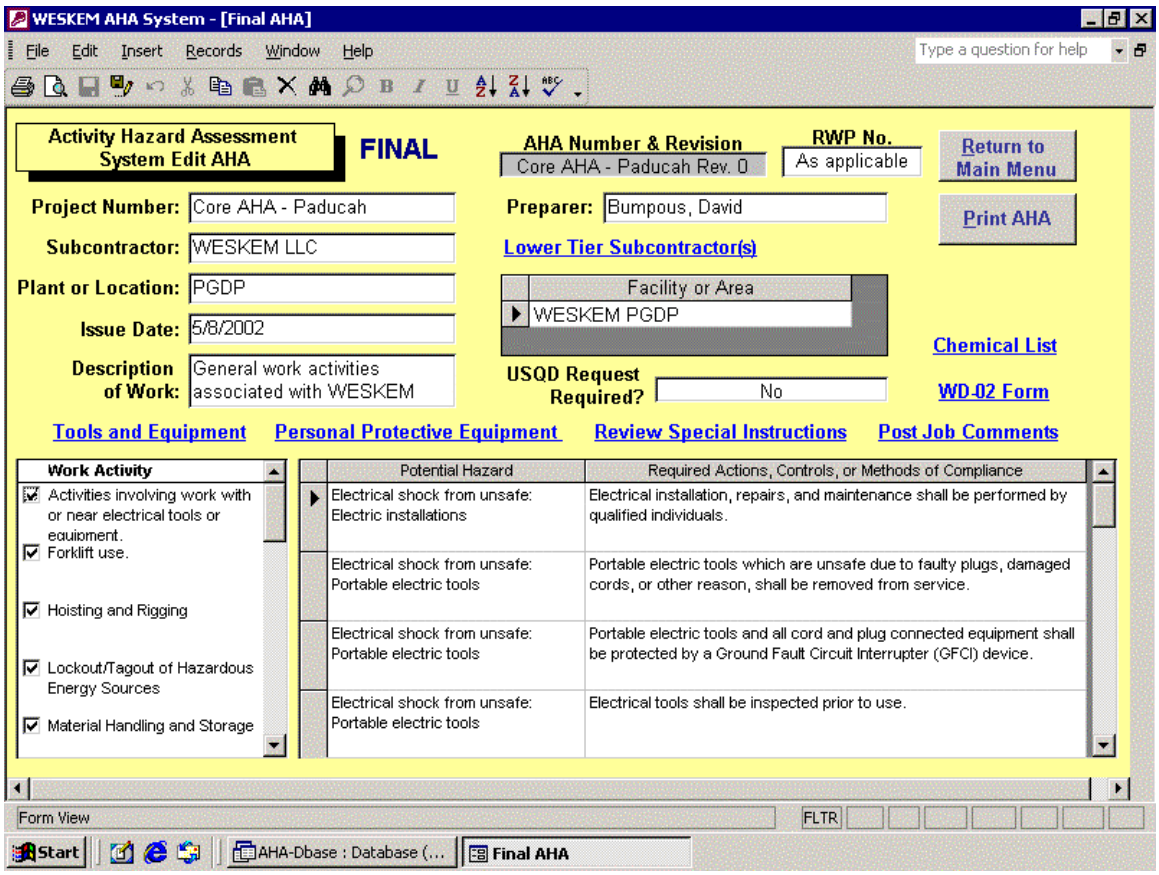

Fig. 1. AHA edit screen.

Identifying Subject Matter Experts (SMEs)

An initial activity is to identify key employees who may be leaving their current jobs or may have knowledge so valuable that it should be available to others, for example, when they are absent due to travel, vacation, or illness. Some considerations include:

- Individuals with expertise for obsolete systems that are still in use and are recognized within the organization as being the only SME, or one of only a few local site SMEs.
- Individuals with expertise in handling rare or infrequent events of high importance (e.g., repair of a unit that fails on average once every 10 years).

Following identification of the SMEs, it is important to determine if these workers are willing to permit their valuable tacit knowledge to be elicited and made available to others. In many cases, the SME has a wide range of expertise, some of which is unique and some that is also known by others. However, the SME is likely to be most familiar with the areas of knowledge that are of greatest importance to the organization. It should be noted, however, that some workers identified as SMEs may say, "I don't have any valuable knowledge; other people know what I know. "It is common for an SME not to realize the valuable tacit knowledge they possess."

In addition, workers may be willing and, in some cases, eager to share their knowledge for a variety of reasons. A worker may view it as an honor to be recognized as an SME. Others may feel an obligation to share their valuable knowledge because of the benefits received during their careers or because it is the right thing to do. Managers may have even asked and made time available for the SMEs to participate and that it is simply part of their job.

However, approximately 10% of the workers are not willing to share their expertise for a variety of reasons:

- Knowledge is viewed as an individual's intellectual property and may be used by that person as a basis for consulting work or another job;
- Fear of layoff or loss of status because of the perception that the unique knowledge provides job protection and recognition and making this information available to others may increase vulnerability;
- Alienation against the company for some real or imagined reason (e.g., lower than expected salary increase or being passed over for promotion);
- Expectation that elicited knowledge will "go into a file cabinet and never be seen again," thus wasting time of the SME; and
- Current work assignments leave no time available to participate in knowledge elicitation.

Knowledge Elicitor should be Familiar with the Domain

The knowledge elicitor should be familiar with the domain through previous education, experience and training. This permits the elicitor to understand specialized domain terminology, be able to ask intelligent questions, and have some recognition of the specific areas to probe further to obtain the valuable undocumented knowledge. Without this depth of knowledge, the elicitor may need to rely on the SME for direction regarding what needs capturing. Furthermore, SMEs are usually extremely busy because they are assigned the most demanding and difficult tasks and may be consulted by others needing access to their unique knowledge. It may be difficult for the knowledge elicitor to have much time with the SME. Therefore, time can be used wisely using available elicitation methods.

Selecting Elicitation Methods

Knowledge elicitation efforts usually take place in stages, and the nature of the knowledge is a major consideration in selecting the appropriate elicitation methods. The first stage is for the elicitor to develop an understanding of the general knowledge of importance available to the SME. The ultimate goal is to develop decision aids that preserve corporate knowledge.

A. Critical Decision Method

Interview-based methods are available to develop a high-level description or overview of the SME's valuable knowledge based in large part on significant events occurring in the past. Specifically, the Critical Decision Method uses a process based on cognitive task analysis, team decision making and situation awareness. A Critical Decision Method session involves case-specific, multitrial retrospection from the participant's own experience. The participant is guided in the recall and recounting of the event and its context following a structured process. The

elicitor gathers information about visual, auditory, and tactual cues that are being used, possibly at an unconscious level. Information such as this, resulting in the performance of an action that is safer and better than anyone else, has high value. The following information provides a detailed description of the Critical Decision Method process. Typically, the process takes about two hours, but is primarily dependent on lengthy or complicated retrospective analyses requiring additional time to construct time lines and decision-point identifications (6).

Step 1: Preparation

1. Training of elicitors to properly conduct the Critical Decision Method process has involved a number of exercises, including experience in the role of interviewee, experience in the development of Critical Decision Method procedures, and experience in preparing an interview guide. As in the exercise of any knowledge elicitation method, effective use of the Critical Decision Method presumes that the elicitor is a skillful facilitator and knowledge elicitor.
2. The knowledge elicitor must become familiar with the domain through analysis of research and technical documents and preliminary interviews (i.e., conversations with domain SMEs, on-site observations, etc.).
3. The goals for knowledge elicitation are specified and defined.
4. SMEs in sufficient number must be available and cooperative.

Step 2: Incident Selection

The opening query poses a particular type of event or situation and asks for examples in which 1) the SME's decision altered the outcome; 2) things would have turned out differently had the SME not been present to intervene; or 3) the SME's skills were particularly challenged. The incident must come from the person's own experience as a decision maker. The goal in this step is to help the SME identify cases that are nonroutine, challenging, or difficult in which one might expect differences between the decisions and actions of an SME and those of someone with less experience, and cases in which elements of expertise are likely to emerge.

Step 3: Incident Recall

The participant is asked to recount the episode in its entirety. The participant is asked to "walk through" the incident and to describe it from beginning to end. The elicitor asks few, if any, questions and allows the participant to structure the account.

Step 4: Incident Retelling

Once the SME has completed the initial recounting of the incident, the elicitor tells the story back, matching as closely as possible the SME's own phrasing and terminology, as well as content and sequence. The participant is asked to provide additional details and verify event sequence. The participant will usually offer additional details, clarifications, and corrections. This sweep allows the elicitor and the participant to arrive at a common understanding of the event.

Step 5: Time Line Verification and Decision-Point Identification

The SME reviews the incident a second time. The SME is then asked for the approximate time of key events. A time line is composed based on the elicitor's judgment about the important events, decisions, and actions, then shared and verified by the SME as it is being constructed. The elicitor's goal is to capture the salient events in sequence, ordered by time, expressed in terms at which important input information was received, and actions that were taken. In some cases, decision-point statements are obvious (e.g., "I had to decide at this point whether to pursue option A or option B."). In other cases, statements could suggest a variety of feasible decision-point alternatives that were considered, evaluated, and discarded affecting the course of the decision-making process.

Step 6: Progressive Deepening

The elicitor leads the SME over the incident account a third time, employing probe questions related to each decision-making event. Probe questions are designed to elicit specific, detailed information about important cues, expected evolution of the situation, goals that were considered, options that might have been evaluated, and the role of experience. This method is useful in generating information about SME reasoning in a real-world task specifying the important cues in various situations that trigger knowledge and cause shifts in lines of reasoning. The elicitor works through each segment of the story asking for additional details and encouraging the SME to expand on the incident account. This step is often the most intensive, sometimes taking an hour or more to collect all relevant information. A collection of sample topics and probe questions that could be used in this sweep of a Critical Decision Method session are listed in Table II.

Table II. Sample Critical Decision Method Probe Questions

Probe Type	Probe Content
Cues	What were you seeing, hearing, and/or smelling?
Knowledge	What information did you use in making this decision and how was it obtained?
Analogues	Were you reminded of any previous experience?
Standard Scenarios	Dopes this case fit a standard or typical scenario? Does it fit a scenario you were trained to deal with?
Goals	What were your specific goals and objectives at the time?
Options	What other courses of action were considered or were available?
Basis of choice	How was this option selected or other options rejected? What rule was being followed?
Mental modeling	Did you imagine the possible consequences of this action? Did you imagine the events that would unfold?
Experience	What specific training or experience was necessary or helpful in making this decision? What training, knowledge, or information might have helped?
Decision making	How much time pressure was involved in making this decision? How long did it take to actually make

	this decision?
Aiding	If the decision was not the best, what training, knowledge, or information could have helped?
Situation assessment	If you were asked to describe the situation to another employee at this point, how would you summarize the situation?
Errors	What mistakes are likely to occur at this point? Did you acknowledge whether your situation assessment or option selection was incorrect? How might a novice have performed/reacted differently?
Hypothetical	If a key feature of the situation had been different, what difference would it have made in your decision?

Step 7: "What-lf?" Queries

The fourth sweep through the incident involves shifting the perspective from the SME's actual experience of the event to a more analytical strategy. The elicitor poses various hypothetical changes to the incident account and asks the participant to speculate on what might have happened differently. In studies of SME decision making, for example, the query might be, "At this point in the incident, what if there had been a novice present rather than someone with your level of proficiency? Would they have noticed X? Would they have known to do Y?" Also, the elicitor can ask the SME to identify potential errors at each decision point, including how and why errors might occur in order to better understand the vulnerabilities and critical junctures within the incident. The purpose of the "what-if" probes is to specify pertinent dimensions of variation for key features contained in the incident account. The reasons for taking a particular action are frequently illuminated by understanding of the choices that were either not made or rejected.

There are still limitations using the Critical Decision Method process. Most decision-making situations yield some information about whether or not the outcome was successful. However, in distributed decision-making environments, employees may address one element of the task, forward the results, but from the lack of feedback, never know whether their judgments or assessments were correct. As a result, employees will not be able to refine their performance and, later, may have difficulty recalling incidents. Furthermore, events used to recount an incident in high workload situations can become merged in memory. This can result in confusion over time-line reconstruction or difficulty separating one incident from another, often realizing midway through the incident account that they are combining two or more events. In such cases, what one can do is construct a generic time line based on a typical work shift. There is over 80% agreement when recalling the same events three days, three months and five months later after eliminating confusion over event reconstruction. In addition, there is over 85% agreement between independent knowledge elicitors when using specific decision strategies (e.g., cue deliberation and action evaluation) to collect, analyze and code information consistently. Disagreements reflected the tendency of a second elicitor to identify too many statements as decision points, suggesting the Critical Decision Method can be modestly sensitive to the domain knowledge of the elicitor/coder, but this is expected for any knowledge elicitation method when someone unfamiliar with the domain analyzes the data. The reliability estimates

obtained in these studies were consistently high, but further emphasizes the need for the elicitor to be familiar with the domain.

B. Simulations and Scenarios

Other approaches may be more suited to knowledge that relates to operations and maintenance processes and equipment. Such knowledge may be elicited with the help of simulations and scenarios using mock-ups or actual equipment. The simulations, constructed scenarios and the think-aloud problem-solving methods encourage the SMEs to describe what they are doing and thinking about as they perform simulated or actual tasks.

C. Concept Mapping

A concept map is perceived regularities in events or objects defined as concepts, having resources associated with them such as images, sounds, web pages, or other concept maps and labeled to represent their relationships (Figure 2). Also, concept maps can be used for knowledge elicitation and storage.

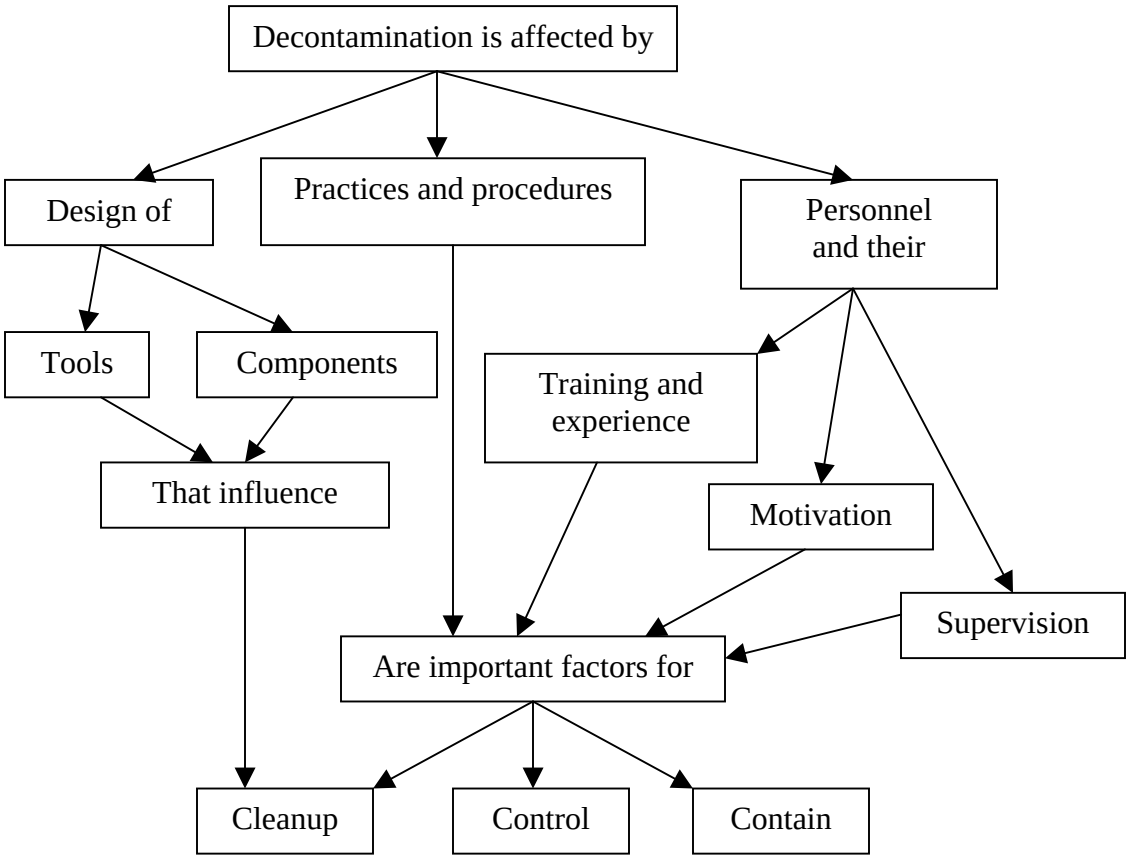

Fig. 2. A high-level concept map for decontamination in a nuclear power generation facility.

Transcription Bottlenecks

Audio or video recordings and photographs may be taken at appropriate times during the elicitation sessions, edited, indexed, and made available to others when access to the expertise would prove beneficial. However, recording an elicitation session consisting of structured and unstructured interviews can create transcription bottlenecks. Transcription, editing, and reviewing audio records of interview sessions are time-consuming activities. Techniques to minimize the editing required to format knowledge for use by others include selective audio recordings or video recordings. Computer speech recognition software can be used to avoid the transcription bottleneck. However, both the elicitor and SME would need to train the speech recognition system in their respective voice patterns. Also, technical terms not found in the speech recognition lexicon would need to be entered prior to the elicitation session to make this approach feasible.

Knowledge Modules – The End Product

The elicited knowledge should be formatted and packaged in a knowledge module comprised of the following attributes:

- The explicit knowledge is directly related to a specific task, activity, or job;
- The information is retrievable when needed after having been elicited from an SME;
- The information is evaluated, edited, and formatted to be usable by others; and
- The information is stored in electronic and/or hard-copy form.

An organization must consider how other employees will access and use the SME knowledge. The available options consist of:

- Incorporating the information into existing training materials;
- Linking the information to a procedural step appearing automatically when it is time to perform that step;
- Involving a person in the field who inserts a CD-ROM in a laptop computer, accesses a web portal, or AHA database to receive guidance on how to perform a task (5).

Figures 3, 4 and 5 show how equipment or processes are tagged and identified, for example, as International Organization for Standardization (ISO) 14001 significant environmental aspects. The tracking number allows the employees to access information about the equipment or process using the plant's ISO 14001 web site (7).

Fig. 3. Accessing information via web site for additional guidance.

Fig. 4. Accessing information via web site for additional guidance.

Fig. 5. Accessing information via web site for additional guidance.

Changes will occur in equipment, processes, procedures, practices, regulations, and responsibilities over time. For a knowledge module to be useful over an extended period, it must be updated and corrected to eliminate errors. Knowledge modules that no longer have value should be eliminated.

No Right or Wrong Methods

There are no right or wrong knowledge elicitation methods. The choice depends on a range of considerations, some of which may not come into play until knowledge elicitation is in progress. For example, the knowledge elicitor may find that an elicitation method not considered or selected during planning may be more appropriate for the type of knowledge used by the SME. Therefore, it may prove desirable to utilize a different method as the knowledge elicitation moves forward. Although reliability lies at the foundation of scientific rigor, in the context of cognitive task analysis there is also a need for flexibility. Thus, understanding and having access to a range of methods along with the flexibility to alter methods being used or planned will result in greater benefit from the knowledge capture process. Furthermore, these techniques are useful for enhancing existing programs such as Integrated Safety Management (ISMS #5 - Feedback), root cause analysis, quality assurance audits and self assessments.

CONCLUSION

A general conclusion from the experience of many researchers is that SMEs love to tell stories. In most cases, practitioners learn more "on the job" by sharing their experiences than through formal instruction. Furthermore, allowing the SMEs to share their experiences has the benefit of reinforcing their cooperation by establishing the elicitor as a listener and helper rather than an interrogator. However, capturing undocumented knowledge is simply more than just the facilitation of storytelling and getting SMEs to talk. The elicitor must take the interview beyond the story to extract key cognitive events, i.e., the "story behind the story." Since SMEs rely heavily on perceptual skill and recognition, but may have difficulty articulating their knowledge of procedures and perceptions, i.e., tacit knowledge, the Critical Decision Method process is a key component to facilitate this effort successfully. Specifically, knowledge elicitation methods that involve probe questions yield better information about perceptually-based assessments (e.g., diagnostic cues, discriminators) than methods by which SMEs are provided little structure or guidance during the elicitation task, even though they are explicitly asked to describe their perceptions.

Furthermore, some of the diagnostic cues typically reveal areas where SMEs had never before explicitly deliberated or specified. Cues derived from field-obtained perceptual experience using the Critical Decision Method process are quite different and often more pertinent when compared to indicators available in existing plant literature (e.g., manuals or procedures). Many of these discrepancies result from the capability of the SMEs to detect very early signs of malfunctions or breakdowns, for example, how color, movements, and sounds contribute to the analysis of a given situation, whereas the existing plant literature focuses on after-the-fact scenarios. Skilled SMEs are highly attuned and alert to these subtle cues that are essential when spotting a situation that could lead to a malfunction prior to exceeding an alarm setpoint.

It is important for organizations to determine early whether potentially valuable undocumented knowledge will be lost with the unavailability of experienced personnel. If this knowledge is worth capturing, these methods can be used to elicit, store, retrieve, and present this knowledge when needed.

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