INL/EXT-17-42604
Rev. 0

# Light Water Reactor Sustainability Program

## Development of an Initial Business Case Framework for Fleet-Based Control Room Modernization

July 2017

DOE Office of Nuclear Energy

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# Development of an Initial Business Case Framework for Fleet-Based Control Room Modernization

Chris Adolfson, Kenneth Thomas, and Jeffrey C. Joe

July 2017

Idaho National Laboratory
Idaho Falls, Idaho 83415

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

# ABSTRACT

This milestone report presents a plan or framework for developing a generic business case for the implementation of technologies that support Control Room Modernization (CRM) in existing nuclear power plants (NPP). The decision to fund CRM activities often depends on demonstrating actual cost reductions that can be credited to budgets and thereby truly reduce operations and maintenance (O&M) or capital costs. The proposed Business Case Methodology (BCM) thus addresses the fact that the lack of a business case is often cited by utilities as a barrier to pursuing large-scale CRM activities.

Using past BCM analyses for CRM [1, 3] as a model for this framework, this BCM proposes to base cost savings 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. 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, but this initial plan will also focus only on a subset of these technologies. Thus, under this BCM model, labor savings can be harvested in terms of reduced overtime and redistribution of work. In short, the BCM addresses the benefits of the technology instead of just the investment costs to the utility. The methodology provides the means to determine the maximum investment that will result in a positive return. 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 utilities currently collaborating with the Department of Energy (DOE) Light Water Reactor Sustainability (LWRS) Program, and other NPPs that are interested in developing similar business cases.

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# ACRONYMS

| | |
|---|---|
| BCM | Business Case Methodology |
| CAP | Corrective Action Program |
| CBP | Computer Based Procedures |
| COSS | Computerized Operator Support System |
| CRM | Control Room Modernization |
| DCS | Distributed Control System |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| HSI | Human System Interface |
| FERC | Federal Energy Regulatory Commission |
| I&C | Instrumentation and Controls |
| INL | Idaho National Laboratory |
| INPO | Institute of Nuclear Power Operations |
| KPI | Key Performance Indicators |
| LWRS | Light Water Reactor Sustainability |
| NPP | Nuclear Power Plant |
| NRC | Nuclear Regulatory Commission |
| O&M | Operations and Maintenance |
| SOER | Significant Operating Experience Report |
| U.S. | United States |

# Development of an Initial Business Case Framework for Fleet-Based Control Room Modernization

## 1. Introduction

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

In other words, these technology enhancements, while addressing technological obsolescence issues, often fail to eliminate workload such as reducing 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 report describes the initial plan to develop this methodology to quantify the business case benefits for control room modernization. Within the U.S. Department of Energy's (DOE) Light Water Reactor Sustainability (LWRS) Program, past pilot projects in control room modernization have developed and used a standard methodology for determining the impact of new technologies in order to assist NPP operators in building sound business cases. This is plan is also being developed in collaboration with a partnering utility under the LWRS Program. Specifically, this milestone report presents a plan or framework for developing a generic business case for implementation of technology that supports CRM for Exelon's Braidwood and Byron nuclear power plants (NPPs).

The business case that is being purposed for further development as the collaboration with Exelon proceeds addresses the benefits that are available from improvements in modernizing the control room. The benefits in control room upgrades are enabled by advanced digital I&C systems as well as new operator interface technologies. The CRM business case will explore the feasibility of saving costs through implementing Computerized Operator Support Systems (COSS) for Operators, and as a result having COSS in the main control room, further realize:

- Reductions in Corrective Action Program Work Due to Operator Error
- Reductions in Control Room Support
- Reductions in Plant Events Resulting in Generation Loss

That is, in addition to cost savings, technologies such as COSS also offer improvements and opportunities in indirect ways that have impact on staffing and key performance indicators of the plant. This will be explored further in this business case analysis.

# 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. The 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 Key Performance Indicators (KPIs). Key to those impacts will be identified where the savings are “harvestable,” meaning they result in an actual reduction in headcount and/or cost.

This BCM 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. 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 BCM consists of six steps:

1. Identify Utility Common Practices
2. Define Model Inputs/Variables
3. Determine Key Business Output Measures
4. Build Business Case Model
5. Perform Input/Variable Sensitivity Analysis
6. Present Business Case Ranges

The outcome of the BCM is a robust financial analysis of the costs and benefits associated with the adoption of a new technology on a nuclear site.

The plan is to perform the six steps of the BCM with Exelon, including compiling BCM Workbook to quantify the total expected value of benefits that could be obtained from developing and installing an advanced hybrid control room modernization, and then validating the result of the methodology with other Exelon independent reviewers.

## 2.1 Background: Enabling Control Room Technologies

The following sections describe BCM in greater detail, in particular the various potential control room technologies that enable cost savings. While not every one of these control room technologies are currently envisioned as being implemented in the Braidwood and Byron control rooms, for the sake of completeness a, summary of all potential technologies is provided in this section.

At the core of BCM, the work efficiencies credited in the business case are based on a set of enabling control room technologies that 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. Operators and operational support staff aggregate these technologies in various ways to support standard work processes performed. 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**

- CBPs
- Mobile Work Packages
- Task-based Operator Displays
- Digital I&C Systems
- Advanced Alarm Systems
- COSS

## 2.2 Cost Savings Opportunities

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

The first step in the process is to identify 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 potential cost savings opportunities for Exelon.

### 2.2.1 Computerized Operator Support Systems

As described in a previous Idaho National Laboratory (INL) report, A Computerized Operator Support System Prototype, INL/EXT-13-29651 [5], a COSS provides assistance to the operators in plant monitoring, fault diagnosis, and fault mitigation. Specifically, a COSS is a collection of technologies to assist operators in monitoring overall plant performance and making timely, informed decisions on appropriate control actions for the projected plant condition. 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. That is, the control room operating crew typically follows a general pattern in reacting to a plant fault as follows.

- Detection – recognizing the symptoms of a plant fault
- Validation – determining that the symptoms are the result of a real plant fault and not a sensor failure
- Diagnosis – determining the specific plant fault
- Mitigation – either correcting or isolating the plant fault such that it is no longer a threat to plant operations or nuclear safety
- Monitoring – monitoring the symptoms of the plant fault to ensure that the mitigation has been successful
- Recovery – restoring the plant to the pre-fault conditions.

A well-designed COSS can assist an operator at each stage of the fault response sequence to reduce workload and confirm important information. Table 1 illustrates the functions of a COSS as it assists an operator in responding to a COSS.

**Table 1: COSS Functions**

| Step | COSS Function |
|---|---|
| Detection: | Detect a plant anomaly before an operator would notice it. This could actually be in the noise-level of the instrument signal and long before it would be noticeable as a parameter trend or reach an alarm set point. |
| Validation: | Determine whether an apparent fault is real or caused by a sensor failure by cross-checking related plant parameters and calculating whether the sensor in question is reading correctly. |
| Diagnosis: | Determine what type of fault would explain the values of the related sensors once they had been validated as reading correctly. This is based on using various means to model the expected behavior of a plant system. This could also include physics-based models that perform calculations for mass and energy balances to accurately determine where the fault condition must be. In other words, the plant system model is compared to the validated readings of the actual plant to precisely locate the point of deviation from expected behavior. The COSS could provide a graphical depiction of the fault to the operator for quick comprehension of the nature of the situation. |
| Mitigation: | Determine if there is a successful mitigation for the plant fault other than putting the plant in a safe condition (e.g., manual reactor trip prior to automatic protective actions). If so, the appropriate procedure could be displayed for the control room crew to begin actions. The COSS either allows the operator to execute the procedure in the normal manner, time permitting, or directly executes the relevant sections of the procedure as a script. |
| Monitoring: | Determine whether the plant parameters indicating the apparent fault are trending towards values that indicate that the fault has been mitigated, and inform the operator that the mitigation actions are being effective. |
| Recovery: | Direct the operator to the appropriate recovery procedures based on the extent of the plant upset due to the fault. An example would be determining the volume of fluid lost during a leak to know the magnitude of the make-up requirement. Another example would be determining the time available to remain in an emergency plant configuration, such as relying on batteries until normal power is restored. |

Clearly, the development of COSS could prove to be enormously beneficial to existing nuclear plants. The improvement in the management of plant upsets, improved operator performance, and ultimately overall system performance should make a positive impact on the industry’s fundamental objectives in the areas of nuclear safety, production, and cost management. Developing a business case for this would help establish a technical basis for these conjectures.

### 2.2.2 Reductions 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 (NRC) and the Institute of Nuclear Power Operations (INPO).

A portion of these errors can be prevented through use of these new control room technologies, including COSS. 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.

### 2.2.3 Reductions in Control Room Support

Ongoing support of plant I&C systems, including the control room Human System Interface (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 do not 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.

CRM 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.

### 2.2.4 Reductions 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 CRM. For example, it is recognized that some utilities have an advantage over most plants with its reactor power cutback system that allows reactors 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, this results 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. Exploration with Exelon as to whether any of their reactors have this type of reactor power runback system would be identified. If so, the opportunity for cost saving from the reduction in plant events resulting in generation loss would be explored.

CRM 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 examined 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, the COSS [5, 6] was described above.

### 2.2.5 Integrated Computer-Based Procedures for Operators

CBPs 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. Additional details can be found in report Pilot Project Technology Business Case: Mobile Work Packages, INL/EXT-15-35327 [4].

### 2.2.6 Operation of Local Control Panel

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.

### 2.2.7 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.

### 2.2.8 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, the 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.

### 2.2.9 Additional Indirect Benefits

There are additional indirect benefits that can be realized through CRM and potentially quantified in BCM. However, these indirect benefits would need to be considered on a case-by-case basis. These indirect benefits are described in greater detail in Appendix A.

# 3. Proposed Data Collection

The plan for data collection is that it would involve conducting a set of interviews at Exelon with key organizational contacts that are familiar with the nature and frequency of the operational and support work activities. It is stressed to all involved that this would be an exercise to determine the theoretical best business case afforded by applying technologies to the selected cost savings opportunities, and do not necessarily reflect an intent by Exelon to pursue them.

In each of the interviews, the research team would review with the Exelon organizational contacts how the technologies could assist in the conduct of the related work activities and together the team would work to determine the correct work efficiency factors to apply. The efficiency factors are 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 would also be 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 would be entered into a BCM Workbook to determine the total savings. Industry-typical labor rates would be applied to the labor savings to convert them to dollars. Other non-labor savings, such as replacement power costs and paper savings would be estimated using industry-typical factors and would be added as part of the total cost savings.

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

In addition, all labor savings identified in BCM Workbook would be 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.

Thus, the next step is to work with Exelon 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.

As the first step, a business case framework will be developed that will enumerate the specific categories of savings that would be enabled by the scope. Then, an effort will be conducted to quantify benefits using station-specific cost and efficiency factors. This will be similar to investigative work for a 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.).

Furthermore, because Braidwood and Byron are nearly identical in their design, Exelon is in process of performing the same digital upgrade to the control rooms at both stations, albeit in a staggered/step-wise fashion. That is, there are 4 units in total receiving the same digital upgrade, but Exelon is doing the upgrade on one unit first (i.e., the lead unit), with the remaining three units on a staggered project schedule to receive their upgrades in succession. Thus, while the initial estimated benefits calculated through the BCM analysis will be for the scope of their current program to upgrade the I&C systems in one NPP unit, it is recognized that the analysis will need to be adjusted to account for the same upgrade occurring at 4 units in succession. Given this situation, the harvestable cost savings could very well be multiplied by a factor of 4, and possibly greater than 4, if it is further assumed that the investment costs to install the same digital upgrade across 4 units goes down as cost efficiencies are realized with lessons learned being passed on from the lead unit to the others following in succession.

Further discussion with ScottMadden is needed to consider the additional cost-savings for performing digital upgrades in a fleet-based context, as the BCM is currently set up for single until CRM activities.

# 4. Next Step: Develop a Case Study of an New Enabling Technology for Exelon – Computerized Operator Support System

After the BCM is performed on the scope of Exelon's current I&C and control boards upgrade program, an additional BCM is planned to be performed to evaluate the cost feasibility of Exelon adding a COSS to the Braidwood and Byron control rooms. COSS is envisioned to be a likely control room upgrade for Exelon, given the scope of their current control room upgrades. Furthermore, all nuclear plants occasionally encounter system and components faults whose cause(s) 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.

COSS 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 determines a boundary area for the location problem.

## 4.1 BCM Analysis of a Hypothetical Installation of COSS

For this particular case study, example data from the INL BCM Guide, INL/EXT-14-33129 [1], were used, but modified accordingly for the assumptions for this analysis. Harvestable labor savings for installing a COSS capability assumes there are 25 difficult to detect and/or diagnose problems in a year and 20% or five of these can be detected and 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.

### 4.1.1 Enabling Technologies

The following technologies enable COSS:

- Digital I&C Systems
- Advanced Alarm Systems
- Task-based Displays
- CBPs
- Intelligent Fault Detection and Diagnosis Capabilities [6]

### 4.1.2 Plant Functions or Program Impacted

- Operations
- Engineering
- Maintenance

### 4.1.3 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]*

### 4.1.4 Assumption and Clarification

Assuming 25 problems can be detected by COSS a year and that each problem impacts 120 hours. (split between Maintenance 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.

### 4.1.5 Estimate of Benefits

Annual Labor Savings (workload reduction in hours): CR Operation: 1800 hours

Harvestability: 100%

Estimated Total Annual Benefit = $133 thousand

Estimated Present Value of Benefits = $838 thousand

## 4.2 Long Term Plans

As this LWRS-utility collaboration continues to flourish, future BCM analyses will broadly consider multiple phases of follow-on CRM activities, such as a BCM for an advanced hybrid control room (mixture of analog and digital retaining the current control board layout) and then eventually a BCM for a fully-integrated control room (compact operator consoles with large overview displays), similar to new nuclear plants.

# 5. Conclusion

This report describes a methodology for achieving what has historically been an elusive goal: to define a business case for CRM. Based on a sound methodology, the BCM makes it 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. That is, by focusing on the benefits of the technology instead of just the investment costs to the utility, the BCM allows utilities to more carefully consider improving the operator interface through digital upgrades to the main control room, instead of foregoing them altogether, or performing like-for-like replacements that do not reduce Operations and Maintenance (O&M) costs (e.g., Reduce operator workload or staffing levels).

One hypothetical CRM activity that was explored in this report was the cost savings potential of implementing COSS at a single unit, under the assumption that this is a likely upcoming control room upgrade for Exelon, our utility partner in this LWRS collaboration. As this collaboration develops further, it is also likely that this BCM analysis will need to assume the same digital upgrade is occurring in succession to multiple units over time. As such, given this difference from how BCMs have been performed previously for other utilities, the goal of performing this hypothetical analysis was to be well positioned to perform the more formal BCM prior to our work with Exelon entering this phase of the collaboration, and to provide a foundation for future BCM technical bases/analyses for fully-integrated advanced digital control rooms.

# 6. Acknowledgements

This milestone report 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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# 8. Appendix A: Additional Indirect Benefits

There are additional benefits that are important to the overall performance of an NPP and that can add significantly to the justification to pursue control room modernization:

**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 NRC, INPO, other regulatory agencies that could be concerned with certain operational events (FERC, EPA, OSHA, etc.), intervening organizations (e.g. Union of Concerned Scientists), 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 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.

In addition to the direct cost savings represented by the CRM opportunities, there are a number of KPIs that are likely to positively be impacted by the use of digital technology:

**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.