INL/RPT-23-74724
Revision 0

Light Water Reactor Sustainability Program

Development of a Technical, Economic, and Risk Assessment Framework for the Evaluation of Work Reduction Opportunities

September 2023

U.S. Department of Energy

Office of Nuclear Energy

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Development of a Technical, Economic, and Risk Assessment Framework for the Evaluation of Work Reduction Opportunities

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September 2023

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Prepared for the
U.S. Department of Energy
Office of Nuclear Energy

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ABSTRACT

Efficient and cost-effective operation of a nuclear power plant (NPP) is essential to ensuring long-term economical and safe operation. Multiple cost saving opportunities exist, referred to here as work reduction opportunities (WRO). These WROs reduce plant operating costs by employing various cost-effective strategies (e.g., implementation of modern technologies). Identifying and objectively screening WROs is an essential task to help reduce overall costs. However, there is no comprehensive framework for assessing WROs in the nuclear industry and evaluating their impact on plant operations. This report presents a novel framework for systematically evaluating WROs from a technical, economic, and risk perspective.

As NPPs continue to add new technology and implement modernization strategies into their current processes, potential WROs are commonly identified. Although most WROs have the potential to reduce costs, not all opportunities will result in significant cost savings due to unforeseen risks, large implementation costs, or benefits that fall short of expectations. Examples of this can be the result of a technology that is not fully developed, uncertainty in the amount of cost reduction, or difficulties introducing a new process into an organization. These uncertainties can manifest several ways and can result in a WRO with limited cost savings or even a loss of investment. The framework developed emphasizes the importance of effectively screening the WROs from a holistic perspective to objectively identify inefficiencies and ensure a positive impact to the organization.

This report presents the Technical, Economic, and Risk Assessment (TERA) as a key methodology for the screening and evaluation of potential WROs. The TERA framework begins with a screening phase where the process is examined through a hybrid combination of Lean Six Sigma and Integrated Operations for Nuclear (ION) guiding principles. This framework examines the current processes using the Lean Six Sigma SIPOC (Suppliers, Inputs, Process, Outputs, Consumers) methodology but retains the ION key elements of People, Technology, Process, and Governance as important factors to the nuclear decision-making process. By combining the principles of Lean Six Sigma and ION, the developed screening process is specific to the nuclear industry in that it systematically evaluates WROs in order to implement new technology that is comprehensively evaluated.

The TERA begins by mapping current processes as they relate to WROs and examining the inefficiencies. Furthermore, the created process map can be used to identify and evaluate potential solutions. Using key performance indicators (KPIs), the TERA evaluates each area—technology, economics, and risk—for uncertainties and to perform cost-benefit analysis. The results of the TERA are important KPIs that allow for an evaluation of different processes and technology implementations. This assessment enables decision-makers to compare various WROs based on metrics and then make informed decisions for which opportunity to implement first.

This research includes not only the creation of the TERA framework, but also the evaluation of its performance. A case study for screening potential WROs at Southern Nuclear Company is presented that utilizes the TERA methodology. Through the use of TERA, various WROs were screened, and the solutions evaluated for cost-benefit expectations.

The report concludes by summarizing the overall effort and implications for utility modernization. The performance of the screening and TERA are discussed as well as the impact on the nuclear industry. The TERA process enables utilities to evaluate and inform investment decisions for WROs and mitigate any potential risks. Through this research, we provide utilities with a valuable framework to optimize operations, reduce costs, and drive continuous process improvement.

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ACRONYMS

AI	Artificial Intelligence
ANSI	American National Standards Institute
CAPCO	Corrective Action Program Coordinator
CDF	Core damage frequency
CR	Condition Report
CR	Condition Report
EU	European Union
FIN	Fix-it-now
FMEA	failure modes and effect analyses
HFE	Human Factors Engineering
HFES	Human Factors and Ergonomics Society
HRL	Human Readiness Level
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
ION	Integrated Operations for Nuclear
IRIS	International Research Integration System
IRT	Issue Response Team
IT	Information Technology
IT	Information Technology
KPI	Key Performance Indicators
LERF	Large early release frequency
LWRS	Light Water Reactor Sustainability
ML	Machine Learning
NPP	Nuclear Power Plant
NPV	Net Present Value
OE	Operational Experience
OE	Operational Experience
OPEX	Operational Expenditure
ORL	Organizational Readiness Level
OSHA	Occupational Safety and Health Administration
PM	Preventative Maintenance
PRA	Probabilistic Risk Analysis
PTPG	People, Technology, Process, Governance

SIPOC	Suppliers, Inputs, Process, Output, Consumer
SNC	Southern Nuclear Company
SSC	Structures, Systems, and Components
TERA	Technical, Economic, and Risk Assessment
TRL	Technology Readiness Level
WO	Work Order
WRO	Work Reduction Opportunity

1. INTRODUCTION

Nuclear power plants (NPPs) have been operational for nearly four decades or more. These NPPs are initiating or continuing to modernize by using advancements in digital technologies, to ensure long-term safe and economical operation. Through these modernization and digitalization strategies, NPPs are presented with opportunities to identify several work reduction opportunities (WROs) that could result in significant cost saving (once implemented) and has the potential to synchronize the data, information, and decision flow; thereby reducing inefficiencies in the process that exist today. WROs are also important for integrated operations for nuclear (ION), which aims to address the modernization gap by providing a sustainable business model and developing technology modernization solutions. For details on ION, see Section 2.

Formally, WRO can be described as a chance to enhance operational efficiency and reduce workload through process improvements or technological advancements. Additionally, WROs are also likely to reduce human factors errors. Several WROs have been identified that include condition-based maintenance, automated planning and scheduling, AI condition report analysis, and others. A collection of 37 WROs, which constitute projects included in the ION business model, is described and analyzed in [1], [2].

Although most WROs have the potential to reduce costs, for numerous reasons not all opportunities will result in cost savings on operations. WROs may have large implementation costs and risks that are not immediately understood, resulting in cost savings that fall short of expectations. For example, cost risk can be partly attributed to a technology that is not fully developed, uncertainty in the amount of achievable cost reductions, or difficulties introducing a new process into an organization. These uncertainties can manifest in numerous ways and can result in a WRO with limited cost savings or even a loss on the investment.

It is difficult to predict cost savings and comprehensively screen WROs due to the complex and interconnected processes in an NPP. The many challenges inherent in NPPs, such as conflicting schedules, regulatory compliance issues, and safety concerns, make screening WROs difficult. Furthermore, screening WROs objectively becomes more difficult when processes involve multiple plant personnel groups introducing subjective perspectives, varying priorities, and resistance to change. Evaluating WROs requires a systematic and objective perspective to understand the risks and investment costs along with developing possible mitigation strategies. However, to the best of our understanding there exists no uniform framework for assessing WROs and their impacts on plant modernization strategies.

The goal of this research is to develop a decision-supporting framework for identification, evaluation, and selection of modernization strategies that offer maximum economic benefits with minimized associated risks and uncertainties. To achieve this goal, the Light Water Reactor Sustainability (LWRS) program researchers at Idaho National Laboratory (INL) developed a Technical, Economic, and Risk Assessment (TERA) framework that enables stakeholders to integrate technical, economic, and risk perspectives to provide a comprehensive evaluation of potential WROs. The framework aims to identify high-priority opportunities that can yield significant benefits to NPPs while minimizing risks.

The TERA framework presented in this report enables:

1. Objective Screening: The TERA framework uses standardized methodologies and metrics to offer an objective screening procedure for WROs. This approach aims to mitigate subjective biases, ensuring a consistent and unbiased evaluation. Using a standardized methodology, existing processes are broken down into individual tasks and their attributes, where inefficiencies can be identified and compared through quantitative metrics.

2. Cost Reductions: The TERA framework aims to improve efficiencies and achieve cost reductions across different WROs. Once WROs are identified, they are prioritized based on possible achievable cost savings along with the reduction in risks. Seemingly different WROs can be evaluated with standardized cost-reducing key performance indicators (KPIs) such as net present value (NPV).
3. Risk Assessment: The TERA framework performs risk assessment to evaluate the potential risks associated with developing and implementing WROs. It aims to identify and mitigate risks related to regulatory compliance and operational disruptions, ensuring that proposed changes do not compromise the overall reliability and safety of the NPP.

Advancing and adopting the TERA framework would provide decision support, scalability and adaptability, and facilitate continuous improvement opportunities to NPPs. For decision support, the TERA framework presents decision-makers with objective KPIs, analysis, and insights for each evaluated WRO. This enables informed decision-making and efficient prioritization based on organizational goals. Scalability and adaptability are achieved as it is applicable to different processes across the fleet and their specific contexts. It can accommodate varying levels of complexity, technological advancements, and operational requirements, making it a versatile tool for evaluating WROs in different settings. The TERA framework lays down a systematic method for evaluating and implementing WROs, thereby fostering a culture of continuous improvement within NPPs. It encourages the identification of inefficiencies, promotes innovation, and supports the ongoing optimization of operations.

This report presents a discussion and initial analysis of WRO identified by the collaborating nuclear stakeholder Southern Nuclear Company in partnership with Sargent and Lundy Associates. The TERA framework has crosscutting impacts and benefits across LWRS pathways. The two LWRS pathways that directly benefit from the TERA framework are Plant Modernization and Risk-Informed System Analysis. The Physical Security and Flexible Plant Operation and Generation pathways could also benefit from the TERA framework.

This report is organized as follows: Section 2 discusses ION research within the LWRS program. Section 3 discusses an overview of the TERA framework and perspective for analyzing WROs. Section 4 discusses how TERA can be used to screen WROs through the use of process maps, Markov Models, and analysis to quantify cost savings for a WRO. Section 5 presents a case study with a partnering utility where we screened four potential WROs and performed a TERA for one of the possible solutions. Section 6 concludes the report, summarizing the TERA benefits and a path forward.

2. INTEGRATED OPERATIONS FOR NUCLEAR

Due to the economic volatility of the United States (U.S.) energy market, the existing nuclear industry business model is no longer profitable or economically sustainable in the current economic climate. Although the nuclear industry has achieved performance records for reliability and safety, the industry's economic performance is struggling. The existing business model has become economically uncompetitive due to high operation and maintenance (O&M) costs. While other industries have successfully kept pace with technological innovations by adopting modernization and digital technologies, the nuclear industry has fallen behind in this category, leaving a gap that must be addressed to remain economically competitive.

ION is a vital research area within the U.S. Department of Energy's LWRS program which aims to address the modernization gap by providing a sustainable business model and developing technology modernization solutions. ION is part of a larger modernization initiative that focuses on the steps and activities required to achieve a streamlined digitalization of the existing nuclear fleet. The major research areas of the LWRS Plant Modernization Pathway are Digital Infrastructure, Data Architecture and Analytics, Human-Technology Integration, and ION. A graphical representation of the Plant Modernization Pathway and the connection between the four main areas of research can be seen in Figure 1.

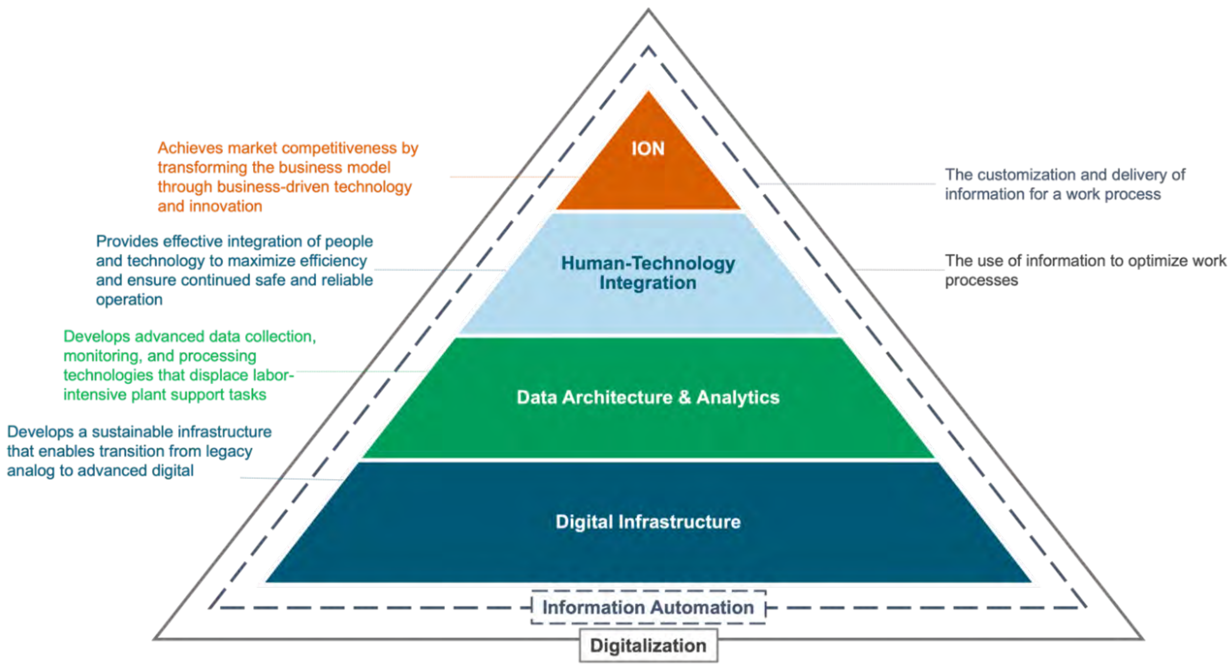

Figure 1. Research and development areas of the U.S. Department of Energy LWRS Program Plant Modernization pathway (adapted and generalized from [3]).

ION features a top-down, business-driven approach which begins by determining a market-based price point for generating electricity and then uses this to determine the underlying budgets, including O&M. Once the budget has been identified, a capability analysis is performed by examining the people, technology, process, and governance (PTPG) involved. This process identifies core capabilities and specific work functions within the organization. As a result, key WROs are identified and methods for streamlining or merging work groups are proposed to reduce costs within the target budget. An illustration of this concept can be seen in Figure 2.

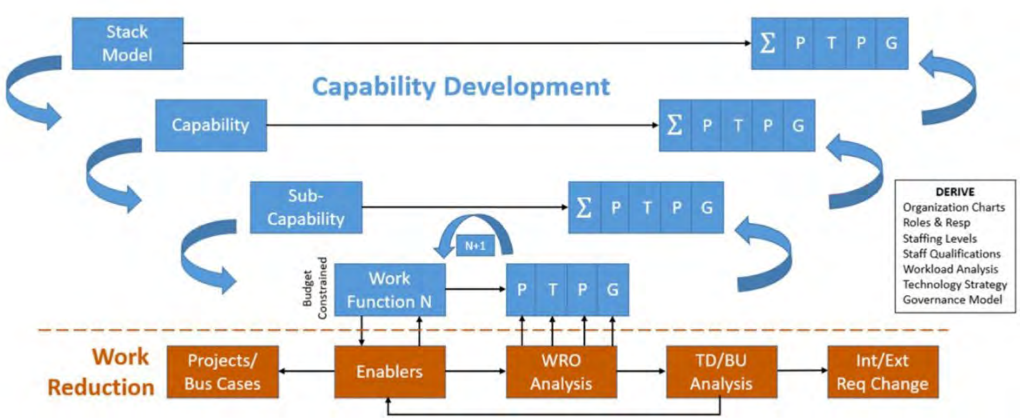

Figure 2. ION top-down approach and capabilities framework (adapted from [4]).

3. TECHNICAL, ECONOMIC, AND RISK ASSESSMENT

The TERA framework serves a two-fold purpose when evaluating WROs: to assess and inform. First, the TERA framework is used to screen and assess different WROs through the lens of a technical, economic, and risk perspective. Although it is easier to use a qualitative perspective for the analysis of

WROs, the TERA framework combines qualitative screening with quantitative models. This is achieved by performing the assessment through a systematic screening and model development process. By doing so, an objective screening of various WROs is enabled where utilities can assess options and decide the path of least risk that is most cost-effective.

Second, the output of the TERA can be used to inform the development and implementation of technologies to achieve WROs. This is achieved by performing modeling and simulation within the TERA context to provide clarity on the relationship between performance parameters and resulting business impacts. During model development and assessment, utilities can set expectations on process performance and define KPIs that could be used for quantifying cost savings and risk mitigation throughout the development of the WRO.

3.1 TERA Framework

Although each process evaluated under the TERA may vary significantly, the framework created has been developed with flexibility in mind. The TERA process consists of three main components: (1) developing a process map of the WRO under investigation, (2) developing models, and (3) using the model to assess cost savings and risk reduction. In this report, Markov chain modeling is used and briefly discussed. For details on Markov chain modeling, see [5]. An overview of the TERA framework being used to assess a WRO can be seen Figure 3.

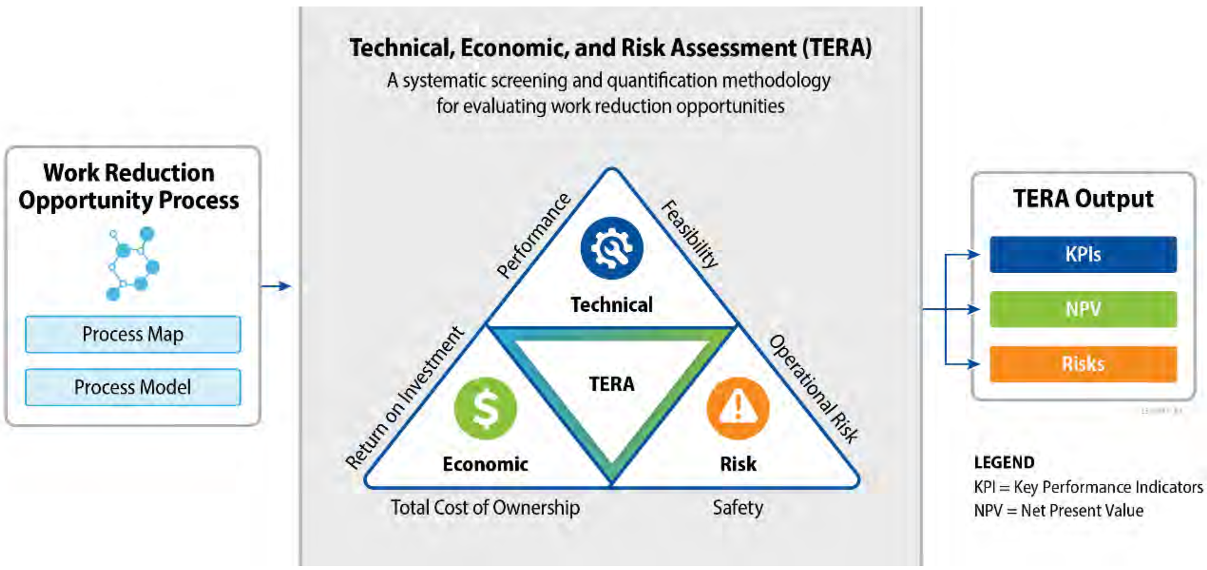

Figure 3. A depiction of the TERA framework showing process model and output.

3.2 TERA Perspective

3.2.1 Technical Assessment

The goal of the technical assessment is to evaluate the technical aspects of WROs and understand how new technologies and processes can be implemented within the nuclear industry. The technical assessment involves the careful consideration of the current process, how it works, and any causes of inefficiencies. Once the current process is understood, the feasibility, effectiveness, and benefits of the proposed solutions will be evaluated. The output of the technical assessment will be a comprehensive analysis of the current process and technical implications for each proposed solution. The technical assessment involves the following facets to be considered when analyzing a process and solution, which are discussed as follows:

3.2.1.1 Technical requirements

1. Functional Requirements

The first facet of the technical assessment is a detailed development and analysis of the functional requirements. This facet involves analysis of the current process to ensure the proposed solution meets the functional capabilities, performance standards, requirements, governance, and constraints that the current process adheres to. For example, a certain process may require outputs exceeding a certain measure for accuracy or quality. It is imperative throughout this assessment that functional requirements are recorded, and the performance of the new solution is measured. This consists of meeting with stakeholders and subject matter experts familiar with the current process to help set up requirements for a proposed solution.

2. Technological solutions

The second facet of the technical assessment is the proposal and evaluation of various technologies (at different technology readiness levels) that can meet the functional requirements. The proposed technologies will be evaluated for their ability to meet requirements, but also their readiness to integrate into the nuclear industry. Furthermore, proposed solutions should be assessed for their compatibility with existing systems, ease of integration, and the potential for customization to meet specific needs. Challenges associated with each proposed solution should be analyzed.

3. Objectives Alignment

Another large part of the technical assessment is ensuring that proposed solutions align with the objectives of the utility. For example, the utility may have safety, efficiency, reliability, reduced downtime, or other predefined goals. This could be on a high-level organizational objective or a low-level individual performance objective. In either case, proposed solutions must be evaluated for their performance in this facet. By defining and aligning objectives, solutions can be clearly evaluated for their performance against predefined benchmarks.

3.2.1.2 Technical risk

Part of the technical evaluation is assessing the technological risk from implementing a new process or altering the process with respect to organization objective.

1. Technology Readiness

Although emerging technologies are becoming increasingly available for use in industrial settings, not all technologies have been rigorously tested in all operating conditions. However, promising technologies should not be ignored solely because they are new. By using the well-known concept of Technology Readiness Level (TRL) [6], [7], we can evaluate the potential risks associated with implementing a newer technology into an existing process. Using the TRL, we can perform an assessment where the risk of successfully implementing a new technology can be quantified as an inverse correlation with the TRL. Also, sometimes it could be easier to adapt lower TRL technology into existing plant systems compared to higher TRL technologies.

2. Technology Feasibility

Replacing existing processes may result in difficult and complex requirements. The degree of difficulty when implementing a new technology can be a result of incompatibility with existing infrastructure, incoming data, or it may not be achievable with existing methods. Technical uncertainties can arise due to the interaction between the new process and dependent or connected systems. As a result, new technologies can cause unpredictable interactions, unintended consequences, and failures between interconnected systems.

3. Technology Performance and Maintenance

Achieving sufficient performance can be challenging for complex technology and success is not always guaranteed. Furthermore, the performance of a deployed model may degrade over time if the input data source changes from the initial training distribution. This may require maintenance and retraining of models to meet current demands.

4. Scalability

While the technology might function well in a representative setting, scaling the technology across a larger system may result in reduced performance. Furthermore, certain technologies may require significant amounts of computing power and even more resources for deployment.

5. Cybersecurity

As new technologies integrate systems or require new information pathways, this could expose vulnerabilities in the organization, cause data breaches, or result in non-compliance with cybersecurity regulations.

Although the list of technical risks is lengthy, it is not necessarily exhaustive. Uncertainties can arise in many aspects during technology implementation but should be accounted for as much as possible. A comprehensive technical assessment with uncertainty identification can help utilities mitigate risks to ensure successful implementation.

3.2.2 Economic Assessment

The economic assessment evaluates the financial viability of identified WROs through a cost-benefit analysis of the proposed solutions. The goal is to assess the potential return on investment and quantify the economic impact of proposed solutions. The method involves the economic assessment of the current process in terms of labor, materials, and capital expenses. Furthermore, the economic assessment will evaluate the proposed solution to quantify the economic benefit to the process, which will include cost savings and NPV estimates.

3.2.2.1 Cost-benefit estimation

To assess the economic impact of the proposed solution, we will use various economic measures for evaluating cost:

1. Current Process Costs

The first step that must occur before we can determine the cost of WRO is to identify the input costs of the current process. This will enable us to benchmark any change in cost from implementing new technology. Furthermore, analyzing the costs of the current process allows us to identify pain points and inefficiencies.

2. Marginal Analysis

As costs become interconnected with the technical assessment, we can use these relationships to study input-output relationships. These relationships can be modeled mathematically and used for studying the effect of changing the input or output of a process on the overall costs. This is commonly referred to as marginal analysis where the inputs are changed incrementally to study the impact each one has on the overall cost. Marginal analysis facilitates comparing benefits and costs, given a change in the process.

3. Technology Investment Cost

The investment required to implement the proposed solution will require cost estimations for each part of the project. This should encompass all states of the project including design, development, deployment, and management. Each of these project phases can be further broken down into training, labor, and capital expenditures which includes hardware acquisition, infrastructure modifications, and installation costs.

4. Regulatory costs

Due to the heavily regulated nature of the nuclear industry, any cost associated with regulatory requirements, documentation, or design change requests can bear significant burdens. While regulatory costs may not have an impact on every project, identifying any necessary regulatory costs that may be incurred during technology integration will ensure economic viability of the proposed solution.

5. Cost Reductions and Returns

Calculating the cost-benefit of an investment requires the quantification of the expected cost reductions or profit gains. These reductions and gains can be realized in many ways including labor hour reductions or plant efficiency gains. With the costs identified and the returns estimated, the NPV calculation of the investment and future returns can be calculated to ensure a positive use of invested capital.

3.2.2.2 Economic risk

To ensure success of the investment, the economic risk evaluation identifies economic uncertainties and potential risks associated with the estimated costs and returns.

1. Cost uncertainty

The cost of a project is not always known in its entirety before the start. It is not uncommon to experience cost overruns, changes in expenses, or change orders that may arise during the implementation. However, the cost uncertainty of these projects can be quantified, and their effects estimated from historical costs of related projects.

2. Performance Uncertainty

One of the major areas of uncertainty in a new project is the actual realized returns after implementation. The returns can be affected by several factors, but most notable is the as-deployed performance of the new technology. If there are scalability, deployment, or degradation issues with the technology, the initial return on investment estimates may not hold true. By adding uncertainty to the expected performance, the return on investment can be better understood with the impacts of model and performance uncertainty.

3. Economic Model Uncertainty

The last type of economic uncertainty has to do with the larger economic forces that interact with expected return on investment. These economic uncertainties may not be within the control of the project, utility, or even the broader nuclear industry. We can include these effects by adding uncertainty to the economic parameters, such as the current price of a megawatt-hour, levels of performance, or expected cost reductions. This allows for a more risk-informed and performance-based requirement.

The economic assessment is the key facet to creating a model that maps the functional and performance requirements to the business aspect. By creating these economic models and including the underlying uncertainty, we can not only assess the business case, we can also inform the development of the project.

3.2.3 Risk Assessment

The risk assessment is designed to identify and evaluate potential consequences associated with the implementation of WROs. Furthermore, WROs will also be evaluated for any impact to the risk and safety profile of the plant. For example, if a proposed solution impacts the reliability of a component, the impact to safety will be evaluated for an increase or decrease in related risk. The goal of the risk assessment is to evaluate proposed solutions and develop risk mitigation and contingency plans to address potential challenges. This will be accomplished through risk identification, risk analysis, and risk mitigation planning. The output of the risk assessment will be a comprehensive analysis of any uncertainties in implementing a new process, due to technical, economic, or safety risk.

3.2.3.1 Personnel and system consequences

New technology has the potential to interact with existing systems, but they may influence the reliability and safety of NPPs. Furthermore, as technology changes a process, the frequency of particularly consequential events may change. Throughout modeling and analysis of the TERA assessment, changes to potential consequences and/or their likelihoods should be quantified.

1. Personnel Safety Risk

There are a few notable examples that could potentially derail a new project due to increased personnel safety risks. For example, a particular task may have an increased probability of experiencing an Occupational Safety and Health Administration (OSHA) reportable event. If this one task, by means of process changes, has decreased its reliance on humans or the frequency of the task is decreased (or both have increased), the probability of OSHA reportable events will also change. While events like this have a direct impact on business costs, they are also included in yearly plant metrics that may have larger regulatory or industry consequences. It is important to evaluate these changes either qualitatively or quantitatively, to assist decision makers in their WRO assessments.

2. Structures, Systems, and Components Consequences

As new processes aid operators and maintenance staff with maintenance decisions, the outcomes of these actions may have a direct impact on the reliability of plant's structures, systems, and components (SSC). If there is a possibility of changing maintenance frequency or maintenance process, the performance and resulting reliability may change. It is important to evaluate the effect of the new technology on maintenance postures. Changes in reliability or availability are examples of how maintenance effects can be quantified as the result of process changes.

3. Plant Safety

As WROs begin to expand into safety-related systems, there could be changes in the overall plant safety parameters, namely core damage frequency (CDF) and large early release frequency (LERF). Although risk metrics are expected to improve (i.e., decreased CDF and LERF) due to implementation of new technologies, the changes in plant risks must be carefully analyzed. For example, transitioning from analog instrumentation and control systems is generally understood as an improvement to plant safety. However, digital systems introduce unique risks associated with potential software failures that necessitate a detailed analysis of plant safety. While most WROs will not impact safety-related systems, there should be an effort to evaluate potential changes to plant safety.

4. Failure Mode Analysis

New technology and new processes may introduce new failure modes (e.g., software failures in digital systems, novel operator action). The potential failure modes should be identified and properly evaluated, for example, through failure modes and effect analyses (FMEA). The associated risks should be properly evaluated to support risk-informed decision making.

3.2.3.2 Implementation risk

Risks of implementing a new technology into an existing business can be categorized into two larger categories: human readiness and organizational readiness. This section presents methods for understanding and quantifying the readiness levels needed for successful implementation of new technologies.

1. Human Readiness Level

The Human Readiness Level (HRL) assessment gauges the risk associated with human aspects of new process implementation and effects from human and technology interaction. This part of the evaluation provides an assessment of the preparedness of individuals involved in the execution of a new process. HRL encompasses factors such as training, skill acquisition, and adaptability to change. By assessing the impact of HRL on the overall process implementation, we can evaluate the success of implementing the proposed WRO from a human perspective, sources of risks and uncertainties, and devise methods to mitigate these risks.

The American National Standards Institute (ANSI) Human Factors and Ergonomics Society (HFES) has created a standard, ANSI/HFES-400:2021, that describes a method for evaluating and scoring human readiness, with respect to system integration, with the scoring system ranging from one to nine [6]. A graphic showing the HRL scale, as described in ANSI/HFES-400:2021, can be seen in

Figure 4. The HRL scale corresponds directly to the TRL and is used to create a map between human readiness and technology readiness to assess the risk of implementation from a human technology integration perspective.

Phase	HRL Level
Basic Research and Development Scientific research, analysis, and preliminary development on paper and in the laboratory occur. This phase culminates in a validated proof of concept that addresses human needs, capabilities, limitations, and characteristics.	***HRL 1:*** Basic principles for human characteristics, performance, and behavior observed and reported ***HRL 2:*** Human-centered concepts, applications, and guidelines defined ***HRL 3:*** Human-centered requirements to support human performance and human-technology interactions established
Technology Demonstrations The technology is demonstrated at increasing levels of fidelity, first in the laboratory and later in relevant environments. This phase concludes with demonstration of a representative system in a high-fidelity simulation or actual environment, with evaluation of human systems designs provided by representative users.	***HRL 4:*** Modeling, part-task testing, and trade studies of human systems design concepts and applications completed ***HRL 5:*** Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design ***HRL 6:*** Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment
Full-Scale Testing, Production, and Deployment Final testing, verification, validation, and qualification occur, with human performance evaluations based on representative users. This phase concludes with operational use of the system and continued systematic monitoring of human-system performance.	***HRL 7:*** Human systems design fully tested and verified in operational environment with system hardware and software and representative users ***HRL 8:*** Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users ***HRL 9:*** System successfully used in operations across the operational envelope with systematic monitoring of human-system performance

Figure 4. Human Readiness Levels, adapted from ANSI/HFES-400:2021 Table 4-1 [8].

2. Organizational Readiness Level

Organizational Readiness Level (ORL) aligns with the HRL but on a broader scale, encompassing the entire organizational perspective. The ORL is an assessment to gauge the organization's overall readiness to adopt new processes and technologies. This assessment factors in the organizational perspectives like management support, cultural alignment, and resource availability for implementing change. The ORL assessment defines implementation success criteria and KPIs, which are used to objectively assess organizational preparedness for the implementation of novel practices. As part of this ORL evaluation, risks and uncertainties are defined and mitigating strategies can be developed. The result is an understanding how the organization can impact success.

3. Solution Inefficiencies

Many new solutions promise new capabilities, but they often require more input from the user. In many cases, the new capability will require users to add more information or enter details about an already simple task in the promise of better tracking or resolution. However, this can lead to users ignoring the extra tasks and resulting in the failed implementation of new capabilities. This is the result of an inefficient solution that was not properly analyzed. Identifying these risks and quantifying any additional work added to the process is a preemptive method to mitigate implementation risk.

4. SCREENING OF WROs

Screening WROs is an iterative process to perform a cost-benefit analysis and evaluate KPIs for each WRO, enabling risk-informed investments for plant modernization. The screening process uses a combination of process re-engineering, Lean Six Sigma, and NPP modernization guiding principles developed by the ION projects [1], [2], [3], [4]. By integrating these process improvement practices, an exhaustive screening methodology for WROs and potential modernization strategies is developed. A flowchart describing how the TERA can be used to screen WROs can be seen in Figure 5.

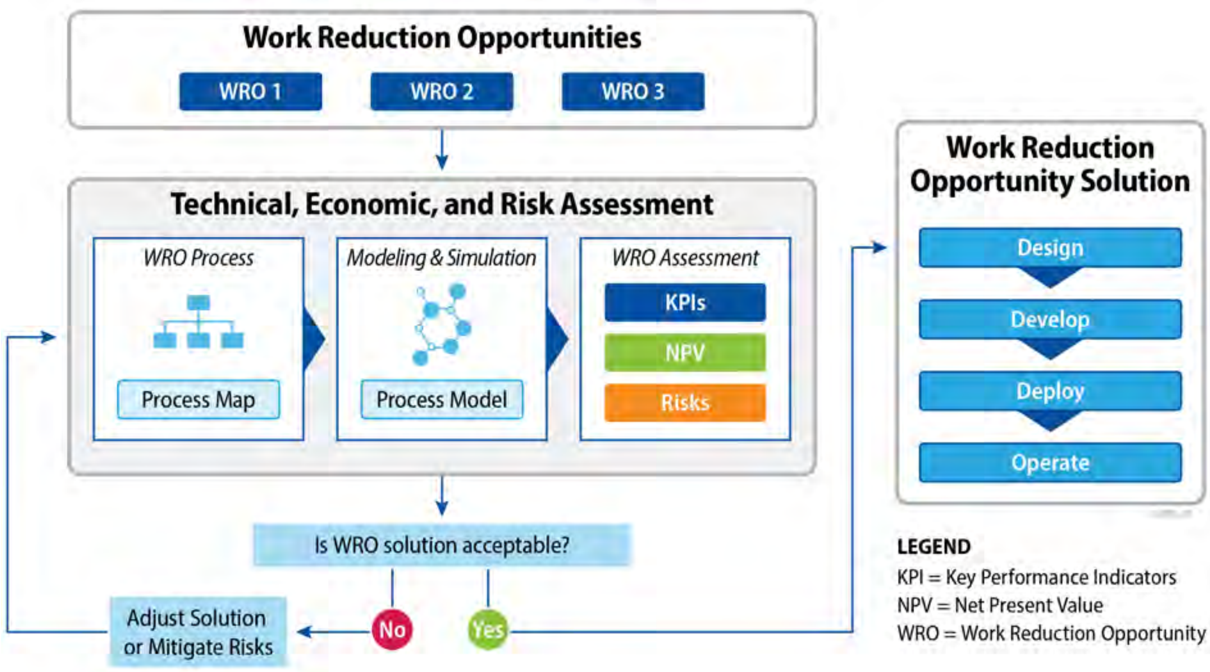

Figure 5. The TERA framework when used to assess WROs, adjust solutions, and mitigate risks.

The first step is the identification of potential WROs in conversation with utilities. Once the WROs are identified, the TERA process discussed in Section 3 is applied. This allows utilities to avoid inefficient capital investment by identifying the pain points in the process and addressing those first. However, eliciting that information can be challenging. Therefore, a robust screening methodology that combines commonly accepted process evaluation methodologies and a nuclear industry perspective has been created.

Utilities will often have identified potential WROs through intimate knowledge of the existing processes. Due to the broad nature of proposed WROs, the screening phase is designed to objectively identify the best path for investment.

1. **Initial Screen**: WROs are introduced to an impartial screener through interviews. The screener gathers as much knowledge as possible within a given timeframe. The essence of these discussions is

to tap into the experiences of the processes, discern the challenges, and sketch a preliminary layout of the existing process. Upon acquiring a broad understanding, the interviewers pinpoint a “process owner” who spearheads further conversations and serves as the primary liaison for interviewers.

2. **Process Mapping**: This phase focuses on further conversations with individuals, diving deeper into the process, specific tasks within the process, and any bottlenecks. This approach aligns with Suppliers, Inputs, Process, Outputs, and Consumers (SIPOC) principles but integrates PTPG to offer an ION perspective. With the interview data collected, the screener crafts a process map that captures vital data, inputs, participants, technology, constraints, governance, and outputs. This map provides a method to analyze and identify the process's inefficiencies, which may manifest as heightened costs, time lags, or employee strain.
3. **KPI Identification**: The screener then identifies the KPIs that define the process performance. This sets the baseline performance threshold, ensuring the final solution enhances the process. The aim is to sidestep investments that yield only negligible performance improvements.
4. **Quantitative Analysis**: Once mapped, the process undergoes a steady-state evaluation, forming a preliminary benchmark for future comparisons. This analysis translates the process map into a Markov model with transition probabilities or rates. The model's steady-state performance reveals the likelihood of time consumption for each phase. Through this model, each process step is evaluated from technical, economic, and risk perspectives by attaching costs to each model step. The costs can be direct labor or materials, or an indirect cost such as safety risk. Multiplying the time consumption per state by the cost per unit of time yields the direct and indirect costs which, when added together, define the process’s overall cost.
5. **What-if Analysis**: Using the Markov model and deduced risk, we explore potential cost reductions or increments by engaging in what-if scenarios. These evaluations involve tweaking the process map based on the proposed solution, modifying the Markov model's temporal parameters, or adjusting costs per phase. The revised process model, reflecting anticipated technology integration outcomes, allows for a recalculation of the expected costs via a revised steady-state analysis and risk computation.
6. **Final Evaluation**: The culmination of the WRO assessment involves a decisive cost-benefit analysis. This phase encompasses project costs to gauge the return on investment. Additionally, it delves into the implementation risks by referencing the ORL [9] and HRL [8]. This final review offers an exhaustive technical, economic, and risk appraisal for each WRO, facilitating risk-informed and performance-based decisions.

4.1 Process Mapping

The process mapping phase consists of reviewing process documents and interviewing numerous people involved in the current process. The process mapping phase consists of elements of Lean Six Sigma, ION principles, and Lean Startup Methods. Through the combination of these well-defined processes and principles, we have created a nuclear-specific process mapping framework and methodology that will be used to evaluate pain points, value of information, and new technology risks.

4.1.1 Process Mapping

When evaluating the process from a technical, economic, and risk perspective, we have combined several well-known process evaluation techniques. This includes guiding principles developed in Lean Six Sigma’s SIPOC, ION’s PTPG, HRL, and ORL. By understanding the methods in each of these evaluation techniques, the current process and risks associated with implementing a new process can be comprehensively evaluated and well-understood. The result is a process map that contains the individual tasks, decisions, data/information flow, and cost information. An example of a high-level process map can be seen in Figure 5.

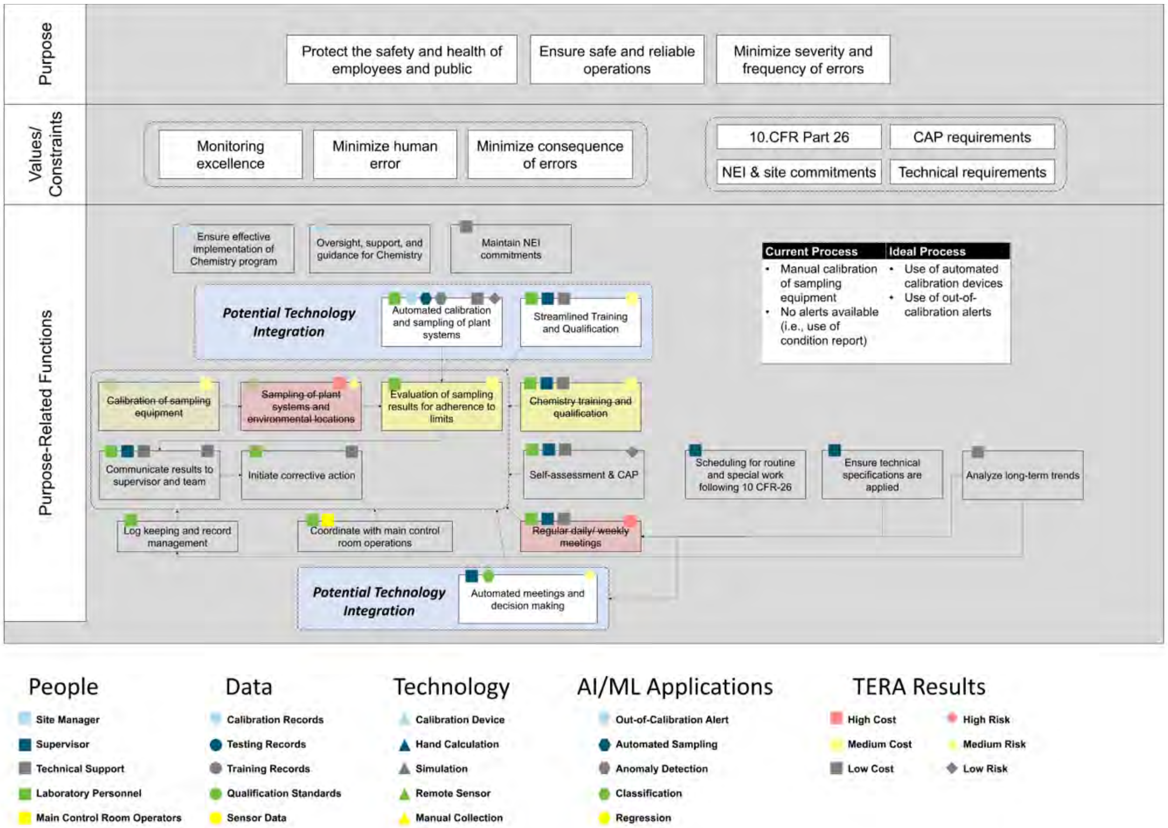

Figure 6. Example of a process map for a chemical safety process. This process map shows an example of how indicators can be used to highlight important features of the process. Included features of this process indicate the people, data, technology, and results of the TERA.

4.1.1.1 Lean Six Sigma – SIPOC

Another method for analyzing processes is through the Lean Six Sigma method known as SIPOC. This method breaks a process down into five main categories: SIPOC. Using this method, processes become easy to disassemble to identify the pain points or inefficiencies. The categories in SIPOC are described as:

- Suppliers – people or organizations that contribute to or are involved in a process
- Inputs – necessary tools, data, or information contributed by suppliers
- Process – steps that transform inputs into outputs
- Outputs – result of the process or an item created in the process
- Consumers – receiver of the output from the process or where the output goes.

Using the SIPOC approach to break it down, we can evaluate the process by identifying the relationship between each of the categories. For example, as the input to the system changes, we can analyze the effect this has on the process, output, and consumer. If the input to a process decreases in quality, we can evaluate how that will affect the output and how the quality of the output affects the quality of the final product received by the consumer. An example of a SIPOC diagram can be seen in Figure 6. For more information on using SIPOC for process analysis, see [10], [11]

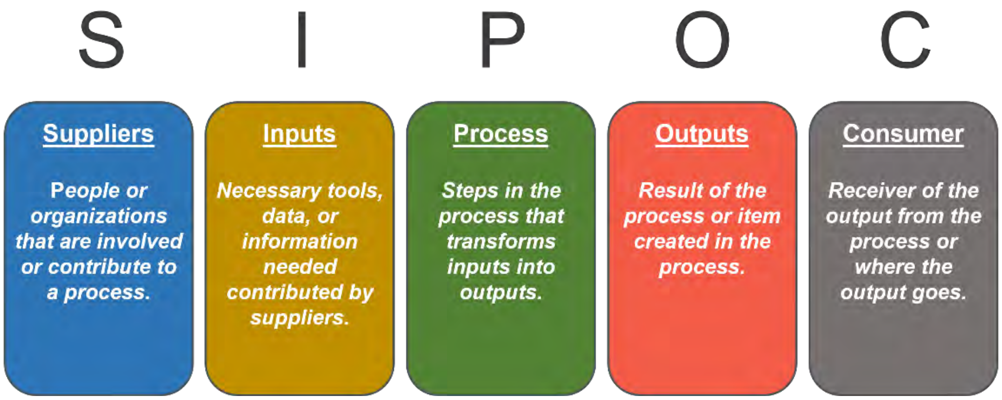

Figure 7. An example of a SIPOC diagram used to analyze a process.

4.1.1.2 PTPG – People, Technology, Process, and Governance

Part of the philosophy for ION is viewing the process or capability through the lens of various categories. The ION philosophy categorizes capabilities as being comprised of four interdependent resources: people, technology, process, and governance. Each of these resources determines how and why the process functions. By breaking down a process into each of these four categories, it becomes easy to see how the process operates and to determine work reduction opportunities. The ION philosophy and integration of PTPG can be seen in Figure 7.

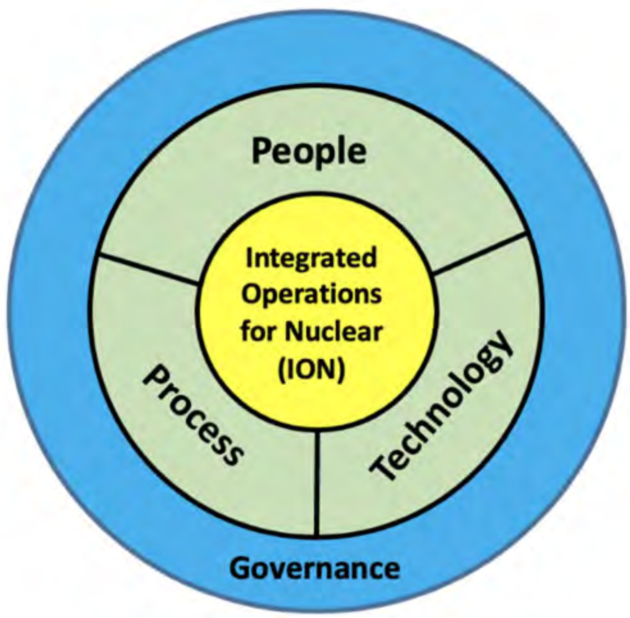

Figure 8. The relationship between ION's focus of people, technology, process, and governance.

4.1.2 Data Mapping

Data mapping involves visually charting where data originates, where they are stored, and how they are used. This aids in ensuring consistent data quality and data security, while also aiding in the streamlining of processes. This is especially important for digital modernization and transformations due to the increasing use of data to support analysis and decision making. The steps typically include:

1. **Identifying Data Sources:** Pinpoint where your data are coming from, whether it is databases, files, or even manual inputs.
2. **Defining Data Destinations:** Determine where these data need to end up. This could be in any system used within the organization.
3. **Mapping Fields**: Connect source data fields to their destination counterparts.
4. **Conversion Rules**: If needed, set rules for data transformations.
5. **Implement and Test**: Apply the mapping and test it rigorously to ensure there is no data loss or discrepancies.

Creating a data map and integrating it with the process map creates a comprehensive picture of where data is stored, how it is accessed, and how it is used to support process functions. For a more information about data mapping, see [12], [13].

4.1.3 Decision Mapping

Decision mapping focuses on identifying decision points within a process and understanding the information and actions leading to those decisions. This helps in evaluating critical decision-making points, potential bottlenecks, and areas of risk. The steps involve:

1. **Chart Decision Points:** Identify all decision junctions within the process.
2. **Detail Decision Criteria:** What information is needed to make each decision?
3. **Visualize Outcomes:** For each decision point, map out potential outcomes.
4. **Analyze Dependencies:** Determine if certain decisions rely on previous ones or on specific data points.

Decision maps can be helpful when integrating decisions and processes together into one cohesive process. These are also helpful when creating and understanding process flow, input-output relationships, and functional requirements for a given process decision. An example of a decision map can be seen in Figure 9.

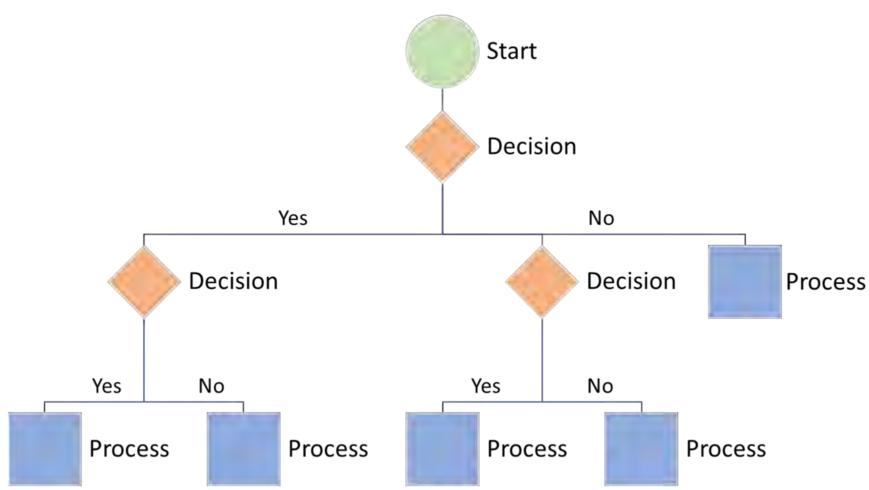

Figure 9. Example decision map.

4.1.4 Eliciting Information

Eliciting information involves gathering detailed, accurate, and relevant information from various sources to gain a comprehensive understanding of the process. This could be done through observations, interviews, questionnaires, or analyzing existing documentation. There are several methods used when employing information elicitation, but the most effective will be a combination of:

1. **Observations:** This is a direct method to observe the process in real-time. This method provides first-hand experience of this process.
2. **Interviews:** Conducting one-on-one or group discussions with stakeholders, experts, or participants. This method allows for deep diving into topics, pain points, and enables quick clarification.
3. **Questionnaires:** Use of written sets of questions that can be distributed to a large audience. This method helps gather information from a large group, can help ensure anonymity, and minimize potential bias.
4. **Document Analysis:** Reviewing existing documentation, records, or reports relevant to the process. This method can help provide historical context and help quickly understand the standard documented process.

Although this is not an exhaustive list, it is important to consider the type of process, the people involved, and the information needed. A comprehensive method for gathering information is imperative to correctly identifying the costs and potential benefits for any WRO.

4.1.5 Performance Metric Identification

Before quantification of process performance can begin, there must be an attempt at defining what KPIs will be used to define the success criteria. The one requirement of the defined success criteria is that they are *measurable*. This means that the improvement or change in the process must be well-defined. This step requires an understanding of the business case and how this process affects the business case.

There are three steps that should be included in defining success criteria.

1. **Technical**: Defining technical KPIs is important for measuring process improvements from a technical performance perspective. This encompasses metrics like efficiency, accuracy, time, and labor reductions.
2. **Economic**: Financial metrics help define business success and ensure investment return. Financial metrics such as yearly cost savings, breakeven point, NPV, return on investment (ROI), and internal rate of return (IRR) are common when comparing investment opportunities. They provide insight into the monetary viability and gains of the process.
3. **Risk**: This area is about gauging risk mitigation. Metrics here could involve assessing reductions in operational, financial, regulatory, safety, or strategic risks. Each of these can be quantified using changes in frequency, severity, or other relevant measures.

By defining measurable criterion, KPIs can be used to evaluate the performance of the implemented process throughout the entire process.

4.2 Process Modeling

The quantitative analysis phase marks a pivotal stage where the high-level process map is transformed into a Markov process model. This transition enables the quantitative analysis of the process in process dynamics, allowing a deeper dive into the process technical, economic, and risk quantifications. In this report, Markov process and analysis are used, for more information see [5].

Markov processes are an essential tool for the modeling and analysis of complex stochastic systems. By modeling with Markov processes, we can use historical data from the plant to fit parameters for the model. Then, using the Markov model, we can assess the impact of the WROs on plant performance, reliability, and safety. Markov models can provide valuable insights to decision-makers that use quantitative outcomes to evaluate implementation scenarios.

Once the Markov model is created, we can assign costs associated with each task (dollars per hour) and determine the approximate cost for that process. By performing a common analysis called a steady-state analysis, we can identify probabilistic amounts of time spent in each state. Then, associating each state with its cost, we can get an estimate of total cost for that process. As we begin to evaluate new solutions and alterations to the process, we can vary the parameters of the model and determine the change to the final cost of the process. Furthermore, due to the probabilistic nature of the model, we can incorporate uncertainty into the process and parameters. Using this uncertainty, we can estimate the risk associated with the process as it pertains to a certain consequence, which can be overrun on cost or an effect on component reliability or uptime.

Furthermore, a sensitivity analysis can be performed using the Markov model to discern primary cost influencers and inefficiencies within the process. A sensitivity analysis is a technique used to study the various sources of uncertainty and major contributors to a given outcome. In the context of an O&M process, we can evaluate the contribution of each parameter to overall cost by varying each one by a small amount and determining the effect on total cost. Doing this sensitivity analysis, we can identify which tasks are the main cost drivers of the process and identify inefficiencies. Additionally, once the model is created, we can perform economic cost analysis by evaluating cost change when different parameters of the model are changed or when tasks are removed entirely. The Markov model enables the evaluation of performance in the process and quantify changes in cost-savings.

4.2.1 Markov Processes

Once the high-level process mapping is completed, the analysis phase can begin by converting the process map into a Markov process. In the context of the TERA Evaluation, Markov processes serve as a dynamic framework where the process's progression is characterized by transitioning between different states. Each state represents a distinct stage or condition within the process, and the transitions between states are governed by probabilities. For time-dependent process, such as a labor-intensive process, it is simple to convert the time-dependent process into a probabilistic process. A diagram of an example process is shown in Figure 9.

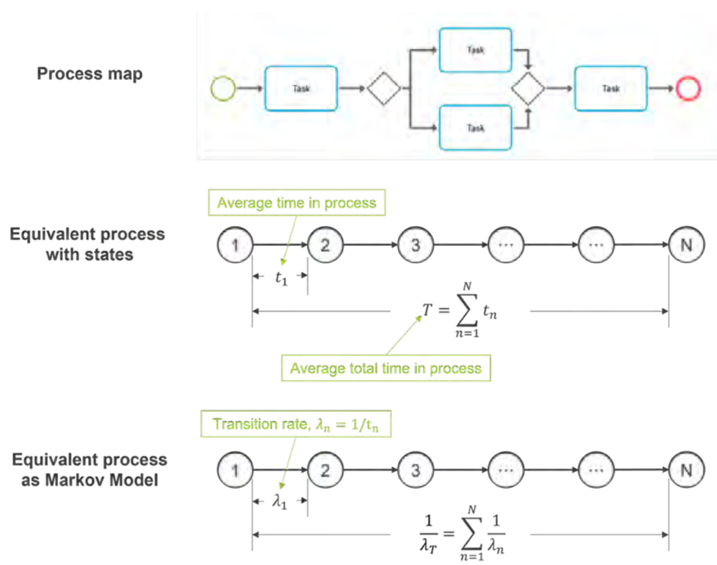

Figure 10. A process map (top) can be turned into an equivalent stochastic Markov model (bottom).

In this example, the process map contains steps with a defined start and finish. To convert the process into a Markov chain, the steps in the process are turned into states as show in the middle of Figure 10. In this intermediate model, the average time spent in each state is defined as t_n, where n denotes the state. The total time spent in that process, T, can be defined as the sum of time for all states in the process, where $n = 1, \ldots, N$. Next, the process can be converted to a Markov chain where the time dependencies between each state are transition rates defined as $\lambda_n = 1/t_n$.

By linking several processes together, we can model a complex series of tasks into a probabilistic model. A diagram of this can be seen in Figure 10.

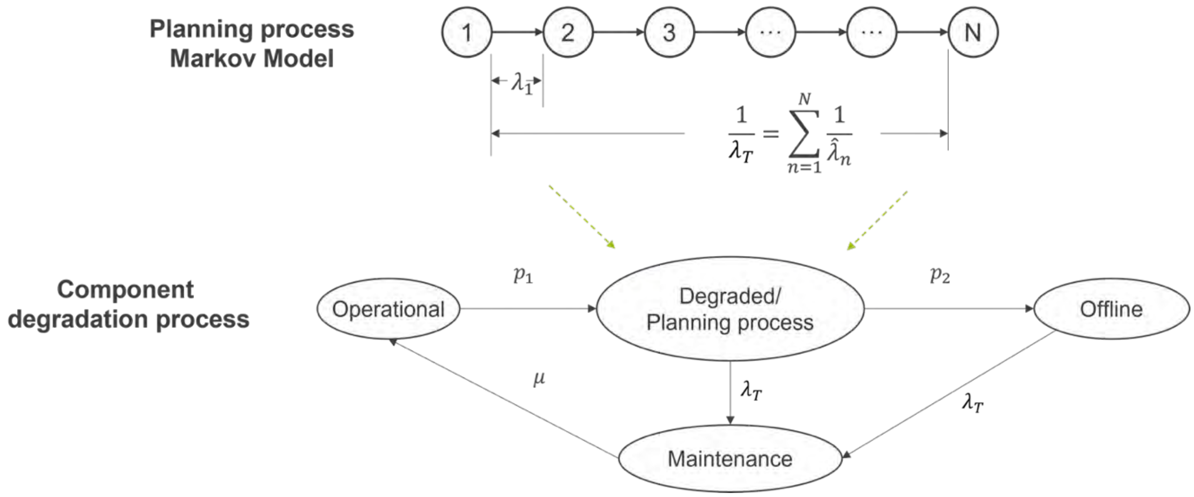

Figure 11. The top figure shows a process shown as a Markov model with transition rates. The bottom figure shows how the Markov model can be integrated into a larger Markov model that describes a component degradation process.

In this example, the step-by-step process is integrated into a larger Markov process that models a component degradation process. In this model, the component may be in one of four states: operational, degraded/planning, offline, and maintenance. In this process, the amount of time the component spends in an operational state depends on the amount of time spent in the other processes. The transition rates that connect each of the states determine that amount of time. These rates are defined at p_1, p_2, μ and λ_T. Rate p_1 is determined by the reliability of the component and the probability of entering a degraded state from healthy operation. Likewise, the probability of entering an offline state from a degraded state is p_2. The rate λ_T defines the average amount of time it takes to finish going through the planning process and entering a maintenance state. This process can represent the amount of planning required before a maintenance action is chosen and started. The rate μ defines the average time spent in maintenance, returning the component to an operational state.

4.2.2 Steady-State Analysis

At the core of the TERA is the steady-state analysis. This describes the long-term average behavior of the process when it reaches an equilibrium of transitions between different states. This describes the average behavior of the process and can be used for predicting dynamics and process behavior. An example of a steady-state analysis for a system with three states can be seen in Figure 12.

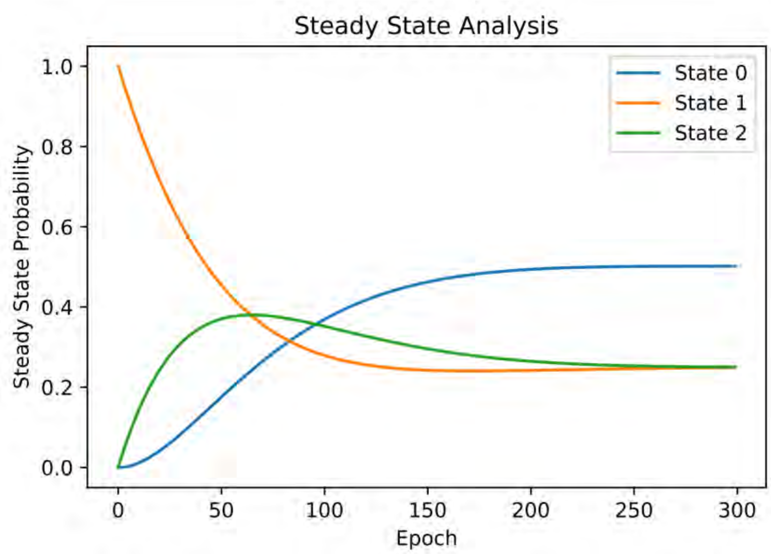

Figure 12. Steady-state analysis example with three states.

To perform a steady-state analysis, the Markov process is used in mathematical computations that determine the probabilities of the process over an extended period of time. By identifying the equilibrium state of the process and the resulting probabilities of residing in each specific state, we can evaluate the cost of that process by means of assigning a cost to each state and multiplying those times the probability (or time spent) of being in each state.

There are several computational methods used for performing a steady state analysis. The three methods we will use for this research are:

- **Direct Solution Methods**: These involve solving linear algebraic equations to derive the steady-state probabilities directly. These are commonly referred to as numerical solution methods [14].
- **Iterative Methods**: An initial estimate of the probabilities is repeatedly refined to converge to the steady-state solution. For more detailed information on iterative and numerical methods, see [15].
- **Monte Carlo Simulations**: Through repeated random sampling, this method estimates outcomes. It's particularly valuable when the system is complex and deterministic methods are computationally intensive or infeasible. For more information about Markov processes and Monte Carlo simulations, see [16].

The selection of the computational method relies on the characteristics of the specific Markov model. For example, while direct solution methods can be efficient for small systems, iterative methods might be preferred when dealing with larger and more complex systems due to the computation simplicity. On the other hand, Monte Carlo simulations can be best for systems where non-deterministic behaviors or non-linearities exist, making conventional methods inadequate.

Through steady-state analysis, we can develop an understanding of the equilibrium states and the respective probabilities of a stochastic process. This can lead to more informed decisions regarding system design, operational strategies, and performance metrics.

4.2.3 Process Cost Estimation

Once the steady state probabilities are identified, costs are assigned to each state to assess the average cost for that process. The steady state probabilities are assumed to be the average time spent in each state over a long period of time. For example, a process with two states, A and B, may have an interaction where the probability of being in the states at any given time would be 0.25 and 0.75, respectively. For calculating the amount of time in each state, this means that 25% of the year will be spent in state A while 75% of the year will be spent in state B.

To identify the time spent in each state during a given time period, each probability is multiplied by the total time available. Continuing the same example, the time spent in each state over a period of $T = 1000$ hours can be calculated as

$$T_A = P(A) \times T = 0.25 \times 1000 = 250 \text{ hours}$$
$$T_B = P(B) \times T = 0.75 \times 1000 = 750 \text{ hours}$$

To calculate the cost for this process, hourly costs can be assigned to each state. If the costs for each state are $10/hour and $5/hour states A and B, the total costs for each state can be calculated:

$$C_{Total} = C_A T_A + C_B T_B$$
$$C_{Total} = \left(\frac{\$10}{hour}\right)(250\ hours) + \left(\frac{\$5}{hour}\right)(750\ hours)$$
$$C_{Total} = \$6250$$

Now that the method for estimating the total cost of the process is established, it can be used to calculate the cost of a new process. By altering the Markov model or the parameters according to the WRO solution, the new cost after implementation can be calculated. By comparing the total cost for each process over a given time span, the WROs can be compared for cost-savings.

4.2.4 Sensitivity Analysis

Sensitivity analysis is a method for quantifying how changes in one parameter affect the output variable. By doing so, the importance of each parameter can be identified. Additionally, a sensitivity analysis can be used to quantify the effect that parameter uncertainty has on the output. This process helps to identify the expected outcome for a range of parameter values.

Using a sensitivity analysis, the impact of changing parameters can be quantified and used for risk-mitigation or resource allocation. The values with large uncertainties or large impact are identified and can be reviewed for further investigation. This will allow utilities to focus on the parameters of the model that have the greatest impact on cost.

Sensitivity analysis has four main advantages in the context of TERA:

1. **Risk Assessment**: By understanding which variables most affect the output, decision makers can understand where the biggest risks lie.
2. **Resource Allocation**: Knowing which parameters are most influential can help in focusing efforts and resources.
3. **Model Validation**: If the model shows high sensitivity to parameters that are believed to be less influential based on empirical data or expert opinion, it may indicate that the model is not accurate or needs refinement.
4. **Uncertainty Quantification**: In cases where the exact values of parameters are not known, sensitivity analysis can help to understand how this uncertainty translates to uncertainty in the outcomes.

Sensitivity analysis can aid decision makers evaluate the interactions between model/process parameters and the business impact, providing a quantitative prioritization for resource allocation.

4.3 Cost-Benefit Evaluation

4.3.1 Breakeven

The final step of the WRO opportunity is to calculate the breakeven point. This is the amount of time it takes to recoup the value of the initial investment cost. Calculating the time to breakeven requires the cost of the initial investment divided by the projected cost savings per time. The breakeven point equation can be seen in the following equation:

$$\text{Breakeven Point} = \frac{\text{Initial Investment}}{\text{Yearly Cost Savings}}$$

Where:

- **Breakeven Point:** This is the time it takes to recoup the value of the initial investment through cost savings. This is commonly expressed in years.
- **Initial Investment**: This includes all upfront costs related to the WRO. Typically, this would comprise the screening cost, development cost, and deployment cost.

$$\text{Initial Investment} = \text{Screening Cost} + \text{Development Cost} + \text{Deployment Cost}$$

- **Yearly Cost Savings**: This is the annual financial benefit realized by implementing the WRO solution. It is calculated by taking the difference in costs between the old and new processes, adjusting for the usage rate and the Operational Expenditure (OPEX). In this context, OPEX is used to evaluate any ongoing costs such as maintenance or electricity use. Yearly cost savings can be calculated as:

$$\text{Yearly Cost Savings} = (\text{Old Process Cost} - \text{New Process Cost} - \text{OPEX}) \times \text{Usage Rate}$$

  where the Usage Rate is determined by the percentage of employees using the new technology versus the original.

Using these cost descriptions, the breakeven point formula provides a estimate of when the WRO will be worth its initial investment.

4.3.2 Net Present Value

Net Present Value (NPV) provides a secondary economic perspective that incorporates the time-value-of-money which evaluates performance of an investment at a given discount rate. In other words, the NPV evaluates whether the project is a good use of investment. The NPV evaluates a project's ability to outperform an investment that would generate returns through interest. To calculate the NPV, the formula used is:

$$NPV(T) = \sum_{t=0}^{T} \frac{\text{Yearly Cost Savings}_t}{(1+r)^t} - \text{Initial Investment}$$

Where:

- $\boldsymbol{r}$: This is the discount rate at which the value of future cash flows is discounted back to present value. It accounts for the time value of money, inflation, and investment risk. It is usually expressed as a percentage.
- $\boldsymbol{T}$: This is the total number of time periods in the NPV calculation. This is the total duration over which the cash flows are expected to occur, commonly expressed in years.
- **Initial Investment**: This includes all upfront costs related to the WRO. Typically, this would comprise the screening cost, development cost, and deployment cost.

$$\text{Initial Investment} = \text{Screening Cost} + \text{Development Cost} + \text{Deployment Cost}$$

- **Yearly Cost Savings$_t$**: This is the net amount of during a particular year, t. This is the annual financial benefit realized by implementing the WRO solution. It is calculated by taking the difference in costs between the old and new processes, adjusting for the usage rate and the Operational Expenditure (OPEX). In this context, OPEX is used to evaluate any ongoing costs such as maintenance or electricity use. Yearly cost savings can be calculated as:

$$\text{Yearly Cost Savings} = (\text{Old Process Cost} - \text{New Process Cost} - \text{OPEX}) \times \text{Usage Rate}$$

where the Usage Rate is determined by the percentage of employees using the new technology versus the original.

The NPV is used to determine if the future expected cash flows (or cost savings) are worth the initial investment. If the NPV is positive, the project is a good investment. If the NPV is negative, the project is a poor investment. Furthermore, we have introduced the Usage Rate term to incorporate the risks associated with a failed implementation or a low adoption rate from the organization.

4.4 WRO Evaluation and Decision Making

Once WRO solutions have been identified and hypothetical scenarios analyzed, decision making involves a careful weighing of benefits against potential risks. The TERA process develops an assessment of the various WROs in the form of KPIs, NPV, and risks. Using the insights from the TERA, decision-makers can rank WRO solutions based on their business impact and potential risks. By doing so, the decision-making process becomes data-driven and risk-informed, ensuring that choices are backed by rigorous analysis and evaluation.

5. CASE STUDY – SOUTHERN NUCLEAR COMPANY

In this section, we will provide an overview of the screening and TERA process applied to SNC's four key elements. The screening and TERA process is described through discussion on the initial key elements, the screening methodology, interviews, process mapping, identification of pain points as WROs, and insights gained through the screening process. The results of the analysis, identifying inefficiencies in the processes and where the modernization efforts must focus, is presented.

5.1 Work Reduction Opportunity Selection

When initially considering potential WROs, SNC recommended four key elements to investigate. As shown in Figure 13, these key elements were screened through the TERA process and distilled into two focus areas. From these focus areas, five WROs were defined and analyzed for review by SNC.

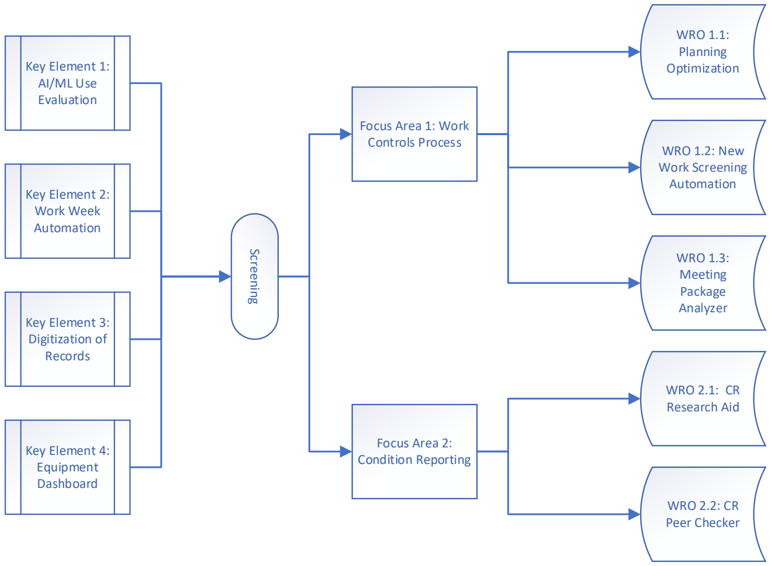

Figure 13. Work Reduction Opportunity Screening.

The following subsections describe the key elements investigated, the screening process used to define the WROs, and the final WROs chosen.

5.1.1 Key Element 1: Artificial intelligence/Machine learning (AI/ML) Use Evaluation: Smart Condition Report

An enhanced condition report (CR) report could be developed to automatically provide links to related internal and external OE to improve the quality of the CR report. The report could use natural language processing to review previous CRs and OE across the SNC fleet and the Institute of Nuclear Power Operations International Research Integration System (IRIS) database and return results based on similar failures. The tool will rank issues based on significance and help the user better identify the focus areas specific to the individual's use case.

Use Case: Currently most employees use a pdf file that is emailed each morning and contains the CRs generated the previous day. This report could be greatly enhanced or replaced with another tool to perform this task more effectively. The tool will display the relevant internal and external OE collected, upcoming preventative maintenance (PMs), workorder and failure history.

5.1.2 Key Element 2: Work Week Automation

The current work week process at SNC is labor intensive and requires a large review team to review upcoming work and implementation preparation. Much of this analysis could be performed effectively with a tool that is able to aid in analyzing the component and plant information found in various databases. This would highlight the projects and work orders that have gaps and need to be manually reviewed. Automated reports could reduce or potentially eliminate certain work week meetings in the current SNC process and allow certain tasks to be performed faster and more consistently.

Use Case: Identify the areas in the work controls process which provide the most potential value in automation. Develop applications that can prepare reports based on the goals of the work controls process reviews to help identify the projects and work orders that need specific attention and focus. The tool would be an aid in identifying "offsets" based on the specific parameters provided.

5.1.3 Key Element 3: Digitization of Records

SNC has a large database of records (D2) that are often non-searchable pdf files. This vast repository of information can be cumbersome to search. Digitizing information would aid the user in being able to fully utilize other software solutions and leverage information currently only accessible through manual searches. This project is key in allowing additional information contained in pdf records to be utilized for other projects.

Use Case: Being able to easily access historical work order, failure analysis, and design basis information would be valuable for SNC. Having this data available digitally would allow tools developed in Key Element 1 to contain more useful and relevant data.

5.1.4 Key Element 4: Equipment Dashboard

A dashboard based on equipment location / system information will be developed to create an easy tool to display relevant information that a system engineer requires to perform their job duties effectively and efficiently. The data set used is like the enhanced CR report, but this dashboard allows relevant information to be seen based on the system or location ID input.

Use Case: A specific system or location identity can be entered into the tool and a dashboard will display work order history, previous failures, industry operating experience (OE), automated system health report scores, Maintenance Rule status, previous IRIS failure history, scheduled PMs, relevant trending data from Aveva Plant Information (PI). This tool will automatically collect and display much of the information that is requested during failure analysis or assessing the impact of a new issue identified in a condition report.

5.2 Screening Methodology

Screening was performed through document review, identification of stakeholders, and conducting surveys. Documents reviewed included procedures, inputs to the processes, and work products created by the processes. These documents highlighted areas that were repetitive and administrative in nature, as these traits are flags for automation and AI/ML opportunities.

Once the document reviews were complete, stakeholder interviews were conducted. Stakeholders were identified through their connection to the processes being considered. Both management and individual contributor level personnel were surveyed for their connections and perspective. Beyond the current users of the processes, the information technology organization (IT) was also considered a stakeholder. This is due to their understanding of business databases and relationships at SNC and their potential involvement in deploying future AI/ML solutions.

Virtual surveys were conducted in groups to encourage collaborative and thorough answers to the questions. Surveys were conducted in multiple stages as necessary based on information gathered throughout the process. Survey questions are included in the appendix. This is the initial list of questions asked during the surveys. During each survey, a selection of these questions was asked based on the stakeholders present and the information that could not be found through document review. Additional questions were asked as needed for clarity and understanding of the processes.

The initial set of questions were developed generically to demonstrate the types of information needed to proceed. During the interviews, it was beneficial to reduce the number of questions asked and to take a more conversational tone. This allowed the participants to feel more at ease and to speak freely about the potential pain points in the processes.

These surveys provided insight into how processes are used and how each step impacts the user. It was beneficial to hear from individuals with direct experience in the processes. Engineers were able to give examples of the variability in the level of effort needed to analyze condition reports. These surveys also served to confirm the accuracy and completeness of the procedures used to govern the processes.

During the risk evaluation questions, examples were given about recent attempts at modernizing business processes. The stakeholders cited issues around change management and stakeholder engagement in the development and deployment stages. It was recommended to consult with the end users of the technology as they are the ones who ultimately need to find the applications useful.

Work Controls managers gave many examples of repetitive tasks that are time consuming, such as needing to access six or more databases/applications to develop the weekly reports.

The IT representatives spoke about current policies regarding advanced AI/ML technology and cloud-based services. These responses were used to form the solution paths for the WROs. For a solution to be successfully adopted at SNC, it was important to consider the current technology being used by the company and to understand the policies that may affect the solutions we propose.

5.3 Final WROs

Through the screening process, the WROs were defined and reviewed for potential benefit for SNC and the industry. This process concentrated on two focus areas, with multiple WROs. The work controls process WROs identified are planning optimization, screening automation, and the work week meeting package analyzer. The CR process WROs identified are a CR research aid, and an automated CR peer checker. Each of these WROs are defined in sections 6.2 and 6.3.

Focus Area 1: Work Controls

- WRO 1.1: Planning Optimization
- WRO 1.2: Screening Automation
- WRO 1.3: Work Week Meeting Package Analyzer

Focus Area 2: Condition Reporting Process

- WRO 2.1: CR Research Aid
- WRO 2.2: Automated CR Peer Checker

The key elements described as digitization of records and equipment dashboards were evaluated and determined to be tools that could assist in alleviating the pain points described in the WROs. The digitization of records can be helpful in searching internal and external OE sources during both the Work Controls and the Condition reporting processes. The equipment dashboards are a way of presenting needed information that is stored across several databases. This tool can be applied to the condition reporting process as a way to display and interact with information collected by the research aid. As such, these key elements are tools to support WRO resolutions and are not considered independent WROs.

5.4 Focus Area 1: Work Controls

The current work week process at SNC is labor intensive and requires a large review team to review upcoming work and preparation for implementation. Based on a review of recent CRs and discussions with Work Controls stakeholders, relying solely on humans for screening, planning, and coordinating work has resulted in avoidable work conflicts and a large backlog of work to be completed. This work is completed based on the knowledge and experience of the individuals performing the tasks, and therefore, the results are not always consistent between users.

The following three WROs were identified as potential use cases for AI/ML or automation technologies. Research into the focus areas was performed to the extent practical. As such, the Work Controls focus area was not explored as fully as the Condition Reporting focus area.

5.4.1 WRO 1.1: Scheduling/Planning Optimization

5.4.1.1 Problem

Scheduling activities is a largely manual task dependent on humans to notice conflicts and bundling opportunities. With a full knowledge and understanding of outstanding work be done, a scheduler may be able to bundle work if it utilizes similar resources, such as scaffolding in the same area or needing the same contractor company on site. If these bundling opportunities are identified in sufficient time, the work to be performed can be done more efficiently. This also requires an understanding and knowledge of allowable flexibility for a scheduled activity.

Additionally, when scheduling work, it is important to avoid conflicting work - for example planning to perform a work order that puts Train A of the system out of service at the same time as a different work order which would take Train B of the system out of service.

Currently, personnel from maintenance, operations, engineering, and work controls look at the scheduled work to try to prevent conflicts and incorporate optimization opportunities.

5.4.1.2 Solution

Once scope has been frozen for a particular work week, a scheduling tool will be run that will identify potential bundling opportunities. This tool will provide a recommended optimized schedule for the week, with any constraints identified. This tool will rely on historical information of what is required for work packages, resource availability, identified float for an activity, and known constraints such as protected train status, scaffolding needs, or cycle plan.

5.4.2 WRO 1.2: Screening Automation

5.4.2.1 Problem

During the “new work” screening process, a series of decision trees are followed to determine if the work should be performed under the tool pouch process, during an outage, by the FIN team, or if it should continue in the process outlined in the Work Controls procedure. The evaluations completed in this stage also look at priority and level of planning needed. This stage of the process is considered a pain point as it is a repetitive manual task based on established practices and decision trees.

5.4.2.2 Solution

When a condition report is screened into the work controls process, an application will use a series of decision trees and historical knowledge of similar conditions to screen the work into the appropriate process. This screening will be reviewed by an individual with knowledge and experience with work controls processes. This application will need to understand the scope of work needed and whether special consideration needs to be given due to potential impacts to safety or other concerns.

5.5 WRO 1.3: Work Week Meeting Package Analyzer

5.5.1.1 Problem

The current process for compiling and reviewing the work week meeting packages is highly manual with the work controls personnel running reports in several different applications and compiling the package for distribution each week. The meeting packages are not optimized for reviewability. The information relevant to a particular group is spread throughout the package such that individuals must search the package for relevant elements prior to discussion during the meeting.

Additionally, it would be beneficial for topics needing discussion to be highlighted. This could include the identification of parts with long lead times or whether spare parts needed for a work order are available in the warehouse.

5.5.1.2 Solution

Each week, an assembly aid will be run for the week's required packages. This aid will pull information and reports from each of the required databases into a single document for review. This aid will allow the user to identify their role/functional area and sort the reports in such a way to optimize readability. Additionally, a summary page will be provided to highlight gaps in the package and elements that are likely to need further discussion as identified through review of historical work week meeting notes.

5.6 Focus Area 2: Condition Reporting Process

In the condition reporting process, two work reduction opportunities were selected based on stakeholder feedback and document review. In Figure 14, Box 1 represents the time spent researching a particular CR from the morning report, and Box 2 represents an optional Peer Check that is performed to help ensure a CR is written with complete and correct information.

With the CR processor research aid and an AI Peer Checker, CR's may be analyzed and resolved in less time, with more efficient information sharing.

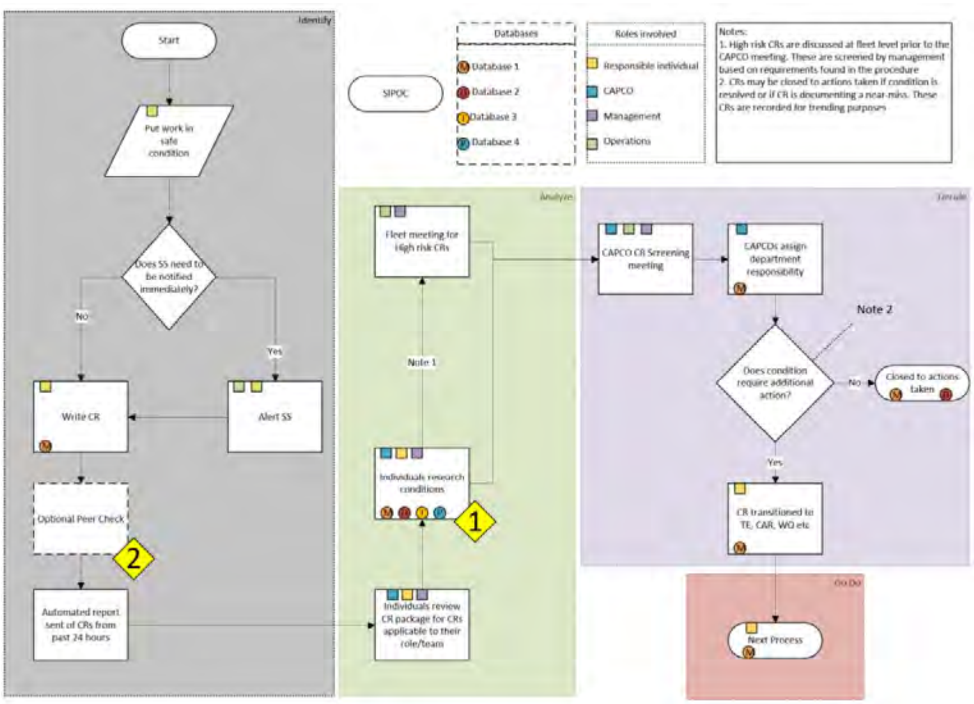

Figure 14. Condition Reporting and Analysis Process Map.

5.6.1 WRO 2.1: Condition Report Research Aid

5.6.1.1 Problem

Once a CR is initiated, the first step to dispositioning is to collect relevant information about the condition. This could include:

- Internal OE searches in [internal databases] to address the following questions:
  - Has this condition previously occurred on this component or system? Has it occurred on similar components?
  - Has it occurred elsewhere in the fleet?
  - What are the most recent work orders performed on or near this component?
- External OE searches in IRIS to address the following question:
  - Has this or a similar condition occurred elsewhere in the industry?
- Plant conditions in Nahar OSU Radiative (NORAD), Oil Systems Incorporated Plant Information (OSI PI), Power Business Intelligence (Power BI), Enterprise Data System, and other databases to address the following questions:
  - Were there any trending indications leading up to the observed condition?
  - What states were the plant and relevant systems in at the time of the observed condition?
  - Did any other systems or components react to the observed condition?

Compilation and analysis of this research is crucial to fully address the condition in the next phase of the process. For CRs with higher risk levels, some of these questions are expected to be answered in advance of the morning fleet calls. For lower risk CRs, the information is relevant to the Corrective Action Program Coordinator (CAPCO) screening meeting later in the day.

While not all this information is immediately needed for every CR, it is eventually required. Curating a full research stack for each CR is time consuming. Information related to any single CR may be relevant to multiple individuals, leading to duplicated efforts if there is no coordinated research plan. This research gathering effort can equate to more than 40 hours spent on a single CR.

5.6.1.2 Solution

Objective: To reduce time spent searching databases and reduce redundant efforts in research; streamline information sharing.

Description: The CR research aid reads each condition report and determines if it is related to equipment reliability. If it is related, then the aid searches for relevant information from a variety of sources. Some of the information included in the results could be recent WOs on related equipment, plant/system status, external OE, and internal OE about how similar issues have been handled previously. This information is compiled and delivered to the end user with a summary of the findings. The summary is a high level look at what documents are included, what information might still be missing, and answers to common questions, such as “when was work last performed on this component?” or “Is this a repeat issue we may want to track?”

Example*: During <Activity> it was found that < Valve> is leaking by, and steam is admitting from under pipe cap causing condensation to fall to the floor at <Location>.*

Functional requirements:

- Understand the problem statement within condition report (Criteria aids writing CR, vectorizes the language model, provide CR summary data to research aid) [Note: this requirement is common to 5.2.3.1 and 5.2.3.2]
  - Is this equipment reliability related?
    - Y/N
  - High risk?
  - Safety related?
    - Personnel
    - Nuclear Safety
  - What failure mode(s)?
    - Example: Valve Packing leaking
  - Potential cause?
    - Example: Overpressure of system
    - Example: Valve packing age
    - Example: Valve packing installation
  - Consequences of failure mode?
    - Example: Puddle
    - Example: Loss of pressure
  - Time
    - Start time
    - Time to alarm setpoint
    - Time to resolve
  - Possible solutions?
    - How has this been resolved in the past?
- Assemble information relevant to CR from databases
  - Internal OE
    - CAP
    - WO history
    - Calibration results
  - External OE - IRIS
  - Plant/system conditions
  - Trends
  - Documentation -drawings, vendor manuals, procedures, System Design Docs, Licensing Basis
  - Component Attributes
- Deliver information to personnel
  - Summary/Data visualization Dashboard –

  – What documents/information was included
  – why/context – What insight was derived
  – What information is still missing
- Additional files

- Rate the relevancy of a CR for individuals based on department and role

5.6.2 WRO 2.2: Automated CR Peer Checker

5.6.2.1 Problem

When investigating a condition report, a common pain point is an incomplete or overly generalized CR. The originator of the CR may have omitted information in the body of the CR or left blank spaces in non-required fields. Such omissions cause investigators to spend more time and effort discovering why the CR was written.

Information missing could include:

- Multiple location IDs involved, but not linked in the form
- The leak rate (in a condition about a leak discovered)
- Time of discovery
- WO or activity being performed when the condition was discovered
- If the condition, or a similar one, was previously recorded

Answering these questions can be difficult for the reviewer if the condition was observed on a different shift or if the originator is not available when the condition is being recorded.

Currently, many of these issues are resolved during the optional peer check performed. During this step, the CR initiator asks a member of their group or other knowledgeable individual to review the CR for technical errors, grammatical mistakes, and completeness. This step relies on another individual having the time and knowledge needed to perform the review.

5.6.2.2 Solution

Objective: To reduce time needed to write complete and correct condition reports

Description: The AI CR Peer checker tool is an optional step an individual can elect to perform once they have written a CR. This tool will examine their CR and make suggestions based on missing or conflicting information. For instance, if the CR initiator mentions a valve leak, the tool will ask if the initiator would like to include the leak rate, or if the user mentions a valve at the 117-foot elevation is leaking on a component at a higher elevation, then the tool will highlight the inconsistency and ask if the initiator would like to resolve the inconsistency.

***Example**: During <Activity> it was found that < Valve> is leaking by, and steam is admitting from under pipe cap causing condensation to fall to the floor at <Location>.*

Functional requirements:

- Understand the problem statement within condition report (Criteria aids writing CR, vectorizes the language model, provide CR summary data to research aid) [Note: this requirement is common to 5.3.2.1 and 5.2.3.2]
  - Is this equipment reliability related?
    – Y/N
  - High risk?

- Safety related?
  - Personnel
  - Nuclear Safety
- What failure mode(s)?
  - Example: Valve Packing leaking
- Potential cause?
  - Example: Overpressure of system
  - Example: Valve packing age
  - Example: Valve packing installation
- Consequences of failure mode?
  - Example: Puddle
  - Example: Loss of pressure
- Time
  - Start time
  - Time to plant impact
  - Time to resolve
- Possible solutions?
  - How has this been resolved in the past?

• Review for inconsistent information
  - Locations and elevations
  - Component type and condition description
  - Component location ID and noun name
• Review for missing information
  - Based on similar condition reports, what information is commonly included?
    - Location and/or elevation
    - Type or rate of failure condition
    - Work being performed when condition was observed
    - Additional affected equipment IDs
    - Immediate actions and results
• Prompt initiator to resolve missing or inconsistent information
  - Using HFE guidance on AI-Human interfaces, the tool will provide feedback and/or recommendations to the initiator

NOTE: *There is some overlap in the functional requirements for 5.2.2 and 5.2.3. Developing these solutions together could result in time/cost savings by leveraging the similarities.*

5.7 Cost/Benefit Analysis

Through analysis of time spent on each of these WRO and potential impact on future states of the process.

Focus Area 1: Work Controls

- WRO 1.1: Planning Optimization
  - It was determined that this opportunity needs further investigation into technological feasibility and economic impact.
- WRO 1.2: Screening Automation
  - It was determined that this opportunity needs further investigation into technological feasibility and economic impact.
- WRO 1.3: Work Week Meeting Package Analyzer
  - It was determined that this opportunity needs further investigation into technological feasibility and economic impact.

Focus Area 2: Condition Reporting Process

- WRO 2.1: CR Research Aid
  - It was determined that this is a viable project due to stakeholder feedback on potential economic savings as well as potential to reduce performance errors.
- WRO 2.2: Automated CR Peer Checker
  - It was determined that this is not a viable project due to stakeholder feedback that it is unlikely to be used frequently.

5.8 Condition Report - Current Process Analysis

5.8.1 Markov Modeling

Before solutions to aid systems engineers can be evaluated, an economic assessment of the current process must be completed. To do this, we have modeled this process using a probabilistic Markov model which describes the process as a series of states and transitions. The condition report process can be modeled as a decision process that interacts with the equipment health and reliability through information gathering, analysis, and a resulting maintenance action.

The CR process starts after some initiating event or observation involving equipment reliability is recorded in the decision report. Once the CR is written, system engineers will be required to diagnose the situation and perform information gathering and analysis. After the research is completed, a maintenance decision is made, and the resulting action is performed. After the maintenance action is completed, the system is assumed to have returned to a healthy/operational state. This is a simplification of a longer sequence of decision making and issue resolutions; however, this high level of granularity will help us evaluate the information gathering and analysis process and its interaction with the equipment reliability without requiring an overcomplicated model. The Markov model for the CR process can be seen in Figure 15.

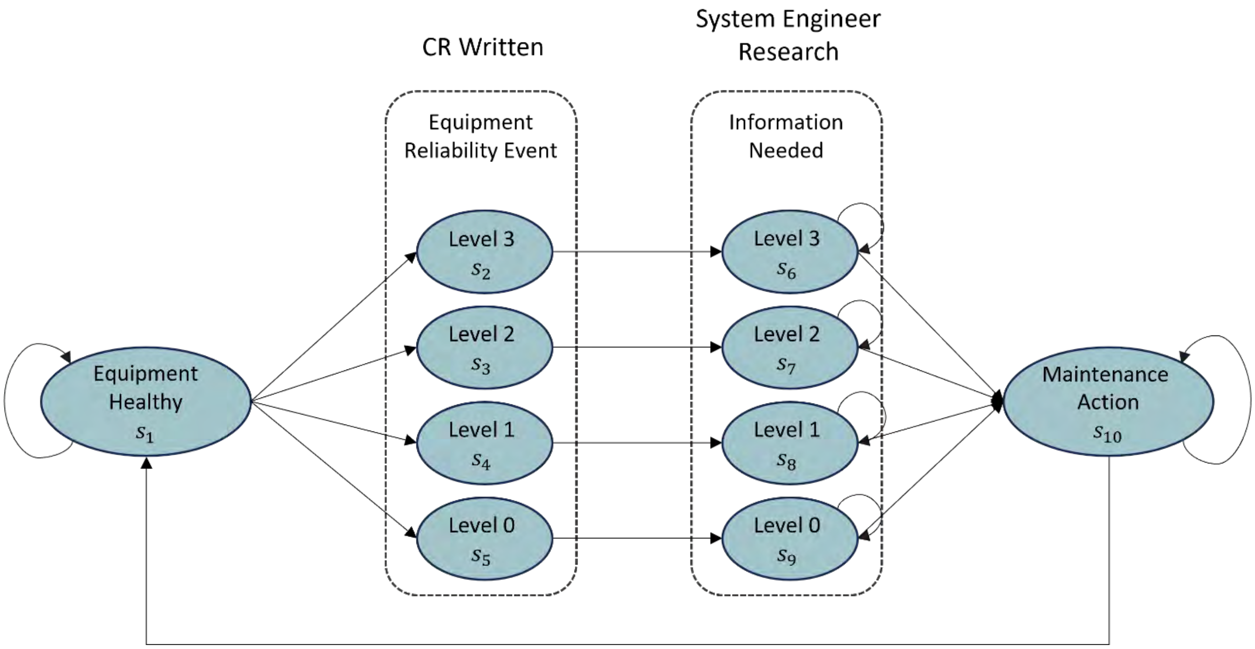

Figure 15. The current CR process with system engineering research hours as the main focus. The blue parts of the model represent the overall process with states. Each state is numbered s_1 through s_{10}, represent all the possible states in the process and are numbered for analysis purposes.

The CR process can be broken down into four main states: equipment healthy, CR written, system engineer research, and maintenance. The states CR written and system engineer research can be further broken down into four independent states, labeled 0 through 3, that correspond to the type of research required for that CR. A level 0 corresponds to a CR that needs minimal research, where a level 3 corresponds to a significant research effort such as a root cause analysis. The information levels and representative research tasks can be seen in Table 1.

Table 1. Information levels and the related research tasks.

Information Level	Representative Research Tasks
3	Root cause analysis
2	Equipment reliability checklist
1	Preventive maintenance change request
0	Minimal system engineering research

The information levels correspond to the amount of time the system engineers must spend researching before the CR can be closed and maintenance started. In Figure 15 each state is numbered, $s_1$through s_{10}, and can be seen in each state's name. In this Markov model, if there is no connection between states means that the probability rate for that transition is zero.

5.8.2 Steady State Analysis

Since this analysis is only focused on the reduction of labor hours, we have assigned costs only for states s_6, s_7, s_8, and s_9. These states require system engineering hours and therefore are the main states of interest. For this analysis, we have assigned each of those states a cost of $100/hour. This rate is assumed to be average across the industry.

As seen in Figure 16, the steady state analysis of the current process results in an expected cost of $2.3M per year. This is due in part to the cost associated with the large number of CRs that must be reviewed regardless of their information needed level. This steady state cost serves as our baseline for evaluating improvements or alterations.

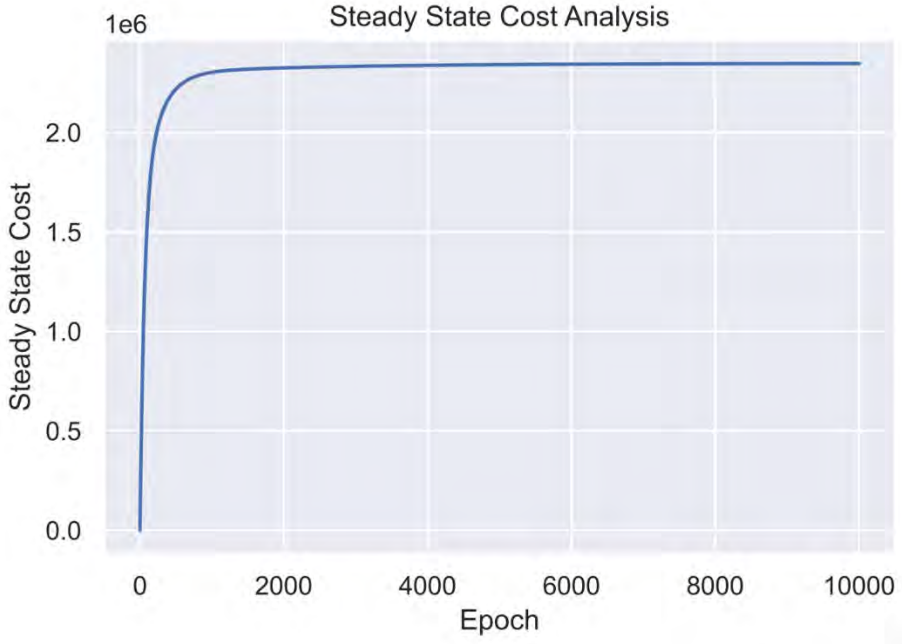

Figure 16. Steady state yearly cost analysis for the current CR research process.

5.8.3 Sensitivity Analysis

Sensitivity analyses were conducted to gauge the impact of various parameters on the overall costs. These analyses provide valuable insights into which variables could be targeted for process re-engineering for maximum cost-effectiveness.

To do this, we varied each parameter while holding the others constant. However, since each row in the Markov transition matrix must sum to 1, the other parameters were changed an amount proportional to their original ratios, such that the row summed to 1. In this analysis, each parameter was increased and decreased by 0.01% to estimate the instantaneous sensitivity. The effect on cost (absolute value) for each increase and decrease in parameter was averaged to get the sensitivity. The results of the sensitivity analysis for each parameter can be seen in Figure 17. The parameters listed in the plot indicate the transition rate from one parameter to another. For example, parameter $p_{1,2}$ is the transition rate from state s_1 to state s_2. Another example is parameter $p_{9,10}$, where this parameter dictates the transition rate from state s_9 to state s_{10}. From the plot, we can see parameters $p_{1,1}$, $p_{8,8}$, $p_{6,6}$, $p_{9,9}$, and $p_{7,7}$ have the greatest sensitivity to parameter changes. These parameters correspond to the amount of time before a CR is written ($p_{1,1}$) and the time spent researching CRs ($p_{8,8}$, $p_{6,6}$, $p_{9,9}$, and $p_{7,7}$).

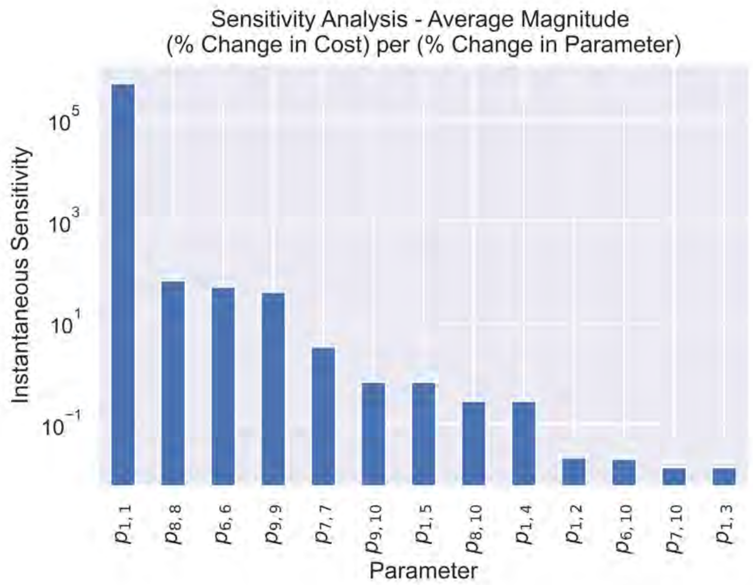

Figure 17. Sensitivity analysis results over all parameters for current process with respect to cost. Average magnitude of percent cost change with respect to percent parameter change, calculated using a 0.01% change of parameter in a positive and negative direction.

Performing a sensitivity analysis on all parameters in a model is useful, but not necessarily helpful when parameters cannot be changed. Figure 18 shows the results when focusing only on parameters that are affected by labor hours. These parameters were chosen due to their ability to be reduced with technology integration. In this figure, we can see that parameter $p_{9,10}$(transition from state s_9 to state s_{10}) has the greatest sensitivity to parameter change. This conclusion comes from the fact that a large majority of CRs have a level 0 research need but still require review.

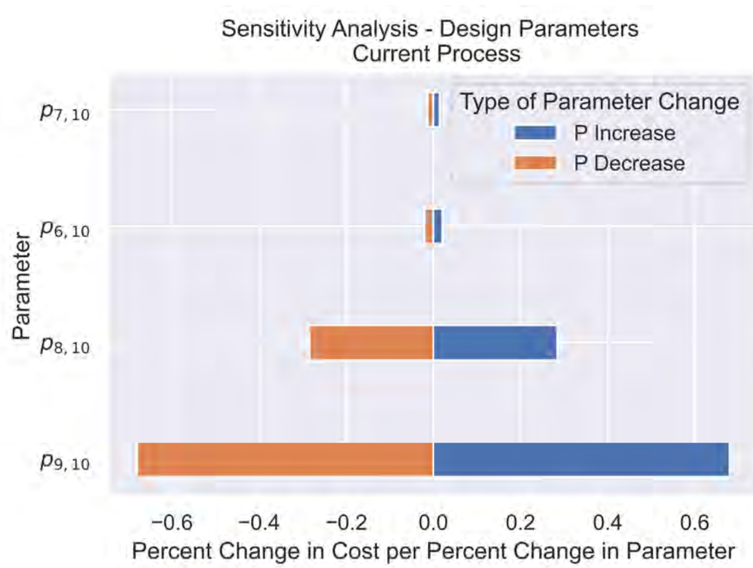

Figure 18. Sensitivity analysis for variables that can be changed or altered in process re-engineering.

5.9 Condition Report - Research Aided Process Analysis

5.9.1 Markov Modeling

When implementing the research aid solution into the Markov model, we have to add new connections and change existing parameters to model the effects. The research aid Markov model, seen in Figure 19, adds additional connection between the states of the written CR to the information needed states with the system engineer. These new connections represent how the research aid can reduce the amount of information the system engineers are required to collect, thereby reducing the time spent researching. The amount of information collected, and the performance of the research aid will ultimately determine the parameters of the new connections. At this point, the parameters are uncertain and need to be quantified through a pilot study.

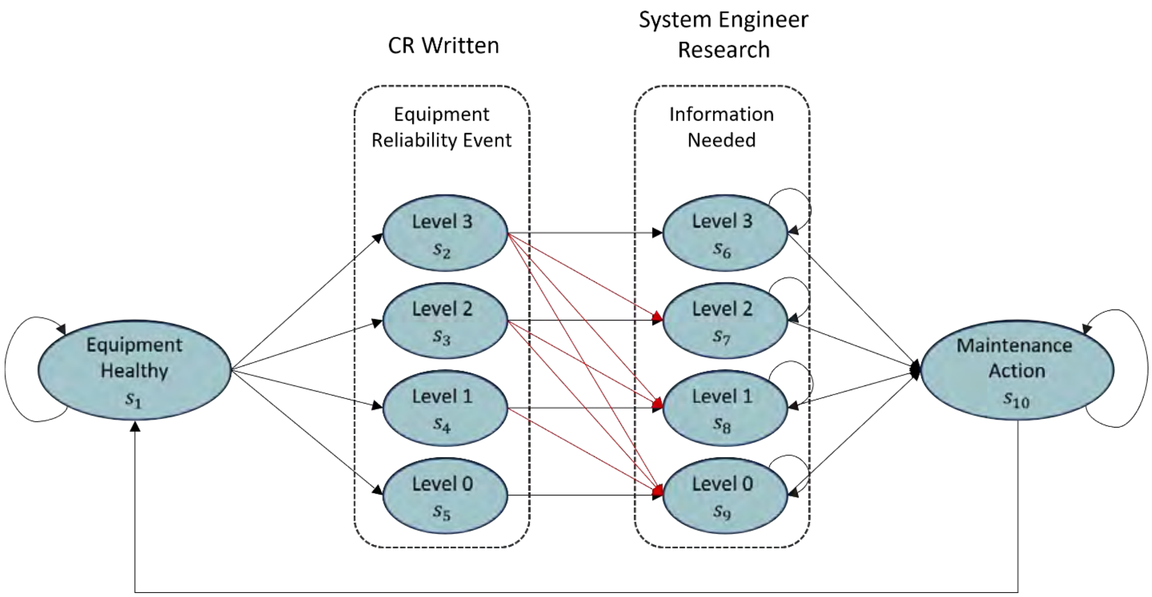

Figure 19. The Markov model of the process with the addition of research aid. The addition of the red arrows shows how the research aid can reduce the level of information needed before reaching system engineers.

5.9.2 Steady State Analysis

If we assume values for the performance of the research aid, we can perform a steady state analysis for the new model. For this stage, we assume that the research aid is nearly perfect, reducing the information needed to a level 0, with 99% accuracy/reliability. That means that 99% of all CRs are reduced to a minimal level of information needed before it gets to the system engineer. The remaining cost in this process can be attributed to the fact that CR information will still require a review after the research aid is implemented. The steady state cost reduction for this scenario can be seen in the Figure 20. As seen from the plot, the research aid is able to reduce the cost of the process to about 75% of the original cost. This corresponds to yearly cost savings of $574K per year.

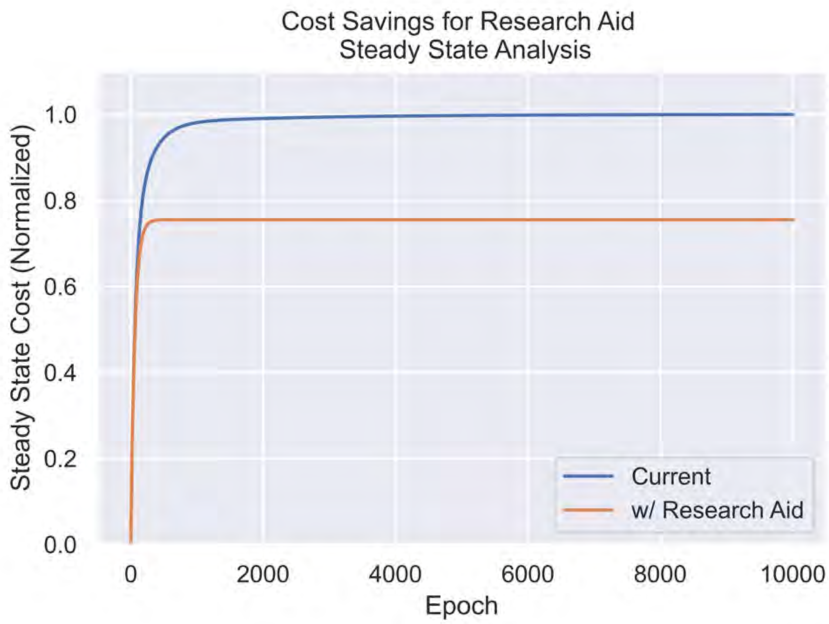

Figure 20. Steady state cost comparison (normalized) for the current process and the new process with the research aid. The research aid can reduce the yearly costs by an estimated $574K.

5.9.3 Sensitivity Analysis

A sensitivity analysis of all parameters was performed on the new process which can be seen in Figure 21. The results are similar to the original process; however, more sensitivity is shown for the parameter $p_{9,9}$. This parameter represents the time spent reviewing level 0 CRs. This parameter has more importance in the new model since the research aid reduces 99% of all CRs to a level 0, which still requires time to review.

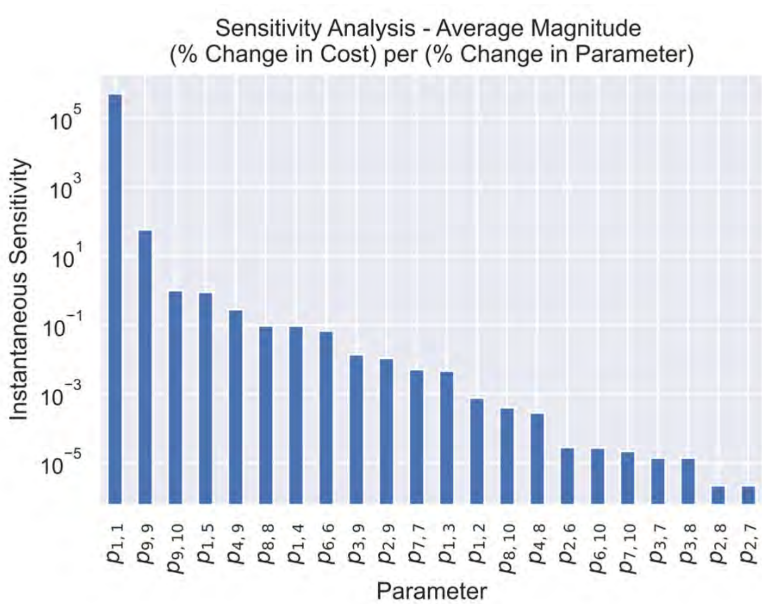

Figure 21. Sensitivity analysis results over all parameters for research aided process with respect to cost. Average magnitude of percent cost change with respect to percent parameter change, calculated using a 0.01% change of parameter in a positive and negative direction.

Focusing on only the parameters of the model that can change or have a direct connection to labor and/or the research aid, we can see what parameters are the most important to the new process. Results of that sensitivity analysis can be seen in Figure 22. From the reduced list of parameters, we can see that the parameters responsible for reducing the information needed level, parameters $p_{4,9}$, $p_{3,9}$, and $p_{2,9}$, have significant impact on performance. From this list, $p_{4,9}$ emerges as the most sensitive parameter due to the large number of CRs that require a level 1 review (state s_4). A change to any of these parameters, even subtle changes, will result in a large change in process cost. Again, $p_{9,10}$ emerges as a sensitive parameter due to the large number of CRs that require review before they are completed. This parameter becomes even more important after the implementation of the research aid due to the increase CR reviews going through state s_9.

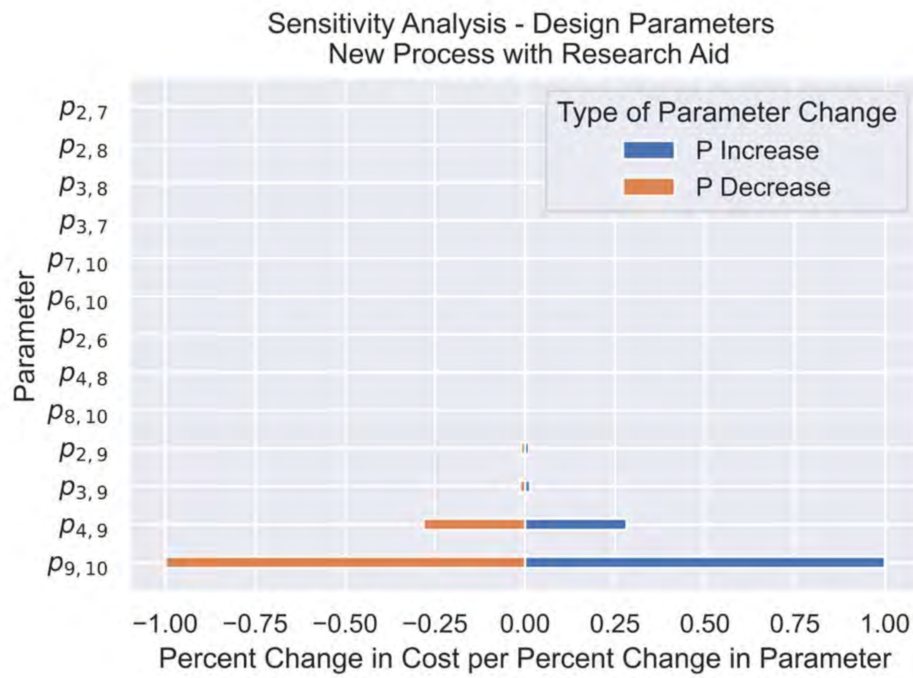

Figure 22. Sensitivity analysis of the design parameters with the addition of the research aid.

5.10 Cost-Benefit Analysis

5.10.1 Project Costs

The costs for implementing the CR solution assumes an initial investment of $2M and yearly savings determined by the Markov process steady state analysis. The initial investment cost makes the following assumptions:

1. The initial investment cost represents all design, development, and deployment costs, which will include costs associated with labor hours to develop the solution, pilot testing costs, and any equipment needing to be purchased.
2. The initial investment will be $2M. While this is a large price, a project with yearly savings of more than $500K/year will take a significant investment to achieve the performance levels that were assumed in the Markov model. In reality, there will be a trade-off between performance and investment that will have to be determined by decision-makers during the design phase.

3. The uncertainty regarding the investment cost is assumed to be plus and minus 20% of $2M. This allows for analysis of the worst- and best-case scenarios for different investment costs.
4. The initial investment is a one-time cost. The initial investment will most likely occur in phases and will achieve differing levels of cost savings over the course of deployment, resulting in breakeven points that may differ from this analysis.

The assumptions made in this analysis represent the best guess of the researchers but may differ from actual costs.

The OPEX was assumed to be $10,000 per year, which included costs for operating new equipment and maintaining systems (software and hardware). For this analysis, we assumed cost savings to be constant during all years. At this point in the project, costs are assumed to be deterministic at these values; however, a probabilistic sensitivity on these parameters can also be performed. The costs for this analysis can be seen in Table 2.

Table 2. Breakeven points for various usage rate scenarios.

Parameter	Value
Initial Investment	$2M
OPEX	$10K/year
Yearly Cost Savings	$574K/year

5.10.2 Breakeven

A breakeven analysis of the research-aided CR process was performed using the assumed costs. We performed three scenarios that included different levels of the Usage Rate, including 10, 50, and 100%. The usage rate corresponds to the implementation risk that arises due to limited use or low adoption rates. This risk was identified as the most significant since it occurs after implementation and can greatly reduce cost savings. The yearly plot of cost savings over a period of 10 years can be seen in Figure 23.

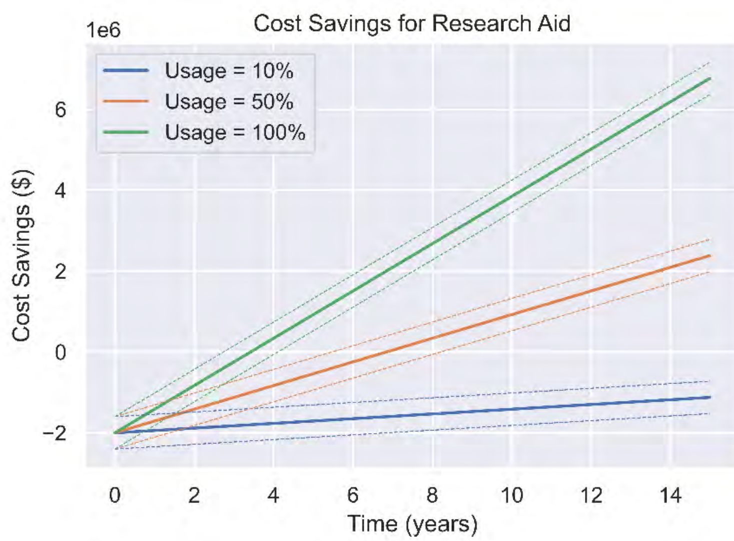

Figure 23. The cost savings for implementing the research aid to help system engineers. Plotted are three scenarios where the tool is used by a varying level of system engineers across the organization. Each scenario has bounds (dashed lines) that describe the initial investment uncertainty of plus/minus 20%.

For the Usage Rate of 100% (meaning all system engineers used the research aid), the breakeven point was determined to be 3.43 years from deployment date. For the Usage Rate of 50% (meaning only 50% of system engineers used the research aid) the breakeven point was just over 6.85 years. For the Usage Rate of 10% (meaning only 10% of employees adopt the new process), the breakeven point was well over 15 years. The results of the breakeven analysis can be seen in Table 3.

Table 3. NPV breakeven points for various usage rate scenarios.

Usage Rate	Breakeven Point
100%	3.43 years
50%	6.85 years
10%	>15 years

5.10.3 Net Present Value

To calculate the NPV for the research-aided CR process, we used the same initial investment and yearly cost savings as the breakeven analysis in the previous section. For the discount rate in this NPV calculation, we used the value of 7%. Although 7% can be considered conservative, this represents the return rate that could be expected from an alternative investment. We performed three NPV scenarios that included different levels of Usage Rate that included 10, 50, and 100%. The yearly plot of expected NPV over a period of 10 years can be seen in Figure 24.

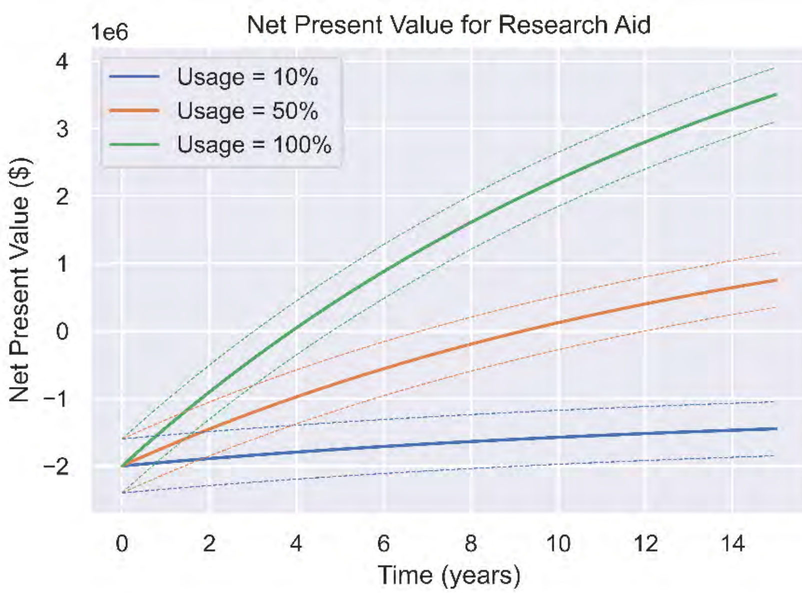

Figure 24. The NPV of the research aid over time and for varying levels of usage. Each scenario has bounds (dashed lines) that describe the initial investment uncertainty of plus/minus 20%.

Figure 24 shows that we can expect the NPV to be positive for the 50 and 100% usage rates. However, the 100% usage rate has the most positive NPV and is positive after 3.9 years. The 50% usage rate scenario does not perform as well, only becoming positive after 10 years. Like the breakeven analysis, the 1% usage rate scenario does not become positive in the 10 years during the analysis. The results of the breakeven analysis can be seen in Table 4.

Table 4. NPV analysis and the breakeven dates for each usage rate scenario.

Usage Rate	Positive NPV Breakeven	NPV after 15 years
100%	3.9 years	$2.24M
50%	9.2 years	$122K
10%	Always Negative	−$1.58M

6. SUMMARY AND PATH FORWARD

The efficient and cost-effective operation of an NPP is a critical factor in ensuring its long-term viability and safety. The lack of a structured approach for identifying and evaluating WROs in the nuclear industry has been a notable gap. This research reduces that gap by introducing the TERA framework tailored for the nuclear industry, relying heavily on the modernization principles developed by LWRS and ION.

Our findings, based on a case study with Southern Nuclear Company, validate the utility of the TERA framework. The methodology successfully screened various WROs considering technical feasibility, economic viability, and associated risks. The use of KPIs facilitated a cost-benefit analysis and offered valuable insights for decision-making.

As part of that collaboration, we conducted targeted surveys aimed at uncovering inefficiencies in condition report processes and T-week processes. The survey revealed two major areas requiring attention—both of which were manual, time-consuming, and cost-prohibitive. An initial TERA assessment using the Markov chain analysis confirmed the high potential for cost reduction through technological solutions and automation in these identified areas.

The TERA framework has been shown to have practical implications for the nuclear industry. It offers a systematic approach for utilities to make informed decisions regarding the implementation of WROs, mitigating risks and capitalizing on opportunities for cost savings and operational efficiencies. The TERA methodology not only has the potential to transform the day-to-day functioning of NPPs but also to contribute to the broader aim of utility modernization.

The path forward for this project will focus on furthering the analysis of the remaining WROs, focusing on the work week process automation. Furthermore, the TERA outcomes and framework will be evaluated through the development of a solution during a pilot phase. The chosen WRO and the solution will be quantified according to the TERA process and evaluated for cost-benefit performance and risk mitigation.

In conclusion, the TERA framework stands as a valuable tool for utilities aiming to optimize operations, reduce costs, and drive continuous process improvement. It is our expectation that the adoption of this framework will aid in the analysis of WROs and improve their implementation in the nuclear industry. By doing so, this framework can reduce overall costs and improve the economical sustainability of the nuclear industry.

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Appendix A

Interview Screening Questions

Screening questions were developed generically, then asked in surveys as they applied to the stakeholders present for each meeting. The following questions are considered a sampling of the questions asked. During the surveys, additional questions were asked as the conversation allowed for clarity and deeper understanding.

Process Questions

1. Suppliers/People
   a. How many people are involved in the process?
   b. What organizations are needed for this process?
   c. What are their roles and responsibilities?
2. Inputs
   a. What information is required for this process?
   b. How is this information collected?
3. Process
   a. Process
      (1) What are the steps in the process?
      (2) Are there simultaneous or parallel steps in the process?
      (3) Which processes can begin before the last one begins?
   b. Information Flow
      (1) What information is used in the steps of this process?
      (2) What information is stored or recorded as part of the process?
      (3) What information is passed onto the next process?
   c. Governance
      (1) What are the existing rules, regulations, or standards governing the process?
      (2) Are there any compliance or legal requirements that need to be met?
      (3) Are there any internal policies or guidelines specific to the process?
      (4) Are there any documentation or reporting requirements for the process?
4. Outputs
   a. What is the output or product this process develops?
   b. What information is created or recorded?
   c. Where does it go?

Risk Evaluation

Economic and risk of failure to adopt the new process due to organizational or project inefficiencies.

The intent of these questions is to provide a general understanding of the organization's "readiness" to embrace new processes and technologies. If the organization is not ready, some mitigating measures should be put in place like visits to the plant and meetings with all involved organizations and stakeholders, demonstration runs, and collection of feedback, etc. This is something that still needs to be done, but in the case of "low readiness" it should be done with much more intention and more frequency.

1. What is your organization's most recent experience of implementing new processes or technology that affects multiple functional areas (e.g., operations, engineering, and maintenance)? Please list all that come to mind for the last 5–7 years.
2. How successful were the most recent attempts to implement new process / technology?
3. What are the reasons for the above implementation experience(s)? Please be as detailed as possible.
    a. Cross-organization support
    b. End product meeting (not meeting) the expectations
    c. Integration of new process with existing processes
    d. Availability of resources
    e. Plant staff readiness to implement the new process / technology
    f. Supplier performance (if applicable)
4. How would you describe the effectiveness of cross-functional communication within your organization? Please explain.
5. What is your organization practice relative to formal requirements development/management?
6. Can the combinations of inputs be adjusted, while continuing to produce the same output, and lower costs?
7. Holding cost constant, can inputs be adjusted to produce more output?
8. Are there any opportunities to reduce costs without compromising quality or safety?
    a. If costs are reduced, will this affect the quality of the output?
9. Are there any investments required to improve process efficiency?
10. Are there any financial or budget constraints that need to be considered?

Information Technology Questions:

1. What are SNC's data privacy concern(s)? How do we navigate those concerns?
    a. What data would the model have access to? Would it be best for the model to only access the data that's accessible to the user?
2. Microsoft Azure and Google Cloud have ML tools that could be used for these ML process automations, document digitization, and data visualizations tasks. Are there any issues with using these commercial, cloud-based solutions?
    a. If cloud-based services are allowed, are there any restrictions related to where the data resides? For example, does it have to reside in the U.S.?
3. If cloud-based services cannot be used, are there any equipment requirements for hosting these models?

4. Do your applications or databases have APIs? If not, how can they be made accessible? How responsive are they?
5. In general, do you have any ideas about how these ML models interface with the existing system, perhaps from previous projects?

Economic Benefit Questions:

To evaluate a tool that aids system engineers in researching issues documented in CRs, we have categorized the information gathering and analysis needed for a CR into effort levels. Data collection and analysis effort increases with the level number. The levels are roughly categorized to contain the following examples:

- **Level 3:** Root Cause, IRT
- **Level 2:** Equipment reliability checklist
- **Level 1:** PMCRs, WO initiated
- **Level 0:** No information gathering/analysis needed. – Closed, no action

1. Approximately what percentage of <u>equipment reliability related CRs</u> are:
   a. Level 3:
   b. Level 2:
   c. Level 1:
   d. Level 0:
2. Considering <u>equipment reliability related CRs</u>, how long does information gathering and analysis take to complete (hours) for each level? (On average or a range)
   a. Level 3:
   b. Level 2:
   c. Level 1:
   d. Level 0:
3. Considering <u>equipment reliability related CRs</u>, approximately what percentage have OE searches performed?
4. For CRs that require OE searches, approximately how long does it take to complete the search (in hours)?

Appendix B

Technical Briefing

Briefing Paper
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September 25, 2023

LIGHT WATER REACTOR SUSTAINABILITY

Development of a Technical, Economic, and Risk Assessment Framework for the Evaluation of Work Reduction Opportunities

Introduction and Background

In the pursuit of achieving operational efficiency, nuclear power plants are identifying work reduction opportunities (WROs) and developing technology-enabled solutions. While these WROs promise potential cost savings, they also come with inherent risks. To systematically understand those risks and alleviate any concerns, the Light Water Reactor Sustainability (LWRS) Program researchers have developed a novel Technical, Economic, and Risk Assessment (TERA) framework that performs a comprehensive evaluation of WROs. This framework is designed to ensure that stakeholders can make informed decisions on modernization investments, minimizing risks and optimizing operations in the nuclear sector.

Technical, Economic, and Risk Assessment

The TERA framework serves a two-fold purpose when evaluating WROs. First, the framework screens and assesses WROs from technical, economic, and risk perspectives (see Figure 1). The screening is performed qualitatively in collaboration with stakeholders. A process map of the screened WRO is developed and evaluated using quantitative models. Second, TERA outputs inform the strategic development and implementation of modernization technologies, along with the potential impact on plant business.

Figure 1. The technical, economic, and risk assessment is used to evaluate WROs.

The TERA framework consists of the following evaluation perspectives:

Technical – The technical assessment focuses on the process itself and the technical solution. This part of the assessment develops key performance indicators that can or are already used, for measuring process performance. Additionally, the technical assessment evaluates the feasibility and requirements of the potential solutions.

Economic – The economic assessment focuses on the cost-benefit performance of the proposed new solution. This involves estimating the costs of the current process, the costs of developing and deploying the new solution, and uncertainties in each of these estimates. Through this assessment, the WRO will be evaluated for cost savings, breakeven period, and the net present value of the investment.

Risk – The risk assessment focuses on the identification and evaluation of potential consequences associated with the implementation of WROs. The risk assessment can also be used to evaluate any potential impacts on plant or personnel safety.

Real-world Application

LWRS researchers collaborated with Southern Nuclear Company and Sargent & Lundy, LLC on a practical application of TERA. Through the rigorous analysis and screening conducted as part of the TERA process, five specific WROs were identified. The WROs were contained within two larger processes known as the work week planning and the condition reporting (CR) process. Within the CR process, one of the more beneficial WROs that was identified during the screening was the creation of a CR research aid for system engineers.

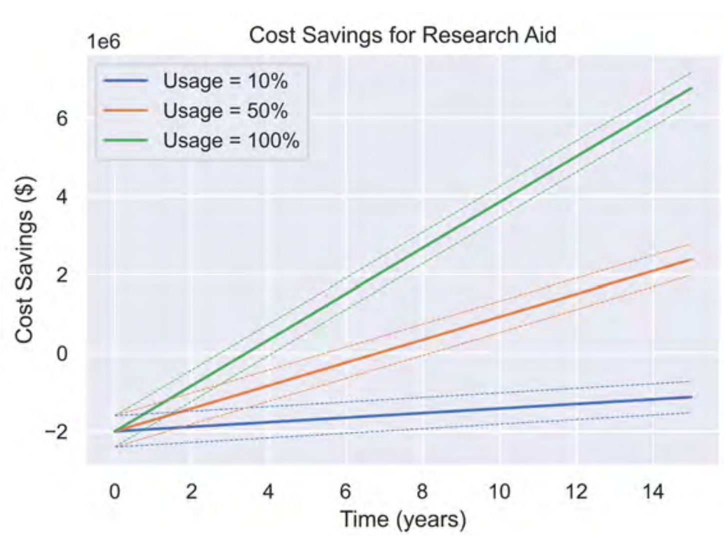

Figure 2. Cost savings of the CR research aid as a function of time.

The analysis of the CR research aid focused on the information-gathering process done by system engineers for equipment reliability-related CRs. Modeling and analysis predicted that a system engineering research aid could cut CR process costs by 25% annually (approx. $570K in yearly cost savings). The cost savings of the implemented research-aided process can be seen as a function of time and different levels of usage in Figure 2. Assuming an initial cost of $2M and a full level of adoption (meaning all system engineers use the new process), the cost savings are overwhelmingly positive with a breakeven date less than 4 years.

Acknowledgments

This report was made possible through funding from the U.S. Department of Energy (DOE)'s Light Water Reactor Sustainability program. We are grateful to Alison Hahn of the U.S. DOE, and Bruce P. Hallbert and Craig A. Primer at Idaho National Laboratory (INL) for championing this effort. We thank

Katie S. Stokes at INL for her technical editing support. We thank Lauren M. Perttula of RED, Inc. for some of the graphics contained in this briefing paper. We would also like to thank Ray Herb and Jesse Budraitis at Southern Nuclear Company, and Christianna Howard, John McCague, Matthew Lowens, and Pareez Golub at Sargent & Lundy, LLC, for their collaborations and contributions to this research.

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More on the LWRS Program: https://lwrs.inl.gov/

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