INL/EXT-16-39098

A Business Case for Nuclear Plant Control Room Modernization

Ken Thomas
Sean Lawrie
Josef M. Niedermuller

June 2016

U.S. Department of Energy
Office of Nuclear Energy

INL/EXT-16-39098

A Business Case for Nuclear Plant Control Room Modernization

Ken Thomas
Idaho National Laboratory

Sean Lawrie
Josef M. Niedermuller
ScottMadden, Inc.

June 2016

Idaho National Laboratory
Light Water Reactor Sustainability Program
Advanced Instrumentation, Information, and Control Systems Technologies
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

SUMMARY

Department of Energy's (DOE's) Light Water Reactor Sustainability Program (LWRS) develops technologies that will make the existing U.S. nuclear fleet more efficient and competitive. The program has developed a standard methodology for determining the impact of new technologies in order to assist nuclear power plant (NPP) operators in building sound business cases.

This paper presents a generic business case for implementation of technology that supports Control Room Modernization (CRM) in existing nuclear power plants. The analysis is presented as a standalone technology upgrade and assumes communications and data networks are in place that will support wireless networks within the plant. It also assumes that digital control systems are in place or being considered in parallel in a separate business case. This business case contends that advanced communication, networking and analytical technologies will allow NPP operators to conduct control room operations with improved efficiency and human factors, and therefore operate with fewer operational events. Labor savings can be harvested in terms of overtime and redistribution of work; significant savings are also demonstrated as reduced time to bring the plant back on line after completion of outages. The benefits are quantified to a rough order of magnitude that provides directional guidance to NPPs that are interested in developing a similar business case.

This business case focuses on modernization of the control room (CR) from an operator interface standpoint and does not encroach on the separate business case for modern digital instrumentation and control (I&C) systems. The implementation of a modern digital I&C system can be accomplished without significant upgrades to the operator interface in the control room by continuing to use the discrete devices on the control boards, supplemented with some digital displays dedicated to the upgraded I&C systems. However, this approach does not capture the full range of benefits in improved operator performance. The CRM business case presented in this report therefore addresses the benefits of new digital technologies beyond the capabilities provided just by the modern digital I&C systems.

CRM is enabled by a suite of technologies, which are described in further detail in the body of this report. They include both hardware and software upgrades:

- Hardware
    a. High-bandwidth wireless networks
    b. Mobile devices
    c. Large overview displays
    d. Component identification technology
    e. Mobile wireless video cameras
- Software
    a. Computer-Based Procedures (CBP)
    b. Mobile Work Packages (MWP)
    c. Task-based operator displays
    d. Digital I&C systems
    e. Advanced alarm systems
    f. Computerized Operator Support System (COSS)

An analysis was conducted to determine how these technologies might impact control room operations at an NPP. The analysis concluded that control room and operator capabilities would be improved with application of these technologies and result in annual benefits for the plant. These improved capabilities were identified and described in further detail in this report:

- Reduced manpower to execute operating procedures, surveillances, and tests
- Minimization of human factors in the CR and reduction in operator errors
- Improved critical path to restart plant after outages
- Remote operation of local control panels
- Computerized operator support systems to diagnose and troubleshoot emerging plant conditions
- Paperless control room processes

A Business Case Methodology (BCM) was employed to quantify the potential benefits for the NPP [1]. The BCM was developed by Idaho National Laboratories (INL) in conjunction with ScottMadden Inc., a management consulting firm prominent in energy markets, particularly in the nuclear generation industry.

The resulting business case demonstrates benefits in both labor and non-labor categories with the application of CRM as illustrated in the summary table below:

Table 1: Summary of CRM Benefits

Control Room Modernization
BCM Present Value

Discount Rate (Internal Rate of Return):		10%	
No. Years of Benefit:		15	years
Annual Benefit (Labor)	$	1.02	million
Annual Benefit (Non-Labor)	$	0.65	million
Annual Benefit (KPI)		n/a	million
Total Annual Benefit:	$	1.66	
First Year Realized Benefit:		3	
Estimated Net Zero NPV Investment:		$10.46	million

In addition to cost savings, these technologies also offer improvements to human performance that have impact on key performance indicators (KPIs) of the plant. Through publication of the findings and the BCM, the nuclear industry is provided with a sample business case for pilot project technologies that can be used as a template for pursuing similar implementations at other nuclear plants.

FOREWORD

Department of Energy's (DOE's) Light Water Reactor Sustainability Program (LWRS) develops technologies that will make the existing U.S.nuclear fleet more efficient and competitive.

The Advanced Instrumentation, Information, and Control (II&C) Systems Technologies Pathway is part of LWRS Program. It 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 (LWR) fleet. This work involves two major goals: (1) to ensure that legacy analog II&C systems are not life-limiting issues for the LWR fleet and (2) to implement digital II&C technology in a manner that enables broad innovation and business improvement in the NPP operating model. Resolving long-term operational concerns with the II&C systems contributes to the long-term sustainability of the LWR fleet, which is vital to the nation's energy and environmental security.

The II&C Pathway is conducting a series of pilot projects that enable the development and deployment of new II&C technologies in existing nuclear plants. Through the LWRS program, individual utilities and plants are able to participate in these projects or otherwise leverage the results of projects conducted at demonstration plants.

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. They provide the opportunity to develop and demonstrate methods to technology development and deployment that can be broadly standardized and leveraged by the commercial nuclear power fleet.

Performance advantages of the new pilot project technologies are widely acknowledged, but it has proven difficult for utilities to derive business cases for justifying investment in these new capabilities. Lack of a business case is often cited by utilities as a barrier to pursuing wide-scale application of digital technologies to nuclear plant work activities. The decision to move forward with funding usually hinges on demonstrating actual cost reductions that can be credited to budgets and thereby truly reduce operating and maintenance (O&M) or capital costs. Technology enhancements, while enhancing work methods and making work more efficient, often fail to eliminate workload such that it changes overall staffing and material cost requirements. It is critical to demonstrate cost reductions or impacts on non-cost performance objectives in order for the business case to justify investment by nuclear operators. For these reasons, the LWRS has created a standard methodology for determining the impact of new technologies in order to assist NPP operators in building sound business cases.

A BCM has been developed with the assistance of ScottMadden, Inc., a management consulting company, to provide a structure for building the business case for adopting pilot project technologies in a manner that captures the total organizational benefits that can be derived from the improved work methods [1]. This includes the direct benefit to targeted work processes, efficiencies gained in related work processes, and avoided costs through the improvement of work quality and reduction of human error.

The BCM is designed to addresses the benefit side of the analysis—as opposed to the cost side—and how the organization evaluates discretionary projects' Net Present Value (NPV), accounting effects of taxes, discount rates). The cost and analysis side is not particularly difficult for the organization and can usually be determined with a fair amount of precision (not withstanding implementation project cost overruns). It is in determining the "benefits" side of the analysis that utilities have more difficulty in technology projects, and that is the focus of this methodology. The methodology is presented in the context of the entire process, but the tool provided is limited to determining the organizational benefits only.

This BCM approaches building a business case for a particular technology or suite of technologies by detailing how they impact an operator in one or more of the three following areas: Labor Costs, Non-Labor Costs, and KPIs. Key to those impacts is identifying where the savings are "harvestable," meaning they result in an actual reduction in headcount and/or cost. Harvestability is not always possible due to plant requirements to maintain minimal numbers of staff to support emergency preparedness programs and pipeline development. However, harvesting of labor savings can be implemented through offsets to contracted work, overtime, and reallocation of duties between functions. Harvestability for control room operators is highly sensitive to the NPP licensing basis and conduct of operations policies, and this is taken into consideration in the individual opportunities for savings.

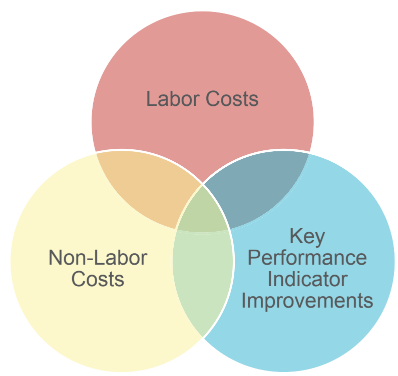


Figure 1: Key Areas of Impact

Impacts to NPPs in these three areas should be quantified and built into a comprehensive business case for the adoption of a technology.

Specifically, the BCM highlights key questions to ask and to guide the utility through, as well as identifies where in the process to employ the Business Case Methodology Workbook (BCMW) for benefits/cost savings identification. The approach enables collaboration between the II&C Pathway and utility partners in applying new digital technologies across multiple NPP organizations and their respective work activities wherever there is opportunity to derive benefit. In this manner, the BCM drives an "economy of scale" that maximizes the value of the technologies relative to the implementation cost.

The BCM leverages the fact that, in spite of what seems to be a wide and disparate array of work activities among an NPP's operational and support organizations, the work activities themselves are largely composed of common tasks. For example, whether the work activities are in Operations, Chemistry, Radiation Protection, or even Security, they have in common such tasks as pre-job briefs, use of procedures, correct component identification, emergent conditions requiring work package alteration, etc. It is at this task level that the technologies are applied; therefore, the benefits of the technologies can be realized across as many plant activities as can be identified to employ these tasks. In this manner, a much more comprehensive business case can be derived that greatly increases the benefit/cost ratio. This has the added benefit of driving consistency across the NPP organizations, which is a fundamental principle of successful NPP operational and safety management.

In May of 2015, the BCM was utilized to evaluate a suite of technologies being demonstrated by the LWRS program [2]. The pilot technology evaluated in this study was titled as MWP, which includes CBP and other automated elements of the work package. This technology enables time savings through features such as smart place-keeping, smart branching, conflict detection and resolution, and seamless transition to other procedures. These features reduce the overhead, conflicts, and switching costs associated with executing procedures across a complex organization.

During the analysis, several improvements were incorporated in the BCMW, including means to estimate cost of labor savings, as well as a Present Value (PV) estimating tool to summarize the benefit of the technology in present terms. The tool is not intended to replace a thorough financial analysis of the project for investment, but rather to provide guidance that is reasonably accurate and directionally correct and inform whether or not to move to project into the next stage of development.

In March of 2015, the general business case prepared for MWP was expanded to include Advanced Outage Management (AOM) technologies [3]. AOM focuses on efficiencies created by a suite of technologies when applied to outage management processes. It is established through work analysis that a considerable amount of time during outages is spent monitoring field activities, gathering information, analyzing plans and schedules, and redirecting workforce in order to achieve outage objectives. The business case hypothesized that modernizing the tools available to managers and field teams alike eliminates many of the manual communications and analysis in the outage control centers, much in the way that technologies allow us to perform common tasks like depositing a check from a mobile device or monitoring our home security system.

The business case developed for MWP focused on labor savings that could be achieved in the field with use of technology. The business case developed for AOM focuses on field coordination and oversight during an outage. This case presents a suite of technologies, postulates the improvements in control room operations, and quantifies the benefits using the BCM and BCMW to provide the present value of CRM to a typical two-unit plant. Assumptions and estimates made during this effort to quantify benefits were verified at a participating operating plant and are considered to be reasonably accurate, if not conservative and representative of industry. This report, along with the associated workbooks, presents a generic business case with a rough order of magnitude that provides directional guidance to NPPs that are interested in developing a similar business case.

CONTENTS

FIGURES

TABLES

ACRONYMS

AO	Auxiliary Operator
AOM	Advanced Outage Management
AWP	Automated Work Packages
BCM	Business Case Methodology
BCMW	Business Case Methodology Workbook
CAP	Corrective Action Program
CBP	Computer-Based Procedures
COSS	Computerized Operator Support System
CR	Control Room
CRM	Control Room Modernization
DCS	Distributed Control System
DOE	Department of Energy
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FTE	Full-Time Equivalent
HIS	Human System Interface
I&C	Instrumentation and Control
II&C	Instrumentation, Information, and Control
INL	Idaho National Laboratory
INPO	Institution of Nuclear Power Operators
KPI	Key Performance Indicator
LWR	Light Water Reactor
LWRS	Light Water Reactor Sustainability
MWP	Mobile Work Packages (including CBP)
NPP	Nuclear Power Plant
NPV	Net Present Value
NRC	Nuclear Regulatory Commission
OCR	Optical Character Recognition
OSHA	Occupational Safety and Health Administration
O&M	Operating and Maintenance
QR	Quick Response
POE	Power Over Ethernet

PV	Present Value
RFID	Radio Frequency Identification
R&D	Research and Development
RO	Reactor Operator (Licensed Operator)
SOER	Significant Operator Experience Report
ST	Surveillance and Test
UCS	Union of Concerned Scientists

A Business Case for Control Room Modernization

1 INTRODUCTION

In spite of a significant number of digital systems now having been implemented in operating nuclear plants, there have been no large-scale changes to the layout or function of their control rooms. Nuclear utilities have understandably been reluctant to undertake significant control room upgrades or modernization projects in consideration of cost, regulatory risk, and impact on the large investment in procedures, training programs, and other support functions that may accompany large upgrades. Also, there is a general desire to retain the high degree of operator familiarity with the current control room arrangements, and thereby avoid potential human performance issues associated with control board configuration changes [4].

Introducing digital systems into the control rooms creates opportunities for improvements in control room functions that are not possible with analog technology. These improvements are actually enabled by the new digital I&C systems even though many times these features go unused. This is especially true of what is called distributed control systems (DCS), in which plant parameters are digital variables that can be used and displayed in multiple ways that are beneficial to operators. This is opposed to analog technology in which a parameter is generally available in just one place on the control boards.

Current human performance engineering principles and techniques are able to leverage these capabilities to support more effective operator performance, resulting in a more human-centered main control room. And these techniques can be applied on a proportional basis for a hybrid control room (mixture of analog and digital I&C technologies), not requiring a full-scope approach to control room modernization, such as refurbishing or replacing an entire main control room. Rather, these improvements can be accomplished through gradual and step-wise related projects that are carried out when digital II&C systems are implemented to replace analog II&C systems to address near-term reliability and operational needs.

As previously mentioned, lack of a business case is often cited by utilities as a barrier to pursuing control room improvements in conjunction with digital I&C upgrades. It has been difficult to identify actual cost reductions that can be credited to budgets and thereby truly reduce O&M or capital costs. Technology enhancements, while enhancing work methods and making work more efficient, often fail to eliminate workload such that it changes overall staffing and material cost requirements. It is critical to demonstrate cost reductions or impacts on non-cost performance objectives in order for the business case to justify investment by nuclear operators.

This business case for control room modernization addresses this need. It identifies specific opportunities to improve operator performance, and plant operations in general, through enhanced Human System Interface (HSI) technologies that can be introduced into NPP control rooms in conjunction with digital I&C upgrades. It identifies how these technologies can create efficiencies in the control room, reduce time to conduct plant evolutions, improve coordination with field operators, and enhance the interface with operational support organizations.

The business case addresses only the benefits of the technologies and quantifies how these translate to cost savings. It does not address the investment cost because that is highly plant specific and depends on the scope of I&C upgrades and the current state of the control rooms. However, the methodology provides the means for applying the investment costs to determine the net savings.

To be clear, this business case does not address the benefits of the digital I&C systems themselves. These systems have a separate business case based on the resolution of obsolescence and reliability issues, performance deficiencies, and declining support base for the legacy systems. Rather, the scope of this business case is to justify the incremental expense of improving the control rooms from an operator performance perspective based on the capabilities enabled by modern digital I&C systems.

2 METHODOLOGY AND PROJECT APPROACH

The BCM provides a structured guide to utilities for building a business case for adopting emerging digital technologies in a manner that captures the total organizational benefits that can be derived from the improved work methods. This includes direct benefits to the targeted work processes, efficiencies gained in related work processes, and avoided costs through the improvement of work quality and reduction of human error.

In addition, the BCM identifies the NPP work processes to employ the BCMW for benefits/cost savings identification. This approach enables collaboration between the II&C Pathway and utility partners in applying new technologies across multiple NPP organizations and their respective work activities, wherever there is opportunity to derive benefit. In this manner, the BCM drives an "economy of scale" that maximizes the value of the technologies relative to the implementation cost.

The BCM leverages the fact that, in spite of what seems to be a wide and disparate array of work activities among an NPP's operational and support organizations, the work activities themselves are largely composed of common tasks. For example, whether the work activities are in Maintenance, Operations, Chemistry, Radiation Protection, or even Security, they are largely composed of such common tasks as pre-job briefs, use of procedures, correct component identification, emergent conditions requiring work package alteration, etc. It is at this task level that the technologies are applied, and therefore the benefits of the technologies can be realized across as many plant activities as can be identified to employ these common tasks. As a result, a much more comprehensive business case can be derived with a commensurate increase in the benefit/cost ratio. This has the added benefit of driving consistency in work methods across the NPP organizations, a fundamental principle of successful NPP safety and operational management.

The business case for CRM is built around a suite of technologies that when fully utilized, increase the efficiency of plant operations and work processes, enhance human-system interfaces, increase situational awareness and limit the potential for human error. Some of the opportunities presented by technology have already been studied in prior pilot project technology business cases [2, 3]. Data collected from participating NPPs to evaluate the benefits of MWP, CBP, and AOM applied to general field operations, both on-line and during outages formed the basis for many of the estimates used to develop this business case. In the case of MWP and CBP, field observations and time trials were conducted to evaluate potential labor and non-labor savings. Similarly, this study made assumptions around availability of technology to support CRM, which includes plant-wide broadband wireless communications and personal devices (i.e., tablets), that would allow workers to follow CBP and communicate with maintenance supervision, work management, operations and other crews as required. The collected data was then analyzed and fed into the BCMW to evaluate the potential annual benefit to the plant.

Additionally, the BCM for CRM, similar to prior studies, is largely dependent on the automation of data transfer in digital systems working in real time. However, while prior business cases were primarily focused on benefits for field work activities both on-line and during outages, the case for CRM focuses on the benefits to control room operations, supervision, and CR support (i.e. Engineering and Maintenance) as a result of advanced technologies. The full suite of required technologies is described greater detail in the next section of this report.

Because much of the analysis required for the CRM business case had already been collected and the business case for a large portion of the combined study had already been produced, the approach for this study focused less on data collection and on-site analysis. Instead, the opportunities presented by technologies for CRM were initially evaluated by industry experts off site using the BCMW, and estimates were made supported by site data received from a participating NPP (e.g., staffing levels, work durations, manpower levels, etc.). The calculated benefits using the BCMW were then presented to and validated by participating NPP management representing a broad range of outage functions. An overview of the approach used for this BCM is outlined below.

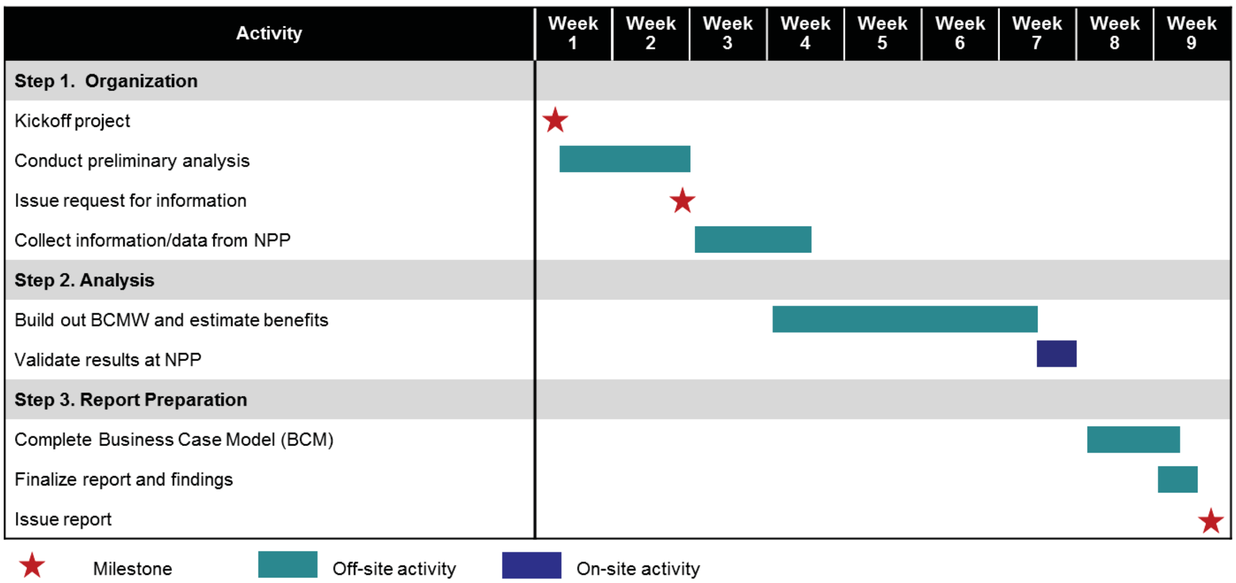


Figure 2: Project Approach

To assist the off-site analysis and validation by partner utility outage management staff, an Opportunity Worksheet was developed and incorporated into the BCMW. This worksheet walked the evaluating team through the analysis of benefits by first asking the team to identify the improved capability (i.e., opportunity) that is enabled by technology. To view opportunities in terms of new capabilities proved to be helpful as many capabilities are enabled by application of a suite of technologies rather than a single "magic bullet." By following this worksheet, the team was able to identify the overall benefits and the outage functions that are impacted by the improved capability. The team then decided how the benefit might be quantified and a calculation was recorded. This helped the team understand if any additional data needed to be collected to support the calculation used. Finally, the calculation was entered into the BCMW worksheets to produce a quantifiable benefit for each task impacted in terms of labor and non-labor savings. A sample of the Opportunity Worksheet is presented in Figure 3 below. The completed Opportunity Worksheet developed for this business case is provided in Appendix A.

Advanced Outage Management - Opportunity Worksheet								
#	Capability	Description of Opportunity	Enabling Technologies	Proposed Benefits	Outage Functions and/or Programs Improved	Annual Savings Calculation	Affected Task(s)	Estimated Annual Benefit
1	**Automated Status Updates**	***Automated status updates*** and other collaboration technologies will significantly reduce the time spent actively retrieving current status of field activities and manually updating schedule management applications and reports. Time savings impact FTE working in the OCC or other satellite centers which can be redeployed. E.g., status of MWP are transmitted in real time from the field to the OCC and incorporated directly into the planning schedule	• Mobile Work Packages (MWP) incl. computer based procedures • Alternative: PDAs that prompt for status updates at predetermined times with menu driven responses (i.e., • Data links to scheduling software and advanced data analytics	Reduction in FTE required to be stationed in OCC or other satellite control centers/war rooms, which can be redeployed to bring knowledge and expertise into the field, offsetting temporary employment. Ancillary benefits include: • Critical path savings • Reduction in OT • Early release of contractors or aux workforce • Improved productivity (reduced wait time/down time) • Improved ability release downstream work (increase in productivity)	• Work Management • Maintenance Craft Supervision • Field oversight (Operations, RP, Chemistry and Engineering)	***Calculation:*** [Estimated number of persons stationed in the OCC and satellite centers] x [outage duration in days (including power ascension] x [No of outages per year] x [% time of shift work spent gathering information] x [% reduction in work due to automation of status updates] ***Assumptions and Clarifications:*** • Outage Duration (days): 34 days outage + 3 days power ascension (37 total days); For Chemistry only: effective outage duration is 25% of the 37 days • Outages per year: 1.33 outages per year (two units on 18 mo. cycle) • Affected shift workers per day (2 x 12hr shifts): > OPS FTE = 26 (4 OCC + 22 Satellite) > MA FTE = 35 (8 OCC + 27Satellite) 16 in war room, 6 in OCC (4 Maint + 2 Maj. Proj), 2 QC, 1 Steam Gen, 1 Turbine) Reactor Services = 9 (2 OCC + 7 Satellite) > RP FTE = 6 (2 OCC + 4 Satellite [1 in SCC and 1-2 dose monitoring]) > CY FTE = 4 (2 Primary + 2 Secondary) > EN FTE = 6 (2 OCC + 4 Satellite) > WM FTE = 8 (OCC) (1 outage Mgr, 2 shift managers, one emergent work Mgr) • Task is "gather information" to status activities • Task hrs = 50% of shift for Work Management; 40% for Maintenance; 20% for other functions is spent to "gather information' • Estimated that collaboration and statusing technologies will reduce workload of information gathering by 80%	Staff OCC and satellite control centers for coordination of activities *[i.e. gather information]* (59a) OP.C.59a. MA.B.59a. WM.B.59a. RP.A.59a. CY.C.59a. EN.C.59a.	OP: $182k MA: $587k WM: $168k RP: $50k CY: $8k EN: $50k Total: $1,045k harvestable out of contractor labor spend

Figure 3: Sample Row from an Opportunity Worksheet

Once the Opportunity Worksheet and the BCMW were completed, the results were validated through a series of interviews with plant personnel at a partner nuclear plant. A list of personnel interviewed is provided in the table below. During each interview, the team walked through the Opportunity Worksheet to confirm assumptions made for a number of people impacted by the opportunity and the estimated efficiencies proposed. The worksheet and associated tasks on the BCMW were adjusted accordingly. In all cases, NPP personnel expressed that the results, in their experience, were directionally correct and reasonably accurate, if not conservative.

Table 2: List of NPP Personnel Interviewed during BCM Validation

NPP Personnel Interviewed during Validation of the AOM BCM	
Assistant Plant Manager	Engineering Section Leader, Digital Modifications
Work Control Manager	Digital Modification Engineer (2)
Operations Shift Manager	I&C Maintenance Section Leader
Site Information System Client Manager	I&C Maintenance Lead (3)
Senior Reactor Operator/IT Specialist	Control Room Supervisor

3 CRM TECHNOLOGIES

3.1 Hardware and Infrastructure

3.1.1 High-Bandwidth Wireless Networks

Plant-wide wireless networks will enable connection of mobile workers to the Control Room, allow real-time status updates from mobile work packages, allow the use of streaming wireless video feeds, and support internet communication options [5]. Lower frequency broadband communications technologies such as 4G LTE and WiMAX have promising potential to offer secure broadband communications that can penetrate containment, thus eliminating the need for temporary modifications during an outage to establish communications inside containment during an outage. For technical information regarding wireless network installation in a NPP, refer to Electric Power Research Institute's (EPRI) Implementation Guideline for Wireless Networks and Wireless Equipment Condition Monitoring [6].

3.1.2 Mobile Devices

Mobile worker devices include any number of hand-held electronic devices that provide information to and allow interaction with field workers [7]. In the CRM concept, mobile worker devices will support MWPs as well as providing voice and video communication capability. A number of form factors are available depending on the specific end user's need, but typically, a mid-sized tablet computer with an embedded camera and wireless network capability is sufficient. The digital cameras that are typically included in the hand-held field devices can be used for a variety of purposes, including recording still pictures or video of the job site, work conditions, or emergent problems. They can be used to identify components in conjunction with applications to read bar codes, QR codes, or even characters with optical character recognition (OCR) technology. Various rugged devices are an option or rugged cases may be used to protect consumer models.

3.1.3 Large Overview Displays

Similar to task-based displays, large overview displays are enabled by digital I&C systems and provide a depiction of overall plant conditions that cannot be obtained through smaller displays. Typically, they will portray the major plant functions of reactor conditions, feedwater and steam generation, turbine/generator, and electrical output. These displays can be instantly converted to a view of the emergency systems when the plant enters such conditions, displaying the emergency core cooling system, emergency feedwater systems, and emergency power systems. Further, these displays can be customized to present timely information as needed by the operators. They can be synchronized to changing plant conditions to display timely information that keeps up with the progression of an event.

3.1.4 Component Identification Technology

There are a variety of technologies that can be used for automated component identification, including bar codes, quick response codes (QR), optical character recognition (OCR), and near-field technologies such as radio frequency identification (RFID). These technologies can be placed on or embedded in component identification tags that are tethered to the components themselves. The field workers can use identification technologies on board the hand-held field devices to query the component identification tags to ensure that they are working on the correct component as specified in their mobile work package. This could involve the use of the digital camera in the field device or an RFID receiver.

3.1.5 Mobile Wireless Video Cameras

High-quality video images are an effective form of communication [7]. Real-time video feeds of an issue or ongoing work can convey much more information than a static picture or voice report. Remote video cameras are currently used in several areas during NPP outages. Currently, these cameras are used to monitor outage progress in containment, on the refueling floor, and in the turbine building. These cameras are typically power-over-ethernet (POE) type cameras that are set up at the beginning of the outage and remain in place for the duration of the outage. If a wireless network is available, wireless-enabled cameras can be used to provide temporary activity monitoring in locations not observable by the POE cameras typically installed. In addition, battery packs could be used to provide completely wireless video monitoring capability. Another option is to use hard-hat-mounted video cameras to stream a video signal to the CR or other satellite center to provide direct viewing of work-in-progress or job conditions.

3.2 Software and Configuration

3.2.1 Computer-Based Procedures

Computer-based procedures are computerized forms of plant procedures that provide the performer with an array of intelligent job aids that make the work more efficient and more accurate. As examples, they enforce human performance requirements, they can validate actions and perform range checking, they enable remote task sharing, they perform computations and put data in tables, they can insert data from external sources (instruments, plant computer, etc.), they can support remote authorizations and approvals, and they can make notifications to other organizations as required by conditions. CBPs automate a lot of the procedure administration and data entry, creating time savings for the duration of the job.

3.2.2 Mobile Work Packages

MWP are computerized forms of work instructions, such as CBP and automated work packages (AWP). They have a number of features that improve work efficiency, human performance, and interface with the larger organization. They have an inherent ability to enforce work standards such that common human errors made with paper-based documents are prevented. They automate the execution of tedious functions such as data recording, computations, document place-keeping, etc. They report status and other information automatically and transparently to interfacing organizations, without requiring the attention of the work package performer. These features in aggregate compose a powerful tool to manage the quality and timeliness of plant work activities while keeping the larger organization informed of important information as it happens.

3.2.3 Task-Based Operator Displays

Task-based displays are configured operator screens in a digital I&C system that have been customized to perform a certain control task. An example would be a task to start-up the main turbine. The display would be designed to present the specific information needed by the operator to perform the related procedure. In a traditional control room, the arrangement of the discrete components (gauges, pushbuttons, etc.) cannot be optimized for every task, but rather have to be put in a logical arrangement typically by system. In a digital system, we are not limited to a single arrangement of the devices, but rather we can group the indications and control functions in a custom arrangement on one or more displays specifically designed to facilitate a given plant task.

3.2.4 Digital I&C Systems

Digital I&C systems are software-based control systems that perform essentially the same functions as their analog counterparts but by using software functions to perform the same indication and control functions that are traditionally done by discrete components. However, they are able to do much more than the analog components because these actions can be combined with any other type of processing to assist the operator in powerful ways. For example, they can determine if a plant parameter is within its administrative limits. With these capabilities, the I&C system can reduce the operator workload and support of much richer set of operator functions.

3.2.5 Advanced Alarm Systems

Advanced alarm systems are replacements for the traditional annunciator systems in current nuclear plants and provide far more function than simply indicating an alarm state has been reached by illuminating a particular inscribed text window in an alarm panel. First, these systems use a general digital display rather than a lightbox alarm panel, providing flexibility to depict alarms in the traditional lightbox format, or they can use the displays to depict the alarms in a variety of formats that are more conducive to human understanding, employing shapes, colors, trends, etc. to convey additional information. They can provide more detailed views in cases where an alarm window actually is a summary alarm of multiple alarm conditions. These systems can filter and suppress alarms that are not relevant to the current state or mode of plant operations. They can filter or suppress alarms that are the consequence rather than the cause of a plant condition or transient. Finally, they can trigger other needed response actions by automatically displaying the Alarm Response Procedure for a particular alarm that comes in and activating a particular plant procedure (Abnormal Operating Procedure or Emergency Operating Procedure) whose entry condition has been met by the condition represented by the alarm.

3.2.6 Computerized Operator Support Systems

A computerized operator support system (COSS) is a collection of capabilities to assist operators in monitoring overall plant performance and making timely, informed decisions on appropriate control actions for a projected plant condition [8]. The COSS does not supplant the role of the operator, but rather provides rapid assessments, computations, and recommendations to reduce workload and augment operator judgment and decision-making during fast-moving, complex events. A COSS generally has the following features:

- Monitoring a process to detect off-normal conditions
- Diagnosis of plant faults
- Prediction of future plant states
- Recommendation of mitigation alternatives
- Decision support in selecting mitigation actions

However, as a class of related technologies, an important distinction to be noted is that they assist human operator as opposed to serving as an extension of the control system. In that regard, the reasoning of the system must be transparent and familiar to the operator and must operate on a time scale that allows the operator to interact with the system, as opposed to the much-faster operating speed of an automatic control system.

4 IMPROVEMENTS TO CONTROL ROOM OPERATIONS

4.1 Introduction

The BCM was created to help NPPs evaluate how application of new technologies can benefit plant operations. Evaluating application of technologies individually may demonstrate marginal benefits, but it is not until the suite of available technologies is evaluated holistically can the synergies be understood and the benefits fully described. The BCM allows users to evaluate the impact of multiple technologies across all plant operations. In this study, time was first spent postulating how outages might be conducted utilizing advanced technologies, and where savings could be realized. To organize thoughts, an Opportunity Worksheet was created to guide users through a process that identifies improvements to capabilities. These improved capabilities were then examined further quantify benefits using the BCMW workbook. The team identified the following capabilities that would be improved by utilization of the suite of CRM technologies described in the previous section.

4.2 Analysis of Improved Capabilities

4.2.1 Integrated Computer-Based Procedures

Discussion

All operational activities in the control room are performed with procedures, including operational alignments, responses to plant conditions, surveillance tests, and support of maintenance/modifications. Procedures can be run entirely in the control room or in conjunction with field operators taking control actions out in the plant. Today, these procedures are paper-based and multiple copies are used when operators are in different locations.

Computer-based procedures enable significant work efficiencies and human performance benefits when they are integrated with digital I&C systems and overview displays. Execution of procedures can be much quicker when data is extracted from the digital I&C systems and other plant data sources (plant process computer, wireless instrument data inputs, etc.). Also, it is possible to execute procedure steps directly from the CBP using soft controls.

Task-based displays and overview displays also contribute to quicker completion of procedures by bringing together all information needed for the procedure steps into a compact view that eliminates the need to move about the control boards to obtain information. These displays are customized to present the information in the exact format needed to complete procedure steps and transfer that information directly into the CBP. Using these types of displays together, situational awareness is obtained at a level not possible with traditional analog control board layouts, thereby reducing the time the operator takes to verify correct plant responses to control actions and overall configuration control of the plant.

Efficiency and human performance features in the CBPs also increase the efficiency with which the operators can complete tasks by handling the procedure use and adherence requirements and performing other procedure requirements such as range checking on entered data values to ensure acceptance criteria is met. Much of the place-keeping, entry of data values, and background information can be entered automatically from plant information sources and work control information. Notifications to site support groups can be built directly into the procedures such that notifications happen automatically allowing for timely execution of procedures (reduced wait times). Test results and other data can be entered directly into the CR procedures from data systems, eliminating scribing errors, and need for verification and sign-offs.

Notifications and step approvals for remote parties are handled directly in the procedure, eliminating the need for parallel communications or even travel within the plant complex for face-to-face discussions.

Procedures for surveillance tests can especially benefit from the integrated data sources. Some surveillance tests can be completed entirely in an automated manner. The control room technology can recognize when a surveillance has been met for a certain component and automatically generate and perform a surveillance procedure in the same manner as if it had been executed by an operator. In other cases, it can be semi-automatic in which portions of the procedure are performed automatically and the balance of the procedure is executed by the operator, again employing the same efficiency features previously discussed.

Coordination of associated field activities is greatly improved using CBPs because all parties can share a common procedure, indicating the current step and who has the action (control room or field). This can potentially reduce procedure performance time by eliminating the need for some human performance protocols used over phones and radios since both parties have access to the identical source material, thereby precluding verbal misunderstandings.

The post-processing of procedures is likewise streamlined by eliminating the need to consolidate multiple copies, to manually route the completed procedure for approvals, and to archive the procedures (when necessary) as a digital record by scanning the paper copy.

For proceduralized surveillances and tests (ST), it was estimated that 30% of STs could be eliminated with automated transmission, evaluation and logging of instrument data in a digital system. Additionally, it was estimated that at least 30% of the remaining STs would be significantly streamlined and would be able to be executed 70% more efficiently, and that the remainder 40% could be executed at least 10% more efficiently.

For control room procedure-driven activities that lend themselves to these efficiencies, a conservative reduction in performance time of 25% is assumed for the purposes of estimating the potential benefit. This applies to both the control room operators (ROs) and the auxiliary operators (AOs) performing the field operations. The 25% reduction in time covers variations in whether one or more ROs are continuously or intermittently involved in the activities.

Enabling Technology(s)

The following technology enables integrated computer-based procedures:

- Digital I&C Systems

- Mobile devices
- High bandwidth wireless networks
- Mobile work packages
- Computer-based procedures
- Task-based displays
- Overview displays

Plant Functions or Programs Impacted

- Control Room Operations
- Field Operations
- Operations Oversight

Calculation of Annual Benefits

[Estimated time (hrs.) spent by control room operators and field support executing control room operating procedures, surveillances and tests] x [efficiency factors for evolutions/STs (see Figure 4)]

Assumptions and Clarifications

The figure below illustrates the reduction in control room and field operator workload as a result of CRM technologies:

Operations Labor Savings Analysis - Integrated Computer-Based Procedures

Control Room Procedure Use (% time)

		RO 1	RO 2	RO 3	Field 1	Field 2
Unit 1	Shift 1	12.5%	75%	50%	80%	40%
	Shift 2	6.25%	37.5%	25%	40%	20%
Unit 2	Shift 1	12.5%	75%	50%	80%	40%
	Shift 2	6.25%	37.5%	25%	40%	20%

Control Room Procedure Use (hrs. per 12 hr. shift) — Total hrs. per day*

		RO 1	RO 2	RO 3	Field 1	Field 2	RO Hrs.	Field Hrs.
Unit 1	Shift 1	1.50	9.00	6.00	9.60	4.80	16.50	14.4
	Shift 2	0.75	4.50	3.00	4.80	2.40	8.25	7.2
Unit 2	Shift 1	1.50	9.00	6.00	9.60	4.80	16.50	14.4
	Shift 2	0.75	4.50	3.00	4.80	2.40	8.25	7.2
		4.50	27.00	18.00	28.80	14.40	49.50	43.20

*Typical daily hours representative of both on-line and outage hrs.

		RO Hrs.	Field Hrs.
Total hrs. in procedure use per day		49.50	43.20
Total hrs. procedure use per year		18,068	15,768
Percent Surveillance/Test (ST)	50%	9,034	7,884
Percent procedures ops/evolutions	50%	9,034	7,884

Procedure Efficiency Gains	%	Gain	RO Hrs.	Field Hrs.
ST Eliminated	30%	100%	2,710	2,365
ST significantly streamlined	30%	50%	1,355	1,183
ST moderately streamlined	40%	10%	361	315
Evolutions streamlined	100%	25%	2,258	1,971
Total hrs. saved annually			6,685	5,834

Figure 4: Estimate of Labor Benefits for CRM

Estimate of Benefits

Annual Labor Savings (workload reduction in hours):

Operations: 12,519 hours

Harvestability: 50-70%

Harvestability of Reactor Operator (RO) man-hours is highly dependent on plant circumstances, control room manning strategy, and licensing basis. A separate study would be required by a NPP to determine the flexibility of CR staffing in their organization. In some cases, a license amendment may be required. That said, it was estimated that 50% of the reduced workload for ROs could be harvestable through reduction in augmented staff above regulatory requirements, reduction in overtime or, depending on unit coverage strategies, use of swing operator. Additionally, shift operators could take up additional activities such as procedure writing, planning clearances, etc. It was estimated that at least 70% of the AO or field operator workload reduction is harvestable.

Estimated Total Annual Benefit = $489 million

Estimated Present Value of Benefit = $3.1 million

4.2.2 Reduction in Corrective Action Program Work

Discussion

The U.S. operating plants have reduced operator errors over the years through training and a variety human performance improvement practices. Yet, there remains a persistent level of error that, while relatively low by historical measures, results in a significant plant workload to deal with repercussions of the errors through the plant's Corrective Action Program (CAP). Indeed, most errors are inconsequential; however, the nuclear industry focuses on behaviors rather than results and therefore takes even near-misses very seriously. At times, errors have actual consequences such as plant trips and transients, reductions in safety margins, lost generation, and regulatory impacts. As consequences increase in severity, more and more process is applied through the CAP to recover from the plant impact (if required), determine the cause, apply corrective actions, and deal with external stakeholders such as the Nuclear Regulatory Commission (NRC) and the Institute of Nuclear Power Operations (INPO).

A modernized control room provides significantly better situational awareness for operators and control room supervisors than a traditional analog control room, which reduces certain types of control room errors. In addition, the new control room technologies offer human error prevention features that further reduce the likelihood that an operator will make an error.

All of the technologies that have been discussed contribute to this improved human performance environment. For example, a digital I&C system coupled with an advanced alarm system can distinguish real plant events from sensor failures, alert the operators and transition them to the correct alarm response procedure, and then transition them to the correct procedure (and case) to mitigate the plant upset. Task-based displays and overview displays provide an enhanced situational awareness for the operator and the entire control room crew. A comprehensive CBP system enables operators to know exactly how all operational and work activities are impacting the plant at a given time.

Computerized Operator Support Systems (COSS) can quickly validate events and diagnose the cause of the events so that operators are assured they are addressing the plant conditions in the right manner.

In this analysis, a portion of these errors are considered to be avoidable through these new control room technologies. As such, they represent an avoided cost in not having to conduct the prescribed CAP activities for the level of significance of these avoided errors. A conservative amount of CAP-related labor for these avoided errors has been estimated for the purpose of quantifying the benefit of this control room modernization opportunity.

Enabling Technology(s)

The following technologies enable reductions in corrective action program work:

- High Bandwidth Wireless Networks
- Mobile Devices
- Large Overview Displays
- Component Identification Technology
- Computer-Based Procedures
- Mobile Work Packages
- Task-Based Operator Displays
- Digital I&C System
- Advanced Alarm System
- Computerized Operator Support System (COSS)

Plant Functions or Programs Impacted

- Control room operations
- CAP Program

Calculation of Annual Benefits

[No of related condition reports (CR) x hrs to process x % avoided]

+ [No of CR resulting corrective actions x hrs to process]

+ [No of CR resulting in apparent cause evaluations x hrs to process]

+ [No of CR resulting in root cause evaluation x hrs to process]

Assumptions and Clarifications

- Assume 12 conditions reports related to control room operations are created of which 50% are avoided
- Of the remaining CRs, 12 result in corrective actions, 3 result in apparent cause evaluations and 1 results in root cause evaluations
- 4 hrs. to process each CR
- 10 hrs. to process each corrective action
- 20 hrs. per apparent cause evaluation
- 1500 hrs. per root cause evaluation

Estimate of Benefits

Annual Labor Savings (workload reduction in hours):

CAP: 1,644 hours

Harvestability: 100%

Estimated Total Annual Benefit = $144 thousand

Estimated Present Value of Benefit = $906 thousand

4.2.3 Reduced Critical Path Time during Outages

Discussion

There is potential to reduce critical path time during outages when Operations is controlling the critical path with proceduralized activities. This is opportunity is further qualified as proceduralized activities in which the pace of completing the procedure is governed by how quickly the steps can be completed as opposed to waiting on changing plant conditions, such as dilution mixing or plant heat-up.

Much of the front-end and middle portion of a typical outage does not lend itself to these savings. At the start of the outage, the pace is dominated by the plant cool-down rate and the time to reach the point where large work activities can be started is reached in 8-12 hours. From there on, the work activities typically control the critical path with the exception of some operations-dominated activities such as train swaps and integrated safety system tests.

However, at the back end of the outage there are periods of time where Operations is controlling the critical path. This is when the safety systems are aligned for operational status (for pressurized water reactors, Mode 4) and then beyond up to the point of reactor start-up and low-power operations. From there on, there is a period of reactor testing, followed by putting the generator on-line and then raising power to 100%. For the balance of plant systems, it is similar proceduralized activities to restore and align them for power operations.

In this critical path savings analysis, credit is restricted to the 36 hours that precedes Mode 4 (or equivalent), continuing through the plant heat-up to putting the reactor on-line. Even so, there are some pauses for testing that is outside the control room and so this is considered.

The credit for critical path reduction using an average procedure performance time reduction of 25%. The is considered to be a conservative and fair assessment in that surveillance testing and plant start-up procedures that lend themselves to the efficiency and human performance features that were discussed in the previous section.

Enabling Technology(s)

The following technologies enable reduced critical path time during outages:

- Digital I&C Systems
- Mobile devices
- High bandwidth wireless networks
- Mobile work packages
- Computer-based procedures

- Task-based displays
- Overview displays

Plant Functions or Programs Impacted

- CR and Field Operations
- Outage management (i.e., schedule analysis)
- Support organizations represented in OCC and satellite CCs

Calculation of Annual Benefits

[No of hours for restart (mode 4 to circuit breaker closure)/24 hours] x [No. of outages per year] x [Replacement power cost per day] x [Percent efficiency gain]

Assumptions and Clarifications

- 1.33 outages per year for two-unit plant on 18-month cycle
- Hrs. on critical path to restart plant controlled by operations is estimated at 84 hrs. (last 36 hrs. of Mode 5 to Mode 4, Mode 4 to reactor startup is 48 hrs.)
- Estimated that ops procedures can be run at minimum 25% more efficient
- Replacement power costs estimated at $400,000 per day
  [Note: This value could vary substantially among utilities (regulated vs. unregulated, etc.)]

Estimate of Benefits

Non-Labor Savings:

Replacement power costs: $467 thousand

Estimated Total Annual Benefit = $467 thousand

Estimated Present Value of Benefit = $2.9 million

4.2.4 Control Room Operation of Local Control Panels

Discussion

The original designs of control rooms for the operating nuclear plants were limited in several ways in how many functions could be brought into the control room. The cable and cabinet required to enable central control of all the plant components was cost-prohibitive. Therefore, only the important and frequently manipulated functions were included in the main control room. There was limited board space for these controls in keeping the control room to a manageable size from a human factors standpoint. Finally, there was a practical limit to the number of control boards you could reasonably have in the control room to have an orderly arrangement for the operators. For these and other reasons, less important functions were relegated to local control panels for which operators would travel to that plant location to operate them. Given that some systems require continuous monitoring while they are in operation, the operators must remain at that local control panel for that duration of operation.

For local control systems and control panels of analog technology, there is an opportunity to convert them to digital technology using a software-based control scheme operated through a digital display. Through a variety of techniques, it is possible to access these digital control displays from the main control room using the displays that are typically on the operators' desks. This also obviously true for local control panels that are already digital-based. These control functions could be integrated into the standard platform for the digital I&C systems (typically a DCS) or can remain as a separate system/platform and operated through the standard operator displays.

The opportunity here is for these functions to be operated from the control room by the control room operators, thereby avoiding having to send a dedicated operator out into the plant to conduct these control functions. This is especially valuable when an operator has to remain at that control station while that plant function is in operation. It is anticipated that the control room operators will have available time to take on these duties as a result of the time savings of other opportunities presented in this report.

In the cases where operators need to monitor physical conditions in the field associated with these local control panels, the use of wireless sensors and direct video streaming can, in some cases, address these concerns to permit remote operation.

Enabling Technology(s)

The following technologies enable control room operation of local control panels:

- Digital I&C Systems
- Task-based displays
- Large overhead displays

Plant Functions or Programs Impacted

- CR and Field Operations

Calculation of Annual Benefits

[No. of panels moved to CR per unit] x [No. of units] x [No. of ROs to operate panel] x [hours of to operate panel] x [no of times operated per year]

Assumptions and Clarifications

- Assume 10 panels per unit (20 for 2-unit plant) can be safely and efficiently operated from the control room
- Assume local operation ties up 2 ROs for one-hour operation (2 man-hours) per week 1.33 outages per year for two-unit plant on 18-month cycle

Estimate of Benefits

Annual Labor Savings (workload reduction in hours):

CR Operations: 2,080 hours

Harvestability: 100%

Harvestability of RO man-hours is highly dependent on plant circumstances, control room manning strategy, and licensing basis. A separate study would be required by a NPP to determine the flexibility of CR staffing in their organization. In some cases, a license amendment may be required. That said, it was estimated that 100% of the man-hour savings could be harvestable through reduction in augmented staff above regulatory requirements, or reduction in overtime

Estimated Total Annual Benefit = $155 thousand

Estimated Present Value of Benefit = $968 thousand

4.2.5 Computerized Operator Support Systems

Discussion

Nuclear plants occasionally encounter system and component faults whose cannot be immediately determined. This is not a safety concern because the plants use symptom-based procedures that enable the operators to take the plant to a safe state whether or not the specific cause of the fault is known. For example, there are a number of ways to detect and compensate for minor leakage of reactor coolant water without knowing exactly where in the system a component or pipe is leaking.

Once the plant is stabilized, either continuing to operate or requiring a shutdown, a trouble shooting and fault investigation effort begins, which can be quite involved and costly. Maintenance is typically the first responder with Engineering getting involved if the cause is not readily found. In these cases, Engineering will typically initiate a rigorous failure investigation process so that important facts are not missed or not fully understood. Because of the rigor and deliberate approach in these types of investigations, they tend to be very time consuming, resulting in some delay before the problem is finally diagnosed and addressed. In some cases, the plant remains in a degraded condition while this effort goes on.

Computerized operator support systems can, in many cases, immediately provide the fault diagnosis that would otherwise require these lengthy and expensive investigations. Examples include fluid leaks, component failures and mis-operation, and other component faults in which there is a change in energy balance across the system. They can identify sensor and instrument failures by detecting that there has been no actual change in the energy balances. Even if the exact cause is not determined, a COSS determine a boundary area for the location of problem.

Labor savings for this capability assumes there are 25 such problems in a year and 20% or five of these can be diagnosed by the COSS, thus saving the Maintenance and Engineering effort. These efforts can vary widely depending on the nature of the problem, so an average 120 work hours are assumed. In the other cases, the efforts are assumed to be 50% more efficient due to the technology.

Enabling Technology(s)

The following technologies enable computerized operator support systems:

- Digital I&C Systems
- Advanced Alarm Systems
- Task-based displays
- COSS

Plant Functions or Programs Impacted

- Operations
- Engineering
- Maintenance

Calculation of Annual Benefits

[No. of problems detected by COSS system per year] x [% fully diagnosed by COSS] x [Hrs. to troubleshoot and diagnose manually by team] + [No. of problems detected by COSS system per year] x [% partially diagnosed by COSS] x [Hrs. to troubleshoot and diagnose manually by team] x [efficiency factor]

Assumptions and Clarifications

Assuming 25 problems can be detected by COSS a year and that each problem impacts 120 hrs. (split between Main and Engineering 50/50). Of these problems, 20% (or 5) can be diagnosed completely by COSS, while troubleshooting for the remaining 80% will be 50% more efficient.

Estimate of Benefits

Annual Labor Savings (workload reduction in hours):

CR Operations: 1,800 hours

Harvestability: 100%

Estimated Total Annual Benefit = $133 thousand

Estimated Present Value of Benefit = $838 thousand

4.2.6 Reduced Control Room Support

Discussion

Implementation of large overview displays will enable the removal of certain types of legacy board display instruments that are not typically associated with the digital I&C system upgrades. Examples would be the replacement of conventional lightbox annunciator panels with digital displays that can mimic the lightbox display as well as more information-rich presentations of alarm information incorporating graphics and color. Another example is chart recorders. Many plants have upgraded to paperless chart recorders, but even these can potentially be replaced with software functions whose trends can be included on general purpose displays in a modernized control room. There are many other examples, such as radiation monitor displays, rod position displays, vibration monitoring displays, loose parts monitoring displays, etc. Display functions that are not required to be continuously visible can be displayed on demand or included in task-based displays when required by operational and testing evolutions.

As a conservative estimate of savings, 0.75 full time equivalent (FTE) of both engineering and maintenance resources are assumed for the ongoing support for the collection of devices that can be removed from the control boards due to the general displays available in a modernized control room. It is assumed that this support can be reduced by 90%, leaving a small residual for support of standard multipurpose displays.

By excluding in this calculation the much-larger engineering and maintenance support resources for those devices that will typically be removed in a digital I&C system implementation, the business case for the I&C upgrade is not affected nor are any savings double counted. Again, these savings are enable by expansive display devices that would be available in a modernized control room as opposed to an I&C upgrade.

Enabling Technology(s)

The following technologies enable reduced control room support:

- Digital I&C Systems
- Task-based displays
- Large overhead displays

Plant Functions or Programs Impacted

- Engineering
- Maintenance

Calculation of Annual Benefits

[Hrs per year I&C Engineering + hrs. per year I&C Maintenance] x [% workload reduction]

Assumptions and Clarifications

- 50% of one I&C Engineer's time is spent troubleshooting and maintaining obsolete instruments on CR panels
- 50% of one I&C Maintenance Technician's time is spent troubleshooting and maintaining obsolete instruments on CR panels
- Available hrs. per year is estimated at 1860 hrs.
- Estimate 90% of this workload is eliminated with modern configurable digital displays

Estimate of Benefits

Annual Labor Savings (workload reduction in hours):

CR Operations: 1,674 hours

Harvestability: 100%

Estimated Total Annual Benefit = $124 thousand

Estimated Present Value of Benefit = $779 thousand

4.2.7 Paperless Control Room Processes

Discussion

There is a significant amount of paper usage in the control room primarily due to the high use of procedures. Based on an average of 120 procedures a day, at an average of 40 pages per procedure, this amounts to nearly two million sheets of paper annually. In addition to the cost of paper, there are ancillary costs associated with ink and supplies, copy equipment purchases/leases/rentals, and personnel time to make these copies. Most of this paper has a very short useful life before it is either discarded or scanned and archived in digital form. There are other types of documents that are printed to support operations adding to the usage.

Paperless control room processes enabled by various CRM include the use of CBPs, task-based displays, and overview displays. Benefits include reduction in paper use and printer consumables as well as costly maintenance of high-capacity printers and plotters.

Enabling Technology(s)

- CBP/MWP
- High-Bandwidth Wireless Network
- Smart Devices (i.e., tablet, PDA)

Plant Functions or Programs Impacted

- Control Room Administrative Support

Calculation of Annual Benefits

[No of procedures processed per year] x [Hrs to process a procedure] + [(Estimated number of procedures executed per online day x No. of online days)] + (Estimated number of procedures executed per outage day x No. of outage days)] x [Number of pages per procedure] x [Cost of reproduction per page]

Assumptions and Clarifications

- Assume 3870 procedures processed per year by Administrative Assistant
- Estimate 15 minutes to process a procedure (reproduce, process and archive)
- Outage paper use:
    - 150 procedures per day
    - 40 pages per procedure
    - $0.10 per page (copier O&M)
    - 47 outage days per year (35 days x 1.33 outages per year)
- On-line paper use
    - 120 procedures per day
    - 40 pages per procedure
    - $0.10 per page (copier O&M)
    - On-line days = 365 – Outage days

Estimate of Benefits

Annual Labor Savings (workload reduction in hours):

CR Administrative Support: 908 hours

Harvestability: 100%

Estimated Annual Labor Benefit = $32 thousand

Annual Non- Labor Savings:

Online: $153 thousand

Outage: $29 thousand

Estimated Total Annual Benefit = $214 thousand

Estimated Present Value of Benefit = $1.3 million

5 SUMMARY RESULTS

5.1 Key Findings

The overall results provided by the BCM are positive. The addition of CRM technologies enhances the human interface and frees up operations to focus on operational control of the NPP. The study demonstrates the scale of savings that is achievable when digital technologies are applied to work processes to the benefit the NPP. Costly manual handoffs of information are reduced, communications are in real time, analysis is supported by analytical tools, and the risk of a costly outage extension is reduced through better management of the critical path operations. A summary of the annual savings is presented the table below:

Table 3: Estimated Total Annual Labor and Non-Labor Benefit of CRM

Benefit Type	Benefit ($000s)
Annual Labor Benefit:	$1,020
Annual Non-Labor Benefit:	$650
Total Annual Benefit:	$1,660

In all cases in this analysis where metrics were not available as a direct result of observation or data analysis, a conservative estimate was applied and validated with the participating NPP. While changes to the inputs would have a linear impact on the outputs, the results reported here are meant to show the lower bound and upside of the BCM as applied to a practical case.

5.2 Labor Savings

The data collected during development of the Opportunity Worksheet was used to complete the labor portion of the BCMW. In cases where work activities were insufficiently described in the Task Library, new tasks were defined in order to more precisely describe labor task savings are attributable to CRM technologies. The BCMW was used to convert efficiencies in terms of labor hours into dollar savings.

All labor savings identified and attributed to CRM were evaluated for harvestability. Harvestability is defined as the fraction of cost savings that can be taken as a budget reduction. Labor savings are only considered harvestable if it results in a reduction in work force.

The BCMW was used to process the efficiencies introduced by CRM to yield annual workload reduction of 21 thousand hours with a potential annual value of $1.43 million. After applying factors for harvestability, the estimated labor savings is $1.02 million. A summary of the labor savings by functional area for the CRM business case is illustrated in Figure 5 below.

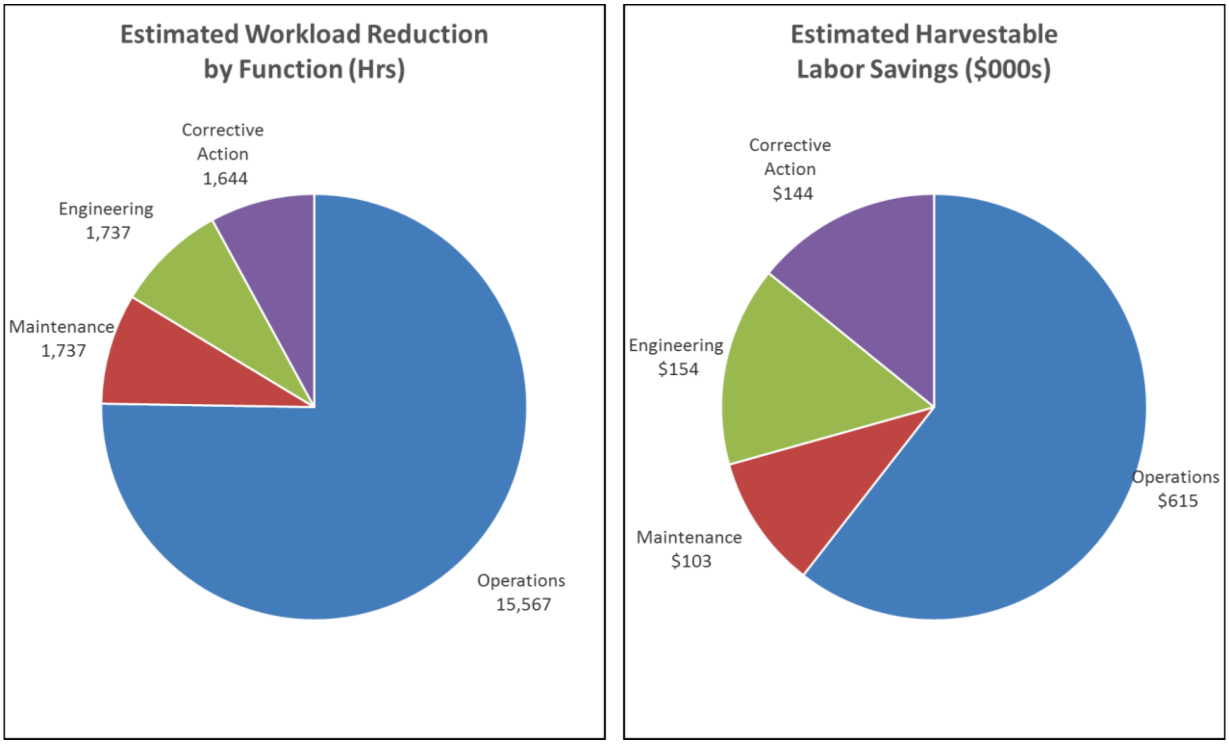


Figure 5: Workload Reduction and Harvestable Labor Savings by Function

5.3 Non-Labor Savings

Non-labor savings were largely estimated in two categories:

1. The elimination of paper from work processes
2. The avoidance of purchase of replacement power due to outage extension during plant restart

Paper savings were largely estimated as the elimination of printed work packages, drawings, schedule updates and meeting presentation materials, and the corresponding reduction of consumable office products that include but are not limited to paper, printer and plotter consumable supplies, printer and lotter maintenance. An all-in rate of 10 cents per standard sheet of paper was used as the cost of consumable produce paper deliverables.

Outage schedule adherence of critical path outage work and timely restart of the NPP allows the operator to avoid costly purchases of replacement power. Replacement power was roughly estimated as $400,000 per day for a two-unit plant.

Figure 6 below illustrates various categories of non-labor savings in relation to annual labor savings identified in the BCMW.

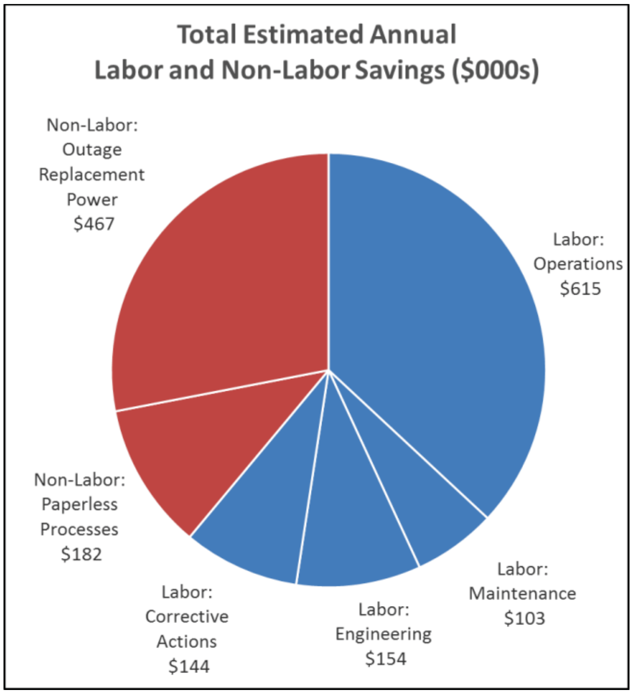


Figure 6: BCM Total Annual Savings

5.4 Estimation Present Value

For guidance purposes, a present value tool included in the BCMW was utilized to estimate the incremental present value of CRM. As the cost of the technology was not evaluated, the PV represents an approximate estimate of the investment that would produce a net zero value if NPV were utilized to evaluate a project. An investment lower than the present value would indicate a positive NPV project, while an investment higher than the present value would indicate a negative NPV project. The calculation assumes that the project benefits will not be fully realized until the third year of implementation at a discount rate of 10%. Discounting over a period of 15 years, the present value tool indicates that an investment of approximately $10.5 million in CRM technologies as part of a plant digital I&C upgrade would be supported by the estimated savings calculated in the business case.

Control Room Modernization
BCM Present Value

Discount Rate (Internal Rate of Return):		10%	
No. Years of Benefit:		15	years
Annual Benefit (Labor)	$	1.02	million
Annual Benefit (Non-Labor)	$	0.65	million
Annual Benefit (KPI)		n/a	million
Total Annual Benefit:	$	1.66	
First Year Realized Benefit:		3	
Estimated Net Zero NPV Investment:		$10.46	million

Figure 7: Business Case Annual O&M Benefits

6 DISCUSSION

In addition to the direct cost savings presented in prior sections, there are additional benefits that are important to the overall performance of an NPP and add significantly to the justification to pursue control room modernization. These benefits are briefly discussed below.

Nuclear Safety Improvement – Credit has been taken for avoided costs when control room modernization is shown to improve operator performance and thereby reduce some number of events that have been caused or complicated by operator error. Examples of these types of situations are documented in the INPO Significant Operating Experience Report (SOER) 10-02 related to operator board monitoring, problem diagnosis, and related decision-making. In addition to the cost savings, actual improvement in nuclear safety will be evident in other measures such as actual annual core damage probability, precursor events, etc.

Plant Performance and Public Perception – because of the transparency of nuclear operations, plant events become public information through a variety of means including NRC reporting requirements, emergency response plan notifications, utility press releases, and NRC public meetings. In addition to the cost savings in avoided plant events described in the Opportunity Section, there is an additional intangible benefit in an improved reputation and public perception of the plant due to fewer events, regardless of the safety significance of them. This would include the Nuclear Regulatory Commission (NRC), the Institute of Nuclear Power Operations (INPO), other regulatory agencies that could be concerned with certain operational events (FERC, EPA, OSHA, etc.), intervening organizations (e.g. UCS), and local stakeholders and communities. While not quantified in the business case, dealing with these entities in response to their concerns can be quite expensive as well as distracting in terms of ongoing operations. It ties up key managers and staff in activities that would better be avoided.

These events can have a cumulative effect that broaden the concerns and required responses by orders of magnitude, as in a situation where the plant's safety culture is called into question. This typically results in broad-based technical audits that inevitably raise additional questions that have to be addressed.

These events also provide opportunities for advocacy groups opposed to nuclear power to portray these events in an unfavorable light, particularly to the local public that is not technically equipped to understand their significance. There are numerous examples around the country where certain plants have had to undertake expensive public relations campaigns to counter this public messaging and restore public confidence in the safety of the plant.

The technologies described in this business case certainly do not address all of these concerns but they can definitely play a role in reducing the frequency and severity of events negatively impact the public perception of the plant.

Operator Job Satisfaction – Operator are keenly aware that typical NPP control rooms are based on outdated technologies that, while adequate to operate the plant and mitigate safety challenges, they are inferior in capability and operator assistance to the technologies they experience in their personal lives, including their automobiles, home electronics including computer games, appliances, personal computing devices, etc. This is particularly true of younger operators just entering the workforce who grew up in a digital world. Control room operators perform tedious tasks with little support and feedback from the technologies they are using. This adds to stress, mental workload, and mental fatigue. As has been seen in other industry sectors such as aviation and process plants, control room modernization has resulted in improved operator job satisfaction where technology has been implemented in a manner to make the operator more successful.

Operator Training Effectiveness – as has been proven in aviation and process industries, improved (Human System Interface) HSI allow operators to more quickly grasp the big picture of what is happening in the plant during various conditions. This improves initial training in that plant conditions can be more readily grasped as compared to having to develop patterns of control board scanning through repetitive practice for information among the vast number of discrete control board devices – and which devices to pay attention to in various scenarios.

Reduced Dose – Operational tasks are often performed in radiation areas in which field operators acquire a moderate amount of dose related to the frequency and duration of these activities. With control room technologies that allow procedures to be conducted more quickly and coordination with the control room to be conducted more efficiently, equipment operators will spend less time in these radiation areas and thus acquire proportionately less dose.

Improved Operator Turnovers – the same display technologies that assist operators during plant operations can also be used to conduct shift turnovers to review the overall plant status, focus on particular system alignments, and even “replay” certain plant evolutions of interest to convey a real understanding of what has transpired during the preceding shift. Obviously this would be conducted on a set of other than those in active use in the control room.

<u>Specific Key Performance Indicators (KPIs) Favorably Impacted</u>

Although new values for improved KPIs could not be calculated as part of this study, a number of KPIs are likely positively impacted by the use of digital technology as follows:

- Production Cost ($/Megawatt-Hour) –due to direct reduction of O&M expense related to field work activities.
- Unplanned Reactor Trips – due to improved human performance during operational and maintenance activities, avoiding component identification errors and procedure use and adherence errors.
- Safety System Performance – due to shorter job durations enabled by the efficiency features of the technology. This reduces unavailability time on important safety systems.
- Forced Loss Rate – due to improved human performance during operational and maintenance activities, similar to Unplanned Reactor Trips.
- Unit Capability Factor – due to fewer human performance-related generation losses and the potential for shorter refueling outages due to improved work coordination.
- Radiation Exposure – due to shorter job durations for work conducted in radiation areas, and the potential to reduce the number of additional workers on a job because of certain technology features, such as remote concurrent verifications.

7 CONCLUSION

The BCM was used to determine the value of CRM technologies if applied to a NPP. The business case presented in this report addresses the benefits of new digital technologies beyond the capabilities provided just by the modern digital I&C systems. A worksheet was developed to help the team work through how various technologies impact outage operations. The resulting findings were validated at a participating operating NPP and then applied to the BCMW quantify the value of benefits of CRM. During the course of the study, several techniques that were developed for conducting analysis of work were deployed and minor improvements were made to the BCMW itself.

The benefits of CRM were successfully quantified and the resulting NPV demonstrated that the continued development of the business case may be warranted as plants address obsolescence and reliability issues that are inherent to legacy analog I&C systems. In validating the BCM, the partner utility is provided with the basis for an internal business case for implementing these technologies based on identified work efficiencies that are harvestable through reduced contracted labor, overtime and possible headcount reductions over time. Additional non-labor savings were identified with improved capability to manage and optimize work processes. In addition, there are several soft benefits that can be realized with progressive adoption of digital I&C systems as exemplified in the prior discussion, such as nuclear safety improvement, plant performance, public perception and operator job satisfaction, among others.

In addition to the direct cost savings identified in the BCMW, there are additional benefits that are important to the overall performance of an NPP and add significantly to the justification to pursue a digital modernization of the control room:

- Nuclear safety
- Plant performance
- Public perception
- Operator job satisfaction
- Training effectiveness
- Reduced dose
- Improved operator turnover

Finally, although not credited financially in the BCMW, there are a number of KPIs that are likely positively impacted with the adoption of CRM technologies, particularly those related to plant performance and human factors.

Through publication of the findings and the BCMW, the nuclear industry is provided with a sample business case for CRM technologies that can be adopted as a template for pursuing a similar independent evaluation for implementation.

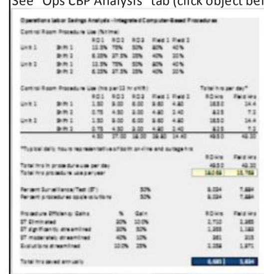
8 REFERENCES

1. Thomas, K., Lawrie S., Vlahapolis, C., and Hart, A., 2014, Digital TechnologyBusiness Case *Methodology Guide*, INL/EXT-14-33129, Idaho National Laboratory.
2. Thomas, K., Lawrie S., Vlahapolis, C., and Niedermuller, J., 2015, *Pilot Project Technology Business Case: Mobile Work Packages*, INL/EXT-15-35327, Idaho National Laboratory.
3. Thomas, K., Lawrie S., , and Niedermuller, J., 2016, *A Business Case for Advanced Outage Management*, INL/EXT-16-38265, Idaho National Laboratory.
4. B. Hallbert and K. Thomas, Advanced Instrumentation, Information, and Control Systems Technologies Technical Program Plan for FY 2016, INL/EXT-13-28055 Revision 4, October 2015
5. St. Germain, S., Thomas, K., Joe, J., Farris, R., 2014, *Status Report on the Development of Micro-Scheduling Software for the Advanced Outage Control Center Project*, INL/EXT-14-33036, Idaho National Laboratory.
6. Rusaw, R., 2009, *EPRI's Implementation Guideline for Wireless Networks and Wireless Equipment Condition Monitoring*, Report No. 1019186, Electric Power Research Institute, Palo Alto, CA.
7. St. Germain, S., Farris, R., Whaley, A., Medema, H., Gertman, D., 2014, *Guidelines for Implementation of an Advanced Outage Control Center to Improve Outage Coordination, Problem Resolution, and Outage Risk Management*, INL/EXT-14-33182, Idaho National Laboratory.
8. Thomas, K., Boring, R., Lew, R., Ulrich, T., Vilim, R., 2013, *A Computerized Operator Support System Prototype*, INL/EXT-13-29651, Idaho National Laboratory

Appendix A

Opportunity Worksheet

Control Room Modernization - Opportunity Worksheet

#	Introduced Capability	Description of Opportunity	Enabling Technologies	Proposed Benefits	Functions and/or Programs Improved	Annual Savings Calculation	Affected Task(s)	Potential Annual Labor Benefit (hrs.)	Annual Non-Labor Benefit (x$1,000)
1	**Integrated Computer-Based Procedures** Concurrent execution of computer based operating procedures between field and reactor operators (including supervision, verification and sign on/off) through use of shared real-time computer based procedures.	CR procedures will be shared with field operators. Integrated communications will enable quicker completion of shared tasks. Will eliminate the need to consolidate CR and field copies of procedures. Some procedures rely on more than one operator due to the expanse of the boards. Call up of task based displays in control room for selected plant evolutions which consolidate required plant data into a single view. Task-Based Displays provide a compact display of all needed indicators and control actions, enabling one operator to perform the task. Notifications to site support groups can be built directly into the procedures such that notifications happen automatically allowing for timely execution of procedures (reduced wait times)	• High Bandwidth Wireless Networks • Mobile Devices • Large Overview Displays • Component Identification Technology • Computer Based Procedures • Mobile Work Packages • Task-Based Operator Displays • Digital I&C System	> Man-hours saved during execution of procedure based activities *Note:* Harvestability of RO man-hours is highly dependent on plant circumstances, control room manning strategy, and licensing basis. A separate study would be required by a NPP to determine the flexibility of CR staffing in their organization. In some cases, a license amendment may be required.	Control Room Operations Field operator support (AO)	***Calculation:*** [Time (hrs.) spent by control room operators and field support executing control room operations, surveillances and tests] x [efficiency factors for evolutions/STs] ***Assumptions and Clarifications:*** See "Ops CBP Analysis" tab (click object below) 	OP.A.1 OP.A.135b OP.B.1 OP.B.135b	12,519	
2	**Reduction in Corrective Action Program Work** Reduction in number of human errors and reportable events as a result of direct communications from plant systems and guided procedures.	CBPs will ensure adherence to procedural requirements and verify correct plant response. Interconnected technologies will guide the operator from recognition of a condition to the correct procedural response. Automated collection of plant data, performance of calculations and final test results can be provided to the operator on a task based screen and/or entered directly into the CR procedures from data systems, eliminating scribing errors, and need for verification and sign-offs	• High Bandwidth Wireless Networks • Mobile Devices • Large Overview Displays • Component Identification Technology • Computer Based Procedures • Mobile Work Packages • Task-Based Operator Displays • Digital I&C System • Advanced Alarm System • Computerized Operator Support System (COSS)	> Reduction in CAP hour and remediation training > Avoided costs (manhour savings) associated with investigation and analysis and implementation due reduction in number of certain events	Corrective Action Program (CAP)	***Calculation:*** [No of CR related condition reports x hrs. to process x % avoided] + [No of corrective actions x hrs. to process x % avoided] + [No of apparent cause eval x hrs. to process x % avoided] + [No of root cause evaluation x hrs. to process x % avoided] ***Assumptions and Clarifications:*** > Assume 12 conditions reports related to control room operations are created of which 50% are avoided > Of the 6 CRs remaining, 6 result in corrective actions, 3 result in apparent cause evaluations and 1 results in root cause evaluations > 4.0 hrs. per CR > 10 hrs. per CA > 20 hrs. per ACE > 1500 hrs. per RCE	CA.A.126a CA.A.126b CA.A.127 CA.A.128	1,644	
3	**Reduced Critical Path Time During Outages**	CBP will allow operations to execute mode 4 to start up critical path activities more efficiently, reducing the outage duration Notifications to site support groups can be built directly into the procedures such that notifications happen automatically allowing for timely execution of procedures (reduced wait times)	• High Bandwidth Wireless Networks • Mobile Devices • Large Overview Displays • Component Identification Technology • Computer Based Procedures • Mobile Work Packages • Task-Based Operator Displays • Digital I&C System	> Replacement power costs *Note:* Savings is sensitive to plant situation and market conditions (i.e., regulated vs. unregulated markets) *Note:* Although not credited as a benefit, some plants may consider and take credit for a portion of contracted and outage labor held over for work that can only be done during power ascension (e.g., steam/turbine related systems, isolation valves)	Outage Operations (Plant shutdown and restart procedures)	***Calculation:*** [No of hours for restart (mode 4 to circuit breaker closure)] x [No. of outages per year] x [Replacement power cost per day] x [Percent efficiency gain] ***Assumptions and Clarifications:*** > 1.33 outages per year for two unit plant on 18 month cycle > Hrs. on critical path to restart plant controlled by operations is estimated at 84 hrs. (last 36hrs of Mode 5 to Mode 4, Mode 4 to reactor startup is 48 hrs.) > Estimated that ops procedures can be run at minimum 25% more efficient > Replacement power costs estimated at $400,000 per day [*Note: This value could vary substantially among utilities (regulated vs. unregulated, etc.)]*	Non-labor - Replacement Power		$467

Control Room Modernization - Opportunity Worksheet

#	Introduced Capability	Description of Opportunity	Enabling Technologies	Proposed Benefits	Functions and/or Programs Improved	Annual Savings Calculation	Affected Task(s)	Potential Annual Labor Benefit (hrs.)	Annual Non-Labor Benefit (x$1,000)
4	**Control Room Operation of Local Control Panels**	For local control systems and control panels that are of analog technology, there is an opportunity to convert them to digital technology at the end of their useful lives, resulting in a software based control scheme operated through a digital display. Moreover, it is possible to access these digital control displays from the main control room by creating remote access to them, as is common in digital technology today. This would be true whether these local control functions were operating on the standard plant control platform (such as a DCS) or remained in another system and were just brought up in a window on the operator's console.	• Digital I&C Systems • Task based displays • Large overhead displays	Labor savings (RO does not need to travel out to field/operation may be executed by a single operator)	Control Room Operations	***Calculation:*** [No. of panels moved to CR per unit] x [No. of units] x [No. of ROs to operate panel] x [hours of to operate panel] x [no of times operated per year] ***Assumptions and Clarifications:*** > Assume 10 panels per unit (20 for 2 unit plant) can be safely and efficiently operated from the control room > Assume local operation ties up 2 ROs for one hour operation (2 man-hours) per week	OP.B.6	2,080	
5	**Computerized Operator Support Systems**	Computerized operator support systems can in many cases provide the fault diagnosis that requires Maintenance and Engineering resources. Examples include small leaks and other component faults in which there is a change in energy balance across the system. Even if the exact cause is not determined, a COSS determine a boundary area for where the problem.	> Large overhead displays > Digital I&C Systems > Advanced Alarm Systems > Computerized Operator Support System	Reduction in Engineering and Maintenance manpower currently used for troubleshooting	Engineering Maintenance (I&C)	***Calculation:*** [No. of problems detected by COSS system per year] x [% fully diagnosed by COSS] x [Hrs. to troubleshoot and diagnose manually by team] + [No. of problems detected by COSS system per year] x [% partially diagnosed by COSS] x [Hrs. to troubleshoot and diagnose manually by team] x [efficiency factor] ***Assumptions and Clarifications:*** Assuming 25 problems can be detected by COSS a year and that each problem impacts 120 hrs. (split between Main and Engineering 50/50). Of these problems, 20% (or 5) can be diagnosed completely by COSS, while troubleshooting for the remaining 80% will be 50% more efficient	MA.A.99 EN.C.99	1,800	
6	**Reduced Control Room Support** Simplified engineering, configuration, troubleshooting and maintenance of instrumentation and controls through elimination of outdated and obsolete MCP components	> Maintenance labor for testing, troubleshooting, and repairing MCB devices will be eliminated where digital control and display systems replace them > Engineering time to qualify replacement parts, respond to Part 21 Notifications, reverse engineer unobtainable parts, etc. will be eliminated where digital control and display systems replace these devices. > A number of functions that today have to be performed by Engineers can be configured by the Operators, such as turning a malfunctioning alarm to a dark state.	> Large overhead displays > Digital I&C Systems > Advanced Alarm Systems > Computerized Operator Support System	> Plant risk in on line maintenance and testing > Elimination of maintenance induced failures > Elimination of as-left configuration errors > Direct manhour savings and cost of parts > Engineering hours > Reduction in temp mods to resolve control and indication problems	Engineering Maintenance (I&C) Procurement	***Calculation:*** [Hrs per year I&C Engineering + hrs. per year I&C Maintenance] x [% workload reduction] ***Assumptions and Clarifications:*** > 50% of one I&C Engineer's time is spent troubleshooting and maintaining obsolete instruments on CR panels > 50% of one I&C Maintenance Technician time is spent troubleshooting and maintaining obsolete instruments on CR panels > Available hrs. per year is estimated at 1860 hrs. > Estimate 90% of this workload is eliminated with modern configurable digital displays	EN.A.92 MA.A.145	1,674	
7	**Paperless Control Room Processes**	Many administrative tasks in supporting records requirements for control room activities will not be required in a digital control room. Examples are archiving procedures, archiving paper from recorders, etc. This also includes reductions in paper usage.	> High bandwidth wireless network > Mobile Work Packages (MWP) > Computer Based Procedures (CBP) > Task Based Displays integrated with plant data systems	> Reduction in CR Administrative Support > Reduction in paper and reproduction costs	Non-labor paper Ops Admin Support	***Calculation:*** [Estimated amount of paper used in control room (online + outage)] x [Cost of reproduction per sheet] + [Estimated Admin time to process procedures and work packages] ***Assumptions and Clarifications:*** > 3870 packages per year (per MWP study) > 15 minutes processing time per package	Non-labor On-line Non-labor Outage OP.D.46a	968	$182

Appendix B

Labor Cost Savings by Key Work Category

Labor Costs (Internal Labor, Overtime, Contractor Spend)									Approximate Base Organization Site Size (FTEs)		
Functional Area		Key Work Categories	Total Estimated Savings (person hrs)	Total Estimated Savings (x $1,000)	Are savings harvestable? (Yes/No)	% Harvestable	Total Estimated Savings (FTEs)	Total Estimated Harvestable Savings (x $1,000)	1 Unit	2 Unit	3 Unit
Operations	OP.A.	Perform Field Operations	5,834	$ 345	Yes	75%	2.1	$ 259	27	33	40
	OP.B.	Conduct Control Room Operations	8,765	$ 649	Yes	50%	2.1	$ 324	30	40	50
	OP.C.	Support Work Management	-	$ -			0.0	$ -	5	6	11
	OP.D.	Perform Planning Activities	-	$ -			0.0	$ -	5	6	10
	OP.E.	Perform Support Activities	968	$ 32	Yes	100%	0.5	$ 32	15	19	27
	OP.F.	Participate in Training	-	$ -			0.0	$ -	11	14	20
Maintenance	MA.A.	Perform Maintenance Activities	1,737	$ 103	Yes	100%	0.8	$ 103	85	140	175
	MA.B.	Support Outage Oversight	-	$ -			0.0	$ -	85	140	175
	MA.C.	Support Work Management	-	$ -			0.0	$ -	4	7	9
	MA.D.	Perform Planning Activities	-	$ -			0.0	$ -	18	30	37
	MA.E.	Perform Support Activities	-	$ -			0.0	$ -	22	37	46
	MA.F.	Participate in Training	-	$ -			0.0	$ -	10	16	20
	MA.G.	Calibrate Maintenance & Test Equipme	-	$ -			0.0	$ -	2	3	4
	MA.H.	Oversee Maintenance Program Implem	-	$ -			0.0	$ -	2	3	4
Work Management	WM.A.	Manage Online Work	-	$ -			0.0	$ -	9	10	13
	WM.B.	Manage Outage Work	-	$ -			0.0	$ -	6	7	9
	WM.C.	Manage Risk and Safety	-	$ -			0.0	$ -	1	2	2
	WM.D.	Perform Support Activities	-	$ -			0.0	$ -	5	8	11
Radiation Protection	RP.A.	Provide job coverage	-	$ -			0.0	$ -	11	13	15
	RP.B.	Maintain records	-	$ -			0.0	$ -	4	5	7
	RP.C.	Maintain equipment	-	$ -			0.0	$ -	6	8	11
	RP.D.	Package/control Radwaste	-	$ -			0.0	$ -	5	8	10
	RP.E.	Plan Exposure of Jobs (ALARA)	-	$ -			0.0	$ -	4	6	8
	RP.F.	Training Activities	-	$ -			0.0	$ -	5	7	9
Chemistry & Environmental	CY.A.	Sample Systems	-	$ -			0.0	$ -	8	9	13
	CY.B.	Data Evaluation and Trending	-	$ -			0.0	$ -	6	7	9
	CY.C.	Operate and Maintain Equipment/Syste	-	$ -			0.0	$ -	2	2	3
	CY.D.	RETS/REMP Program Monitoring	-	$ -			0.0	$ -	3	3	4
	CY.E.	Training Activities	-	$ -			0.0	$ -	3	3	5
Engineering	EN.A.	Perform Engineering activities	837	$ 74	Yes	100%	0.4	$ 74	36	43	52
	EN.B.	Monitor and report	-	$ -			0.0	$ -	15	17	19
	EN.C.	Perform Support Activities	900	$ 80	Yes	100%	0.4	$ 80	37	40	46
	EN.D.	Training Activities	-	$ -			0.0	$ -	2	2	3
Training	TR.A.	Conduct Training	-	$ -			0.0	$ -	21	25	28
	TR.B.	Oversee Accreditation	-	$ -			0.0	$ -	6	7	8
	TR.C.	Perform Support Activities	-	$ -			0.0	$ -	8	10	13
	TR.D.	Training Activities	-	$ -			0.0	$ -	4	5	6
Performance Improvement	PI.A.	Track and Trend Performance	-	$ -			0.0	$ -	4	5	7
	PI.B.	Perform Support Activities	-	$ -			0.0	$ -	4	5	6
Security & Access	SY.A.	Maintain Physical Security	-	$ -			0.0	$ -	180	190	200
	SY.B.	Control Access Authorization	-	$ -			0.0	$ -	7	8	9
	SY.C.	Oversee Maintenance Program Implem	-	$ -			0.0	$ -	5	6	7
Procedures	PR.A.	Manage procedure/program documents	-	$ -			0.0	$ -	10	13	16
Emergency Preparedness	EP.A.	Develop and Conduct Drills	-	$ -			0.0	$ -	3	4	5
	EP.B.	Perform Support Activities	-	$ -			0.0	$ -	2	3	4
Corrective Action Program	CA.A.	Process Condition Reports	1,644	$ 144	Yes	100%	0.8	$ 144	10	13	19
	CA.B.	Process Outage Related Events	-	$ -			0.0	$ -	10	13	19
	CA.C.	Monitor and manage records	-	$ -			0.0	$ -	5	7	8
		Total Savings:	20,685	$ 1,426			7.1	$ 1,016	768	1008	1232

Total Harvestable Annual Savings (person hrs)	**Total Harvestable Annual Savings (x $1000)**	**Total Unharvestable Annual Savings (person hrs)**	**Total Unharvestable Annual Savings (x $1000)**	**Total Harvestable Savings (FTEs)**	
14,844	$ 1,016	5,841	$ 411	7	

Appendix C

Labor Cost Savings Summary Report

Labor Cost Savings Summary Report

#	Task Number	Functional Area	Work Category: Task	Est FTE Savings	Est Labor Savings (x $1,000)	Basis for Calculation	Key Enabling Technologies
1	OP.A.1.	Operations:	Perform Field Operations: > Conduct operator actions (stroke valves, start pumps, realign systems, etc.)	0.95	$ 117	Item (1) from Opportunity Worksheet: Based on estimated hours of field operators performing procedural activities in conjunction with RO's, work to perform evolutions is estimated to be 25% more efficient with CBP and related technologies. See tab titled "Ops CBP Analysis" for more detail	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications
2	OP.A.135b.	Operations:	Perform Field Operations: > Conduct surveillances and tests	1.86	$ 229	Item (1) from Opportunity Worksheet: Based on estimated hours of field operators performing procedural activities in conjunction with RO's, work to perform STs is either eliminated through digital communications (30%), made significantly more efficient (30% of STs 50% more efficient), or moderately streamlined (40% of STs 10% more efficient) with CBP and related technologies. See tab titled "Ops CBP Analysis" for more detail	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications
3	OP.B.1.	Operations:	Conduct Control Room Operations: > Conduct operator actions (stroke valves, start pumps, realign systems, etc.)	1.09	$ 167	Item (1) from Opportunity Worksheet: Based on estimated hours RO's performing procedural activities in the Control Room, work to perform evolutions is estimated to be 25% more efficient with CBP and related technologies. See tab titled "Ops CBP Analysis" for more detail	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications
4	OP.B.135b.	Operations:	Conduct Control Room Operations: > Conduct surveillances and tests	2.13	$ 328	Item (1) from Opportunity Worksheet: Based on estimated hours of RO's performing procedural activities in conjunction in the Control Room, work to perform STs is either eliminated through digital communications (30%), made significantly more efficient (30% of STs 50% more efficient), or moderately streamlined (40% of STs 10% more efficient) with CBP and related technologies. See tab titled "Ops CBP Analysis" for more detail	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications
5	OP.B.6.	Operations:	Conduct Control Room Operations: > Operate Equipment/Systems	1.00	$ 154	Item (4) of Opportunity Worksheet: Estimated 20 control panels (10 per unit) can be replicated on task based displays to operate remotely from Control Room. Calculation of savings based on eliminating field time calculated as 2 RO's spending one hour to execute field operation once per week on average for each panel	Task based displays and CBP features that allow operators to conduct remote operation of local control panels from CR
6	OP.E.46a.	Operations:	Perform Support Activities: > Print and assemble work packages	0.47	$ 32	Item (6) of Opportunity Worksheet: 3870 work packages for surveillances and tests @ 15 minutes each to process by an Admin (including printing, scanning and archiving)	CBP features that eliminate the need to have paper versions of procedures, automated filing and storage of data, verifications and sign-offs
7	MA.A.99.	Maintenance:	Perform Maintenance Activities: > Participate in troubleshooting activities	0.43	$ 53	Item (5) of Opportunity Worksheet: of estimated 25 problems that a COSS system can identify, 5 of these can be fully diagnosed by the system, and 20 of these can be efficiently diagnosed by a team with greater efficiency (50%). Each diagnosis is assumed on average to take up 120 man-hours, evenly split between Engineering and Maintenance.	COSS, Digital I&C Systems, Advanced Alarm Systems
8	MA.A.145.	Maintenance:	Perform Maintenance Activities: > Install/remove temp mods (instrumentation, jumpers) for testing/maintenance	0.40	$ 50	Item (7) of Opportunity Worksheet: Estimate that 50% of an I&C Technician's time is spent troubleshooting, repairing, and replacing obsolete components in Main Control Room. 90% of this activity can be eliminated with the introduction of a modern control room design with digital controls, displays and instrumentation.	Replace CR components with modern DCS, annunciators, chart recorders, misc. components and circuitry
9	EN.A.92.	Engineering:	Perform Engineering activities: > Design Modifications/Change Requests	0.40	$ 74	Item (7) of Opportunity Worksheet: Estimate that 50% of an I&C Engineer's time is spent troubleshooting, repairing, and replacing obsolete components in Main Control Room. 90% of this activity can be eliminated with the introduction of a modern control room design with digital controls, displays and instrumentation. (Note that a DCS on it's own does not necessarily address all HSI in Control Room)	Replace CR components with modern DCS, annunciators, chart recorders, misc. components and circuitry
10	EN.C.99.	Engineering:	Perform Support Activities: > Participate in troubleshooting activities	0.43	$ 80	Item (5) of Opportunity Worksheet: of estimated 25 problems that a COSS system can identify, 5 of these can be fully diagnosed by the system, and 20 of these can be efficiently diagnosed by a team with greater efficiency (50%). Each diagnosis is assumed on average to take up 120 man-hours, evenly split between Engineering and Maintenance.	COSS, Digital I&C Systems, Advanced Alarm Systems
11	CA.A.126a.	Corrective Action Program:	Process Condition Reports: > Processing condition reports	0.01	$ 2	Based on typical 1 operator error per month. Assumed 12 Condition Reports (CR) per year for a 2 unit station. Estimate 4 hrs. per report and elimination of 50 percent of reports avoided due to DCS together with CBP features	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications, digital placekeeping and procedural checks
12	CA.A.126b.	Corrective Action Program:	Process Condition Reports: > Conduct Corrective Actions for Condition Reports	0.03	$ 4	Assumed 6 condition reports result in required corrective actions. Estimate 50 hrs. per CR for corrective actions and elimination of 10 percent of CRs due to DCS together with CBP features	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications, digital placekeeping and procedural checks
13	CA.A.127.	Corrective Action Program:	Process Condition Reports: > Apparent Cause Evaluations	0.03	$ 4	Assumed 3 condition reports result in apparent cause evaluations. Estimate 20 hrs. per evaluation and elimination of 50 percent of CRs due to DCS together with CBP features	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications, digital placekeeping and procedural checks
14	CA.A.128.	Corrective Action Program:	Process Condition Reports: > Root Cause Evaluations	0.72	$ 133	Assumed 1 condition report results in root cause evaluations. Estimate 1500 hrs. per evaluation and elimination of 50 percent of CRs due to DCS together with CBP features	General CBP features, especially concurrent execution, automated data input to data sheets, computations and verifications, digital placekeeping and procedural checks
15		:					