A BUSINESS CASE FOR NUCLEAR PLANT CONTROL ROOM MODERNIZATION

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ABSTRACT

This paper presents a generic business case for implementation of technology that supports Control Room Modernization (CRM) in existing nuclear power plants (NPPs). The business case is based on advanced digital instrumentation and control (I&C), human-system interface (HSI), and work process technologies that allow NPP operators to conduct control room operations with improved human factors and efficiency, and therefore operate with fewer operational events. Labor savings can be harvested in terms of reduced 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, providing directional guidance to NPPs that are interested in developing similar business cases.

The technologies employed in CRM include large overview displays, task-based operator displays, computer-based procedures, advanced alarm systems, computerized operator support systems, and wireless networks, among others.

The CRM business case is founded on the following categories of cost savings:

- Integrated Computer-Based Procedures for Operators
- Reduction in Corrective Action Program Work Due to Operator Error
- Reduction in Outage Critical Path Time
- Operation of Local Control Panels
- Reduction in Control Room Support
- Reduction in Plant Events Resulting in Generation Loss
- Paperless Control Room Processes

In addition to cost savings, these technologies also offer improvements to indirect ways that have impact on key performance indicators of the plant.

Key Words: Control Room Modernization, Business Case, Instrumentation and Control

1 INTRODUCTION

Business cases for control room modernization have proven to be difficult. There has been no systematic basis for enumerating and quantifying the benefits of control room modernization. This has resulted in some plants forgoing the operator interface improvements when implementing digital I&C technology. The return on this investment has not been apparent, and therefore nuclear utilities have typically elected to interface new digital I&C systems to the same or similar discrete components on the control boards, and operate them in the same manner as before.

This paper describes the development of a new methodology to quantify the business case benefits for control room modernization. This work is being conducted in collaboration with Arizona Public Services' Palo Verde Nuclear Generating Station (PVNGS) and is being conducted under the U.S. Department of Energy's (DOE) Light Water Reactor Sustainability (LWRS) Program. Within the LWRS Program, it is part of a pilot project with PVNGS to pursue control room modernization in association with the station's Strategic Modernization Program for selected I&C systems.

The business case is being developed in two phases. The first phase is described in this paper and addresses the benefits that are available from the improvements in modernizing the control room. This phase addresses the benefits in control room upgrades that are enabled by advanced digital I&C systems and well as new operator interface technologies. However, it does not address the additional benefits that can be obtained from the digital I&C systems by themselves. Rather, a later phase of the project will look at these additional benefits from the underlying digital I&C systems in addition to the control room modernization benefits.

2 BUSINESS CASE DEVELOPMENT

A generic methodology to determine the value of digital technologies applied to an NPP was previously developed by ScottMadden Management Consultants for the LWRS Program. It is documented in INL report Digital Technology Business Case Methodology (BCM) Guide, INL/EXT-14-33129 [1]. This included an accompanying BCM Workbook (customized spreadsheet) that enables the quantification of benefits across all benefiting station organizations. It has been used in previous projects to develop business cases for other advanced digital technologies in the areas of mobile work packages and advanced outage management technologies, as documented in a previous report by ScottMadden entitled. More recently, it has been used in a study to quantify the benefits for control room modernization as documented in INL report INL/EXT-16-39098, A Business Case for Nuclear Plant Control Room Modernization [2].

The results of the study were investigated and validated with PVNGS, and then compiled in a BCM Workbook to quantify the total expected value of benefits which could be obtained from advanced hybrid control room modernization. The benefits are presented in Section 5 of this paper.

3 ENABLING CONTROL ROOM TECHNOLOGIES

The work efficiencies credited in the business case are based on a set of enabling control room technologies are deployed to support targeted operational tasks. Some are commercially-available today while others are the subject of ongoing research and development efforts to bring them to a production-ready state. These technologies are aggregated in various ways to support standard work processes performed by operators and operational support staff. These enabling technologies are:

Hardware

- Advanced digital I&C platforms
- High-bandwidth wireless networks
- Mobile devices
- Large overview displays
- Component identification technology
- Mobile wireless video cameras

Software

- Computer-Based Procedures
- Mobile Work Packages
- Task-based operator displays
- Digital I&C systems
- Advanced alarm systems
- Computerized Operator Support Systems

4 COST SAVINGS OPPORTUNITIES

Control room modernization provides various opportunities for cost savings both in the control room and in operational support functions. Using a BCM Workbook, a set of opportunities were defined and investigated with knowledgeable plant staff to determine the labor savings and other forms of benefits that can be derived from them.

The first step in the process was to identify those opportunities in three categories:

1. Examination of how operators spend their time at present, including operational control of the plant, conducting operational testing, and authorizing and directing the work of support groups.

2. Examination of the work efforts of the support groups

3. Consideration of capabilities of emerging digital technologies.

The following paragraphs describe the cost savings opportunities that were identified for this business case.

4.1 Integrated Computer-Based Procedures for Operators

Computer-based procedures (CBP) and task-based displays help operators conduct plant evolutions quicker and more accurately. They provide the plant information in a concise form that is tailored to the task being conducted. They allow the control room operator to share procedures with field operators in a manner that improves communications. Conducting evolutions more efficiently frees up operators to tend to other types of duties, and therefore can reduce the labor burden on the control room, leading to reduced staffing requirements where there is license flexibility to do so. Benefits derived from computer-based procedures were previously documented in report Pilot Project Technology Business Case: Mobile Work Packages, INL/EXT-15-35327 [3].

4.2 Reduction in Corrective Action Program Work Due to Operator Error

A modernized control room provides significantly better situational awareness for operators and control room supervisors than a traditional analog control room, which leads to a reduction in certain types of operator errors. New control room technologies offer human error prevention features that further reduce the likelihood that an operator will make an error. 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 to mitigate the plant upset. Task based displays and overview displays can provide an enhanced situational awareness for the operator and the entire control room crew. A comprehensive computer-based procedure (CBP) system can enable operators to know exactly how all operational and work activities are impacting the plant at a given time.

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 and the Institute of Nuclear Power Operations.

A portion of these errors can be prevented through use of these new control room technologies. As such, they represent an avoided cost in not having to conduct the required CAP activities that would otherwise be undertaken for these types of errors.

4.3 Reduction in Outage Critical Path Time

There is potential to reduce critical path time during outages when Operations is controlling the critical path for the duration of procedure-based activities. This opportunity is further qualified as procedure-based 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.

At the back end of the outage, there are periods of time when Operations dominates the critical path. That is when the safety systems are being aligned for operational status (for example, preparation for Mode 4 for pressurized water reactors), continuing through plant heat-up and reactor start-up. This is followed by reactor testing, putting the generator on-line, and then conducting the power ascension and related testing to 100% power. Portions of these operational activities lend themselves to improved efficiency translating to critical path time savings.

4.4 Operation of Local Control Panels

Local control systems and control panels with analog technology present an opportunity for conversion 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 controls from the main control room using the common HSI on the operators' desks. Local control panels that are already digitally-based are even easier to convert. These control functions can be integrated into a digital I&C platform (typically a distributed control system (DCS)) or can remain a separate system/platform but operated through the common operator HSI.

The opportunity here is for these functions to be operated from the main 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. In most cases, the control room operators will be able to monitor these remote processes while they conduct other control room activities.

4.5 Reduction in Control Room Support

Ongoing support of plant I&C systems, including the control room HSI, requires a substantial engineering effort. Component failures often require engineering support in troubleshooting and cause determination. In traditional I&C circuits, with logic devices (relays), interlocks, and other circuit devices scattered through any number of panels, connected by an array of cables, the troubleshooting effort to determine which component is defective can be quite involved and time-consuming. This also entails some amount of risk of disturbing unrelated circuits that could trip the reactor or cause other spurious operations.

Considerable engineering support time is spent dealing with obsolescence and reliability issues, addressing them with substitute components using equivalence evaluations, commercial dedications, and design changes. At times, acceptable spare parts cannot be obtained and so they have to be reverse-engineered and specially manufactured at considerable cost.

There is also the day-to-day support of dealing with control room deficiencies, such as maintaining a "blackboard" approach to alarm panels in which failed alarms are not allowed to be illuminated when they are not in alarm state. Other workarounds are sometimes required to support ongoing operations when there are control and indication failures.

As a larger problem, the nuclear industry is dealing with a shrinking supplier base as the original system and component suppliers have focused their product lines on broader markets and have integrated digital technologies into their components. So, in these cases, while spare parts are actually available, the introduction of embedded digital devices means the utility will have to undergo expensive digital qualification of the devices to use them. Conversely, there is a group of suppliers emerging to provide analog replacement circuit components, but these devices are very costly (due to the limited market) and provide none of the benefits of digital technology in reducing operational costs.

As an alternative to a design largely based on discrete analog components, control room modernization enables the removal of a large number of discrete components driving these escalating support requirements, replacing them with software, digital components, and digital display devices. These systems are software based, meaning that they don't degrade in the manner of discrete devices. They are easier to troubleshoot and they have internal diagnostic and health monitoring capabilities that enable them to self-report problems.

Similar to the reduced engineering costs, there will be reduced maintenance costs due to the conversion of plant I&C systems to standard digital platforms. This will include routine preventative maintenance, troubleshooting and repair activities, as well as the development, fabrication, and installation of modifications when the current configuration cannot be supported.

Digital I&C systems also enable the elimination of certain classes of periodic testing, both for safety systems for technical specification compliance and for non-safety systems. Other types of maintenance and testing can be simplified due to the digital technology, such as channel calibrations.

Control room modernization will reduce the number of spare parts that must be maintained due to the elimination of many discrete devices that are replaced by the digital systems. Analog control systems have a many unique devices that are replaced with software functions in a digital system.

Finally, control room operators will be able to perform some minor maintenance functions themselves rather than having to rely on the maintenance organization for analog control circuits. An example would be taking an alarm out of service when it is invalid due to a field component failure. Also, there will be no need for maintenance to install jumpers to support certain off-normal requirements. Rather, these options can be built directly into the I&C system software for operator control options.

4.6 Reduction in Plant Events Resulting in Generation Loss

This opportunity for savings addresses generation losses with an historical basis that are preventable due to the higher reliability of the digital I&C platforms or the improved human performance of the operators due to control room modernization. It is recognized that Palo Verde has an advantage over most plants with its reactor power cutback system that allows the reactor to remain at power even during events that require a power runback such as a turbine trip or a feedwater perturbation. In some cases, these upsets can result in a reactor trip and a forced outage. Still, these result in generation losses for the time it takes to stabilize the plant, investigate and repair the failure, investigate the human error, and return the plant to full load.

Control room modernization is expected to improve operator performance in event detection, diagnosis, and mitigation. The plant's history of events where there were shortfalls in operator performance will be examine to see if they can realistically be reduced or eliminated with the technology improvements of a modernized control room. This includes consideration of improved human factors for earlier awareness and understanding of the changing plant conditions, immediate queuing of the required alarm response and mitigation procedures, and more expeditious progress through these procedures to turn the transient or off-normal condition in the desired direction, where possible. One such technology is described in a previous INL report, A Computerized Operator Support System Prototype, INL/EXT-13-29651 [4], which provides assistance to the operators in plant monitoring, fault diagnosis, and fault mitigation.

The combination of I&C and control room modernization technologies can lead to improved capacity factors due to a lower forced loss rate, as well as the occurrence of consequential plant events.

4.7 Paperless Control Room Processes

There is a significant amount of paper usage in control room operations, maintenance, testing, records, and other plant support functions. Much of this is due to the volume of procedure use, although there are many other paper-intensive processes used by the operators. Digital I&C systems along with control room modernization, and the automation of related support functions, have the potential to create a paperless work processes, resulting in higher work efficiency along with the cost and environmental benefits of decreased paper usage. Use of paper processes are generally more inefficient and bulky to conduct, especially when an operational activity requires a number of procedures to be used simultaneously.

As an example, based on an average of 120 procedures a day, at an average of 40 pages per procedure, this amounts to nearly 2 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 after being scanned and archived in digital form. There are other types of documents that are printed to support operations adding to the usage.

Another substantial benefit is automated data entry and single point manual data entry. Today, when operators record data in procedures, that data is frequently transposed by personnel throughout the plant into other formats for other reports. Digital systems, including computer based procedures, and a seamless digital environment, allow that data to be captured automatically and distributed to whatever report needs that data, also automatically.

5 DATA COLLECTION

Data collection for this project involved conducting a set of interviews at PVNGS with key organizational contacts who were familiar with the nature and frequency of the operational and support work activities. It was stressed to all involved that this was an exercise to determine the theoretical best business case afforded by applying these technologies to the selected cost savings opportunities, and did not necessarily reflect an intent by PVNGS to pursue them.

In each of the interviews, the research team reviewed with the PVNGS organizational contacts how the technologies could assist in the conduct of the related work activities and together the team worked to determine the correct work efficiency factors to apply. These efficiency factors were multiplied over the total number of occurrences per year of each of the work activities to determine the total annualized benefit. Other types of benefits were also noted and recorded, such as an expected reduced rate of human error and reduced efforts in the corrective action program when such errors occur.

The data for all of the cost savings opportunities was entered into a BCM Workbook to determine the total savings. Industry-typical labor rates were applied to the labor savings to convert them to dollars. Other non-labor savings, such as replacement power costs and paper savings were estimated using industry-typical factors and were added as part of the total cost savings.

The logic for all of the cost savings was entered into the BCM Workbook to preserve the basis of the efficiencies and to serve as guidance for other NPPs who might want to apply the methodology. The formula for each cost savings calculation was similarly recorded in the BCM Workbook.

In addition, all labor savings identified in BCM Workbook 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. That said, the non-harvestible labor savings still represent an opportunity for operational improvement, such as having more time for operators to conduct oversight functions, which in turn improve the quality of plant operations.

6 RESULTS

The resulting total value of the efficiencies and avoided costs of CRM opportunities was an annual workload reduction of approximately 21,000 hours, equal to $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.

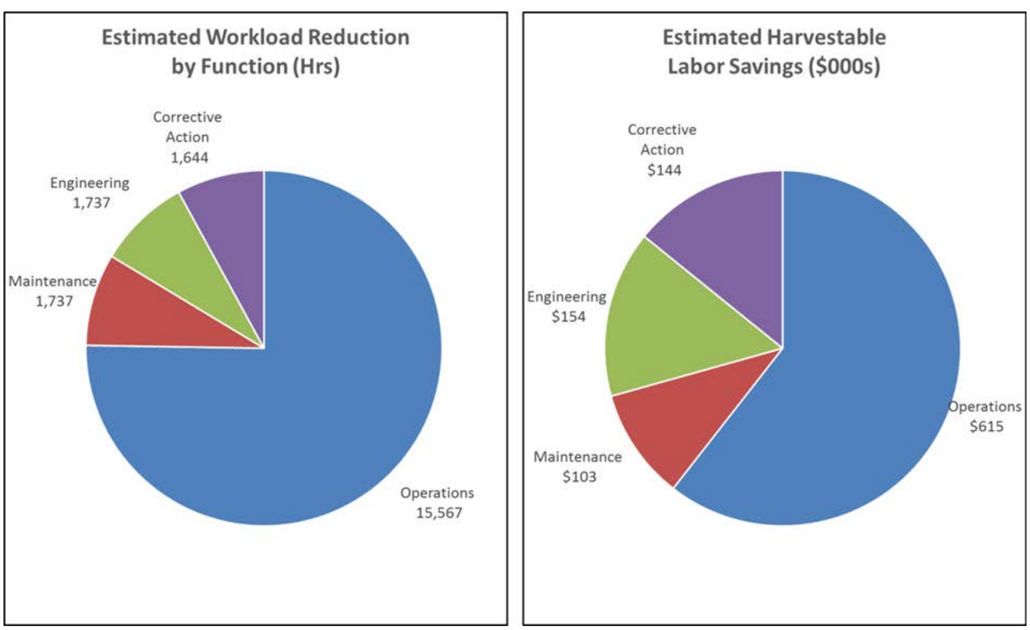

Figure 1: Workload Reduction and Harvestable Labor Savings by Function

Non-labor savings were largely estimated in two categories:

1. The elimination of paper in work processes
2. The avoidance of purchase of replacement power due to outage extension

Once again, it should be noted that the savings factors used were industry-typical figures since this was meant to be a generic business case and not necessarily representative of PVNGS.

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.

Additionally, reduction in critical path time allows the plant to avoid costly purchases of replacement power. Replacement power was roughly estimated as $400,000 per day for an out-of-service nuclear unit. It is recognized that replacement power cost is a concept germane to a vertically-integrated, regulated utility as opposed to a merchant plant. For merchant plants, the daily value of the plant output as representative of critical path time could be higher.

Figure 2 below illustrates various categories of non-labor savings in relation to annual labor savings identified in the BCMW.

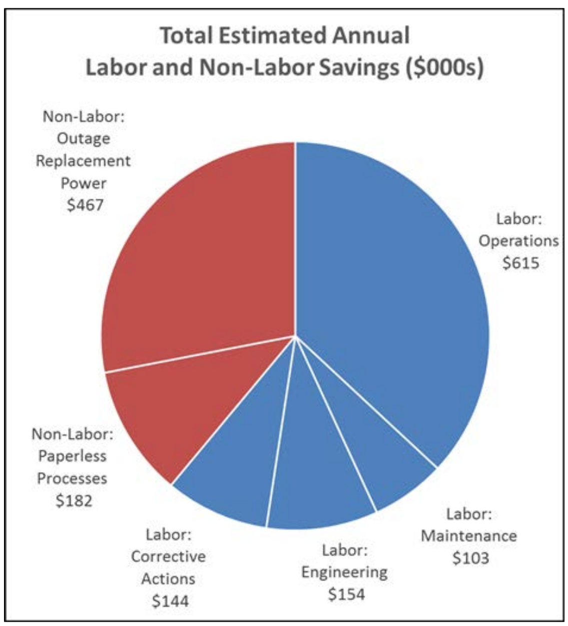

Figure 2: BCM Total Annual Savings

For projecting the cost savings over time, a present value (PV) calculation, as shown in Table 1, was utilized to estimate the incremental PV 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 net present value (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 NPV calculation 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.

Table 1: 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

7 IMPROVEMENT IN KEY PERFORMANCE INDICATORS

In addition to the direct cost savings represented by the CRM opportunities, 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, 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.

8 NEXT STEPS

The next step to work with PVNGS to apply this generic business case to the actual scope of their current program to upgrade certain I&C systems and modernize the control boards related to these systems in the main control room. This will be an expanded effort compared to the generic business case in that it will consider the cost savings potential inherent in the I&C system upgrades themselves and not just how they enable benefits in control room modernization. For example, advanced digital control systems have capabilities to conduct self-testing, eliminating the need for certain surveillance tests. These types of savings were not captured in the generic control room modernization business case, but will be in this future effort. Moreover, this new effort will consider two levels of control room modernization: 1) an advanced hybrid control room (mixture of analog and digital retaining the current control board layout) and 2) a fully-integrated control room (compact operator consoles with large overview displays), similar to new nuclear plants.

As the first step, a business case framework is being developed that will enumerate the specific categories of savings that are enabled by the scope of the PVNGS Strategic Modernization Program. Then, an effort will be conducted to quantify these benefits using station-specific cost and efficiency factors. This will be similar to investigative work for this generic business case, consisting of a new round of more detailed interviews supplemented by more thorough analysis of plant data sources (e.g. work schedules, operations procedure use history, etc.).

9 CONCLUSIONS

This paper describes a new methodology for achieving what has been an elusive goal; that is, to define a business case for control room modernization. Based on a sound methodology, it is possible to systematically determine the broad array of benefits that accrue to operations and the plant support organizations through the deployment of advanced digital technologies. While this is an ongoing work, there is reason to believe that a compelling business case will emerge to pursue control room modernization for operating nuclear plants. Future results will be made known to the industry through the LWRS Program publications in support of industry efforts to reduce nuclear operating costs and extended operating life.

10 ACKNOWLEDGMENTS

The authors thank the Palo Verde Nuclear Generating Station staff for their outstanding support of this project.

This paper was made possible through funding by the U.S. Department of Energy (DOE) Light Water Reactor Sustainability (LWRS) Program. We are grateful to Richard Reister of the DOE and Bruce Hallbert and John Wagner of Idaho National Laboratory (INL) for their support of this effort.

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