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Resolving Emergent Issues During Nuclear Plant Outages

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SUMMARY

This report discusses the development of capabilities for resolving issues that emerge at nuclear power plants during scheduled and unscheduled plant outages. These capabilities combine the use of mobile technologies for field workers with advanced collaboration capabilities in the outage control center to quickly assess and develop resolution plans for emergent issues threatening the outage schedule or safety margin.

A nuclear plant outage is a large, complex undertaking involving thousands of activities typically over the course of 3 to 4 weeks. A particular need in outage management is the ability to determine, communicate, and assess outage work status in a timely manner to support real-time decision making in order to react to changes and additions to the work plan. This report discusses new technologies and methods being developed to allow nuclear power plant outage managers to quickly assess and resolve issues that emerge during nuclear plant outages that may impact schedule and plant safety. Nuclear utilities spend millions of dollars of scarce resources each year conducting plant outages. This research is important because it can significantly reduce the cost of outages, and provide a margin of safety by reducing human error potential, which translates into helping keep the nuclear industry competitive with other energy sources.

This report also discusses previous research projects investigating the use of new digital technologies as well as new methods designed to improve the overall management and successful outcomes of emergent issues. It summarizes the research logic and technology deployment strategies used to demonstrate that outages can be improved through the strategic use of collaborative software applications and commercially available mobile technologies.

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ACRONYMS

COTS	commercial off-the-shelf
DOE	Department of Energy
ICC	Information Control Center
II&C	Instrumentation, Information, and Control
INL	Idaho National Laboratory
LWRS	Light Water Reactor Sustainability
NPP	nuclear power plant
OCC	outage control center
PSC	plant status control
WEC	work execution center

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1. INTRODUCTION

This research effort is a part of the Light Water Reactor Sustainability (LWRS) Program sponsored by the Department of Energy (DOE) to provide the technical foundations for licensing and managing the long-term, safe, and economical operation of existing nuclear power plants (NPPs). The LWRS Program serves to help the U.S. nuclear industry adopt new technologies and engineering solutions that facilitate the continued safe and efficient operation of NPPs and extend their current operating licenses.

The 2010 Research and Development Roadmap (2010 Nuclear Energy Roadmap) prepared for the DOE Office of Nuclear Energy organizes it's activities around a number of objectives that ensure nuclear energy remains a compelling and viable energy option for the United States. One DOE objective is that of partnering with the utility industry to develop, demonstrate, and deploy new digital technologies that can improve the reliability, sustain the safety, and extend the life of existing NPPs.

One factor that contributes to the utility industry's economic and financial success is plant availability, which is affected by executing operations and maintenance activities properly while at power and the successful accomplishment of planned and forced outages (periods of time when nuclear reactors are shut down or taken off-line for maintenance, repairs, refueling, etc.) As nuclear plants age, maintenance and outage tasks can become more complex and difficult; there can be as many as 15,000 activities to be accomplished during a typical plant outage. The LWRS Program Outage Control pilot project was thus tasked with developing capabilities for resolving issues that emerge during outages.

Emergent issues generally consist of new problems that arise such as equipment failure, unexpected interactions between work activities, and other unanticipated conditions, that deviate from the expected progress of planned outage activities. When emergent issues arise, outage managers must quickly assess their impact on the overall outage plan and schedule, consult with knowledgeable individuals on the nature of the problem and possible resolutions, determine the solution that will result in the least impact on the overall outage objectives, then communicate needed changes in plans and schedules to the affected activity managers. Resolving these emergent issues may involve outside vendors, suppliers, engineers, and other technical problem solvers as well as replacement parts that may or may not be available for aging equipment, thus requiring the assistance of offsite electrical or machine-shop contractors. Being unable to coordinate the complex nature of emerging issues with these contractors can cause major schedule delays and significant increases in outage costs, which can be as much as $1 million per day (Thomas and Hallbert 2012). Thus, the ability to recognize, evaluate, and effectively manage these emergent issues is a key component in meeting outage schedules and holding costs in check.

In spite of the impressive reductions made over the years in outage durations by the nuclear industry, information management and decision analysis has typically been supported by methods developed decades earlier. The current industry norm for dealing with emergent issues consists of impromptu meetings, telephone calls, "white board" solution sessions, manual transcription of agreed-upon changes into work process systems (e.g., work orders, schedules, risk management, radiation work permits, safety tagging, and warehouse parts), and communication throughout the organization using outage status meetings, emails, and direct phone contacts. This process is often repeated dozens of times over the course of an outage. Inherent in this process is the (1) inefficient use of time, (2) heavy reliance on manpower, and (3) risk of human error, thus delaying schedules and impacting overall outage goals.

Virque and Ponzio (1986) believed that outage durations, which generally last between 20 and 30 days, could be shortened by applying effective outage controls. This research study considers a new approach that deploys technologies to increase the efficiency of managing emergent issues by combining the use of mobile technologies for field workers with advanced collaboration capabilities in outage control centers (OCCs) to quickly assess and develop resolution plans for emergent issues threatening the outage schedule or safety margin, while reducing the probability of human error.

2. RESEARCH APPROACH

This research draws upon the results of two recent NPP outage studies, which Idaho National Laboratory (INL) participated in, that illustrate the benefits of using currently available technologies combined with innovative software adaptations to identify and resolve emerging issues during nuclear plant outages. The following two studies apply to this research:

- The Advanced Outage and Control Center Study (Weatherby 2012), which used technology deployment strategies to allow outage management teams to make consistent and strategic decisions during an actual outage or emerging issues activity and demonstrated that outages can be improved through the strategic use of collaborative software applications and available commercial off-the-shelf (COTS) mobile technologies.
- The Human Performance Pilot Project (Farris and Medema 2012), which identified a mix of hardware and software capabilities that reduce the mental workload of field workers (improved safe plant operations), increase overall field work efficiency, improve plant status control (PSC), and incorporate or replace the need for the current mix of human performance job aides. This project demonstrated conceptual ideas that can improve human performance and explored the potential use of portable handheld devices in the field to reduce human error and human variability in routine fieldwork, increased reliability, and improved validation methodology.

In each study, elements of an improved process for resolving emergent issues were developed and demonstrated and scenarios were performed by nuclear plant workers that confirmed the ability to more rapidly assess and respond to emergent issues. These studies are summarized below.

2.1 Byron Study—Advanced Outage and Control Center Strategies

Previous research at the Byron NPP found that commercially available communication technologies, when linked with Web-based collaborative software applications, represent a relatively inexpensive solution to improving outage management techniques (Weatherby 2012). While these individual technologies (handheld Smartphones, Smart Displays, tablets, and iPads) exist in the marketplace, they are not useful to outage managers until they are applied in a way that allows outage management teams to make consistent and strategic decisions during an actual outage or emerging issues activity. These capabilities are enabled through the use of collaborative software applications focused on work tasks common to the nuclear industry.

The Byron project developed and deployed new technologies that will help NPP outage managers to conduct more efficient and event-free outages. This research is important because nuclear utilities spend millions of dollars of scarce resources conducting outages at their plants each year, and can incur additional costs when unanticipated or emerging issues are not well managed. A reduction in or the avoidance of costs translates into a savings to the utilities that keeps the nuclear industry competitive with other energy sources.

The Byron study successfully demonstrated that the use of collaborative technologies can reduce error and increase the quality of decisions made during outage and emerging issues management. Findings from this study are presented in a report that contains the research methods, collaboration efforts, and conclusions of the research team (Weatherby 2012).

2.1.1 Byron Study Approach

Improved outage safety and efficiency is very much a function of how well work processes are executed, and is therefore a research area that lends itself well to this type of applied research. In collaboration with INL, DOE has previously conducted work in nuclear plant process improvement and application of digital technology to overcome work inefficiencies and human performance problems inherent in traditional, paper-based work processes. Based on this previous work and discussions with utility partners, Exelon Nuclear in particular, the research team developed the following hypothesis:

> More efficient and safer outage tasks are enabled by a technology-based system in which real-time outage work status information reveals potential issues before they become problems, supports a shared problem solving environment, and facilitates high quality decision making.

In 2011, INL researchers and Exelon management developed and deployed an integrated information sharing approach using SMART Technologies' SMART Board™ interactive displays and SMART Technologies Bridgit™ conferencing software. This enabled outage managers to communicate among the plant's OCC, its work execution center (WEC), and other remote platforms equipped with the SMART technologies.

In January of 2012, the INL research team developed a Pilot Project Technology Demonstration Plan to guide the field demonstration of the concepts described below.

The research team developed the system requirements and selected the technology components to support the pilot project demonstration based on a redesigned work process, human factors principles, and selected scenario performance elements.

Based on a literature and Web-based search, the research team chose to work with a smaller supplier (Ovalpath Inc, of San Jose, California) which could develop software support capabilities in the short term. Ovalpath modified their existing Wizzpers™ data capture technology to meet the pilot project objectives.

2.1.2 Technology Deployment

The required steps of an Exelon valve line-up validation procedure were loaded onto the Wizzpers database which could be displayed on both the SMART boards and the hand-held devices simultaneously. In addition, a copy of the plants bar-code library was also loaded onto the database, see Figure 1. This would allow the software to interrogate the equipment bar-code tags to assure that the correct piece of equipment had been selected by the field team.

Once the procedure was loaded onto the Wizzpers system, the research team configured the various graphical user interfaces to track the progress of the procedure in real time. The user interfaces were accessed through handheld devices and SMART boards. For the purpose of the demonstration, the graphical user interfaces were designed to display status information in a number of different ways. Three user interfaces were graphically displayed:

- The first user interface scrolled information as it was received by the management team in the OCC, WEC, or other remote location.
- The second user interface displayed information in a task-based format that provided interactive capabilities to the OCC and WEC management team.
- The third user interface displayed the actual location of work teams in the field and tracked and located critical support personnel who need to be present for task completion.

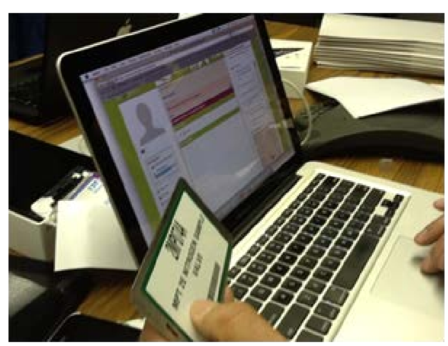

Figure 1. Pretest checking of barcode scanning capability.

Figure 2 provides a logical flow of how the different user interfaces were used to provide valuable information and guidance to everyone involved in the execution of a task.

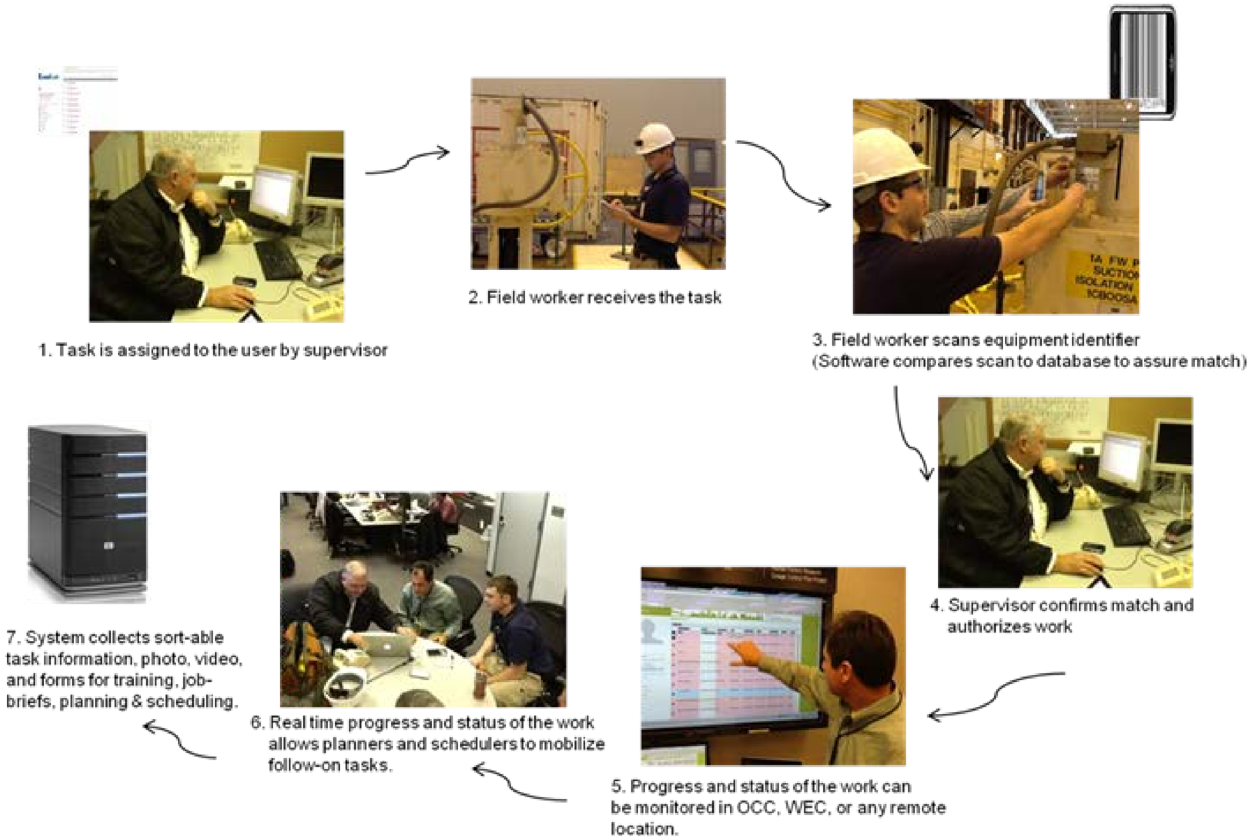

Figure 2. The process of information sharing while executing a task.

2.1.3 Conclusions

This ongoing LWRS pilot research project demonstrated that COTS technologies currently used for other applications could be configured in a unique way to solve many of the complex problems associated with outage management and its supporting functions. For example, the technology was modified by the research team while on site to provide radiation mapping and feedback to functions supporting the outage. All of the concepts and technologies worked as expected to the extent that they could be tested under actual field conditions in an NPP. While some unanticipated barriers were present in the deployment of the technologies, the research established the foundation for continuing efficiency and safety initiatives which can be demonstrated and applied in a cost competitive method as applied to outage management. These technological capabilities were found to be extremely important to the Exelon Byron NPP that participated in the research. At the time this report was written, Exelon decided to move forward with these capabilities (Ovalpath and handhelds) to enhance their competitive posture and to assist in sustaining the efficient life of the Byron facility.

Based on Figure 2 above, the following improvements and adaptations significantly increased the effectiveness of the decision making and resolution (terminal state) of the test scenario:

1. The supervisor assigned a task by the using the remote collaboration software that enabled the supervisor and OCC to track the task from inception through completion.

2. The field worker accepted the task and was provided with specific actions necessary to assure the task was the correct action and on the correct component.
3. The field worker was able to scan the bar code (correct component validation) and photograph the component prior to affecting the plant status.
4. The supervisor was able to visually identify the correct component, verify that the correct bar-code was scanned, and direct the field worker to proceed from a remote location.
5. Progress on each task is monitored in the OCC, WEC, and War Room as needed.
6. Follow-on tasks can be placed “on-deck” to support a seamless transition between work groups and work tasks.
7. The system stores a historical record of each task (with visual, audio, and task time-stamping) that enables managers to evaluate the task, plan for future tasks, train, and prepare pre-jobs. In addition, the software automatically produces records without diverting task time from workers.

As detailed above, this research project successfully developed and deployed new technologies that will assist NPP outage managers in conducting more efficient and error-free outages. The research team found that commercially available communication technologies, when linked with Web-based collaborative software applications, represent a relatively inexpensive solution to improving outage management techniques and overall work processes. While these individual technologies readily exist in the marketplace, without a clear understanding of human performance, human factors, and work processes, purchasing of these COTS mobile technologies would not, by themselves, be useful to field workers, outage managers, and OCC personnel.

2.2 Duke Study—Human Performance Pilot Project

The Human Performance Pilot Project was conducted by Farris and Medema (2012) “Improved Plant Operator Performance in Plant Configuration (Status) Control,” which called for developing prototype technologies for NPP PSC and fieldwork processes with associated study of field trials at a commercial NPP. This milestone was completed in February 2012. The INL research team completed the following list of activities to achieve this milestone:

- Demonstrated both operations and maintenance activities at the Catawba Flow Loop Training Facility with Duke Energy personnel as well as representatives from other prominent energy utilities within the United States. These tasks completed in February, 2012 included normal operations activity and normal maintenance activity in the Catawba maintenance training facility.
- Assembled an array of mobile technologies that constitute a platform for field activities in a NPP in order to address correct component (correct train/plant) identification through Bar Code Reader technology, Procedural linkage between action and component verification, and visual concurrent verification by remote operator at Information Control Center (ICC).

This study identified a mix of hardware and software capabilities that would reduce the mental workload of field workers (improved safe plant operations), increase overall field work efficiency, improve PSC, and incorporate or replace the need for the current mix of human performance job aides. This project demonstrated conceptual ideas that can improve human performance and explored the potential use of portable handheld devices in the field to reduce human error and human variability in routine fieldwork, increased reliability, and improved validation methodology.

Research activities were primarily performed at Duke Energy’s Catawba Nuclear Power Station in York, South Carolina. In addition, research and simulator laboratory work took place prior to the demonstrations in the Human Systems Simulation Laboratory at INL.

This project was positioned to bring three parties together – NPPs with urgent and long-term needs, vendors and other entities with COTS technological solutions, and third party facilities centered between the needs and solution-driven positions. The INL is a natural for this facilitative "central" coordinating role in that it brings a neutrality and some funding to help seed the needed problem solving.

2.2.1 Duke Study Approach

A strategy was developed to transform the in-plant work activities by working with industry to define the current processes (process modeling), seeking opportunities to improve these processes using COTS technology, and defining a new model that would fundamentally change the approach to field work in NPPs.

INL Human Factors researchers sought to answer three significant questions regarding improvements in human performance and PSC:

1. Would modern wireless handheld technology with embedded error prevention tools increase efficiency, performance, and decision-making, while reducing human error?
2. Would the use of the handheld device grant field workers the ability to focus on the task with error prevention mitigated by such devices?
3. What impact would handheld wireless technology have on PSC?

Figure 3. Motion J3500 Tablet PC and Motorola MC-75A.

2.2.2 Emergent Issue Resolution for Diesel Maintenance Scenario

The scenarios were designed by INL researchers and Catawba NPP Operations and Maintenance trainers to create a foundation for the research development, demonstration, and deployment process. These process flow (maps) diagrams see Figure 4, along with written operations and maintenance instructions, allowed the research team to focus on real world challenges faced by field workers. In addition, the process maps created a physical diagram that could be used by the software developer to incorporate needed elements of the research project. As previously mentioned, the technology employed COTS software along with software developed by INL and to ensure use in proofing concepts explored in the initial phase of the project.

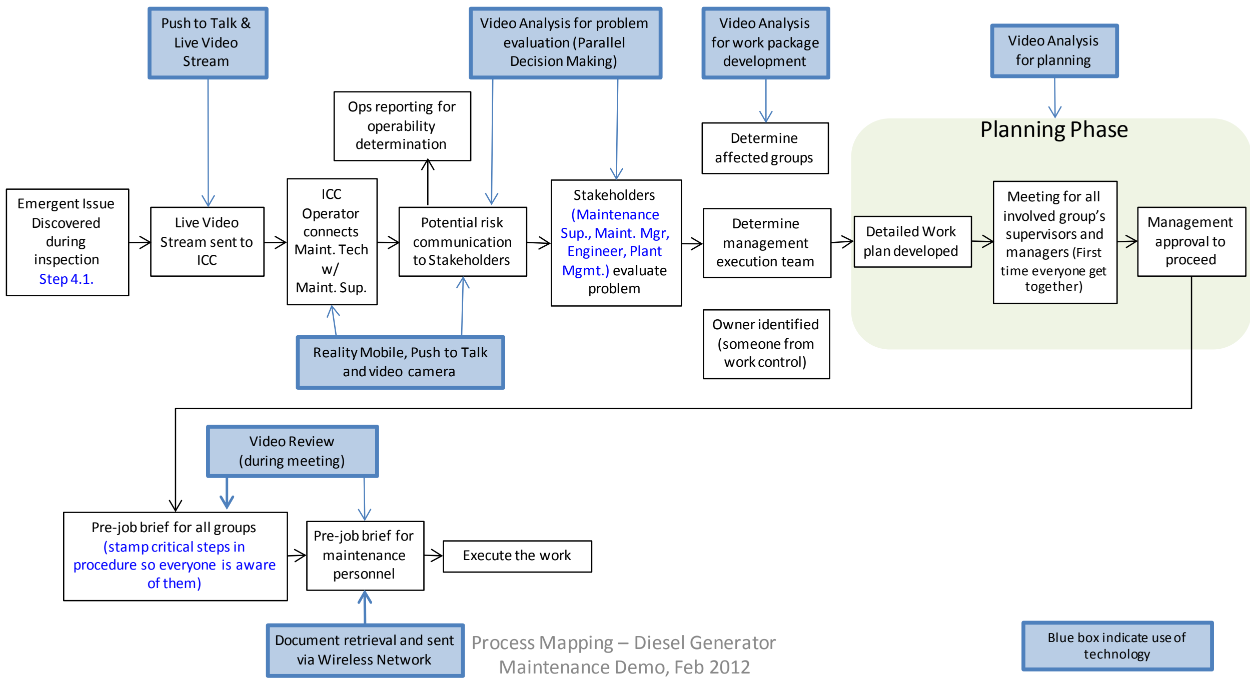

Figure 4. Diesel generator maintenance demonstration process map.

The scenarios that were developed were chosen on the following bases:

- A commonly occurring process with possibility of finding an emergent issue
- Involved communication between the field worker in the field and the supervisor or other plant personnel
- Normal operating and maintenance procedure usage
- Provided opportunity were the current work process could be addressed with wireless handheld technical solution
- Would show a stark contrast between the current processes (as is state) and the possible futuristic processes (to be state)

The maintenance scenario consisted of the following primary elements:

1. A maintenance technician verifies they are performing work on the correct component.
2. Technicians remove a diesel cylinder head cover
3. Technicians perform a number of inspections of the diesel head internals that include taking photographs, annotating the photos, and attaching notes
    a. These items become embedded into the procedure and are transmitted in real-time back to the ICC for further distribution to stakeholders
4. Technicians review operating experience (Lessons Learned) which has been embedded into the procedure (annotated digital photographs of past problems to watch for)
5. During the inspection the technicians find an emergent (simulated) issue – in this case, a cracked valve spring inside the diesel head

6. Technicians establish communication with the ICC via video streaming using the Reality Vision software as shown in Figure 5

Figure 5. Maintenance technicians informing information center of emergent issue.

7. The information concerning the cracked valve spring is conveyed to management personnel (e.g., Main Control Room supervisors, engineers, planners) in order for parallel decision-making, to occur.
   a. With all stakeholders receiving information in real-time, parallel decisions are easier to obtain versus the current process of series decision-making (i.e. personnel inform superiors of problem sequentially).
   b. This opens the lines of communication and increases the availability of information based on experience, expertise, and updated knowledge to help plant personnel make effective decisions.

2.2.3 Operational Emergent Issue Scenario

A scenario was developed based on a process map developed by Catawba Operations staff and INL researchers (see Figure 6). The basic scenario and demonstration was developed based on the following key elements:

1. An operator doing his daily rounds discovers a leak.
2. The operator reports the leak to command center.
3. The supervisor gives the go-ahead to write a work request.
4. The operator writes and submits the work request.
5. The work request is processed and a work order is created.
6. The operator isolates the leak.
7. The operator hangs the tag.

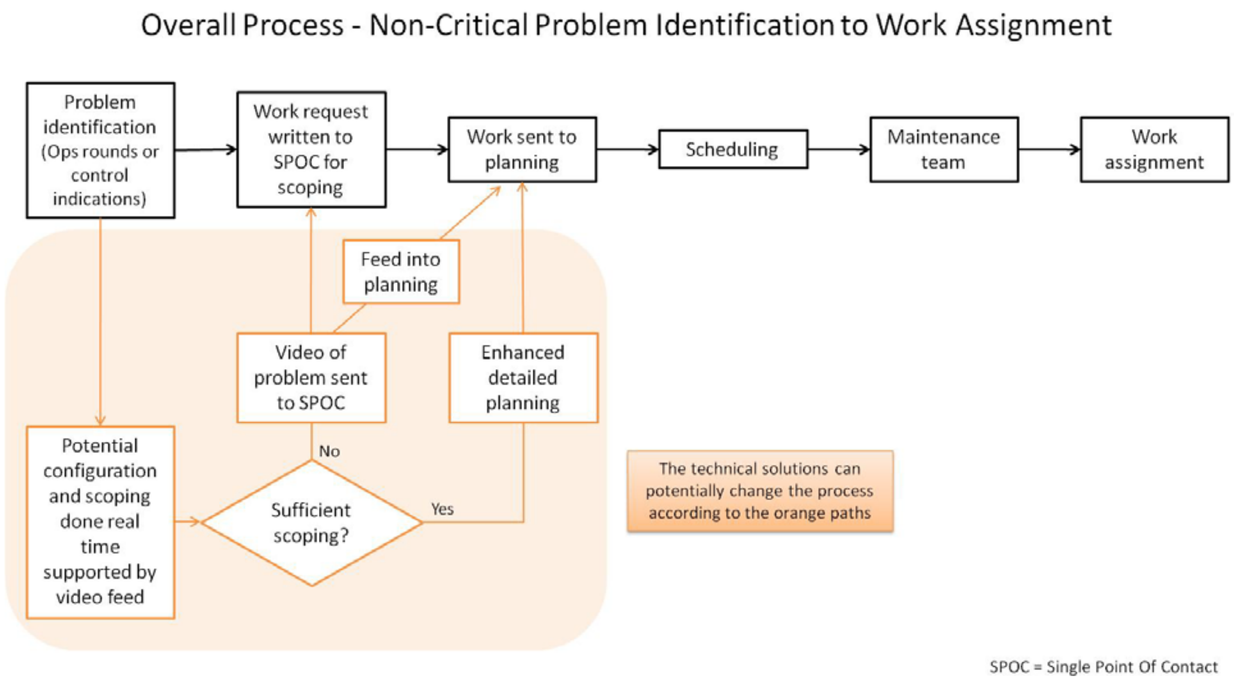

Figure 6. Operational scenario process map for emergent issue.

The detailed operational emergent issues scenario consisted of the following elements:

1. An operator doing his daily rounds discovers a leak and captures the leak in a video.
2. The operator reports the leak to command center and transfers the video recording of the leak to the supervisor in the command center.
3. The supervisor gives the go-ahead to write a work request by sending a message from the command center to the operator's device.
4. The operator in the field writes and submits the work request using the form on the device as shown in Figure 7, scans the valve barcode, and attaches a photo of the leak to the work request.

Figure 7. Remote work request submittal for emergent issue.

5. The work request is processed and a work order is created.
6. The operator isolates the leak by verifying the correct component, closing the valve, ensuring the electronic diagram in the Command Center automatically updates.
7. The operator hangs the verified correct red tag on the verified correct component, photographs both the valve tag and red tag, and ensures the information in the Command Center is automatically updated.

2.2.4 Study Results

Employing the technology afforded opportunities for improving both accuracy in positioning plant components (PSC) and decision-making by providing plant personnel with rich data (e.g. electronic forms, diagrams, video and voice) in real time. The research team leveraged the latest COTS technology, which resulted in making the right actions by field workers easy and the wrong actions difficult, if not impossible. Early testing of field worker performance with emerging technologies has been done to ensure the safety and usability of systems prior to large-scale deployment. Further, this research was designed to motivate and drive transformational change and shift the current strategy to a long-term approach to a more sustainable Instrumentation, Information and Control (II&C) modernization by the commercial nuclear utilities.

Participants in the scenarios noted that the technology allowed them to follow the procedure precisely and carefully one step at a time, allowing them to focus solely on the task at hand rather than rushing ahead. The ability to communicate with other departments and receive real time input from outside sources, along with rich reference data such as photos and video was well received. Component verification was viewed as another positive feature, ensuring and actually forcing field workers to be 100 % sure they were working on the correct component.

2.2.5 Human Performance Pilot Project Conclusions

The Human Performance Pilot Project (Farris and Medema 2012) developed and demonstrated concepts to enhance human performance in executing procedural activities and improve efficiency and safety through the use of mobile technologies. A mix of hardware and software capabilities were developed aimed at addressing emergent issue resolution in real-time, reducing the mental workload of field workers (integrated requirements and operator aids into the software), increasing overall field work efficiency (remote concurrent verification, rich data availability, and improved audio/visual communications), improving PSC (electronic schematics updated in real-time), and incorporating or replacing the need for the current mix of human performance tools (electronic validation of components-barcode scanning, embedded operating experience, and computer based procedures enforces procedural use and adherence).

The team’s efforts showed that the concepts developed and demonstrated are achievable today, rather than futuristic and elusive when supported by human factors and human performance principles.

3. IDENTIFYING AND RESOLVING EMERGENT OUTAGE ISSUES

The experience gained from the two research projects summarized in the previous section led to the development of the emergent issue resolution model and related technology development plan described in this section. The approach used to identify and resolve emerging outage issues combines the use of mobile technologies with advanced collaboration capabilities in established outage control centers where emerging issues threatening the outage schedule or safety margin can be quickly assessed and corrected.

3.1 Emerging Outage Issues

Major repair work (or emerging work) encountered during the course of an outage can be very disruptive when it is completely unexpected. As a case in point, the discovery of emerging work has contributed to 10 to 15% of outage extensions, and, on average, the amount of work identified after the start of an outage has represented approximately 20 to 25% of the total outage work, a figure that has been as high as 40 to 50% for some outages (Knowles et al. 1992).

The effective management of emergent issues is concerned with managing the unknown or the unanticipated. An emerging issue evolves from the discovery of a condition that was not previously anticipated or was discovered after plans to conduct a scheduled activity such as an outage have been set. The challenge is to obtain the correct information in a timely manner and to process that information with a decisive, goal-oriented strategy.

How people make decisions, and the information they receive, plays an important role in successful emerging issues management. Decision-making is a process by which people evaluate alternatives and select a course of action. The process involves seeking information relevant to the decision at hand, estimating probabilities of various outcomes, and attaching values to the various outcomes (Sanders & McCormick 1993).

It is well documented that the way a choice is framed or structured can dramatically alter the choices people make when faced with high workload, time constraints, risk, or stress. Nygren and Ransom-Flint (1997), suggests that the way a task or decision context is initially framed may play a significant role in how individuals process information, choose strategies, and make decisions. Framing has sometimes been used to describe what can be more broadly characterized as problem definition or problem representation. An argument can be made that framing in a risky decision environment has a potentially large affective component as well, particularly when a stress-producing workload and time constraints are imposed on the decision maker or when the situation being framed is clearly seen as physically, economically, or professionally threatening or risky (Nygren and Ransom-Flint 1997).

Typically, outage managers receive framing and structuring information via telephone or radio, which severely limits the outage manager's mental model of actual field conditions. Outage managers are also extremely time limited in terms of personally going to a problem location for a first-hand look at the situation. Such a trip could also entail entry into confined spaces, adding the dimension of exposure to other hazards. These issues were considered when the research team began developing the approach to managing emergent issues. Visualization, therefore, was considered a key component to help people frame a problem and reduce stress or uncertainty levels.

Previous work (Weatherby 2012) discussed the need for 'real-time truth' in outage management. Real-time truth is defined as getting the right information at the right time in order to make the right decisions. Getting the right information at the right time (which can be an iterative process between managers and field workers) can reduce the unknown and increase confidence in the selected decision and action plan. When an emerging issue arises, how that particular issue is viewed from the onset determines the quality of the actions deployed to solve it.

Framing or structuring is the first phase of the decision analysis process. The framing/structuring phase of the process is the most critical. Regardless of how good the rest of the analysis is, it can never make up for a bad problem frame (Skinner 1999). Decision problems are classified according to whether they are ill-structured or well-structured, depending on the extent to which the decision maker feels familiar with the initial state of the problem, the terminal state, and the transformations required to reach a desired terminal state. Three main factors contribute to ill-structuredness: uncertainty, complexity, and conflict (MacCrimmon & Taylor 1975). For example, if a member of the outage management team receives a radio or phone call regarding an emerging issue such as a leaking seal, the manager or management team may conclude that they are familiar with the problem, that the problem is a "simple-fix," and that no conflicting issues must be solved before reaching the desired terminal state. A potential consequence of incomplete or misleading information (poor framing/structuring) is simply taking the wrong action that leads to more delay or unanticipated safety issues.

Interviews with outage professionals have shown that incomplete or misleading information from field personnel who discover an emerging issue are the most troubling part of creating high quality resolutions. Field experience with handheld and control center visualization technology has shown that real-time (video) or near-time photos substantially increase the confidence level in decisions designed to resolve emerging issues. An example of this is the capability to visually see the rate and extent of a leak of fluids from piece of equipment in the field, or the actual size of a crack in a pump housing. While someone may be able to describe a leak or crack over a conventional radio channel or telephone, a visual representation by streaming video or photo imaging is a powerful contributor in framing the correct actions needed to resolve the problem.

Interacting real-time with the workers at the issue location to have them gather additional information needed for problem characterization and solution development is another important method. This is the idea of the various organizational reps in the OCC quickly gathering at the Smartboard to have a virtual meeting with those on the location to get the additional information that all of these organizations will eventually need to solve the problem. This is done sequentially today and takes several hours at a minimum – problem discovered and reported when the workers come back from the location, meeting held that identifies the additional info needed, workers return to get this info, second meeting held to discuss the new info and formulate a response.

An appropriate frame is developed when the problem is clearly understood by all the process participants, and factors affecting the problem have been clearly identified. The two key words here are *clearly* and *understood* (Skinner 1999). These terms are synonymous with real-time truth and can be substantially increased by the use of handheld and display technologies to frame the issue and include the necessary decision makers in the decision process. Because of the complexity of many emerging issues, moving from problem identification to problem resolution (it's terminal state) can involve many decision-makers at various locations. For example a well-framed or structured decision may involve managers, engineers, suppliers and vendors, planners and schedulers, as well as outage field personnel. The research team used these principles when designing the software systems necessary to include numerous decision makers and information sources.

The decision phase proceeds down two highly interrelated tracks – how to solve the specific issue and how to adjust the outage schedule and resource allocation to minimize the impact on the overall outage objectives – critical path schedule, cost, dose, and human resource considerations such as work-hour limits due to the Fatigue Management Rule, etc. In the Decision phase, outage managers typically begin by attempting to gather as many "experts" as necessary to form a high quality decision. Additional information is also gathered to assist in the decision process. Drawings, schematics, PM records, and other technical references are gathered as necessary to assist in the decision process. In some instances, an attempt is made to pull all of the necessary people and technical resources into one room. This is referred to as an outage "war room" by many utilities. This process takes time and may be physically impossible due to the geographic location of people, and the unavailability of hard-copy plant technical documents. The research team considered these conditions and noted that although people could not always physically be present during the decision process, it was important that their input be considered in the collaborative effort. In addition, decision makers must have access to plant technical information and off-site experts. Therefore, the software and display technologies must be capable of bringing these information sources into one collective and accessible location.

In the Action Phase, outage managers are concerned with the progress of the corrective actions designed in the Decision phase. Progress must be monitored to determine additional impacts on the outage critical path or other circumstances requiring attention. The ability to monitor task progress was identified as a key capability of the redesigned system. The system as tested is capable of providing real-time, automated task updates to the outage control center management team at any location.

The follow-up stage of the emerging issues process is commonly overlooked yet contains important opportunities to reduce work and strengthen the process in the future. Interviews with plant outage managers provided an important list of attributes that have been missing from past practices. These included the ability to develop a historical log of task steps that were taken to reach resolution to the emerging issue, the ability to reduce paperwork by automatically producing the necessary forms and other documentation necessary for nuclear operations, and the capability of looking back at tasks (post outage) to refine work methods and train field personnel. The research team considered these needs and designed the field demonstration software to accommodate the outage manager's requests.

3.1.1 Proposed Process for Managing Emerging Issues

Following the findings produced by the Byron and Catawba field demonstrations, the research team validated that the following capabilities will be important contributors to both managing future emerging issues, and the design of future outage control centers.

The following upgrades are considered as the minimum foundational capabilities necessary to improve the efficiency and safety of emerging issues management. They are presented under the headings discussed above.

3.1.1.1 Framing Phase

During the framing phase the problem is identified and communicated to the OCC and WEC via handheld device capable of identifying specific pieces of equipment by bar code or unique identification number. Schematics and drawings are automatically referenced and uploaded into the OCC and WEC database. Video and still photos are taken and transmitted to the emerging issues team by workers or supervisors in the field. Visual displays are opened in the OCC, WEC, and other selected areas. Outage management identifies the necessary players to frame the problem and begin analyzing the impacts on schedule, resources, and safety. Appropriate vendors and suppliers are linked electronically to participate in the real-time remote collaboration as necessary. Support staff such as engineering, radiological controls, and other key functions access the emerging issues display panel via desktops, laptop, tablet or smartphone devices. Potential solutions are discussed through remote real-time collaboration between the OCC and those at the issue location. Additional information is collected relevant to possible solutions.

An illustration of how the technology can create a highly interactive, collaborative approach to the resolution rather than the present serial, silo'd approach in which each organization reacts individually to what they need to perform their part is shown in Figure 8.

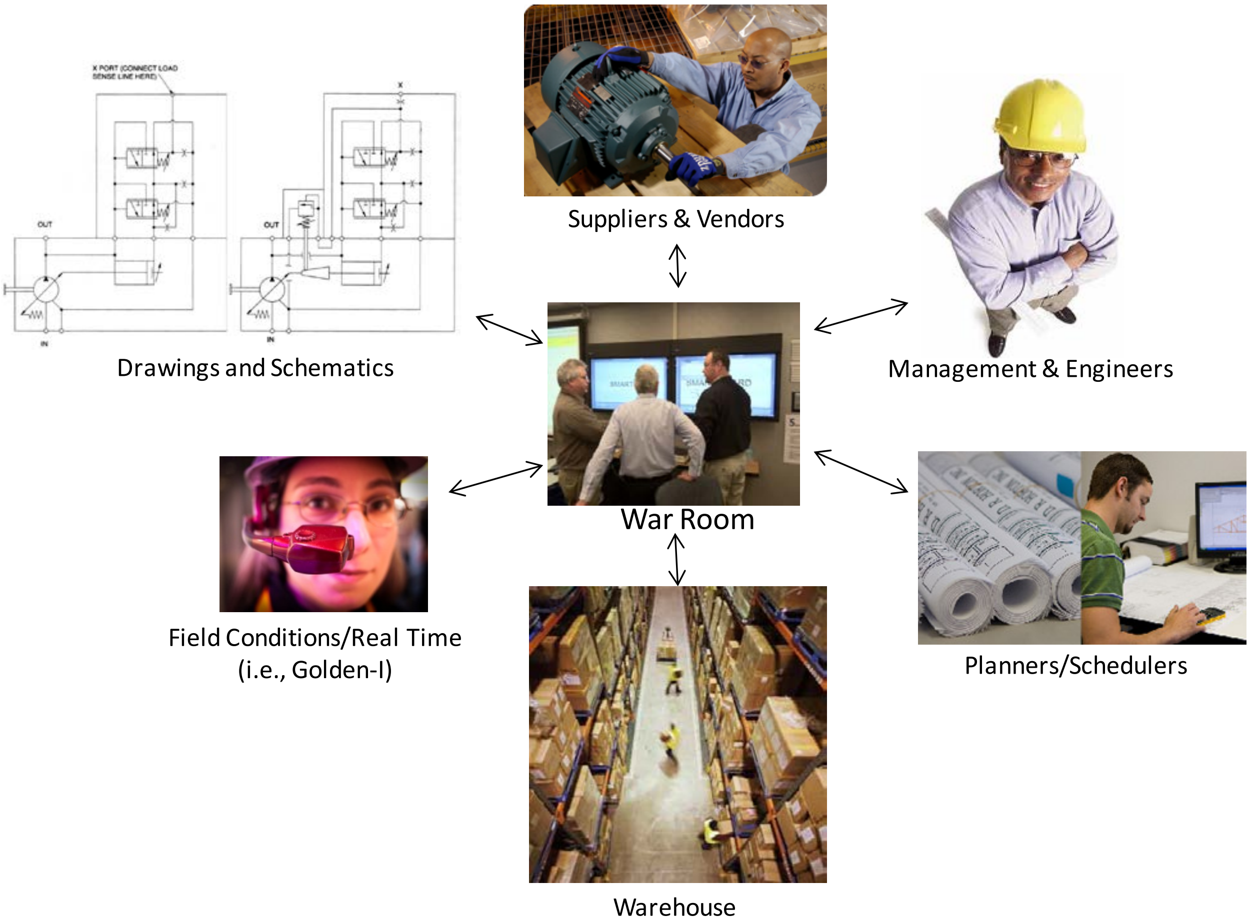

Figure 8. Illustration showing how technology can create a highly interactive, collaborative, approach to resolving emergent outage issues.

3.1.1.2 Decision Phase

Depending on safety significance, some decisions must be elevated to the plant operational review committee for the decision. In these cases, the real-time collaborative capabilities can enable this group to have much better collective situational awareness.

During the decision phase GPS capability allows quick identification and location of field support staff to assist with resolutions or additional information needs. Real time collaboration is enabled through audio and video links. Audio and video links allow all decision makers to see specific field conditions and interface with support functions including warehousing, purchasing, vendors, suppliers, and professional staff. An audio/video historical log is created to record the decision process and methods used to solve the problem.

3.1.1.3 Action Phase

During the action phase, real-time collaboration allows managers and field supervisors engage with workers in the plant to monitor work progress. This allows follow on activities to be staged and readied once the emerging work issue is completed. Plant status can be monitored and plant reconfiguration can be tracked with bar-code scanning and photo verification capabilities. The software system provides the outage management team with immediate and “real-time truth” and reduces the uncertainty, complexity, and conflict commonly observed in outages where field conditions cannot be readily monitored. Demonstration participants also commented that the work becomes more of a shared responsibility. This was noted as a positive attribute where decisions between managers and field workers are guided by close communication and photo/video recognition of field conditions.

3.1.1.4 Follow-up Phase

Emerging issues are tracked and monitored (using the technology upgrades) to ensure that the problem was resolved as intended.

An audio/video historical log is created to record the decision process and methods used to solve the problem. This retrievable historical record can be accessed by managers and other decision-makers after the event to:

- Review for process improvements
- Act as a training aid for future equipment maintenance activities
- Create a basis for pre-job briefings
- Provide accurate scheduling timeframes for future work
- Inform maintenance and emerging issues teams about what tools are necessary, what supplies are needed, and safety considerations for future work
- Allow the creation of a key player list to be notified to assist in future decision making.

This low-cost approach to emerging issues management allows accurate framing of the problem before entering solution space, involves key players that provide problem, and reduces costs by providing an expedited decision process involving the key players and the necessary technical documentation.

A comparison of current versus future technologies and capabilities for managing emerging issues is provided in Table 1.

Table 1. Comparison of current versus future technologies/capabilities for managing emerging issues.

Emerging Issues Phase	Definition	Current Technologies/ Capabilities	Proposed Technologies/Capabilities	Improvement
Framing or Structuring Phase	Discovery or recognition phase of the emerging issue	• Telephone • Wireless Telephone • Radio • Digital Camera • Whiteboard	• Wireless Local Area Network (WLAN) • Web-based information sharing software • Video/Photo capable handhelds • Smart Technologies Interactive touch screen displays	Allows immediate notification of conditions with audio/visual capabilities. Displayed at multiple locations for high confidence framing and structuring of the problem.
Decision Phase	Data collection, connecting with technical experts and schedulers, senior decision makers	• Still-camera photos • Telephone • Hard-copy diagrams and schematics • Limited internet capabilities • Single location "war room" concept	• Internet supported net meeting capable • Real or near-time audio/video/ still photos • On-line reference material (diagrams, schematics, PM history)	Allows all necessary decision makers to support preparation for action phase while at remote locations.
Action Phase	Implementing the selected actions necessary to mitigate or move the issue to a terminal state.	• Radio or telephone status updates	• Real-time status updates via software task monitoring • Streaming video or task-supported photos • Remote task monitoring using web-based software	Allows a collaborative environment to manage emerging issues to final terminal state.
Follow-up or Closure Phase	Ensuring the task is completed as planned and developing historical records	• Radio or telephone status updates • Hard-copy records	Complete historical record via software applications	Creates electronic records, video and photo archives, training aids, and pre-job foundation materials.

4. CONCLUSIONS

Effective and timely emergent issue resolution is an essential element of successful outage management, and poorly managed emerging issues can result in impingement on the plants outage critical path. Affordable technology solutions enable plant managers to access real-time information about emerging issues and develop solutions with high confidence of their success. Testing of the fundamentals of this technology has shown promising results at Exelon's Byron plant and at Duke's Catawba plant. Presentations and demonstrations of this technology's capability at numerous conferences and utility working groups have received very positive reviews.

The capabilities described throughout this report represent a significant advancement over the current approach for management of emerging issues typically employed by operating nuclear plants. While the advancements described in the report represent a significant step forward, much work remains to be completed to maximize the capability and usability of this approach. They include:

- Determining the best communication technology for use in plants without wireless systems
- Solving issues with wireless communications where plant infrastructure impedes the wi-fi signal
- Overcoming security issues to assure that plants are not vulnerable as a result of technology deployment
- Allowing electronic access to internal technical information such as drawings, schematics, and other technical references used in decision making without compromising the plants IT firewall
- Developing a method to integrate scheduling software and the reporting capabilities already present in the software. This will allow an additional level of granularity when reporting and managing task steps in work activities
- Assuring that enough band-width is available to allow uninterrupted streaming video
- Developing methods to integrate emerging issues management with ongoing outage management tasks (i.e., reduced stress and outage disruption).

5. FUTURE WORK

This report concludes the planned research activities associated with emerging issues. As the LWRS outage pilot project continues its research into improving the way outage issues are managed, the technology solutions described in this report will further be refined and integrated into the overall outage management design phase of LWRS research. Because of the success of early trials using this approach, several utilities have expressed interest in further developing these capabilities. In fact, a major U.S. utility has dedicated funding towards refining this technology and deploying it in nine of its nuclear plants.

Beginning in the fall of 2012, a 2-year outage control center project will commence with the intention of fundamentally examining and redesigning the outage process at NPPs. Arizona Public Service has expressed an interest in partnering with this important research and the development of a research plan has commenced.

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