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Light Water Reactor Sustainability Program

Automated Work Packages Architecture: An Initial Set of Human Factors and Instrumentation and Controls Requirements

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Automated Work Packages: An – Initial Set of Human Factors and Instrumentation and Control Requirements

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ABSTRACT

The work management process in current fleets of national nuclear power plants (NPPs) is so highly dependent on large technical staffs and quality of work instruction, that it puts nuclear energy at somewhat of a long-term economic disadvantage and increases the possibility of human errors. Technologies such as mobile portable devices and computer-based procedures can play a key role in improving the plant work management process, thereby increasing productivity and decreasing cost. Automated work package (AWP) is a fundamentally enabling technology for improving worker productivity and human performance in NPP work activities because virtually every plant work activity is accomplished using some form of a work package. As part of this year's research effort, the architecture of AWP is identified along with an initial set of requirements, both of which are essential and necessary for implementation of AWPs in NPPs.

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Summary

The U.S. Department of Energy's Office of Nuclear Energy funds the Light Water Reactor Sustainability Program to develop the scientific basis for extending the operation of commercial light water reactors beyond the current 60-year license period. Probably the highest priority for an operating nuclear power plant (NPP) fleet is remaining competitive in the electricity generating market while continuing its excellent nuclear safety record and absorbing regulatory-driven costs associated with new safety requirements such as those arising from the Fukushima event.

The work management process is one of the core business processes for the operation and maintenance of NPPs. The preparation of work packages is a key element of this overall process and is prepared by a work planner. A work package supporting a work management activity is required to consider many variables associated with planning and executing maintenance/work activities. The prepared work package is not only required to balance the effective utilization of available human and material resources but should also help ensure a desirable outcome for the high–risk task.

In current operating fleet of NPPs, the work management process uses paper-based work packages which are typically bulky, expensive, and cumbersome. Moreover, the paper-based work packages rely on human performance to correctly obtain plant information, enter it into the work packages and procedures, successfully complete the steps of the process in the right sequence, and ultimately validate correct results have been obtained. Because of the complexity of these activities and the sheer bulk of the paperwork, errors frequently occur that cause incorrect final results, rework, time delays, excessive safety system unavailability, and latent nuclear safety issues. This operating model is of particular concern because it is so highly dependent on large technical staffs and quality of work packages.

Technologies can play a key role in improving maintenance productivity (completing task in less time) by offsetting labor costs, reducing bulk of the paper required to carry out a task, reducing the handling and processing of paper documents, minimizing non-value tasks, focusing resources on wrench time, reducing error traps, presenting the right information at the right time to the right person, minimizing the amount of rework and latent nuclear safety issues, and by allowing field workers to get just-in-time training to enhance situation awareness.

To address the outstanding issues related to the work management process, researchers and vendors are looking into utilizing different technological options to replace the paper-based work packages. Electric Power Research Institute is directing the research required to develop electronic work packages (eWPs) as a step to phase out the paper-based work packages by utilizing technology. In its simplest form, an eWP is an electronic copy of the process currently conducted on paper, i.e., PDFs or similar types of electronic documents used to display the information needed in the work package. Hence, the work package in the eWP system is presented and used in a manner very similar to the current work package. Alternatively, automated work package (AWP) is defined as dynamic presentations of the work package designed to guide the user seamlessly through the logical sequence of the process. AWP is fundamentally an enabling technology for improving worker productivity and human performance in NPP work activities because virtually every plant work activity is accomplished using some form of a work package. The AWPs research will provide a generalized platform for introducing many types of beneficial technologies into plant work activities designed to enhance work quality, cost management, and nuclear safety.

The focus of this project is to research, develop, and deploy new capabilities for field workers in NPPs that will enable work planners to have near real-time interaction with workers in the field executing a task, and provide just-in-time instructions or additional information (as required/requested). The project

aims to provide field workers with an ability to tap into distributed database (plant information and status control, content data, videos, pictures, vendor documents, material inventory, and licensing requirements) to maintain situation awareness and reduce error traps.

As fiscal year 2014 effort, the report presents AWP architecture and an initial set of human factors and instrumentation and controls requirements deemed essential for implementation of AWPs in NPPs.

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FIGURES

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ACRONYMS

AWP	automated work package
CBP	computer-based procedure
CBWO	computer-based work order
DOE	Department of Energy
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPRI	Electric Power Research Institute
eWP	electronic work package
HVAC	heating, ventilation, and air conditioning
II&C	Instrumentation, Information, and Controls
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operation
IT	Information Technology
LAN	local area network
LCO	limiting condition for operation
LWRS	Light Water Reactor Sustainability (Program)
mWM	mobile work management
NPP	nuclear power plant
PBP	paper-based procedure
PVNGS	Palo Verde Nuclear Generating Station
QoS	Quality of Service
R&D	research and development
TAG	Technical Advisory Group
XML	Extensible Markup Language

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1. INTRODUCTION AND BACKGROUND

The Advanced Instrumentation, Information, and Control (II&C) Systems Technologies Pathway, part of the Department of Energy (DOE) sponsored Light Water Reactor Sustainability (LWRS) Program conducted at Idaho National Laboratory (INL), conducts targeted research and development (R&D) to address aging and reliability concerns with the legacy instrumentation and control, and related information systems of the U.S. operating light water reactor fleet. This work involves two major goals: 1) to ensure that legacy analog II&C systems are not life-limiting issues for the light water reactor fleet, and 2) to implement digital II&C technology in a manner that enables broad innovation and business improvement in the nuclear power plant (NPP) operating model.

Within this R&D framework, six areas have been identified that enable capabilities needed for long-term sustainable plant operation. In each of these areas, a series of pilot projects are planned that enable the development and deployment of new II&C technologies in existing NPPs. The Electric Power Research Institute (EPRI) participates in the research program in a jointly coordinated and collaborative research role. EPRI technical experts directly participate in the formulation of the project technical plans and in the review of the pilot project results, bringing to bear the accumulated knowledge from their own research projects and collaborations with nuclear utilities. The pilot projects conducted through this program serve as stepping–stones to achieve longer-term outcomes of sustainable II&C technologies. They are designed to emphasize success in some crucial aspect of plant technology refurbishment and sustainable modernization.

The automated work package (AWP) project under the Advanced II&C Systems Technologies Pathway is fundamentally an enabling technology that would introduce many types of beneficial technologies into plant work activities to enhance work quality, cost management, and nuclear safety. This will be achieved by combining, integrating, and enhancing the capabilities developed under mobile technologies and computer-based procedures (CBP) pilot projects, along with developing a real-time (near real-time) plant status capability.

This report addresses the DOE Milestone – M3LW-14IN060311 – Report the requirements for automated work package technologies for a sample of nuclear power plant work processes (performance).

1.1 Introduction

The work management process is one of the core business processes for the operation and maintenance of NPPs. The preparation of work packages is a key element of this overall process. The current work management process requires a large number of organizational resources to implement a work package. Work management is defined by the Institute for Nuclear Power Operations (INPO) AP-928 (2003) as the "process by which maintenance, modification, surveillances, testing, engineering support, and any work activities that require plant coordination or schedule integration are implemented." Work management is generally divided into seven phases as shown in Figure 1.

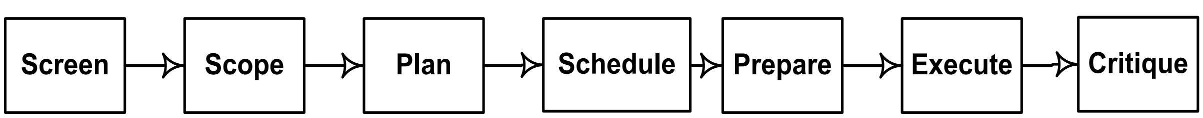

Figure 1. Flow diagram for the work management process (EPRI, 2013a).

A work planner preparing a work package to support a work management activity is required to consider many variables associated with planning and executing maintenance/work activities. A work package is a compilation of documents including a work order, work instructions, and any other supporting references/materials (for example, drawings, vendor manuals, weld process sheets, operating experience, safety analysis, permits, etc.). The work order is a document used to control work and/or testing, and a work instruction is information for performance of the work to be accomplished. When applicable, approved procedures may suffice as work instructions (EPRI, 2007).

The prepared work package is not only required to balance the effective utilization of available human and material resources, but should also help ensure a desirable outcome for the high risk task. A work package has different attributes, namely: cover sheet(s), pre-job briefing, contingency plan, work instructions, necessary parts/special tools/equipment, feedback mechanism, and references (as shown in Figure 2). The format, structure, and content of a work package are discussed in detail in (EPRI, 2013a).

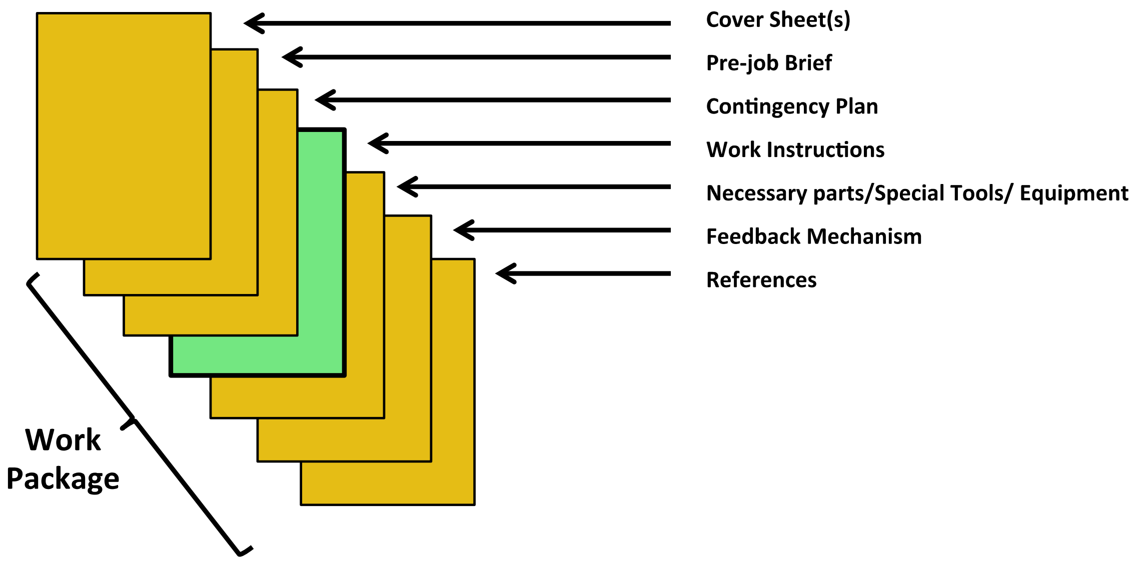

Figure 2. Typical elements of a work package (EPRI, 2013a).

In current operating fleet of NPPs, the work management process uses paper-based work packages, which are typically bulky and cumbersome. In addition, they are expensive and wasteful of paper to print, and the volume of paper can be overwhelming to transport to the job site and manage while there. Further, for activities in a radiation control zone, taking the needed and contingency paperwork to the job site often increases the amount of contaminated waste generated. Moreover, the paper-based work packages rely on human performance to correctly obtain plant information, enter it into the work packages and procedures, successfully complete the steps of the process in the right sequence, and ultimately validate correct results have been obtained. Because of the complexity of these activities and the sheer bulk of the paperwork, errors frequently occur that cause incorrect final results, rework, time delays, excessive safety system unavailability, and latent nuclear safety issues.

This operating model is of particular concern because it is so highly dependent on large technical staffs and quality of work instruction. Other forms of electricity generation tend to be more technology-centered and less labor–dependent. This puts nuclear energy at somewhat of a long-term economic disadvantage in that labor is generally a rising cost, whereas technology costs typically fall over time (on a price/performance basis).

Technologies can play a key role in improving maintenance productivity (completing task in less time), offsetting labor costs, by reducing the bulk of paper required to carry out a task, reducing the handling and processing of paper documents, minimizing non-value tasks, focusing resources on wrench time, reducing error traps, presenting the right information at the right time to the right person, minimizing amount of rework and latent nuclear safety issues, and by allowing field workers to get just-in-time training to enhance situation awareness.

To address the outstanding issues related to the work management process, researchers and vendors are looking into different options to utilize technology to replace the paper-based work packages. EPRI is directing the research to develop electronic work packages (eWPs) as a step to phase out the paper-based packages by utilizing technology. At this point, it is important to establish a distinction between eWP and AWP. In its simplest form, an eWP is an electronic copy of the process currently conducted on paper, i.e., PDFs or similar types of electronic documents used to display the information needed in the work package. Hence, the work package in the eWP system is presented and used in a manner very similar to the current work process. The more advanced eWPs allow for hyperlinks to provide additional information (i.e., photos, appendices, etc.), some user inputs (e.g., recorded values), and mark-up capability (e.g., writing notes and conducting traditional place keeping in the PDF). Electronic procedures are currently offered by a variety of vendors. Alternatively, AWP is defined as a dynamic presentation of a work package that guides the user seamlessly through the logical sequence of the process. The AWP is a fundamentally enabling technology for improving worker productivity and human performance in NPP work activities because virtually every plant work activity is accomplished using some form of a work package.

The AWP research project will provide a generalized platform for introducing many types of beneficial technologies into plant work activities designed to enhance work quality, cost management, and nuclear safety. The focus of the project is to research, develop, and deploy new capabilities for field workers in NPPs that will allow work planner to have near real-time interaction with the workers in the field executing a particular task, and providing just-in-time instructions or additional information (as required/requested). The project aims to provide field workers with an ability to tap into distributed database (plant information and status control, content data, videos, pictures, vendor documents, material inventory, and licensing requirements) at the right time to maintain situation awareness and reduce error traps. A field worker would be able to grade the quality of the work packages based on the criteria defined in (EPRI, 2006) and directly communicate it to the work planner, thereby making the work packages more tractable.

As an initial effort, the report presents AWP architecture and an initial set of requirements deemed essential for the implementation of AWP in NPPs. Prior to the discussion on requirements, a brief background on work packages in NPPs is provided.

1.2 Background

INPO noted, “Work instruction and procedure shortfalls contribute to maintenance errors.” As a result, over the last several years in the nuclear power industry, there has been a trend in Areas for Improvement written on work package quality. An EPRI Technical Advisory Group (TAG) on Work Package Standards was formed to develop and maintain an industry guideline document regarding work package quality. Some of the key contributions of the TAG have been to provide guidance for determining the most appropriate type of work instructions (level 1 or level 2) and identifying those circumstances when work instruction or even a work package may not be required (level 3). The determining factors or criteria affecting the level of work packages as per (EPRI, 2013b) includes:

- Complexity of the task and frequency with which work is performed
- Availability of technical procedure(s) defining the work
- Risk of unit or generator trip or transient
- Risk of lost generation
- Risk of entry into a limiting condition for operation (LCO) or work using greater than 50% of allowed LCO time
- Industrial safety and radiation exposure
- Need for special controls
- Reliance on skill of the craft (worker).

The nuclear industry is starting to leverage some of the initial vendor solutions such as DataGlance, OvalPath, etc., to streamline the work management process. These vendor solutions are eWPs with the ability to create and format work orders, procedures, and feedback mechanisms. This functionality is portable and is available on mobile technologies such as handheld tablets, iPADs, and ruggedized laptops to be utilized by field workers in NPPs.

In addition to currently available vendor solutions, INL, under the Advanced II&C Systems Technologies Pathway funded by the U.S. DOE LWRS Program, conducted a research project investigating the deployment of mobile technologies for NPP workers (Farris and Medema, 2012). This enabling project provided:

- Guidance to NPPs for successful deployment of mobile technologies to improve field worker's human performance and efficiency
- An overview of current mobile technologies hardware and software capabilities,
- Support to decision-making about deployment of mobile technologies at a commercial NPP,
- A business case for mobile technologies implementation.

Another project under the Advanced II&C Systems Technologies Pathway that would benefit AWP research is the computer-based procedure (CBP) project. The objective of the CBP project is to define design requirements for CBPs to ensure improvement over the current process of using paper-based procedures (PBPs) in the nuclear industry. The project also evaluates how to streamline and distill the information in the PBPs and make use of the advantages of dynamic presentation to increase efficiency, improve the ease of use, reduce opportunities for errors, and incorporate human performance tools into the normal flow of the procedure. The project has performed a series of activities including a literature review, a qualitative study, and a user needs survey, all of which were utilized to develop a model of procedure for usage. Requirements for the design of CBPs were derived from this model (Oxstrand and Le Blanc, 2012a and 2012b). The project developed prototype CBPs based on identified requirements and field evaluated them from a human factors perspective in training facilities at different NPPs. Field workers from different utilities participated in the prototype evaluation studies (Oxstrand, Le Blanc, and Fikstad, 2013; Oxstrand, Le Blanc, and Bly, 2013).

The findings and results from the mobile technologies and the CBP projects will be used as a foundation for the current AWP research effort.

1.3 Project Objective

The objective of the report is to identify the essential requirements for the development of AWP technologies for NPP work activities. Some of the initial requirements identified include: information repositories, communication network infrastructure, interoperability of technologies, cyber security, human-machine interface, development of procedures, and backup or recovery system.

The overall objective of the AWP pilot project is developing prototype work packages for field workers that can be executed on mobile devices (Hallbert and Thomas, 2014). Target work packages will be selected from the areas of operations, maintenance, chemistry, radiation protection, and security. The selected work packages will be tested in a host utility NPP, exercising all of the capabilities of the mobile technologies and interconnectivity among those technologies. Human factors evaluations will be conducted during these tests to determine the gains in productivity and human performance, as well as identification and mitigation of any negative human factors that are introduced. The final deliverable will be a technical report on how to deploy this concept for a wide range of work package–based plant activities using mobile technologies.

A parallel activity of this project will develop and demonstrate a prototype for the automatic creation of a work package in order to document that surveillance requirements have been met through the acquisition of plant performance data through wireless instrumentation and monitoring technology. In other words, this would automate the production of surveillance or test work packages when requirements can be verified to have been met through normal or test alignments for plant systems. This capability has the potential to reduce labor requirements for a significant number of plant test activities. Even when operator or technician involvement is needed to conduct the test or surveillance, the production of the documenting work package can be highly automated.

2. AWP ARCHITECTURE AND AN INITIAL SET OF REQUIREMENTS

One of the key aspects of implementing a mobile work management (mWM) process in the nuclear industry is to understand where you are and where you want to go as an organization. This entails documenting the "as is" workflow which is a complicated task. To document the "as is" process adequately, input from several individuals in affected departments is needed.

It is highly recommended a detailed comparison between the existing paper-based system and the future electronic based system be performed. This is done by work flow diagrams that start at a high level, and then drill down to the specific details including databases accessed and personnel involved.

2.1 Defining AWP Architecture

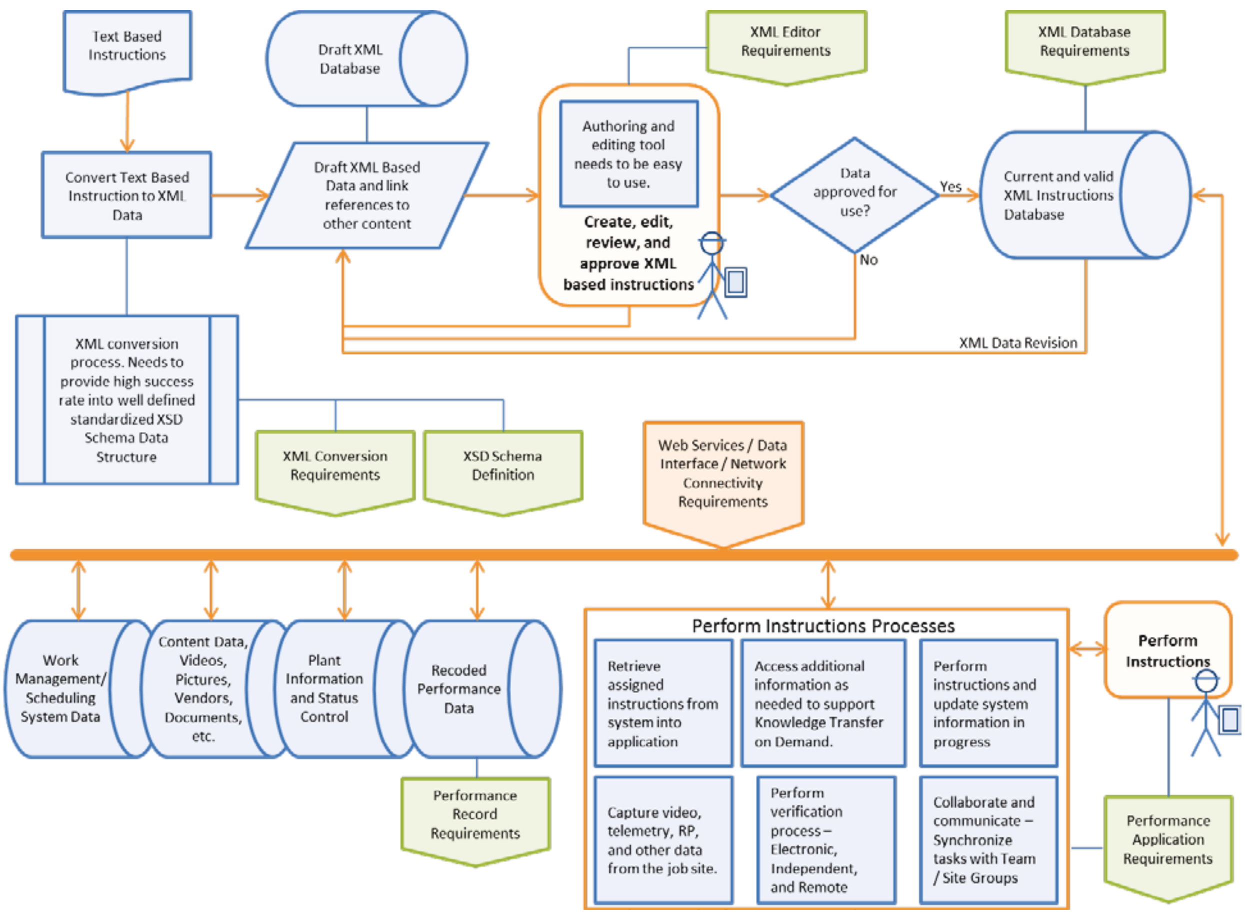

Figure 3. A graphical representative of AWP architecture proposed by the host utility partner.

As mentioned above, in order to achieve a product that will be useful to field workers and maximize the cost, efficiency, and human performance gains, it is important to look at the work process as a whole rather than focusing only on individual pieces. Here in Figure 3, the main pieces those are important for the overall AWP process are presented and connected (via, communication network connectivity).

As seen in Figure 3, the process starts out with the current "Text–based Instructions." These need to be converted into data, preferably as per an industry-wide standard data structure. But in the nuclear industry such a standard does not yet exist, but researchers and vendors are currently working on defining such a standard. It is preferred that the underlying data structure should be based on Extensible Markup Language (XML), as it defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. To support production of context-sensitive procedures, it is important to design the underlying data structure that is compatible across different systems and platforms.

One of the main elements of the AWP architecture is the Authoring and Editing Tool. This tool will be the interface layer between the underlying data structure and the computer-based version of the instructions (i.e., the CBP) to be used on a mobile device. The tool is expected to be used by planners and procedure writers, most likely by individuals with little or no software development knowledge or skills. Therefore, the tool must be as easy (or easier) to use, than the templates and forms used today.

The lower half of Figure 3 illustrates the many types of information within the AWP architecture including scheduling, pictures, documents, current plant status, and operation mode. The box labeled "Perform Instruction Processes" is the CBP portion of the work package.

One important function of the architecture is the communication network connectivity, which connects all the main elements of the AWP architecture. In order to ensure the holistic approach adequately connects all of the main pieces and forms one big integrated system, there are multiple sets of requirements that need to be defined. These requirements include the underlying data structure, the databases, the authoring and editing tool, performance records, and requirements for the CBP part of the system.

2.2 Defining Requirements

To establish AWPs for field workers in current fleet of NPPs, it is essential to identify requirements so that conformance with existing regulatory requirements can be ensured and no future challenges are introduced. The architecture presented in Figure 3 is used as the basis to define seven initial requirements that include:

- Information repositories
- Communication network infrastructure
- Interoperability of technologies
- Cyber security
- Human machine interface
- Development of procedures
- Backup or recovery system.

2.2.1 Information Repositories

Figure 4 provides a graphical representation of a distributed information repository that would act as the hub of diverse information necessary to support AWP development and execution in NPPs. At present, the versatility of information (as depicted in Figure 4) is mostly available in offline mode in current fleet of NPPs. Some of the restrictions might include the inability to provide and receive information online, a lack of common communication architecture, the manual entry of information into the repository, and a lack of near real-time status updates. These restrictions prevent both work planners and field workers from accessing the information repository to obtain just-in-time training, plant status information or additional documents (if required) to complete the task in progress. The work planner cannot concurrently monitor the progress of the assigned work order as well as the availability of field workers, and thus is delayed, waiting for the feedback to be entered into the information repository before the work planner can access them.

There exists a need to interconnect these distributed information repositories, enhance them, build additional repositories (if not available already), and update them so work planners and field workers can access and store information as needed. This information repository infrastructure must be able to identify and capture heterogeneous data formats, as data streams will be coming from work planners, field workers, equipment vendors, engineering, procurements, constructions, equipment surveillances, maintenance activities, scheduling, and human performance evaluation records.

Some key considerations that an owner of a NPP needs to account for while preparing the information repository system suitable for AWP implementation include:

1. A workable scheme should be developed that will provide a consistent standard across different information repositories, especially if the plant is part of a fleet.
2. The information repository should be based on expandable technologies with the ability to identify, prioritize, link, track, and maintain data that will be become available in the future and was not conceivable in the past.
3. Current technologies should be leveraged to automate data collection.
4. The repository must be established and maintained with a software quality assurance program, i.e., it must address software and hardware testing and the concept of verification, validation, and certification.
5. Much of the data entered, edited, or accessed must be controlled. Repository software should clearly identify who has approval and change authority for each data element (i.e., who "owns" the data).
6. Data structure should be based on XML, which is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable, or any other similar widely used format. This underlying data structure has to be designed in such a way that design concepts can be realized.
7. Special emphasis should be placed on establishing the material equipment list database as it represents the primary sources of component and related part information. This information is used for configuration control, equipment reliability, and maintenance operations. Identification of the correct spare part(s) facilitates the component's original design function(s), and therefore maintains the system and facility design configuration.

Once the information repository is developed, it is important to have a program in place to maintain the information as per industry-accepted practice. Some of these practices include (EPRI, 2011)

- Identification of the source of information
- Ensuring a uniform change control process is in place
- Establishment of control and tracking systems to make the users (work planners and field performers) aware of whether the information is historical, current (as-built), or pending (as-designed)
- A definition of priority for update frequency
- An establishment of an assessment program for process and data integrity
- Timely information retrieval
- A minimization or elimination of redundant information, if possible, except in the case of backup systems, where duplication data copies must be allowed.

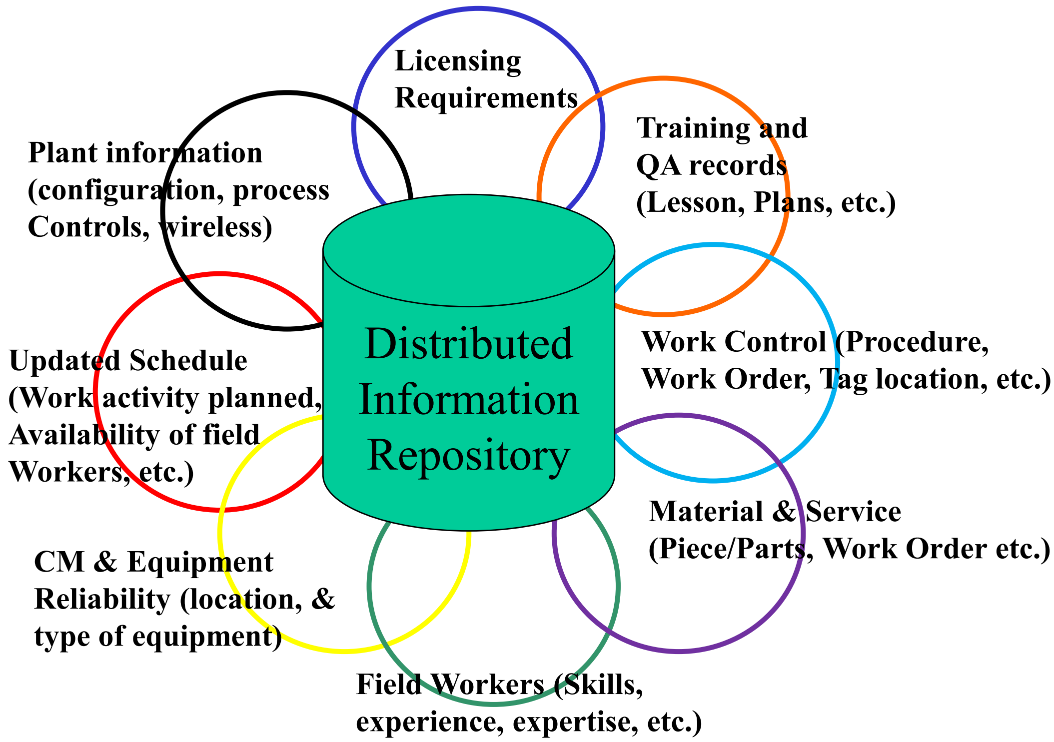

Figure 4. Elements of distributed information repository.

2.2.2 Communication network infrastructure

The communication network infrastructure comprised of both wired and wireless systems forming a hybrid network (as shown in Figure 5) is essential to realize the vision of making information available, "*anywhere*, *anytime*, and *to anyone*." Such communication connectivity consists of various standards, protocols, architectures, characteristics, models, devices, as well as modulation and coding techniques. Implementation of wireless system is preferred over wired system as the cost associated with installing and maintaining additional wired communication infrastructure is prohibitive. In addition, establishing and providing wireless network access to NPP workers can open up the information door to a new level of productivity and execution improvements. Currently, only a few plants have permanent widespread wireless systems installed in the plant. Several plants temporarily install wireless for outages or have partial wireless coverage. The existing wireless plant networks are mostly used for dosimetry, voice communication, equipment monitoring, and remote video radiation protection monitoring.

For successful implementation of AWPs, widespread wireless connectivity is highly desirable. Partial or no wireless connectivity provides only incremental benefit to plant productivity. At the same time, it is well understood that safety-related systems will not be instrumented with wireless technologies.

A number of key issues must be understood and managed prior to installing wireless networks in NPPs. These include: electromagnetic compatibility (EMC), cyber security (see Section 2.6), and optimal bandwidth utilization. Understanding these key issues and the regulatory requirements associated with each will likely yield a higher success rate of wireless installation.

Numerous sources of electromagnetic interference (EMI) exist in the NPP environment. Over the years, several studies, test, and analyses have been performed to evaluate and understand the relationship between wireless systems and EMC. In summary, these analyses identified EMI emission sources in

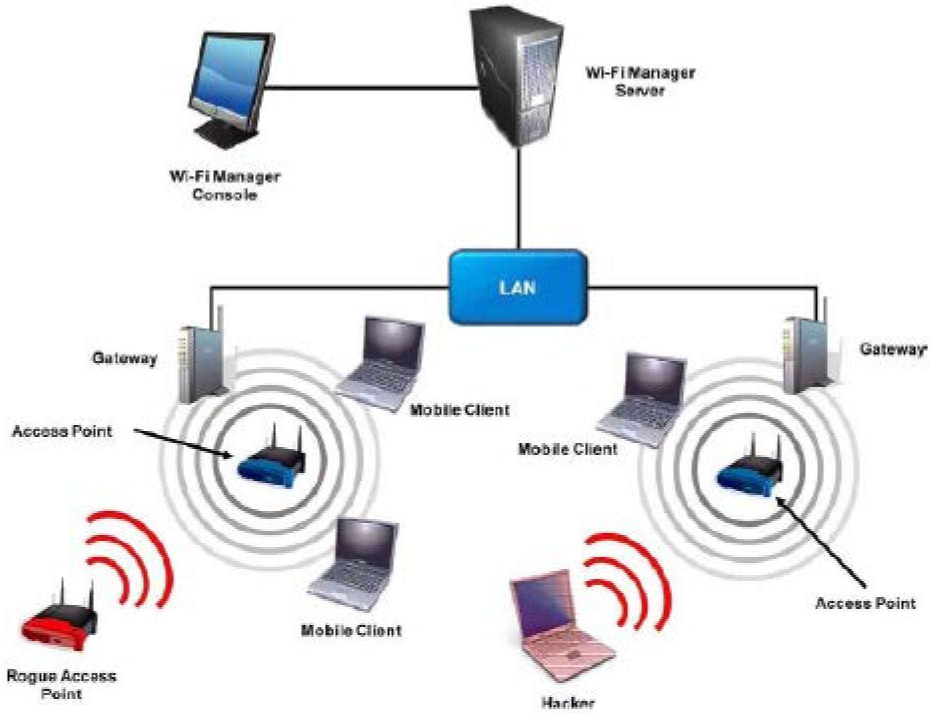

Figure 5. Communication network connectivity via wired and wireless technologies.

NPPs, recommending appropriate standards for equipment testing before and after implementation of wireless technology, defining plant and equipment emission limits, and detailing proper grounding, cable separation, emissions control of portable transceivers, and listed EMI sources in the vicinity of EMI-sensitive equipment.

Implementation and continuous access to a wireless network in addition to the local area network (LAN) creates too much traffic for the server, slowing down the system and creating poor performance. So for NPPs working on implementing AWP, it is important to not over–burden the communication network. The trade-off between a wireless network and a wired network needs to be balanced to eliminate the potential of too much traffic and the slowing of system performance. Also, it will be a good idea to keep wireless and wired networks separate because, if the wireless network goes down, field workers can use local docking stations connected to the LAN for work package updates. If wired and wireless networks need to coexist then periodic updating/synchronization of field work status is recommended. Bandwidth should be determined considering expected work package communication data transfer and frequency of transfer. This leads to the next requirement on interoperability of technologies.

2.2.3 Interoperability of Communication Technologies

Interoperability is fundamental to good information handover. Therefore, the technical implementation plan should strive to establish interoperability across all communication networks and devices. An ideal interoperable environment would address interoperability between applications, information, knowledge, and technology platforms to support operational independence, managerial independence, geographic distribution, incremental implementation, and emergent behavior (EPRI, 2009).

Operational Independence
Each application (or subsystem of applications) within the interoperability environment should be able to operate and provide value on its own right, independent of the interoperability strategy and its specific configuration.

Interoperability Platform
Operational independence should also be present if the application connects only occasionally to the interoperable environment. Its basic operation should not depend on the existence of the interoperable environment or one specific configuration versus another.

Managerial Independence
Closely associated with operational independence is managerial independence. Given the multitude of groups and organizations involved in projects, a mix that can also vary over time during a single project, the success of an interoperable environment should not depend on how the individual applications and subsystems are acquired or who operates them.

Incremental Implementation
In an environment of changing requirements and unforeseen future requirements, where we don't know everything at the beginning of a project, it is an absolute necessity that an interoperability platform enables and support incremental, evolutionary implementation.

Emergent Behavior
In the long term, emergent behavior is perhaps the strategic goal. Experience has shown interoperable environments enable innovation in terms of new behaviors, new processes, and new opportunities that allow information to become more than the sum of its parts by creating new value for the project as a whole as well as the individual project participants. Of course, this requires, 1) an interoperable environment be implemented with the potential to suggest these emergent behaviors, and 2) the interoperable environment must enable new opportunities to change processes, business models, and deliverables in light of these opportunities.

Communication technologies are emerging very rapidly, with the advent of new models, characteristics, protocols, and architectures. This rapid evolution imposes many challenges and issues to be addressed, and of particular importance are the interoperability issues of the following wireless technologies: Wireless Fidelity (Wi-Fi) IEEE802.11, IEEE 802.16, Single Channel per Carrier, Digital Video Broadcasting of Satellite, and Digital Video Broadcasting Return Channel through Satellite. Due to the differences amongst communication (especially wireless) technologies, these technologies do not generally interoperate easily because of various interoperability and Quality of Service (QoS) issues.

Implementation of AWP warrants investigation into end-to-end interoperability issues and QoS requirements such as bandwidth, delay, jitter, latency, packet loss, throughput, and several performance criteria. The following research questions need to be considered when assessing the interoperability of communication technologies:

- What are the major issues when considering end-to-end interoperability and the ways by which different communication systems and technologies interoperate with each other?
- What are the categories (such as user-level or network level) and types of QoS requirements for communication networks?
- What are the most suitable testing tools to test interoperability issues in such an environment?
- What is a suitable test plan, testing methodology for assessing end-to-end interoperability and QoS requirements?

- Based on the results for communication networks, what are the recommendations to address various interoperability issues?

2.2.4 Cyber Security

Cyber security is another critical and ever-increasing concern for wireless technology. Cyber security can be defined as the protection of data and systems in networks (wired and wireless) from unauthorized access or attack. The open nature of wireless transmissions makes it more vulnerable for intrusion into a plant network than a wired transmission.

There are two major cyber security concerns related to the use of wireless technologies in NPPs. One is the understanding and subsequent satisfaction of the regulatory requirements; the other is the proper use of methodologies to protect data transmissions across wireless networks.

2.2.5 Human Machine Interface

The previously mentioned CBP research effort identified an initial guidance for the user machine interface design (Oxstrand et al., 2013). Even though the guidance was specifically developed for instructions and procedures, it is generalizable to a mWM process to address the following aspects.

Dynamic Context Sensitivity
Traditional procedures printed on paper are static, i.e., the content on the page will not change after it is printed. This limitation relaxed when information is presented using digital technologies. Dynamic context sensitivity is defined as a dynamic presentation of the process which will guide the user seamlessly through the logical sequence. The automated system should make use of the inherent capabilities of the technology, such as incorporating computational aids and providing easy access to additional information and just-in-time training. In addition, the technology used for AWPs allows for human performance tools to be integrated into to the overall work process. Some tools can be completely incorporated into the CBP system, such as pre-job briefs, place keeping, correct component verification, and peer checks. Other tools can be partly integrated in a manner that reduces the time and labor required, such as concurrent and independent verification.

Maintain Focus on Task
It is always important to keep the worker focused on the task at hand. This becomes even more critical when transferring from a paper-based process to a process conducted via handheld device. It has been proven that if the human machine interface is not properly designed, the use of technology, it can take focus away from the actual task (Oxstrand, Le Blanc, and Fikstad, 2013; Oxstrand, Le Blanc, and Bly, 2013). In order to maintain focus on the task, the interaction with the technology and the device should be kept to a minimum at all times. This is accomplished by simple navigation schemes, requiring a minimum number of actions to execute a step, easy access to supplemental information when needed, etc. In addition, embedding human performance tools into the process will keep the worker focused on the task rather than using the applicable human performance tool.

Reduce Burden on Worker
The AWP should reduce the user's burden throughout the work package process as well as keep the user engagement at a high level. This is done by finding balance between automation and decision support, and operator engagement and the execution process. The high-level solution to achieving this balance is to always provide a means to relay information to the user regarding the progression of the process.

Example include: completed steps in the procedure, future action items, decisions made that influenced path through the process, etc.

2.2.6 Development of Procedures

As discussed previously, work instructions and procedures are an integral part of the AWP. In order to ensure the CBP process will be more efficient and support a high level of human performance as the current use of PBPs design requirements need to be developed. This is one of the objectives of the CBP research effort. An initial set of procedure requirements was published *in Computer-Based Procedures for Field Workers in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements* (Oxstrand and Le Blanc, 2012b). In summary, the CBP should:

1. Guide operators through the logical sequence of the procedure. The CBPs should be designed so they automatically take operators through the specified procedure path based on initial conditions and operator input.
2. Ease the burden of place-keeping for the operator. CBPs should keep track of where the operator is in the procedure, mark steps as completed, and highlight the current step.
3. Make the action steps distinguishable from information gathering steps. CBPs should use some method to differentiate steps by which an operator manipulates the plant from steps to simply check a condition or value.
4. Alert operator to dependencies between steps. Typically, the operator has to rely on previous experience or on a caution or warning in order to identify the situations in which he needs to read ahead in the steps. CBPs should alert the operator when he reaches a step with dependencies, rather than relying on him to read ahead (or remember from previous experience) to detect the dependency. Additionally, if a CBP system has access to real-time plant data, the system should alert the operator when plant status changes in a manner that affects the operator's task.
5. Ease the burden of correct component verification for the operator. CBPs should employ some method to automate correct component verification (e.g., include barcode scanning or text recognition functionality).
6. Ease the identification and support assessment of the expected initial conditions. Some method of illustrating the expected initial conditions in a simple and easy to understand manner should be available to the operator through the CBPs. For example, a schematic or piping and instrument diagram of the relevant equipment could be available on-demand.
7. Ease the identification and support assessment of the expected plant and equipment response. Some method of illustrating the expected equipment and plant response in a simple and easy-to-understand manner should be available to the operator through the CBPs. For example a schematic or Piping and Instrument diagram of the relevant equipment could be available on-demand.
8. Include functionality that improves communication. In the event that an operator encounters a situation that requires contacting a supervisor to resolve, the operator needs to be able to efficiently and accurately describe the problem. Tools such as texting, capturing photographs and streaming video have all been identified as highly desirable to have built into any device that display CBPs.

In addition, the CBP research effort identified requirements specifically for procedures to be used outside the main control room, i.e. procedures for workers in the field. These are the types of procedures that most commonly are part of work packages. Examples of requirements specific for field CBPs are that they should:

- Be designed so the operator controls the procedure pace.
- Make calculations when the necessary information is available.
- Alert users when procedure steps or conditions have been violated.

- Alert users when conditions require transitioning to another procedure.
- Evaluate step logic when the necessary information is available.
- Be designed so it is easy for the user to "undo" an unintended or incorrect action (an error of commission).
- Allow the operator to look ahead and back in the procedure.

A significant challenge to shifting from a paper-based process using PBPs to an automated process using CBPs is the need to convert existing PBP documents into data that can be used by a CBP system. This underlying data structure must be designed in such a way that design concepts can be realized. This is of utmost importance in order to produce context-sensitive procedures. The underlying data structure also must be designed in such a manner that it ensures the procedure data can be used by a variety of systems and platforms. The development of an industry-wide standard for the underlying data structure is recommended (Oxstrand, Le Blanc, and Bly, 2013).

2.2.7 Backup or Recovery System

The information technology (IT) division should ensure NPP and project data assets are kept physically secure and protected for integrity and defended against corruption or loss. Any data loss is unacceptable, but circumstances may occur when there is a threat of data loss beyond reasonable control.

A "disaster recovery" plan describes those processes and actions that are put in place before, during, and after a postulated event that has the potential to interrupt IT and computing services or cause irreparable data loss. Typical events that can trigger the disaster recovery plan include:

- Physical and natural disaster – fire, flood, storm, explosion, etc.
- A design-basis plant event resulting in operations movement to the emergency operation facility or site evacuation
- Internal (sabotage) and external security compromises.

The relative importance and urgency of service restoration is determined by how critical the service interruption and/or data loss will be to safe and viable operation of the NPP, the project and NPP site.

The NPP IT manager, together with the project manager, site manager, and other key project management officials should ensure the conditions under which business continuation plans must be activated have been defined, potential risk determined, and suitable plans developed for short-term operations recovery and as well as long-term restoration of services and data.

The IT personnel, as required, should develop, document, and execute plans for events such as the following:

- Loss of partial or total network operation or connections
- Loss of Wide-Area Network connection to primary or supporting computing center
- Physical loss of, or inability to access, primary server/computing center and/or data repository
- Power loss
- Unauthorized physical penetration
- Unrecoverable loss of enterprise data
- Hardware casualties.

The IT personnel should conduct pre-event planning for those events that centers around redundant and installed-spare philosophies, such as extra servers, disk drives, and remote computing locations that may be switched into the nuclear power plant IT network. In addition, the IT personnel should develop a plan and process for the periodic backup of data from processing computers (servers). Backup media should be removable and portable, and be intended solely for the purpose of data recovery. Backup recovery must also describe plans to account for interruption in wireless connectivity supporting AWP architecture.

3. RESULTS OF PROTOTYPE FIELD EVALUATION

Previous work on mobile work instructions for field workers has focused on operations procedures. The current effort is expanding that research to include work orders, associated processes, and instructions. The research team has initiated a field evaluation to test a computer-based work order with Palo Verde Nuclear Generating Station (PVNGS).

Staff at the collaborating utility selected a heating, ventilation, and air conditioning (HVAC) preventative maintenance work order to use for this field evaluation. The work order provides instructions for taking weekly readings from the plant's four HVAC chillers (and related equipment), and for handling out–of–range readings. In order to meet the needs of the HVAC technicians conducting the selected task, the research team modified the existing CBP system to include the following ability to:

- Store readings data for trending
- Import previous readings into current work order
- Export data to be used for trending
- Take notes while executing the work order
- Match readings data to acceptable ranges, alert users to out–of–range conditions, and provide a list of actions for out–of–range readings
- Enable sections of steps to be performed in any sequence as the task allows
- Execute the work order across multiple days and with multiple users
- Activate conditional steps based on multiple conditions
- Handle new functionality by utilizing an improved data structure.

The INL team visited PVNGS the second week of September, 2014. The goals of the visit were to validate the computer-based version of the work order, gather feedback from plant staff, make revisions to the computer-based work order system if needed, and to provide training to the HVAC technicians.

During that week, the INL research team met with and briefed multiple plant employees including two senior HVAC technicians, the HVAC planner, and a procedure writer. During these conversations, the team was able to gather valuable information that was of great benefit to both improving the CBP system for the pilot field evaluation study and moving the overall CBP research forward.

The researchers left the CBP system at PVNGS. During the duration of the study, participants in the pilot evaluation study will include HVAC technicians tasked to take the chiller readings each week. The task will be carried out for each of the three units at the plant. The duration of the study is initially planned to be 26 weeks. It is expected the study will result in data for 78 users of the Computer-based Work Order (CBWO) system, however it is likely several participants will conduct the task multiple times (resulting in fewer than 78 participants).

The participants will be asked to fill out a brief web-based questionnaire after completing the task using the CBWO system. The questions target the experience of conducting the task with the CBWO system compared to the traditional paper-based process. The goal of the questionnaire was to assess the usability of the CBP system and device. The questionnaire was also developed to gain more detailed feedback on the design of the user interface and the overall experience using the CBP. The questionnaire was designed to be short and simple so it wouldn't add much additional burden to technicians to increase the likelihood they would take the time to respond. The wording of the survey questions was reviewed by plant personnel to ensure operators would feel comfortable answering the questions candidly.

4. SUMMARY AND PATH FORWARD

Work packages for NPP field activities are typically bulky and cumbersome. In addition, they are expensive and wasteful to print, and the volume of paper can be overwhelming to both transport and manage at the job site. Moreover, the paper-based work processes rely on human performance to correctly obtain plant information, enter it into the work packages and procedures, successfully complete the steps of the process in the right sequence, and ultimately validate correct results have been obtained. Because of the complexity of these activities and the sheer bulk of the paperwork involved, errors frequently occur that cause incorrect final results, rework, time delays, excessive safety system unavailability, and, if errors go undiscovered, latent nuclear safety issues.

This operating model is of particular concern because it is so highly dependent on large technical staffs and quality of work instruction. Technologies can play a key role in improving maintenance productivity (completing the task in less time), offsetting labor costs, reducing the bulk of paper required to carry out a task, reducing the handling and processing of paper documents, minimizing non-value tasks, and focusing resources on wrench time, reducing error traps, presenting the right information at the right time to the right person, minimizing amount of rework and latent nuclear safety issues, and allowing field workers to get just-in-time training to enhance situation awareness.

The AWP research project will provide a generalized platform for introducing many types of beneficial technologies into plant work activities. These technologies are capable of enhancing work quality, cost management, and nuclear safety. Additionally, the project is designed to research, develop, and deploy new capabilities for field workers in NPPs that will allow work planners to have near real-time interaction with field workers executing the task, and provide just-in-time instructions or additional information (as required/requested).

As an initial effort, the report briefly discussed the background on work packages in NPPs. The report presents AWP architecture and an initial set of requirements that are deemed essential for implementation of AWP in NPPs. As part of the research, the team has initiated a field evaluation to test CBWO with PVNGS. The qualitative analysis of the field evaluation will be performed in early fiscal year 2015.

Moving forward, the research team will continue the field validation study at PVNGS with data collected continuously until the end, scheduled to be early 2015. The research team will then conduct a debriefing with the maintenance technicians who participated in the study to gather any additional feedback, and discuss opportunities for future collaboration activities to enhance the AWP research and prototype system.

The researchers will conduct an additional field evaluation hosted by another utility within the upcoming year. During this field evaluation study, more AWP-specific functionality will be incorporated into the prototype system, such as the pre-job brief, lists of equipment, parts needed for the task, etc. The research team and the utility are currently in the process of selecting instructions or procedures to be used for the study. Among the considerations are those tasks shared between operators in the main control room and workers in the field. The focus would be on the use of mobile technology and the human factors issues related to successfully executing shared procedures between these two groups.

In a parallel instrumentation and controls research activity, researchers will investigate wireless network and sensor technologies to achieve near real-time automated plant surveillance, plant status information, and digital verification. The immediate focus of the project will be to carry out research into the wireless component position indication required (desired) during normal, abnormal, or emergency operating conditions. A hierarchical matrix ranking components/systems for which position indication information is required will be created based on criteria such as risk, labor costs, etc.

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