INL/RPT-24-80099
Revision 0

Light Water Reactor Sustainability Program

Digitalization Mapping and Assessment Process Supporting ION Strategic Transformation Activities

September 2024

U.S. Department of Energy

Office of Nuclear Energy

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Digitalization Mapping and Assessment Process Supporting ION Strategic Transformation Activities

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September 2024

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

EXECUTIVE SUMMARY

The existing fleet of commercial nuclear power plants (NPPs) is an important asset in the nation's portfolio of electrical generating resources. Its continued safe and reliable operation is critical to providing a large source of carbon-free electricity to power the nation's economy. The United States Department of Energy's (DOE) Office of Nuclear Energy's Light Water Reactor Sustainability (LWRS) Program develops the scientific bases, methods, and tools for the continued economical operation of the nation's commercial NPPs without impacting safety. The Plant Modernization Pathway within the LWRS Program focuses on providing guidance to industry on the full-scale implementation of modernization solutions for NPPs that significantly reduce the technical and financial risks associated with modernization.

This research is focused on helping the nuclear industry understand how to digitize and digitalize their NPPs so that they can design their modernization solutions to be scalable, sustainable, and integrated both laterally and horizontally within their organization. That is, this research creates a digital transformation in NPPs by reshaping work processes and by identifying business efficiencies.

In partnership with industry, and using four previously established guiding principles for digitalization, this research supported NPP modernization through assessing readiness for digitalization as a means to achieve integrated operations for nuclear. Specifically, this research created an assessment to review an entire organization's work processes to gather information about the digitalization health of the plant. A survey tool was developed that is customized, inexpensive, and user-friendly, and that generates a rapid, efficient, and effective digitalization status report of a plant's work processes. The results were used to develop a digitalization plan.

The survey assessment identified optimal candidate processes that would most benefit from digitalization initiatives. These candidate processes were revealed through several analytical frameworks. The first analysis calculated mean digitalization health indicator scores for all endorsed activities, which allowed the research team to rank and color code the results for easy identification. It is important to note that the survey assessment tool produces individual health indicator metrics, allowing current and future utilities to interrogate indices of work processes according to their own organizational priorities, business considerations, and desired end state.

The second analysis was from the perspective that organizations are composed of different innovator personality types (e.g., generators, optimizers, conceptualizers, and implementers), which differentially affect the organization's ability to comprehend and adapt to change (i.e., opportunities to innovate). Understanding the relative composition of innovator types at NPPs allows them to gather insights into the strengths and weaknesses they have in innovating how work is performed.

Recognizing that not all cost-saving opportunities are equal, the third analysis used the Technical, Economic, Risk, and Adoption (TERA) assessment. The first phase of the TERA, the Identify phase, was performed to evaluate work reduction opportunities (WROs) and highlight the areas of greatest potential.

Using the findings from the digitalization survey as the foundational input, these data were systematically analyzed and quantified to prioritize WROs and cost-saving initiatives. The key results from the TERA included a digitalization opportunity score for each activity and a calculation of potential cost savings. These two outputs formed the bases for calculating a priority index and rank for the activities assessed. From the prioritization calculations, the TERA can then help the utility (1) decide what digitalization priorities to invest money in implementing and then (2) calculate how much should be invested in the digitalization initiatives selected to achieve cost savings and/or an acceptable return on investment.

Last, on-site interviews conducted at the partnering utility complemented the survey findings by revealing inefficiencies in the standard work processes that occur cross-departmentally, due to the absence of digitized and digitalized processes. The interviews also provided an opportunity to collect survey feedback and lessons learned for future iterations of the assessment tool.

The analytical methods used (i.e., digitalization health indicator scores, the TERA), as well as discussions with the utility partner revealed that the opportunities identified had a strong potential to make work processes more efficient and improve overall performance of the NPP.

The digitalization assessment tool will evolve in an iterative fashion incorporating lessons learned from this year's efforts. Future directions include increasing the number of data inputs beyond human-centric survey data such as plant key performance indicators, software deep dive, benchmarking with other utilities, raw data review and routine process review. Each input will be evaluated as a supplement to the worker perspective in a bid to provide a more comprehensive digitalization status of an organization.

Further works in this research space include adapting the tool to identify motivators and barriers to modernization more broadly, including the adoption of artificial intelligence digitalized solutions. And, unlike this year's effort that focused on one plant at one utility, another step will be to evaluate the assessment tool at the fleet level, incorporating a measure of digital transformation readiness. This project will continue to partner with industry to help implement the top priority opportunities to improve work processes, reduce costs, and improve overall NPP performance.

ACKNOWLEDGMENTS

This report was made possible through funding from the U.S. Department of Energy's LWRS Program. We are grateful to Bruce P. Hallbert, Craig A. Primer, and S. Jason Remer at INL for championing this effort. We also thank Vivek Agarwal and James E. Lainsbury at INL for peer review and technical editing of this report, respectively.

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ACRONYMS

AI	artificial intelligence
DOE	Department of Energy
INL	Idaho National Laboratory
IO	integrated operations
ION	integrated operations in nuclear
IRB	Internal Review Board
KPI	key performance indicator
LWRS	Light Water Reactor Sustainability Program
NPP	nuclear power plant
NPV	net present value
PM	plant modernization
PTPG	people, technology, process, and governance
ROI	returns on investment
SME	subject-matter expert
TERA	technical, economic, and risk adoption
WRO	work reduction opportunity

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1. Digitalization Mapping and Assessment Process Supporting ION Strategic Transformation Activities

The U.S. nuclear industry is the foundational source of carbon-free energy (Cometto & Keppler, 2019). Providing about one-fifth of the nation's clean energy, the continued operation of our large-scale nuclear power plants (NPPs) is the best way to offer energy in a market with a rapidly growing demand for power, much less a carbon-free source of power. Assuredly, new and innovative designs for nuclear power generation sources are in development that will hopefully begin contributing to the nation's energy portfolio in the next decade. Other clean energy sources, such as wind and solar, also continue to grow and contribute to the national energy portfolio. These developments and the evolving energy landscape require the legacy nuclear fleet to evaluate its current operating models and determine what nuclear operations should look like in the future.

Three main forcing factors are motivating this introspection of nuclear utilities (Hallbert & Thomas, 2013; Remer et al., 2023):

1. *Longevity.* The critical role that legacy nuclear plants play in our energy portfolio has spurred many to pursue license renewals that allow them to operate for many decades to come. However, the equipment, technology, and business models of these 40-to-60-year-old plants must be updated for them to feasibly continue operations for another half century.
2. *Cost-competitiveness.* The labor-intensive business models of the industry are contributing to high power-production costs and thin profits that present both a need and a challenge to plants to transform and implement impactful business solutions.
3. *Securing and retaining skilled industry professionals.* The aged and outdated processes, equipment, and technology at these plants do not meet the expectations or skills of the new generations of skilled workers. Mixed with the impending development of advanced reactors, there will be a high demand for those with experience in nuclear power, straining the human resources available to legacy nuclear plants.

This is where the Light Water Reactor Sustainability (LWRS) Program steps in. A Department of Energy (DOE)–funded program, LWRS is committed to helping legacy nuclear power overcome labor-intensive business models and practices by implementing science- and technology-based solutions. These solutions are targeted to help manage and modernize the aging systems, structures, components, and processes at plants so safe and cost-effective operations can continue into the foreseeable future (U.S. Department of Energy, 2024). The LWRS Program is structured by five pathways that focus on different aspects of nuclear utility operations. The work discussed in this report was performed under the plant modernization (PM) pathway. The PM pathway is committed to supporting business model transformations through business-guided innovation, labor and process efficiency gains, and enabling data-centric decision-making by implementing targeted digital technologies and restructuring plant processes.

The PM pathway within LWRS has adopted the integrated operations (IO) approach developed over the last couple decades by international oil and gas industries (Thomas et al., 2020). IO is a holistic approach to transforming a business by involving all levels of an organization to adopt and embrace a new mindset and approach to how work gets done. It is about deploying sustainable solutions and practices within an industry and building the capability to continue developing new and efficient processes that create or improve organizational capabilities and align with business goals. On a large scale, it involves integrating people, processes, and information across the organization horizontally as well as up and down the organization laterally. Figure 1 depicts the IO elements from leadership mindset at the top to data points at the bottom. The green circle represents the holistic approach to the IO elements in that they must all be considered together and iteratively. A key advantage of IO is the ability to begin with small, incremental changes that empower the worker to steadily improve the way that work is performed. These incremental changes are connected through unified business and capability targets such that together these solutions become integrated.

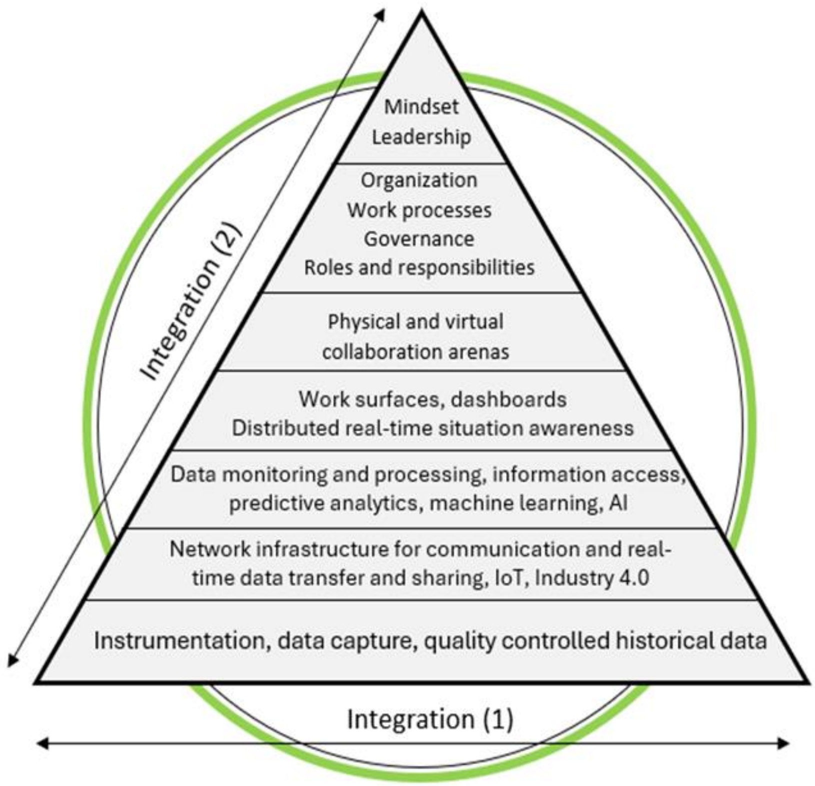

Figure 1. The lateral and horizontal integration described in IO.

1.1 Integrated Operations for Nuclear

Termed integrated operations for nuclear (ION), modernization efforts led by LWRS are working to ingrain the IO model and way of thinking into the nuclear industry. The benefit of this approach is that it establishes a growth mindset that influences each modernization effort to work toward a common goal. It is also an economical method that allows plants to approach each change at a manageable level and scope. Each individual effort and success is guided by long-term goals such that over time plants can begin evolving into a more agile, innovative, data-centric, and collaborative business model capable of adapting to the shifting energy and technology landscape.

Managing smaller individual efforts such that they can be successfully implemented within the ION model requires analyzing the elements that make up all operations and capabilities within a business. These elements are people, technology, process, and governance, or PTPG (Figure 2). Many industries tend to overvalue the role technology has in extinguishing organizational burdens. Technology enables opportunities and can make some tasks simpler, but in isolation it is not enough. Several decades of human factors engineering research shows us that technology implementation absent consideration of people and processes can often lead to failures (McLeod, 2022). There must be an analysis of the function and task allocation between the people and technology that will impact the roles, abilities, and decisions the human has in performing a task. This in turn impacts how a process can be carried out. Some supporting tasks may be eliminated by a new system, but it should always make a process more efficient by equipping human performers with knowledge, skills, and the authority to carry out their responsibilities. The first three elements (people, technology, process) are bounded and directed by governance, which includes organizational goals, desired capabilities, and regulatory requirements.

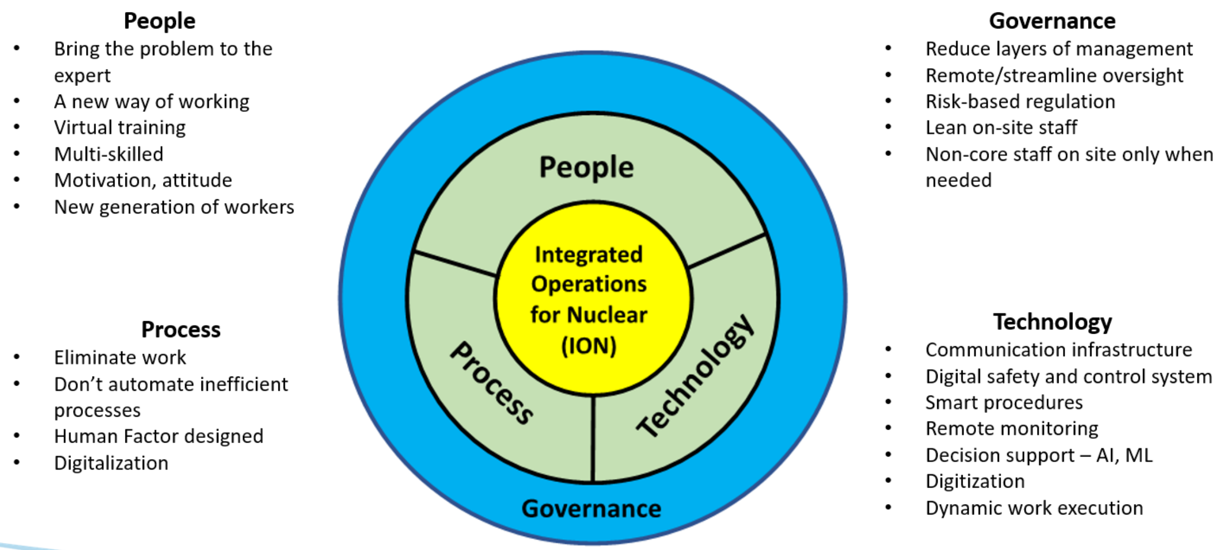

Figure 2. PTPG characteristics for ION.

1.2 Digitalization

Digitalization is a research effort within the PM pathway that is helping NPPs understand how to take ION's holistic approach by designing their modernization efforts to be scalable, sustainable, and integrated both laterally and horizontally within their organization. The digitalization effort is focused on the process element of ION, by enabling digital capabilities that collect, synthesize, and distribute data-driven information to the right people at the right time. Decision-making speed and accuracy can be improved with the inclusion of real-time, data-driven insights. By assessing digitalization solutions through the PTPG lens, processes can become streamlined in a way that serves to bring the organization closer to the ION business model. This is accomplished by applying a human factors engineering approach to the needs assessment, digitalization development, and organizational implementation and adoption.

Digitalization is the critical steppingstone from digitization to digital transformation (Figure 3). It means optimizing work processes by exploiting digital opportunities brought about by information being available in a digital format. An example is a field engineer taking pictures of components that need maintenance and uploading the images to a server. An application on the server then determines what parts are needed, sees if they are in inventory, orders them (if needed), and schedules the work. The digitalization project addresses the critical industry need to maximize digital upgrades and advancements, which is important to ensure NPPs remain financially competitive.

Last year's research efforts identified four key guiding principles that NPPs can use to effectively digitalize their work processes (Hall et al., 2023).

Guiding Principle 1: Develop a Digitalization Plan
The digitalization plan should describe the end-state vision and the approach to digitalization. It should describe what is feasible in the near term. It should also consider organizational and cultural barriers to digitalization. For example, plant technicians may see digitalization as a threat to their jobs rather than a way to do their jobs more efficiently.

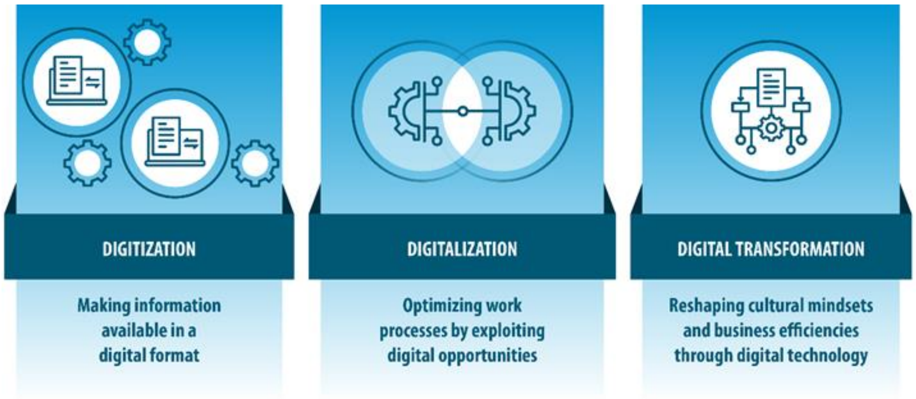

Figure 3. Digital transformation process for the U.S. nuclear industry.

Guiding Principle 2: Apply Human Factors Engineering
Human-system interaction should be emphasized, along with a user-centric design that supports cooperation between the human user and the digitalized technology. Altogether, this guiding principle in the digitalization initiative increases human control and trust in the system, a critical ingredient for success.

Guiding Principle 3: Establish Data Governance
Governance is the set of policies, programs, and procedures by which an NPP collects, manages, and controls its interconnected data resources. The key aspects of data governance are data accessibility, data quality, security, ownership, and knowledge.

Guiding Principle 4: Anticipate Unintended Consequences
Digitalization can introduce unforeseen changes due to unexpected interactions that emerge in dynamic systems. If every process is automated without consideration for human involvement, overall human-system performance will not improve. The unintended consequences of digitalization need to be anticipated and mitigated.

1.2.1 Current Research Efforts

Different NPPs are at different stages in the modernization journey. Therefore, it is important that the digitalization effort can help determine a proper digitalization scope for a plant given its constraints, motivations, and capabilities. Thus, this year's efforts align with digitalization Guiding Principle 1: Develop a Digitalization Plan. Working with an industry partner, this year's research efforts resulted in the creation of an assessment method that can review an entire organization's work processes and gather information about the digitalization health of the plant. The assessment tool was administered to plant employees, the results of which were used to develop a digitalization plan. The plan identified the optimal candidate processes that would most benefit from a digitalization initiative. The research activities for digitalization are presentenced in Figure 4.

The methodology took a two-tier approach: first, a survey was developed and administered to 489 plant employees to produce a comprehensive evaluation of the plant's digitalization status. The survey delivered to each employee was customized to their work activities and produced rapid results. Second, in-person digitalization interviews were conducted on-site at the plant with three-dozen employees. Together, these data were analyzed to uncover key digitalization opportunities that yield the highest payback in terms of increased process efficiencies. Importantly, these research activities were used to develop a specific digitalization plan for the plant with supporting success metrics.

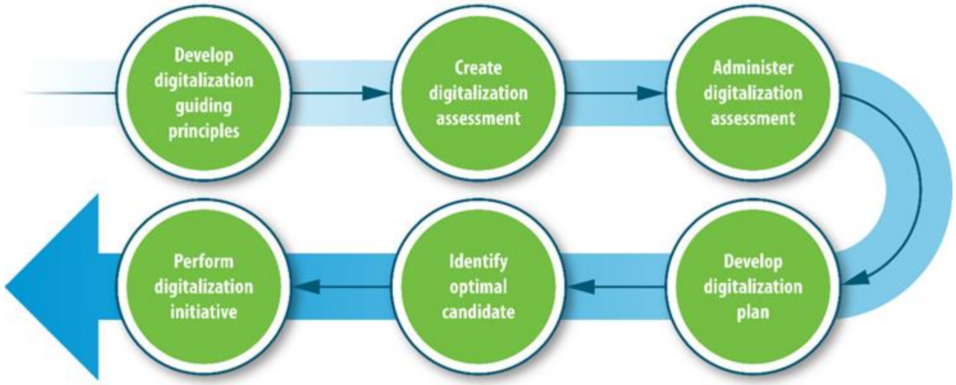

Figure 4. LWRS digitalization road map.

The methods outlined were designed to complement each other. The survey was the main assessment tool developed because on-site interviews are expensive, time-consuming for both data collection and analysis, difficult to replicate, and involve a very small sample of plant employees. Surveys on the other hand, while not interactive, are inexpensive, rapid, wide reaching and produce standardized findings.

Chapter 2 of this milestone presents the survey methodology and results. We document the state-of-the-art research in survey development, best practices for remote survey deployment, and present the main findings. Digitalization status scores were assigned to each work process endorsed. The results were filtered through the technical, economic, and risk adoption (TERA) methodology to identify digitalization opportunities with the highest gross returns on investment (ROI) and supporting success metrics (Chapter 3). We document the on-site interview assessment in Chapter 4 and suggest low-cost immediate potential solutions. Last, Chapter 5 summarizes the implications of this work, lessons learned, and future research directions based on the findings.

2. Survey Assessment

2.1 Best Practices for Survey Development

The research team developed an online survey that takes inventory of the digitalization level of current work processes that plant employees routinely engage in. We aimed to identify areas for which digital optimization is present and areas where it may be lacking. To achieve this, we incorporated best practices for online survey development. Online surveys have become increasingly popular in recent decades because unlike traditional face-to-face, over-the-telephone, or mail survey formats they are less expensive and offer faster data collection rates (Callegaro et al., 2015). The efficacy and validity of survey data is dependent on how the survey is constructed and deployed. Here is a summary of the five most important considerations for online survey development.

2.1.1 Survey Considerations

1. *Question wording.* The survey questions should be neutral. They should not be leading, inviting participants to answer a certain way (Knutsen & Presser, 2010). The wording of the questions should be kept simple, and the survey should begin with the easier questions first. The questions should not include more than one topic; those that do are known as double-barreled questions.

2. *Question format.* Multiple-choice questions are less labor-intensive to answer and ideal for respondents with limited time, such as NPPs workers. Notwithstanding, one open-ended question was reserved at the end to give respondents an opportunity to comment on any items we had missed. The multiple-choice questions also had the benefit of limiting subjectivity in responses and producing quantitative data ideal for a TERA analysis.

3. *Length of the survey.* Revilla and Ochoa (2017) found that web survey completion should take approximately 10 minutes and not exceed 20 minutes. This timeframe amounts to an ideal survey length ranging from 25 to 30 questions (Sharma, 2022). The research team was mindful not to overburden respondents with a lengthy survey, which can lead to fatigue, to respondents being less likely to put an adequate amount of effort into answering the questions, and to questions being skipped or unattended (Rolstad et al., 2011).
4. *Respondent motivation.* Individuals must feel motivated to use their mental energy to provide a sufficient response to a question (Artino Jr et al., 2022). A lack of attention can negatively affect the reliability and quality of the information provided (Huang et al., 2015), leading to inaccurate conclusions. Strategies to boost motivation include providing information on the survey's purpose (Colbert et al., 2021), providing an incentive such as a reward for completion (LaRose & Tsai, 2014; Smith et al., 2019); note – this strategy is not successful in every case—see Wu et al., (2022), and communicating that responses will help others.
5. *Survey deployment.* Pre-invitations and follow-up reminders have been shown to encourage response rates (Sammut et al., 2021; Smith et al., 2019). In addition, having the survey invitation come from senior leadership inside the organization has also been shown to facilitate participation; this is known as the champion effect (Barroso & Ramos, 2023).

2.2 Method

2.2.1 Participants

A link to the survey was sent out to approximately half the company employees (489) from various departments on April 29, 2024, and closed on May 3, 2024. Random sampling was performed by the company's innovation director, or champion (see Survey Considerations 5 above). He sent survey invitations to company employees. Notably, some craft departments such as field workers were underrepresented. There was a total of N = 167 survey starts (35%) with N = 115 survey completions (25%). Seven respondents were from a non-nuclear department. The research was approved by the INL Institutional Review Board (IRB), and all respondents indicated consent to the research (IRB approval INL000179).

2.2.2 Process Selection

The goal of the survey was to assess the digitalization status of the plant work processes with which individuals are routinely engaged. There are many processes and subprocesses performed at each NPP. Therefore, the first step was to identify the most frequently used processes. Working with an NPP subject-matter expert (SME), cross-functional processes were identified that span the entire organization. These processes were then evaluated as prospective candidates to be included in the survey. For example, an activity that is part of the corrective action program (CAP) is condition reporting, which is an expectation of all NPP workers. Selecting cross-functional activities was critical to ensure that the survey results would produce a horizontal perspective from all participating departments, as well as a vertical perspective from different employee levels within the various organizations. Together, these diverse viewpoints strengthened the psychometric properties of the survey: reliability and construct validity were increased (i.e., this method helped to more accurately assess the digitalization level of a given activity, allowing replication of findings).

A database was created from a standard NPP enterprise asset management template, similar to the one used by the industry partner, so that every plant process could be identified and evaluated for inclusion in the survey. This list consisted of 27,000 fields tied to data entry screens for all NPP processes and subprocesses. The SME condensed the fields to approximately 100 standard NPP processes and subprocesses by removing duplicates. From the remaining fields, 15 cross-functional processes were identified.

To validate that the 15 cross-functional processes were representative of frequently performed activities at an NPP, employees from a different utility (not the partnering plant) were asked to provide feedback. This occurred during the utility's innovation week when LWRS researchers were invited to set up a booth. All employees, representing a wide range of departments and positions, were encouraged to attend. When company employees approached the booth, they were asked to identify work processes that would benefit most from a digital upgrade that could help make them less manual and less error prone. N = 14 plant employees responded from varying departments; the majority endorsed the 15 processes presented (Table 1). From their additional suggestions, the research team decided that procedures was an important addition, as well as several department-specific activities that were added to the list.

Table 1. The 15 cross-functional process and feedback from plant staff.

	Processes Presented	Additional Suggestions
1	Work management schedule	Onboarding
2	Maintenance work	Information Technology (IT)
3	CAP	Procedures
4	Training	Component monitoring
5	Tag out	Operations
6	Emergency preparedness	Chemistry
7	Inventory/Procurement	RAD protection
8	Doses/Contamination	Computer-based training
9	Security	Equipment reliability
10	Master equipment list	Avoiding conflicts
11	Personnel/HR	Work package planning
12	Design change	-
13	Projects	-
14	Contractor/Vendor	-
15	Accounting	-

In conjunction with the plant's innovation director, a comprehensive list of 53 subprocesses was then developed that supported the 16 finalized cross-functional processes. See Appendix A for the full list.

The list of NPP activities was matched to department and job position. A standard nuclear organization chart was used to identify key departments and positions at the plant. This list was augmented by the plant's innovation director, resulting in 12 key departments and five key staff positions (Table 2). It is worth noting that most U.S. NPPs have a very similar organizational structure.

At the beginning of the survey, participants were asked to indicate their department and position within the company from the items in Table 2. Based on these selections, the survey was programmed to present participants with a customized set of activities particular to that job role, ranging from seven to 19 activities. The research team's SME and the plant's innovation director conducted the precise matching of activities to job roles. A critical aim of the survey methodology was to communicate to the respondents that their time was valuable and would not be wasted on questions that are irrelevant to their job role. We believe this strategy not only increased motivation to complete the survey (see Survey Considerations 4) but helped strengthen relations between the research team and the plant's employees moving forward.

To ensure that the survey was not too long and labor-intensive (see Survey Considerations 3), participants were asked to select seven activities from the list (the survey advanced with a minimum of five selections). In addition, by allowing participants to self-select, it is likely that this method increased motivation to engage because it gave them an opportunity to respond to activities they felt the most strongly about (see Survey Considerations 4).

Table 2. Number of activities performed by department and position.

Department	Control Room Worker	Field Worker	Manager	Staff Worker	Supervisor
Administration	0	0	9	9	10
Chemistry	0	8	9	10	13
Engineering	0	14	15	14	19
Independent Oversight	0	0	11	10	13
IT and Innovation	0	0	10	8	12
Licensing	0	0	11	10	13
Maintenance	0	11	12	12	17
Operations	11	10	11	12	16
Performance Improvement	0	0	7	8	11
Quality Services	0	0	10	10	12
Radiation Protection	0	12	13	11	18
Security	0	10	12	11	14
Work Management	0	0	11	9	13

2.2.3 Questions Selection

To effectively interrogate the digitalization level of each identified NPP work process, it was necessary to develop health indicators for each process. Frequency, duration, and workload were selected to understand how often, how long, and how much effort it takes to perform the activity. Three questions inquired about the digital tools used and their user-friendliness. Finally, the reliability and effectiveness of the current system to complete the activity was assessed. We developed questions for each health indicator with the goal of creating short, neutral questions (see Survey Considerations 1). Except for requiring respondents to name the digital tools used to complete the activity, all questions were formatted as multiple choice (see Survey Considerations 2). The full list of health indicators, corresponding questions, and response formats are presented in Table 3. The survey cycled through the health indicators for each of the seven activities selected by the participants, which took up most of the survey.

2.2.4 Survey Construction and Deployment

Beyond the health indicator questions for each of the seven processes, two questions at the end of the survey required participants to nominate one activity that was a good example of an efficient digital process, and one that they would most like to see digital innovations applied to. Responses were multiple choice and based on the self-selected activities from the start of the survey.

The question that followed inquired how the participants saw themselves supporting innovation, based on work developed by Basadur et al., (2014) that maps to four stages of the creative problem-solving process. Participants were shown four innovative personality types and asked to pick one most like them. This question aimed to gain a better understanding of the composition of the cognitive strengths of the organization that are essential to cultivate an innovative environment. The last question asked participants if there was anything else they would like us to know; this was open-ended and intended to catch any important considerations that were missed.

In keeping with best practices to increase survey engagement, participants were given the option to be entered into a raffle to win a $20 Starbucks gift card (see Survey Considerations 4). Winners were determined randomly by the survey manager who sent names to us, the research team. Participants were also invited to let us know if they wanted to meet with us during the upcoming plant visit. This methodology was used to reassure plant staff that we valued their time and took seriously their answers. Last, participants were reassured of their anonymity and thanked for their time.

Table 3. Digitalization health indicators.

Indicator	Survey Question	Response Format
Frequency[a]	On average, how often do you perform the activity?	1 (yearly)–6 (daily)
Duration	How much time do you spend performing the activity each time?	1 (<10 minutes)–5 (>5 hours)
Digital	How much of the activity is digital?	1 (all paper)–5 (all digital)
# programs	How many software programs do you use for this activity (e.g., SAP + Excel)?	0–6+
Tools	Provide the name(s) of the software program(s) you use for this activity and rate their user-friendliness.	Open-ended
User-friendliness	Provide the name(s) of the software program(s) you use for this activity and rate their user-friendliness.	1 (not user-friendly)–3 (user-friendly)
Workload	How much effort by you is required to complete this activity?	1 (way too much)–4 (very little)
Reliability	How often does the activity reach the desired outcome on the first attempt?	1 (rarely)–3 (most of the time)
Effectiveness	How effective is the activity at achieving its intended goal?	1 (not very)–3 (very)

[a] Frequency is not an indication of digitalization health, and performing an activity does not necessarily indicate a problem. However, when considering digitalization initiatives, it is important to identify and target high-frequency activities.

The survey was built out using Qualtrics software (Qualtrics, Provo, UT). Upon completion of the pilot version, it was cross validated by four NPP experts: an INL employee, a nuclear vendor, a nuclear solution provider, and a utility employee. Valuable feedback regarding the following was incorporated into the survey:

1. The wording of some questions for greater clarify and/or to suit an NPP population
2. Duplicative questions
3. Cautioning against too many open-ended questions
4. Streamlining question presentation and ease of response
5. The response format for software program questions.

The survey was then piloted by five plant employees: two from administration, two from licensing, and one from quality services. No feedback was provided.

In conjunction with us, the collaborating plant's public affairs department crafted a presurvey announcement (Appendix B) the week before deployment (see Survey Considerations 5) that not only raised awareness of the survey but communicated the benefits and value of employee engagement (see Survey Considerations 4). The announcement was based on an impact statement provided by the research team that included the following elements:

1. The overall goal of the program
2. Who is sponsoring the work and why
3. Timelines for deliverables
4. How the organization benefits from the effort
5. How the individuals involved in the survey and interviews benefit from the effort.

The survey went out at 7:39 a.m. the Monday following the presurvey announcement and was sent from the plant's innovation director's email. The email invitation reiterated the value of employee engagement (see Appendix C). At the end of day 1 there were N = 27 survey respondents. At the end of day 2 there were five more. On day 3, the chief nuclear officer sent a brief reminder to staff to complete the survey (see Survey Considerations 5), communicating how responses would be used to bring value to the plant and the wider industry (see Survey Considerations 4). Responses climbed to N = 89. Finally, a "last chance" email was sent on day 4 from the plant's innovation director. The survey closed on day 5 at 4 p.m. with a total engagement rate of N = 167. Excluding N = 12 participants who spent >1 hour with the survey open, the average survey completion time was 10.84 minutes (see Survey Considerations 3). The research team benefited from the great support of the organization's senior leadership team, which distributed and supported the survey and reinforced to staff the importance of participation.

2.3 Results

2.3.1 Main Findings

Appendix A lists the start and finish N for each process. All available data was used to generate the main findings and there were no exclusions. For instances in which there was a discrepancy between the number and names of the software programs used to complete an activity, the highest value was used. User-friendliness ratings were averaged across all software programs used to complete an activity. All 13 departments and all five staff positions were represented in the data. There were four activities that were not selected, so there is no data available on their digitalization status (Table 4).

Table 4. Activities not selected.

Activity	N
Confined Space	0
Measurement and Test Equipment	0
OPEX Program Administration and Trending	0
Work Package Use	0

As expected, there was a wide range of responses for each of the health indicators across all activities combined (Table 5). Examining the data at this high level produces a crude understanding of the digitalization status of the organization's activities. For example, mean digital score across all activities was M = 4.33, indicating a mostly digital, and not paper, status. Notwithstanding, there was variability in responses. Overall, most work activities produced health indicators that were primarily in the yellow, indicating middle-of-the-road digitalization status. There were no activities reported to be, on average, entirely paper based, with all using at least one digital software program. High-frequency items—Dose Recording and Reporting and Testing Process—completed daily were in the bottom three for lowest-ranked total status and were in the orange. Contributing factors for Dose Recording and Reporting were higher workload and lower effectiveness, while Testing Process had a higher number of software programs and lower reliability. However, these processes each had N = 1.

Table 6 shows activities in which at least one respondent reported an all-paper status. The number of programs used to complete activities was on the lower side, with user-friendliness approximately in the middle. Interestingly, employees regarded workload favorably with an average score indicating a manageable amount of required effort to complete the activities. Overall reliability and effectiveness were favorable.

To better understand the digitalization status of individual activities, mean digitalization health indictor scores for all endorsed activities are presented in Table 7. Selected work activities fell into two main categories. There were 19 activities that were endorsed by ≥13 participants, with the remaining endorsed by ≤6 participants.

The findings are ranked and color coded from red (indicating poorer comparative health) through deep green (indicating greater comparative health) and arranged by frequency, with daily activities at the top and yearly activities at the bottom. For the rapid identification of general digitalization status, the total column indicates one color score that averages across the seven health indicators. Each health indicator was first normalized on a 0–1 scale to allow a composite total score. When interpreting these findings, caution must be exercised to consider how many individuals provided information about each activity (i.e., N). For example, the top-six frequency activities indicating daily activity had <5 respondents. However, the two that follow had N = 21 and N = 134, respectively, indicating greater reliability that responses represent an accurate digitalization status of the work activity.

Table 5. Mean health indicator scores for all activities combined.

	Frequency	Duration	Digital	# Programs	UF	Workload	Reliability	Effective
Valid Responses	828	828	828	823	705	788	787	786
Mean	4.37	2.76	4.33	1.66	2.29	3.07	2.81	2.64
SD	1.57	1.19	0.91	1.22	0.62	0.71	0.45	0.52
Minimum	1	1	1	0	1	1	1	1
Maximum	6	5	5	6	3	4	3	3

UF = user-friendliness; SD = standard deviation

Overall, most work activities produced health indicators that were primarily in the yellow, indicating middle-of-the-road digitalization status. There were no activities reported to be, on average, entirely paper based, with all using at least one digital software program. High-frequency items—Dose Recording and Reporting and Testing Process—completed daily were in the bottom three for lowest-ranked total status and were in the orange. Contributing factors for Dose Recording and Reporting were higher workload and lower effectiveness, while Testing Process had a higher number of software programs and lower reliability. However, these processes each had N = 1.

Table 6. Activities for which at least one respondent reported an all-paper status.

Activity	N
Action Items Tracking	134
External Operating Experience Use	56
Job Briefings	13
Ordering of Supplies/Parts	35
Plant Access Processing	4
Procedure Use and Revision	90
Reporting of Conditions, Equipment, Facility Issues	69
Security Rounds	3
Work Schedule Use and Update	47

The three lowest-ranked total-status activities that had N > 10 were Plant Projects Management, Modifications, Engineering Changes, and Plant and Department Meetings and are orange-yellow. Plants and Department Meetings was a high-frequency activity and thus may be a candidate for a digitalization deep dive. The other two activities had frequency scores >4, suggesting that they were completed at least weekly. Plant Projects Management had a comparatively lower digital ranking than other activities (orange), between “half paper/half digital” and “mostly digital”, on average. Modifications, Engineering Changes was reported to have a higher duration (between “1–5 hours” and “>5 hours”), workload was closer to “slightly too much” than “some, but manageable,” and approximately two to three software programs are currently used to complete the task. Nonetheless, user-friendliness of these programs was on the higher side (pale green).

Table 7. Digitalization status of all selected plant activities.

	N	**Frequency**	**Total**	Duration	Digital	# Programs	UF	Workload	Reliability	Effective
Plant Database Management and Security	4	6.00		2.75	4.50	2.00	2.08	2.75	2.75	2.50
Security Rounds	3	6.00		4.67	2.33	2.00	2.20	3.33	3.00	2.67
Operator Rounds, Log Keeping, Turnover	2	6.00		3.50	4.50	2.00	1.83	3.50	2.50	2.50
Security Equipment and Zone Management	2	6.00		5.00	4.00	1.00	2.00	3.00	3.00	2.50
Dose Recording and Reporting	1	6.00		3.00	5.00	3.00	1.67	1.00	2.00	1.00
Testing Process	1	6.00		4.00	5.00	4.00	2.50	2.00	1.00	2.00
Plant and Department Meetings	21	5.95		3.62	3.67	1.62	2.62	2.86	2.75	2.52
Action Items Tracking	134	5.37		2.47	4.42	2.36	2.23	3.04	2.86	2.62
Lesson Plan Creation	6	5.33		4.33	4.00	2.50	2.87	3.00	2.83	3.00
Plant Radiological Surveys	3	5.33		3.33	4.00	1.00	2.67	3.33	3.00	3.00
Sampling and Monitoring	3	5.33		4.00	3.67	1.33	2.33	3.00	3.00	2.67
Plant Access Processing	4	5.25		3.50	3.50	2.00	3.00	3.25	3.00	3.00
Regulatory Interface/Commitment Tracking	4	5.25		2.50	4.00	1.50	2.58	3.00	2.75	2.50
CAP Program Administration	16	5.19		2.75	4.63	1.25	2.32	3.13	3.00	2.69
Job Briefings	13	5.08		2.31	2.54	1.31	2.53	3.31	2.92	2.69
Rad Shipping	4	5.00		4.00	4.25	1.50	2.67	3.25	3.00	3.00
Simulation	4	5.00		4.00	3.75	0.50	2.00	2.33	2.33	2.67
Employee Observation and Coaching	46	4.78		2.67	4.28	1.04	2.34	3.09	2.82	2.36
Plant Drawings and References	21	4.76		2.76	4.14	1.85	2.54	2.95	2.75	2.60
Work Schedule Use and Update	47	4.55		2.92	4.40	1.79	2.17	3.04	2.83	2.60
Remote Monitoring and Sampling	4	4.50		3.50	2.75	2.50	2.40	3.00	2.50	2.50
Investigation and Evaluation Process Administration	2	4.50		3.50	4.50	1.50	1.75	2.00	2.50	2.50
Physical Plant Work	2	4.50		3.00	4.00	2.50	2.13	3.00	3.00	3.00
Radiologically Protected Area Access	13	4.46		2.46	3.92	0.83	2.14	3.46	2.92	2.85
Outage Schedule Use and Update	6	4.33		4.17	4.67	4.00	2.23	2.50	2.67	2.50
Plant Projects Management	13	4.31		3.15	3.69	2.08	2.23	2.92	2.67	2.67
Modifications, Engineering Changes	15	4.27		4.20	4.07	2.47	2.57	2.67	2.87	2.87
Employee Timekeeping	23	4.17		1.74	4.91	1.09	1.71	2.68	2.68	2.64
Work Management Performance Indicators	5	4.00		3.00	4.80	2.20	2.47	3.60	3.00	2.20
CAP Operability Review	1	4.00		3.00	5.00	3.00	3.00	3.00	3.00	3.00

Work Package Creation	1	4.00		2.00	5.00	1.00	1.00	3.00	3.00	3.00
Controlled Documents/Records Management	20	3.95		2.95	4.05	1.35	2.22	3.00	2.85	2.80
Training and Qualification Verification	68	3.94		2.16	4.62	1.43	2.34	3.42	2.96	2.96
Procedure Use and Revision	90	3.91		3.10	4.32	1.55	2.27	2.83	2.76	2.66
Critical Digital Asset Administration	5	3.80		2.80	4.40	1.80	2.80	3.40	2.60	2.60
Plant/Component Health	5	3.80		3.20	4.60	1.80	2.42	3.00	3.00	2.60
Reporting of Conditions, Equipment, Facility Issues	69	3.67		2.22	4.61	1.07	2.13	3.31	2.78	2.57
Budget Management	17	3.65		3.00	4.53	1.59	2.47	2.94	2.63	2.50
Ordering of Supplies/Parts	35	3.63		2.63	4.43	1.31	2.68	3.27	2.82	2.79
External Operating Experience Use	56	3.52		2.63	4.48	1.57	2.01	3.25	2.68	2.45
Surveillance Management	2	3.50		4.00	3.50	2.50	2.00	3.00	2.50	2.50
Technical Specification Review	17	3.41		3.00	4.65	1.06	2.35	3.06	2.82	2.65
Plant Audits and Assessments	5	3.40		4.60	3.60	3.80	2.66	2.60	2.80	2.40
Equipment Failure Evaluation	6	3.33		3.67	3.83	1.67	2.00	3.20	3.00	3.00
Clearance and Tagging	3	3.00		2.67	4.00	2.67	1.75	2.33	3.00	3.00
Plant Rad Monitors	2	3.00		4.00	3.50	2.00	1.83	2.50	2.50	2.50
Vendor Audits and Assessments	2	2.00		3.50	3.50	2.00	2.33	2.50	2.50	2.50
Safeguards Information Administration	1	2.00		1.00	5.00	3.00	3.00	4.00	3.00	3.00
Tool Checkout	1	1.00		2.00	3.00	1.00	1.00	1.00	2.00	1.00
Anchors		1		1	1	0	1	1	1	1
Anchors		6		5	5	6	3	4	3	3

UF = user-friendliness

For high-frequency and high-duration activities, Security Equipment and Zone Management and Security Rounds scored on the lower side on total status. Other than longer durations, contributors to these scores were lower program user-friendliness for the former and lower digital for the latter. However, few individuals contributed to the metrics of these activities: N = 2 and N = 3, respectively.

Action Items Tracking was by far the most widely performed activity (N = 134) and warrants a closer look because this activity did not make the top 20 for total digitalization status, indicating room for improvement. Additionally, it scored higher on the frequency ranking (between "daily" and "two to three times weekly").

Last, to gain an understanding of the digitalization status of an organization's work activities, those activities that are in good health and that are reported to be working well for the staff must be considered. Safeguards Information Administration scored highest in overall digitalization status (deep green), although it is performed infrequently and was endorsed by only one individual. The three highest total-status activities that were endorsed by N > 10 individuals were Training and Qualification Verification (N = 68), Ordering of Supplies/Parts (N = 35), and Radiologically Protected Area Access (N = 13). All three were reported to be highly reliable and effective and take comparatively less time to complete than other reported activities.

2.3.1.1 By Position

The survey results were analyzed by employee position within the organization to determine the digitalization status of activities across different roles. As seen in Table 8, there was N = 1 control room worker and N = 8 field workers who responded to the survey. The small sample size for these positions makes it less likely that a valid digitalization status of the activities associated with these roles was obtained. Note – as a result, we attempted to interview individuals from these positions during the plant visit to gain a more comprehensive picture of the digitalization status of their various duties.

Table 8. Digitalization status by position.

Position	N	Frequency	Duration	Digital	# Programs	UF	Workload	Reliability	Effective
		(1–6)	(1–5)	(1–5)	(0-6+)	(1–3)	(1–4)	(1–3)	(1–3)
Control Room	1	1.00	3.29	3.75	2.86	2.14	3.21	2.57	2.14
Field Worker	8	1.88	3.32	2.45	1.16	2.31	3.96	2.92	2.61
Manager	24	2.15	2.91	4.01	1.73	2.35	3.75	2.77	2.54
Staff Worker	98	2.88	2.81	4.30	1.65	2.26	3.86	2.79	2.68
Supervisor	38	2.55	2.47	4.16	1.42	2.26	3.85	2.86	2.65

UF = user-friendliness

For the managers, staff workers, and supervisors, important insights included job role activities having a higher digital score, and the user-friendless of the programs used to perform job duties was favorable. The amount of effort required (i.e., workload) was perceived as low, and reliability and effectiveness of the activities were on the higher side (i.e., positive ratings).

2.3.1.2 By Department

The survey results were analyzed by department within the organization to determine the digitalization status of activities across different departments. A list of 13 departments was generated from the enterprise asset management template and verified by the plant's innovation director. To assist generalizability of the survey, the list did not include some smaller or unique departments within a given NPP. However, individuals from these departments could endorse the main departments to which they belonged.

As shown in Table 9 Administration and Engineering were endorsed more than other departments, collectively accounting for 42% of employees who engaged with the survey. The plant production departments were underrepresented. Most departments scored on the higher end for digital, with Security (N = 13) being a notable standout with a score indicating closer to "half digital/half paper" processes. Most departments used approximately two programs to complete activities and had adequate user-friendliness. Licensing (N = 5), Quality Services (N = 7), and Training (N = 8) indicated slightly more effort needed to complete activities than other departments. Reliability and effectiveness were favorable for all departments.

Table 9. Digitalization status by department.

Department	N	Frequency	Duration	Digital	# Progs.	UF	Workload	Reliability	Effective
		(1-6)	(1-5)	(1-5)	(0-6+)	(1-3)	(1-4)	(1-3)	(1-3)
Administration	35	2.8	2.47	4.36	1.55	2.34	3.13	2.85	2.74
Chemistry	5	2.41	2.59	3.97	1.85	2.19	3.18	2.82	2.54
Engineering	35	2.6	3.01	4.22	2.11	2.27	2.99	2.83	2.64
IT and Innovation	16	3.17	2.63	4.22	1.85	2.33	3.12	2.76	2.6
Licensing	5	2.68	2.68	4.24	1.68	2.16	2.81	2.89	2.52
Maintenance	17	2.85	2.57	4.07	1.6	2.18	3.08	2.76	2.53
Operations	6	2.03	2.73	4.17	2.38	2.21	3.07	2.85	2.56
Performance Improvement	5	2.14	2.61	4.6	1.7	2.44	3.3	2.89	2.74
Quality Services	7	2.86	2.83	3.99	2.06	2.12	2.76	2.68	2.53
Radiation Protection	5	2.24	3.18	3.79	2.58	2.31	3.03	2.88	2.79
Security	13	1.92	2.87	3.27	1.96	2.56	3.29	2.83	2.71
Training	8	2.58	3.06	4.06	1.74	2.11	2.92	2.67	2.71
Work Management	12	2.37	2.96	4.31	2.48	2.3	3.2	2.78	2.59

UF = user-friendliness; IT = information technology

2.3.2 Efficient and Deficient Digitalization

Once participants had cycled through rating the digitalization health indicators for each of the activities they had selected, the names of the activities appeared on the screen. One pointed question asked the participants to select a good example of an efficient digital process, and the other asked them to select an activity to which they would most like to see digital innovations applied. The results are broken down into the top ratings for each department in Table 10. A total of N = 111 respondents answered one or both questions. N = 5 participants rated the same activity for both, and so these responses were excluded from the analysis. For cells in the table that are blank, there was no consensus reached among department employees, and each responded with a different activity. The Maintenance and Work Management departments had two top-ranked activities needing innovation.

Action Items Tracking was the most endorsed activity as both a good and not-so-good example of an efficient digital process. Although it was the most selected activity overall, and by a significant margin, it is interesting that it appears in both columns. This warrants further investigation. Digging a little deeper, it is not uncommon to find processes within organizations that work well for some departments but not others. Very often, digital solutions are designed with individuals from one department or one specific perspective in mind, to optimize their digital engagement, ease of use, and human performance. However, when a process spans multiple departments, maximizing across perspectives requires digitalization. Digitalization takes a holistic approach to enabling digital capabilities and serves to harmonize and synthesize a work process across its life cycle. These results support the main findings that Action Items Tracking may be a good candidate for a digitalization initiative, especially given it is a high frequency activity (between "daily" and "two to three times weekly").

Table 10. Top efficiency and deficiency ratings by department.

N	Department	N	Efficient	N	Needs Innovation
21	Administration	5	Controlled Documents/Records Management	6	Action Items Tracking
4	Chemistry	2	Sampling and Monitoring	2	Action Items Tracking
21	Engineering	7	Action Items Tracking	5	Plant Projects Management
12	IT and Innovation	4	Action Items Tracking	4	Procedure Use and Revision
4	Licensing	-	-	-	-
10	Maintenance	3	Training and Qualification Verification	2	Procedure Use and Revision
				2	Work Schedule Use and Update
4	Operations	2	Action Items Tracking	3	Work Schedule Use and Update
4	Performance Improvement	2	Action Items Tracking	2	Employee Observation and Coaching
5	Quality Services	-	-	-	-
4	Radiation Protection	-	-	-	-
5	Security	2	Radiologically Protected Area Access	-	-
6	Training	3	Procedure Use and Revision	2	Training and Qualification Verification
6	Work Management	2	Procedure Use and Revision	3	Work Schedule Use and Update
		-	-	3	Outage Schedule Use and Update

IT = information technology

2.3.3 Innovation Type Results

The last multiple-choice question did not elicit feedback about digitalization activities. Instead, participants were asked to think about themselves and how they saw themselves supporting innovation within their organization. Teams and organizations must encompass a range of cognitive strengths to cultivate an innovation climate. Having innovative capability equips an organization with the means to comprehend and adapt to evolving conditions, to take advantage of new opportunities, and to harness the knowledge, creativity, and skills of its members to enact beneficial changes (Merrill, 2020).

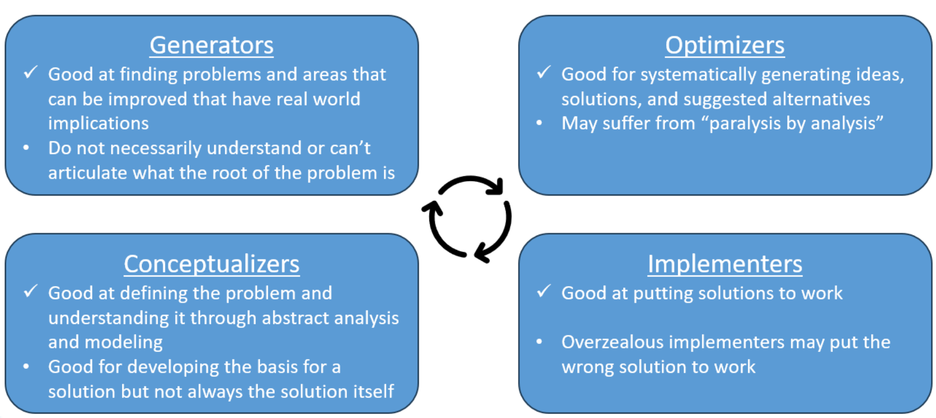

Figure 5. Innovator types and their characteristics.

Understanding innovator types that make up an organization or a position provides insight into the strengths and weaknesses an organization has for innovating how work is performed. An extensive survey starting in 2006 and ending in 2021 and encompassing over 100,000 individuals across various industries and roles, led to the identification of four distinct types of innovators, as detailed in Figure 5. These innovator types are delineated based on the different stages of problem-solving and the execution of solutions. Ensuring effective innovation, which encompasses problem identification, definition, optimization, and implementation, also requires a balanced composition of innovators within dedicated teams or within an organization. However, a notable challenge arises from the natural tendency of innovator types to gravitate toward specific roles or industries, which can lead to an uneven distribution of these problem-solving abilities within a company. Balancing the distribution highlights the importance of strategic team assembly to ensure that each phase of the innovation process is adequately addressed by the right mix of cognitive approaches. In alignment with this perspective, respondents were requested to self-identify with one of the four innovator types to assess the breadth and distribution of innovative skills currently available within the facility.

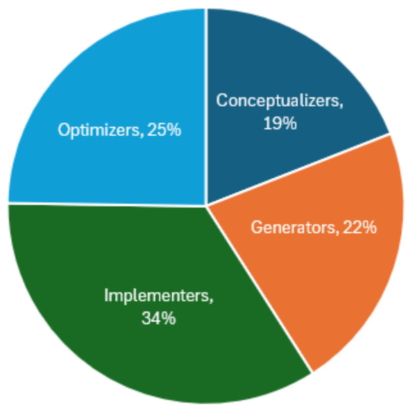

Figure 6. Innovator types across all respondents.

Results showed that implementers make up the largest portion of respondents, and conceptualizers the smallest portion (Figure 6). Generators and optimizers were similar in size as well as proportional to an even split (close to one-quarter of the respondents each). This broad look at composition indicates the facility staff may focus less on clear problem definition and analysis and more on putting a proposed solution to work. Notably, overly enthusiastic implementers may select an incorrect solution.

The survey structure allowed us to break down innovator type composition by position (Figure 7). Interestingly, across positions managers were least likely to be implementers and most likely to be conceptualizers. Optimizers, the second-most common innovator type across the organization, were more likely to be staff workers and supervisors than managers. Staff workers were as likely to be generators as optimizers. Last, of the four innovator types, supervisors were least likely to be generators.

2.3.4 Open-Ended Responses

The last question on the survey asked participants if there was anything else they would like us to know. There were 19 entries, nine of which were variants of “no” or “nothing to add.” The remaining 10 responses are listed in Table 11. Six different departments were represented. Most feedback comprised employee’s thoughts about digitalization, with some comments concerning the nuclear industry’s struggles with modernization at large. Action items tracking, scheduling, and tool checkout activities were called out as needing updated or redesigned solutions. Poor user interfaces across applications was another concern. Last, artificial intelligence (AI) was mentioned twice as an avenue for digitalized solutions for the future.

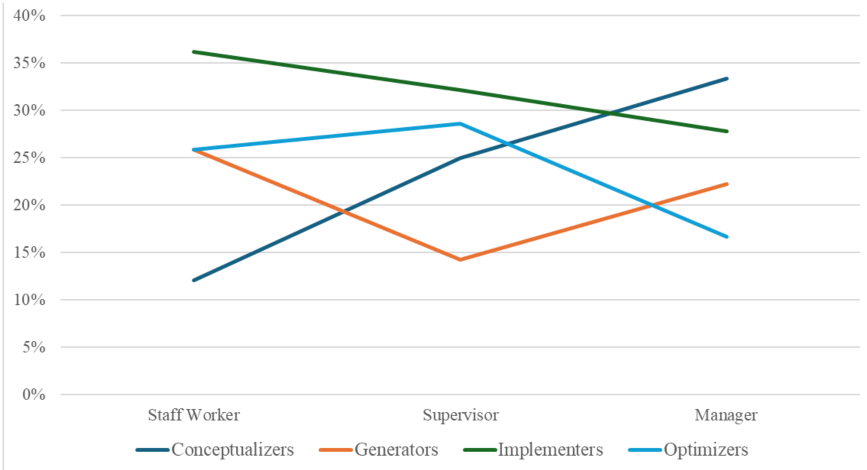

Figure 7. Innovator types by position.

Table 11. Survey responses to the open-ended question.

Department and Position	**Response**
Engineering staff worker	The inefficiencies at the plant are not easily fixed through direct digitization. Every purchased tool requires integration which is a larger capital investment than the actual software. The only upgrade that my site could use is a redesign of the action tracking software. It's a bit clunky, the tracking tools may not be revisable because the clunkiness is defined by all the stakeholders that need different parts of our action tracking tools. My team mostly maintains the calculations at the plant and we have been working on better automated reporting and formatting tools so that revisions can be run much more efficiently. We are aggressively challenged on this by low margins on the installed plant.
Engineering staff worker	The commercial nuclear industry seems to prefer benchmarking against itself, rather than looking outside to other industries for potential solutions.
Engineering supervisor	Transitioning from analog to digital has been extremely difficult for existing utilities currently in the nuclear market.
Work management manager	We utilize 5 different programs for our scheduling and scheduling updating process. We need a more efficient and 21st-century solution to scheduling.
Licensing supervisor	Many of the digital platforms we use have very poor user interfaces. Some are custom designed and some are commercial. In either case poor layout and navigation between different program functionalities leads to considerably more time required to complete what should be simple tasks. In addition, "managing" an inefficient user interface, particularly one that requires a careful sequence of steps, can lead to greater human error rates since it's common to be multitasking with divided attention during these tasks.
IT and innovation staff worker (non-nuclear)	Digital solutions need digital protections! Firewalls, virus scanners, AC power protection, Air conditioned computer rooms, Backups (stored OFFLINE) for stopping RansomWare and BlastWare.
IT and innovation staff worker (nuclear)	AI could be implanted in more areas other than CAP. AI could learn and build better activity from previous projects and unhidden risks, if any. Outages where project critical paths can be altered to limit duration times for each task and identify any potential risks. AI in Information Technology as one example, eWP and Asset Suite have integration pulling data back and forth between each system. When there are issues with work orders, there is a lot of manpower in determining where a task or work order is being

	held. AI could identify those, learn, correct the issue before it's noticed by a worker, supervisor, etc. This could be used for multiple systems where there are servers, applications, and computers that support Outages and day-today work. AI is not assumed of taking manpower out of the picture, it is to deliver results quickly and lessen the workload and stress on workers and IT professionals dealing with critical timelines. Small Module Reactors, AI could produce and predict results when more energy is required in certain locations. We are already saving power with smart devices, such as adjusting thermostats, turning off lights when you're not home, etc.
Maintenance staff worker	In terms of supporting innovation, I would fit in multiple buckets and want to be involved from start to finish for topics where I have relevant experience. Good-faith motive is a key requirement for true innovation. If the goal is to eliminate head count, then it's probably not actually innovative.
Maintenance staff worker	The clearance process is highly cumbersome and non-intuitive. Checking out and checking in a tool is a strange process full of quirks. It also is non-intuitive and gives you no feedback that the M&TE [measurement and test equipment] has been checked out or checked in successfully.
Operations staff worker	Most of our processes have been converted to digital. Most software is frequently updated, integrated with other software and responds well to our established processes. We are missing the next link to be readily available to access data stored in various databases using AI, Machine learning and algorithms. Data includes attachments to digital processes and raw chart data. This would enable accurate predictions based upon historical performance, including equipment reliability, failure mechanisms, human performance related events, and so forth. It would also improve the accuracy of causal analysis following unexpected events/failures.

3. Technical, Economic, and Risk Adoption (TERA) Assessment

In this section, we use the survey findings to identify, quantify, and prioritize digitalization opportunities as an initial phase to performing a TERA. The TERA is a comprehensive framework for evaluating work reduction opportunities (WROs) in the nuclear industry that, when adapted, makes an excellent framework for assessing digitalization opportunities.

3.1 Evaluating Innovation Opportunities in the Nuclear Industry

While most WROs carry the potential to reduce operational costs, several factors may produce discrepancies between the projected and actual savings. For example, implementation costs, performance expectations, and risks associated with WROs can be miscalculated, leading to disappointing ROIs. Such challenges can stem from the use of inaccurate or incomplete data, immature technology, uncertainties surrounding achievable cost reductions, an organizational inability to effectively communicate modernization benefits to users, a lack of human readiness to adopt the technologies, or difficulties in integrating new processes into existing workflows. Such uncertainties can manifest in various ways, potentially rendering a WRO ineffective or even producing a loss on investment.

The intricate, interconnected nature of NPP processes makes it difficult to accurately predict cost savings and comprehensively screen WROs. The many challenges inherent in NPPs (e.g., conflicting schedules, regulatory compliance issues, and safety concerns) further complicate the screening process. Furthermore, objectively screening WROs becomes increasingly difficult when reporting systems are biased toward reporting regulatory compliance issues versus economic impact and processes involving multiple plant personnel groups, introducing subjective perspectives, varying priorities, and potential resistance to change.

Considering the risks, investment costs, and potential mitigation strategies involved, it is crucial to have a systematic and objective approach for evaluating WROs. Using advancements in operations and technological innovation projects, recent research aimed to bridge the current modernization gap by developing a decision-supporting framework for identifying, evaluating, and selecting modernization strategies that maximize economic benefits and minimize associated risks and uncertainties. The TERA framework was developed to address these concerns and reduce the financial risk associated with WROs. The TERA framework enables stakeholders to integrate technical, economic, risk and adoption perspectives into a comprehensive evaluation of potential WROs. This holistic approach identifies high-priority opportunities that can yield significant benefits for NPPs and minimize potential risks.

3.2 The TERA Framework

The TERA framework serves a twofold purpose when evaluating WROs: to assess and inform. First, the different WROs and their solutions are screened and assessed through the lens of a technical, economic, risk, and adoption 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, utilities can assess options and decide the path of least risk that is most cost-effective by objectively screening various WROs.

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. Additionally, during solution development and assessment, utilities can set expectations on process performance and define key performance indicators (KPIs) that could be used for quantifying cost savings and risk mitigation throughout the development of the WRO solution. This creates a dynamic nature to the TERA framework, in which the model can be used to continuously reevaluate the WRO solution during development to ensure that the project is on track and capable of achieving the promised returns.

Although each process evaluated using the TERA framework may vary significantly, the framework 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 quantitative models or the process, and (3) using the models to assess cost savings and risk reduction. An overview of the TERA framework being used to assess a WRO can be seen in Figure 8.

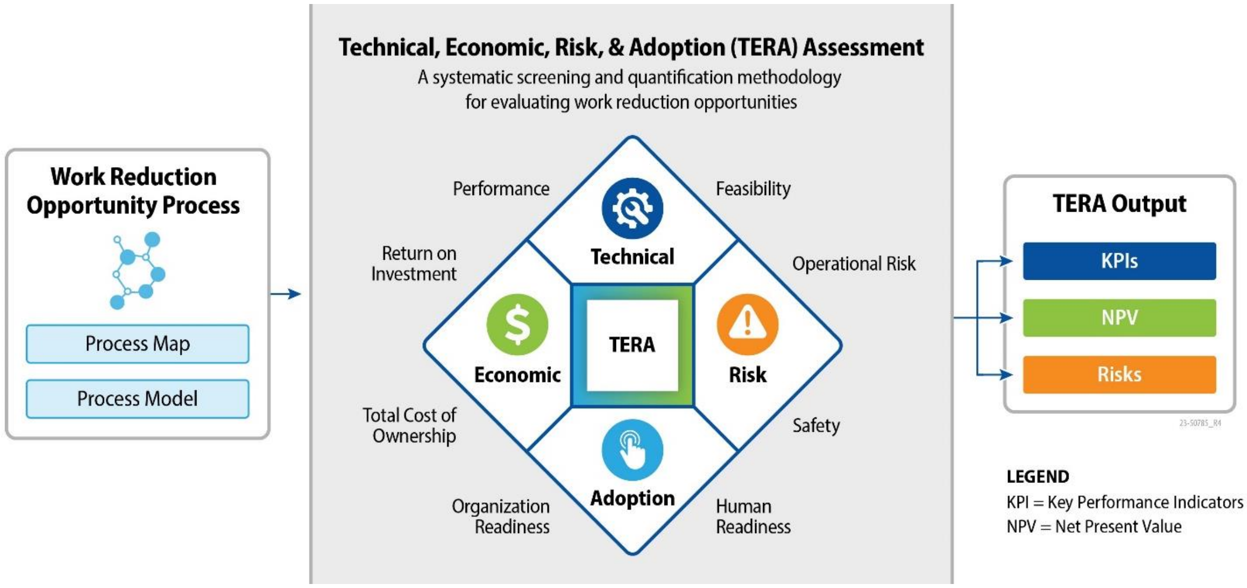

Figure 8. A depiction of the TERA framework showing process model and output.

The TERA process enables the following:

- *Objective screening.* The TERA framework uses standardized methodologies and metrics to enable objective WRO screening. This approach mitigates subjective biases, ensuring a consistent and unbiased evaluation. Per the standardized methodologies, existing processes are broken down into individual tasks and their attributes, with inefficiencies being identified and then compared based on quantitative metrics.
- *Cost reductions.* The TERA framework is intended to improve efficiencies and help NPPs achieve cost reductions across different WROs. Identified WROs are prioritized based on the potential cost savings and risk reduction they convey. Seemingly different WROs can be evaluated based on a set of standardized cost-reducing KPIs, such as net present value (NPV) and total cost of ownership.
- *Risk assessment.* The TERA framework utilizes risk assessments for evaluating the potential uncertainties associated with integrating new technologies during WRO implementation. These assessments are aimed at identifying and mitigating risks related to regulatory compliance, operational disruptions, and technology coexistence and ensuring that the proposed changes do not compromise overall NPP performance, reliability, or safety.
- *Adoption assessment.* The TERA framework also addresses potential barriers to the adoption of new technologies, which could impede successful implementation. By incorporating human readiness levels and organizational readiness levels, the framework evaluates the readiness of both individuals and the organization as a whole to adopt and integrate new technologies. This helps in identifying and overcoming obstacles to ensure a smooth transition and successful implementation.

3.3 The TERA Process

Figure 9 shows how the steps of the TERA framework can be integrated as part of a larger initiative, taking users from identifying potential WROs to solution management.

1. *Identify*. The identification phase is the initial step where potential processes for automation are identified and prioritized. This phase involves evaluating various processes within the organization to determine which ones are most suitable for automation. Key factors considered include the time, frequency, and number of employees involved, as well as the process's usability, complexity, and repetitiveness. The goal is to create a prioritization quad chart that visually represents the potential impact and feasibility of automating each identified process, allowing for an informed decision on where to focus automation efforts.
2. *Screen*. In the screening phase, a detailed analysis of the prioritized processes is conducted to understand their structure, risks, and inefficiencies. This step includes process mapping to visualize the current workflow, identifying potential risks and error modes, and conducting sensitivity analyses to assess how the process may respond to changes. Additionally, pain points within the process are identified, highlighting areas that are most problematic or time-consuming. The output of this phase is a finalized process map, providing a comprehensive view of the process and its weaknesses.
3. *Design*. The design phase focuses on identifying and evaluating the most suitable technologies for automating the process. This involves selecting the appropriate technologies, estimating their economic performance, conducting a detailed risk assessment, and developing strategies for adoption. The goal is to create a detailed TERA model that includes a plan for implementing the automation solution. This phase ensures that the selected technologies not only meet the technical requirements but also align with economic goals and minimize potential risks.

4. *Develop*. In the development phase, the selected automation solution is built and tested. This phase includes developing the solution, conducting pilot studies, and gathering user feedback to evaluate its performance. The TERA model is continuously assessed during this phase to ensure the solution meets the desired outcomes. Iteration is key in this step, as the solution is refined based on feedback and performance evaluations until it is ready for full implementation.

5. *Implement*. The implementation phase involves deploying the developed solution in a controlled manner. A change management plan is followed to ensure smooth integration into existing workflows, and the solution's performance is closely monitored. The TERA model is reevaluated during this phase to address any unforeseen issues that may arise during implementation. This step is crucial for ensuring that the solution is effectively integrated and begins delivering the expected benefits.

6. *Manage*. The final phase, management, involves the ongoing monitoring and evaluation of the implemented solution. Continuous monitoring ensures that the solution remains effective, and periodic reevaluations of the TERA model help adapt the solution to any changes in the organization or external conditions. This phase also involves making iterative improvements to the solution as needed, ensuring its long-term success and alignment with organizational goals.

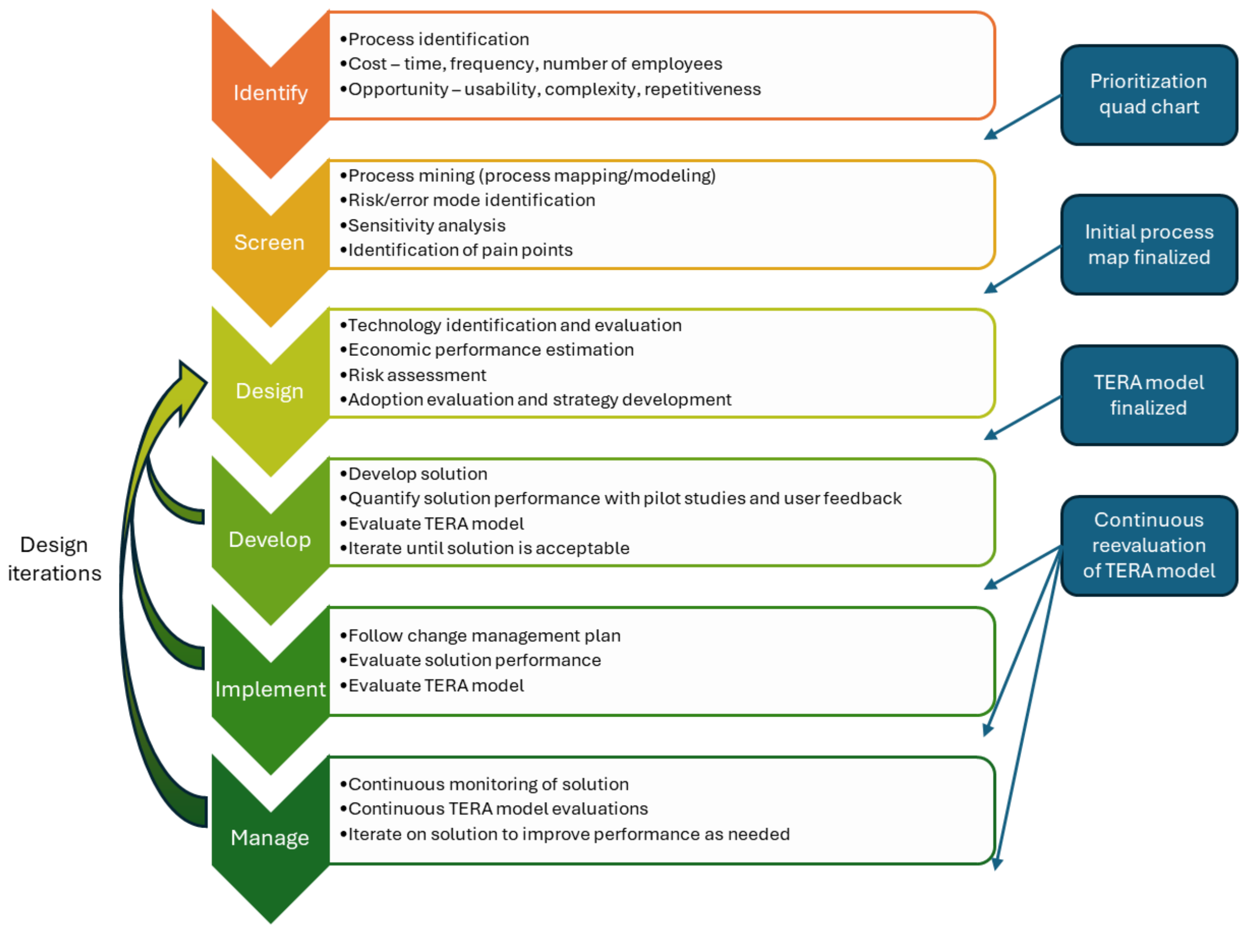

Figure 9. Steps involved in developing a WRO solution with TERA used for evaluations.

3.4 Using TERA to Prioritize Digitalization Opportunities

The TERA process contains many steps, from identifying to managing an implemented WRO. As part of this effort, we used the findings from the digitalization survey as the foundational input for the initial step of the TERA process in the identify phase.

In the identify phase, the survey results are systematically analyzed and quantified to identify potential digitalization initiatives that offer significant WROs and cost savings. The survey provides valuable insights into the current state of plant operations and highlights the areas where digitalization can help.

A key tool and output of this phase is the creation of a prioritization quad chart. This chart will help decision-makers visualize the digitalization opportunity and impact (costs savings) for each process. High-impact, high-opportunity processes will be prioritized, while initiatives with lower impact or lower opportunity will require further evaluation. Performing this prioritization ensures that only promising initiatives are moved forward into the subsequent stages of the TERA process.

3.5 Costs and Opportunities (Quantified from Survey Findings)

The survey data was used to prioritize WROs as digitalization opportunities. By examining the labor costs associated with each activity and the potential for digital improvement, it is possible to systematically identify and rank opportunities based on their impact and feasibility. The goal is to create a clear pathway for implementing digitalized solutions that deliver the most value to the organization.

To achieve this, the survey data was broken down into two primary categories: labor costs and digitalization opportunities. Specific equations were applied to quantify each activity's costs and digitalization potential. Using these metrics, a prioritization matrix and index was developed, allowing for effective visualization and the ranking of the opportunities. The aims of this structured approach were to:

- Identify and prioritize the most impactful digitalization opportunities
- Provide a strategic framework for implementing digitalized solutions
- Quantify potential cost savings and investment opportunities
- Ensure a swift return on investment by focusing on high-value areas first.

This evaluation will serve as a roadmap for the nuclear utility company, guiding them toward a more efficient and digitally advanced operational model.

3.5.1 Process Cost Estimation

To effectively prioritize digitalization opportunities, the survey data is categorized into labor costs and digitalization opportunities. This breakdown provides a clear understanding of the current resource allocation and the potential areas for improvement.

Estimated Yearly Labor Costs

Labor costs form a significant part of operational expenses in the nuclear industry. By quantifying these costs, the most resource-intensive activities—and therefore the prime candidates for digitalization—can be identified. The labor costs are broken down as follows:

- *Number of employees (performing each activity)*. This metric captures how many employees indicated that they perform a particular activity. Higher numbers indicate activities that could benefit substantially from automation.
- *Duration of activity*. This measures the amount of time spent on each activity. Longer durations suggest that even small efficiencies can lead to significant cost savings.
- *Frequency of activity*. This indicates how often each activity is performed within a given period. Activities that are performed frequently offer more opportunities for savings through digitalization.

- *Labor rate.* For this analysis, we standardized the labor rate at $100/hour. This uniform rate allows for a consistent comparison of the cost implications across different activities.

Using these components, total labor cost for each activity can be calculated using the following equation:

$$Labor\ Cost = Number\ of\ Employees \times Duration\ of\ Activity \times Frequency\ of\ Activity \times Labor\ Rate$$

The estimate of yearly labor costs for each activity will help determine the priority of each activity and provide a quantitative estimate for cost-savings predictions. It should be noted that the frequency and duration of activity survey responses were binned into ordinal categories. We converted into a singular value to compare digitalization opportunities for each activity by using estimates/averages of the frequency and duration bins to estimate the total duration for all survey respondents. Tables 12 and 13 show the survey bins conversions of average values used in the computation of labor costs. Using these values, the results for yearly costs for each activity can be seen in Figure 10.

Table 12. Duration bin conversion factor.

Duration Bins	Time/Activity (Hours)	Comment
More than 5 hours	7.500	Conservative estimate
1–5 hours	3.000	Average
31–59 minutes	0.750	Average
10–30 minutes	0.333	Average
Less than 10 minutes	0.167	Conservative estimate

Table 13. Frequency bin conversion factor.

Frequency Bins	Activities/year	Comment
Daily	240	260 days minus 20 vacation/holiday
2–3 times per week	120	Average
Weekly	48	Average
Monthly	12	Average
Quarterly	4	Average

3.5.2 Digitalization Opportunity

The digitalization opportunity is quantified as the sum of survey scores for the following digitalization health indicators relating to the activity: digital, number of programs, user-friendliness, workload, reliability, and effectiveness. Higher cumulative scores indicate greater opportunities for improvement.

To quantify and compare these scores effectively, we calculated the digitalization opportunity score using the following method:

$$Digitalization\ Opportunity\ Index = \sum Normalized\ Survey\ Answers$$

The digitalization health indicator scores were normalized from zero to one within their respective categories to ensure appropriate scaling for accurate comparison. By breaking down the data into these categories, we can systematically identify and prioritize activities based on their labor cost implications and potential for digitalization. This structured analysis lays the groundwork for developing a prioritization matrix and index, guiding strategic decisions in implementing digitalized solutions. The results from the digitalization opportunity estimation can be seen in Figure 12.

3.6 Digitalization Prioritization

After breaking down the data into labor costs and digitalization opportunities, the next step is to prioritize these opportunities to maximize their impact. This section outlines this approach using a prioritization matrix and a prioritization index score to identify and rank the most valuable digitalization opportunities.

3.6.1 Method

Prioritization Matrix

The prioritization matrix is a visual tool that helps to rank opportunities based on their potential cost savings and digitalization improvement potential. It allows for the quick identification of activities that should be prioritized.

- *Cost savings axis.* Activities are plotted based on their estimated yearly cost savings opportunity (equal to estimated yearly cost calculated section 3.5.1).
- *Digitalization opportunity axis*. Activities are plotted based on their digitalization opportunity score.
- *Quadrants*. The matrix is divided into four quadrants, helping to categorize activities into high-priority, medium-priority, low-priority, and non-priority areas.

The prioritization matrix helps decision-makers visually evaluate each opportunity in comparison to the others. The quadrants and position of each opportunity provide a general guideline for the prioritization of each opportunity. It should be used as one tool in the decision-makers' repertoire and balanced with their own goals and objectives. Figure 10 is an example of a digitalization priority matrix.

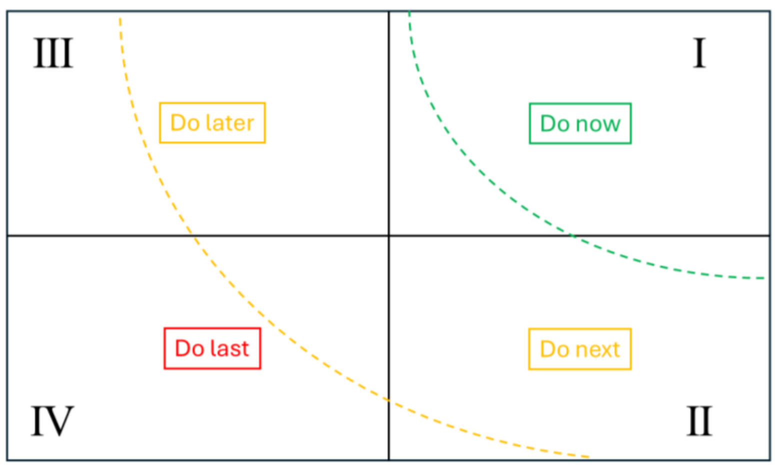

Figure 10. Digitalization priority matrix.

Prioritization Index

To create a numerical ranking of opportunities, the prioritization index score is calculated. This score combines potential cost savings and the digitalization opportunity into a single metric:

$$\begin{aligned} Prioritization\ Index\ Score = {} & Normalized\ Estimated\ Yearly\ Cost\ Savings \\ & \times Normalized\ Digitalization\ Opportunity\ Score \end{aligned}$$

Normalization. Both the estimated yearly cost savings opportunity and the digitalization opportunity score are normalized (from zero to one) to ensure they are on a comparable scale.

For this prioritization, the decision was made to multiply the cost savings and digitalization opportunity score together to ensure that activities that have both attributes are selected first. This removes the possibility of selecting a superficially attractive digitalization opportunity that in effect

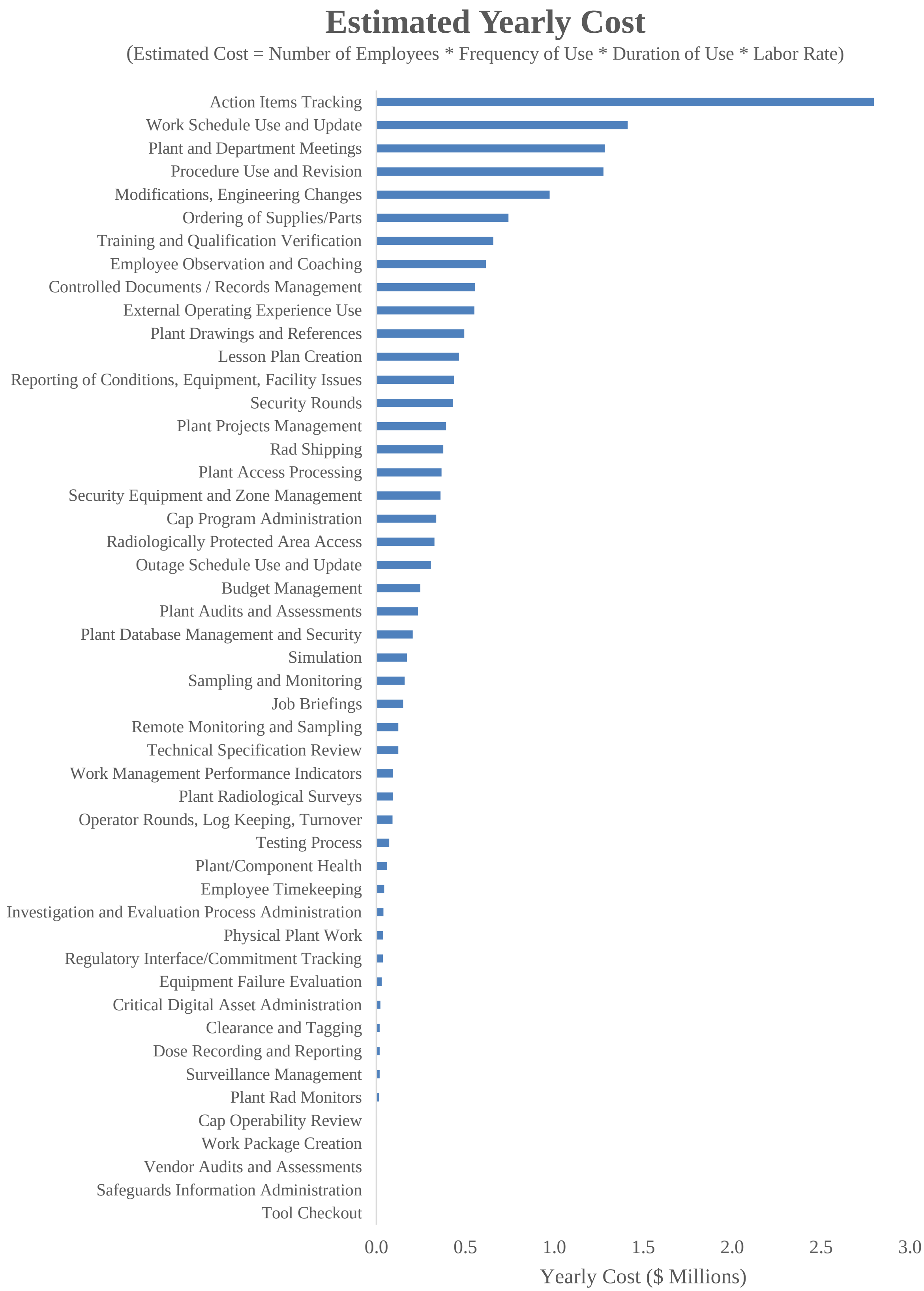

Figure 11. Estimated yearly costs for each activity, based on a labor rate of $100/hr.

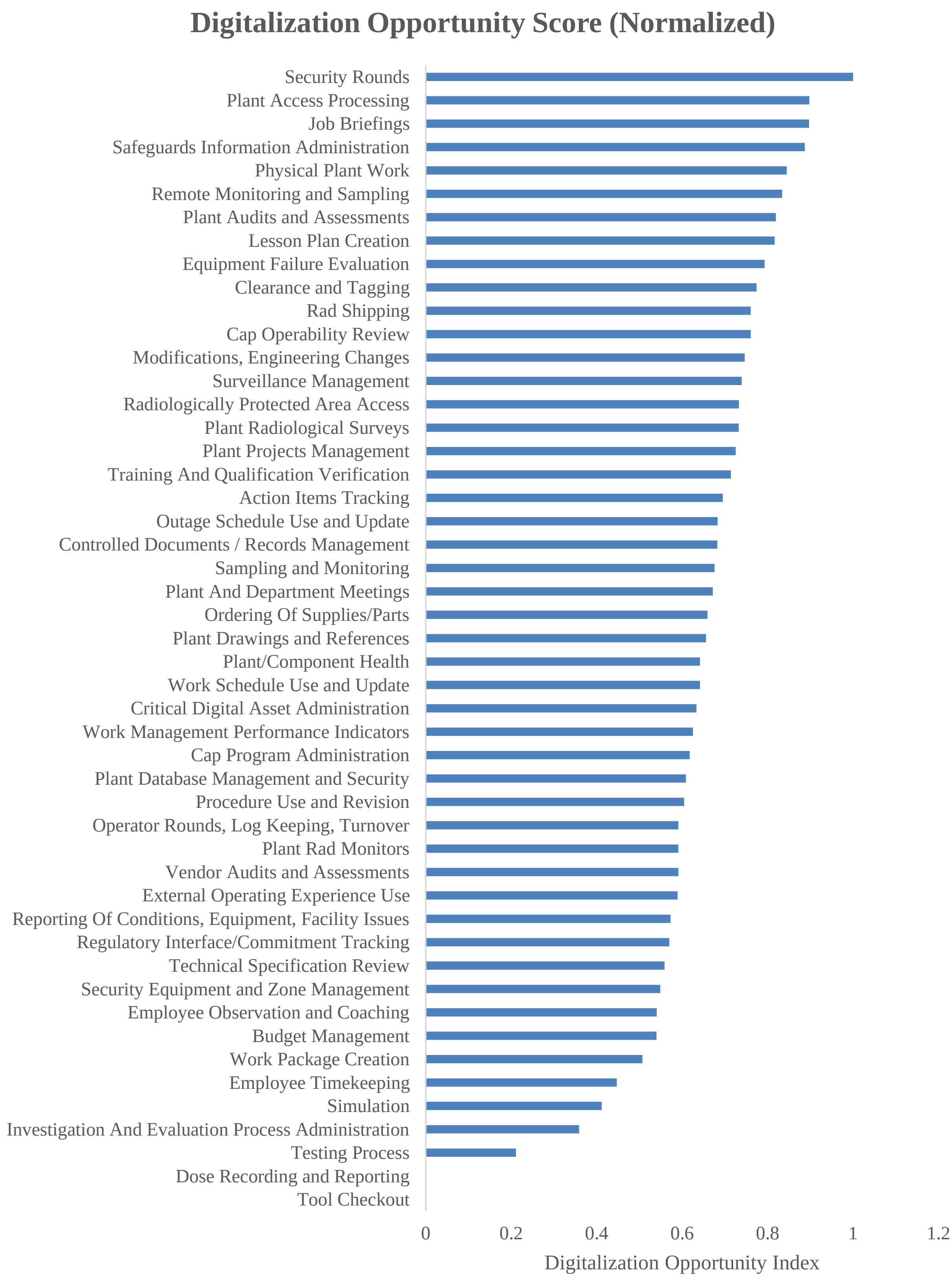

Figure 12. Digitalization opportunity score (normalized) for each activity.

provides minimal cost savings. For example, if we assume there exists an activity in which only one person performs a manual task, the costs of implementing the automation would most likely outweigh the cost savings opportunity. With digitalization for a large organization like an NPP, the prioritization should first focus on activities that provide both attributes. Table 14 provides an example of the prioritization framework.

Table 14. Example of the digitalization prioritization framework.

Activity	Digitalization Opportunity	Cost Savings Opportunity	Prioritization Index Score	Prioritization Ranking
A	0.9	0.9	0.81	1
B	0.5	0.5	0.25	2
C	0.8	0.1	0.08	3

Implementation and Prioritization Strategy

Implementing a structured and prioritized digitalization strategy is crucial for maximizing ROI and achieving operational efficiency in a nuclear utility company. This strategy focuses on identifying and addressing the most impactful digitalization opportunities first, leveraging quick wins to build momentum and confidence, and systematically tackling more complex projects.

1. **Identify and Prioritize Top Opportunities**
    - Use the prioritization matrix and index score to pinpoint the highest-priority digitalization opportunities.
    - Focus on activities that offer significant cost savings and efficiency improvements.
    - Start with quick wins: activities that are easy to digitalize and provide immediate benefits to build momentum and demonstrate the value of digitalization.
2. **Develop a Roadmap and Gain Experience**
    - Create a comprehensive plan for implementing digital solutions, starting with the highest-priority opportunities.
    - Ensure necessary resources, timelines, and milestones are in place to support successful implementation.
    - Tackle simpler projects first to allow the organization to gain valuable experience in digitalizing and automating processes, building confidence among employees and stakeholders.
3. **Monitor, Adjust, and Expand**
    - Continuously monitor the progress of digitalization initiatives to ensure they are on track.
    - Be prepared to adjust priorities based on new data, feedback, and changing organizational needs.
    - Once the low-hanging fruit has been addressed, shift focus to more complex or less immediately impactful opportunities, leveraging the gained experience and confidence to tackle these projects effectively.

By following this structured approach to prioritization, the most impactful digitalization opportunities can be identified and addressed first, maximizing ROI and paving the way for a more efficient and technologically advanced operational model.

Digitalization Opportunity Matrix

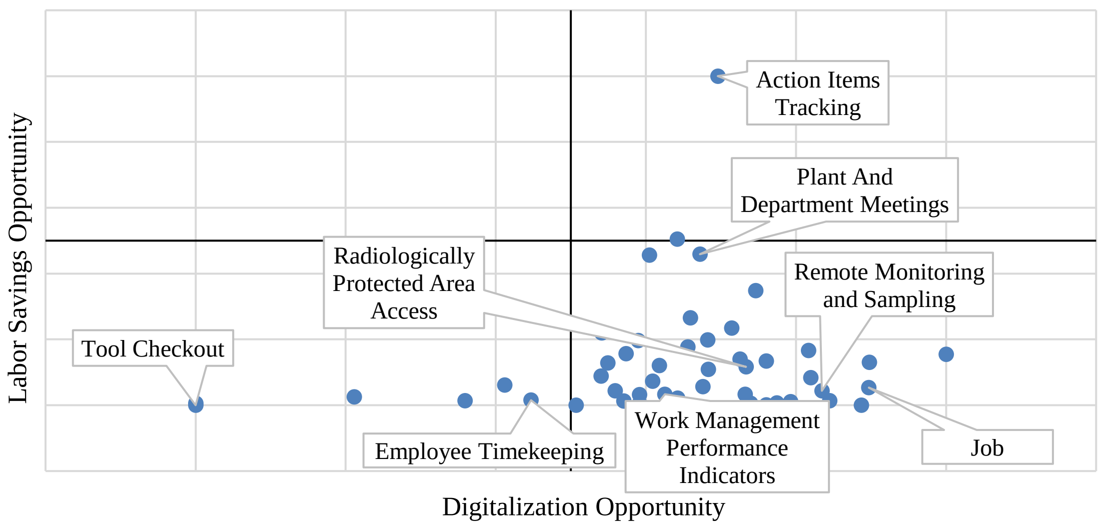

Figure 13. Results of the quantitative analysis for the digitalization opportunity matrix.

3.6.2 Results

This section presents the results of the quantitative analysis conducted for the digitalization opportunity matrix (Figure 13) and priority index score (Table 15 and Figure 14). These results help to identify and rank the activities that offer the highest potential for digitalization based on their normalized digitalization opportunity and potential cost savings.

Key Takeaways

The prioritization results provide a clear view of where the most significant digitalization opportunities lie within the organization. Key takeaways from the data are the following:

1. **Top-Prioritized Activities**
   - *Action Items Tracking*. This activity ranks highest with a normalized digitalization opportunity score of 0.696 and potential cost savings score of 1.000. This indicates that it is both a high-value target for digitalization and offers substantial cost savings potential, making it a prime candidate for immediate attention.
   - *Work Schedule Use and Update*. With a priority index score of 0.324, this activity is the second highest, reflecting significant opportunities for both digitalization and cost savings. Digitalizing work scheduling processes can streamline operations and enhance productivity.
   - *Plant and Department Meetings*. Ranking third with a score of 0.308, digitalizing meeting management can improve efficiency and reduce time spent on coordination, leading to better use of resources.
2. **Moderate-Prioritized Activities**
   - *Procedure Use and Revision and Modifications, Engineering Changes*. These activities have priority index scores of 0.276 and 0.260, respectively, and present valuable opportunities for digitalization. Streamlining these areas can lead to improved compliance and reduced errors.

Table 15. Results of the quantitative analysis for the digitalization priority index score and ranking.

Process	Digitalization Opportunity (Normalized)	Potential Cost Savings (Normalized)	Priority Index Score	Priority Ranking
Action Items Tracking	0.696	1.000	0.696	1
Work Schedule Use and Update	0.642	0.505	0.324	2
Plant and Department Meetings	0.672	0.459	0.308	3
Procedure Use and Revision	0.605	0.456	0.276	4
Modifications, Engineering Changes	0.746	0.348	0.260	5
Ordering of Supplies/Parts	0.659	0.265	0.175	6
Training and Qualification Verification	0.714	0.235	0.168	7
Security Rounds	1.000	0.154	0.154	8
Lesson Plan Creation	0.817	0.166	0.136	9
Controlled Documents / Records Management	0.682	0.198	0.135	10
Employee Observation and Coaching	0.541	0.220	0.119	11
Plant Access Processing	0.898	0.131	0.117	12
External Operating Experience Use	0.590	0.197	0.116	13
Plant Drawings and References	0.656	0.177	0.116	14
Rad Shipping	0.761	0.134	0.102	15
Plant Projects Management	0.726	0.140	0.101	16
Reporting of Conditions, Equipment, Facility Issues	0.573	0.156	0.090	17
Radiologically Protected Area Access	0.733	0.117	0.086	18
Outage Schedule Use and Update	0.683	0.109	0.075	19
CAP Program Administration	0.618	0.120	0.074	20
Security Equipment and Zone Management	0.549	0.129	0.071	21
Plant Audits and Assessments	0.820	0.083	0.068	22
Job Briefings	0.897	0.054	0.048	23
Budget Management	0.540	0.088	0.048	24
Plant Database Management and Security	0.609	0.073	0.044	25
Sampling and Monitoring	0.676	0.057	0.038	26
Remote Monitoring and Sampling	0.835	0.044	0.037	27
Simulation	0.412	0.061	0.025	28
Technical Specification Review	0.559	0.044	0.025	29
Plant Radiological Surveys	0.732	0.033	0.024	30
Work Management Performance Indicators	0.625	0.033	0.021	31
Operator Rounds, Log Keeping, Turnover	0.592	0.032	0.019	32
Plant/Component Health	0.642	0.021	0.014	33
Physical Plant Work	0.845	0.013	0.011	34
Equipment Failure Evaluation	0.793	0.010	0.008	35
Regulatory Interface/Commitment Tracking	0.570	0.013	0.007	36
Employee Timekeeping	0.447	0.015	0.007	37
Testing Process	0.211	0.026	0.005	38
Investigation and Evaluation Process Administration	0.359	0.014	0.005	39
Clearance and Tagging	0.775	0.006	0.005	40
Critical Digital Asset Administration	0.634	0.008	0.005	41
Surveillance Management	0.739	0.006	0.005	42
Plant Rad Monitors	0.592	0.006	0.003	43
CAP Operability Review	0.761	0.001	0.001	44
Work Package Creation	0.507	0.001	0.000	45
Vendor Audits and Assessments	0.592	0.000	0.000	46
Safeguards Information Administration	0.887	0.000	0.000	47
Dose Recording and Reporting	0.000	0.000	0.000	48
Tool Checkout	0.000	0.006	0.000	49

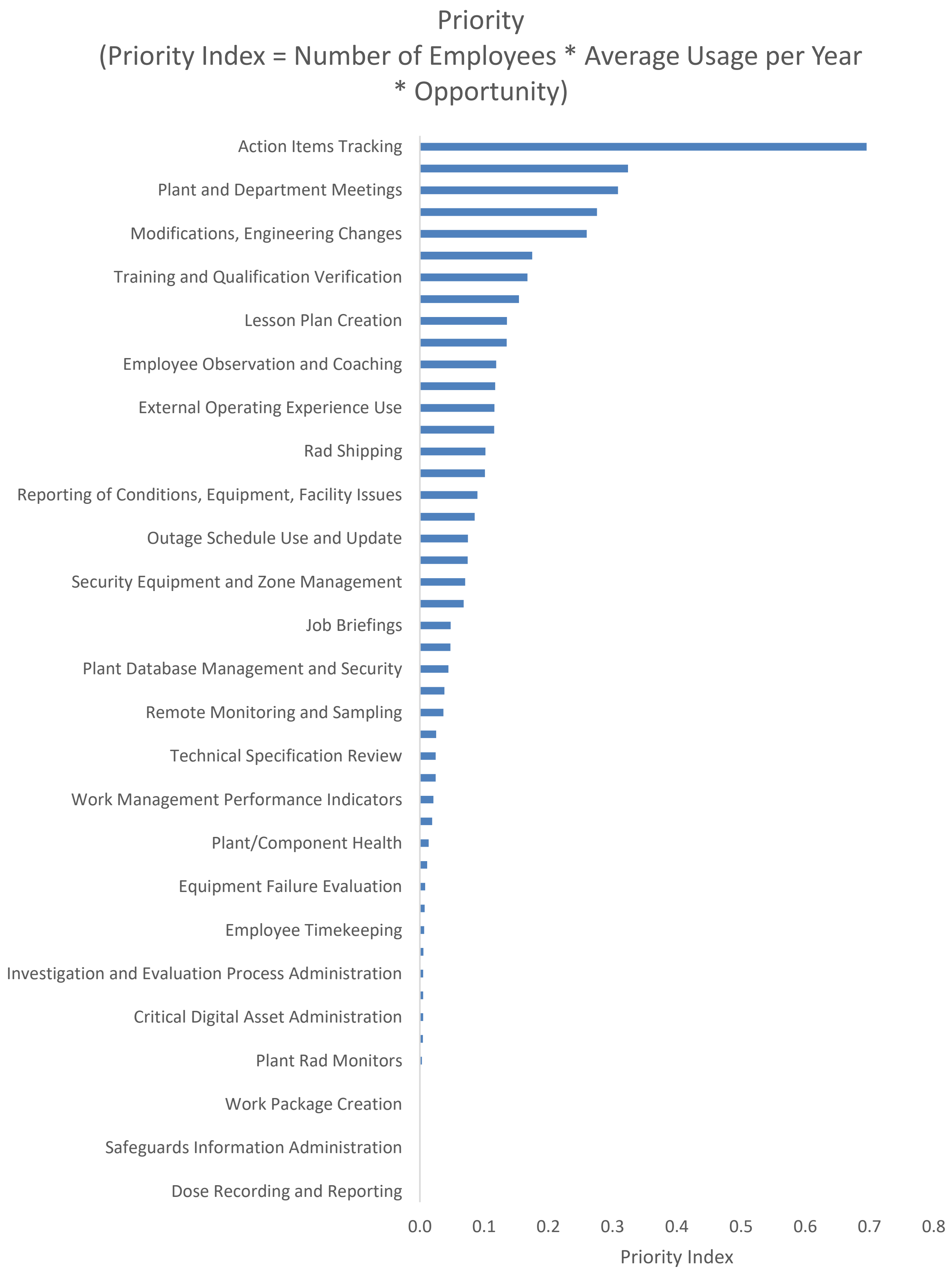

Figure 14. The digitalization priority index scores for each activity.

- *Ordering of Supplies/Parts and Training and Qualification Verification.* These activities, with scores of 0.175 and 0.168, respectively, suggest moderate potential for improvements. Digitalized solutions here can enhance procurement efficiency and training effectiveness.

3. **Lower-Prioritized Activities**
   - *Security Rounds and Lesson Plan Creation*. Despite having high digitalization opportunity scores, their potential cost savings are relatively lower, reflected in their index scores of 0.154 and 0.136, respectively. These activities may still benefit from digitalization but are less critical compared to others.
   - *Employee Observation and Coaching and Plant Access Processing.* These activities, with priority scores of 0.119 and 0.117, respectively, show that while they have potential for digitalized improvements, the cost savings may not be as substantial.

4. **Minimal-Impact Activities**
   - *Tool Checkout and Dose Recording Reporting.* Activities such as these have very low or zero scores, indicating minimal potential for digitalization or cost savings. These should be deprioritized in favor of more impactful opportunities.

3.7 Digitalization Investment Evaluations

3.7.1 Method

The cost-benefit evaluation delves into crucial financial metrics employed in assessing the feasibility and success of WRO implementation. NPV provides an economic perspective that incorporates the time value of money, which is used to evaluate the performance of an investment at a given discount rate. In other words, the NPV evaluates whether the project represents a good investment. The NPV evaluates whether the project will exceed the returns generated by using that same investment to accrue interest. The formula for calculating NPV is:

$$NPV(T) = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_0,$$

where C_0 is the initial investment cost, C_t is the net yearly cash flow (or cost savings) in time t, r is the discount rate at which the value of future cash flows is discounted back to present value, and T is the total number of time periods covered in the NPV calculation. The initial investment cost includes all upfront costs related to the WRO, such as screening, development, and deployment. The discount rate—usually expressed as a percentage—is used to evaluate the ROI and accounts for the time value of money, inflation, and investment risk. The net yearly cash flow (or cost savings) is the net annual financial benefit realized by implementing the WRO solution and should consider existing process costs, new process costs, operational expenditures pertaining to the new process (new ongoing costs), and the expected usage rate. For this work, we assumed a 50% process cost savings to evaluate the maximum investment cost that yields a positive NPV. It should be noted that the process cost savings percentage is only for estimation and demonstration purposes: the actual value could be higher or lower depending on the complexity of the process, the technology readiness, and the adoption rate. A sensitivity analysis of this value is performed in section 0.

3.7.2 Results

In this section, each digitalization initiative is evaluated to identify the maximum investment amount that achieves a positive NPV within 2 years, using a 5% discount rate and assuming 50% process cost savings. The focus is on determining a maximum investment to ensure that the NPV of the cost savings from these initiatives is positive over the specified period. It should be noted that investments of this size should provide at least 50% process cost reductions, otherwise the process solution may not be the best use of investment budgets.

Table 16 shows the results of this analysis, sorted by the digitalization priority index. It is sorted by priority index to ensure that processes with a good combination of time savings *and* digitalization opportunity are at the top. Certain processes may cost significant amounts (and thus warrant large investments), but these same processes may not provide good digitalization opportunities. This analysis helps stakeholders understand the financial impact of digitalization and identify maximum investment amounts when seeking technical solutions.

Table 16. Maximum investment amounts to achieve a positive NPV in 2 years, assuming a process cost reduction of 50% and a 5% discount rate.

Process (Sorted by Priority Index)	**Priority Index**	**Maximum Investment (50% Process Cost Savings)**
Action Items Tracking	0.70	$2,601,408
Work Schedule Use and Update	0.32	$1,313,302
Plant and Department Meetings	0.31	$1,193,741
Procedure Use and Revision	0.28	$1,186,862
Modifications, Engineering Changes	0.26	$905,440
Ordering of Supplies/Parts	0.17	$689,965
Training and Qualification Verification	0.17	$610,692
Security Rounds	0.15	$401,633
Lesson Plan Creation	0.14	$431,755
Controlled Documents/Records Management	0.14	$515,522
Employee Observation and Coaching	0.12	$572,141
Plant Access Processing	0.12	$339,900
External Operating Experience Use	0.12	$512,299
Plant Drawings and References	0.12	$459,553
Rad Shipping	0.10	$349,569
Plant Projects Management	0.10	$363,515
Reporting of Conditions, Equipment, Facility Issues	0.09	$406,684
Radiologically Protected Area Access	0.09	$303,270
Outage Schedule Use and Update	0.07	$284,490
CAP Program Administration	0.07	$313,218
Security Equipment and Zone Management	0.07	$334,694
Plant Audits and Assessments	0.07	$216,993
Job Briefings	0.05	$139,456
Budget Management	0.05	$229,265
Plant Database Management and Security	0.04	$189,660
Sampling and Monitoring	0.04	$147,265
Remote Monitoring and Sampling	0.04	$114,168
Simulation	0.03	$158,980
Technical Specification Review	0.02	$113,982
Plant Radiological Surveys	0.02	$87,020
Work Management Performance Indicators	0.02	$87,082
Operator Rounds, Log Keeping, Turnover	0.02	$83,673

Plant/Component Health	0.01	$55,875
Physical Plant Work	0.01	$34,957
Equipment Failure Evaluation	0.01	$27,147
Regulatory Interface/Commitment Tracking	0.01	$34,027
Employee Timekeeping	0.01	$39,884
Testing Process	0.01	$66,939
Investigation and Evaluation Process Administration	0.01	$36,816
Clearance and Tagging	0.01	$16,797
Critical Digital Asset Administration	0.00	$20,268
Surveillance Management	0.00	$16,735
Plant Rad Monitors	0.00	$14,503
CAP Operability Review	0.00	$3,347
Work Package Creation	0.00	$1,488
Vendor Audits and Assessments	0.00	$837
Safeguards Information Administration	0.00	$62
Dose Recording and Reporting	0.00	$16,735
Tool Checkout	0.00	$-

To determine the optimal investment amounts, the relationship between variable investment amounts and the required process cost reduction was analyzed to ensure a positive NPV after 2 years with a 5% discount rate. Action Items Tracking was chosen for this analysis since it is the highest on the priority index. Figure 15 shows how changes in the expected process cost reduction percentage influences the investment amount while still maintaining a positive NPV. The chart shows that, as expected, as cost reductions increase, larger investments are justified to maintain a positive NPV. Additionally, decision-makers can use this plot to assess whether a proposed solution is above or below the critical investment line. Solutions above the line represent poor investments, resulting in negative NPVs, while those below the line are favorable, leading to positive NPVs. In other words, solutions above the line cost more than the benefit they provide, and solutions below the line cost less than the benefit they provide.

3.7.3 Sensitivity Analysis

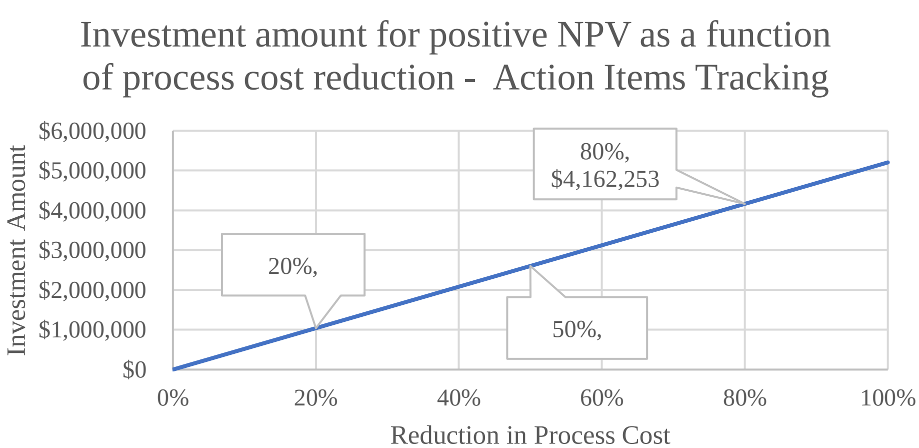

Figure 15. The relationship between a variable investment amount and the required process cost reduction to ensure a positive NPV after 2 years with a 5% discount rate.

Additionally, the relationship between investment amounts, cost reduction, and breakeven lengths (i.e., time to achieve a positive NPV) was analyzed. The plot in Figure 16 demonstrates that longer breakeven periods (e.g., 3 years) allow for larger investments as the return time extends. Conversely, achieving a positive NPV after just 1 year requires a smaller initial investment.

The varying breakeven periods represent different decision-making profiles. While shorter return periods are generally more advantageous, some decision-makers may prefer longer breakeven periods based on their investment strategies and risk tolerance. The analysis shows that longer breakeven periods provide more flexibility in investment size, but shorter return investments are more attractive for decision-makers seeking quicker returns.

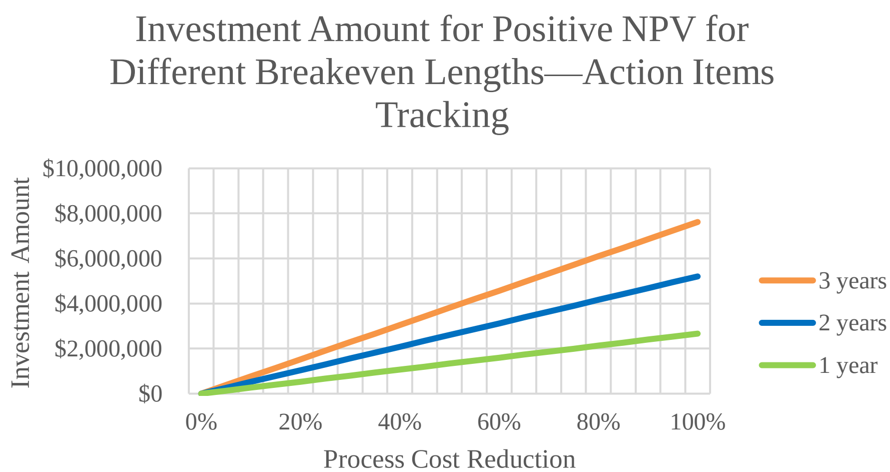

Figure 16. Investment amount for positive NPV for different breakeven target dates.

3.8 Discussion

The analysis of digitalization opportunities using the TERA framework provides a systematic approach to identifying and prioritizing digitalization opportunities in the nuclear industry. By applying a structured and quantifiable assessment approach, we can ensure that decision-making is data driven, reducing the likelihood of biases and loss on investment. The key findings of this study show that by leveraging the survey data and a prioritization process, high-value digitalization opportunities can be efficiently identified and evaluated.

The key outcome was to establish a prioritization matrix and prioritization index score for each opportunity. This allowed us to visually and quantitatively assess the digitalization opportunities based on their potential cost savings and digitalization opportunity score (based on the health indicators). The results showed that Action Items Tracking is a top priority, with a high potential for cost savings and digitalization improvements. Other activities such as Work Schedule Use and Update and Plant and Department Meetings were also indicated as high-priority areas for digitalization. It should be noted that activities not identified as high priority could still provide digitalization benefits; rather, they should be analyzed additionally by key stakeholders to confirm their prioritization is low.

The digitalization investment analysis (section 3.7.2) provides valuable insights and tools for decision-makers to evaluate opportunities. The investment analysis showed the maximum allowable investment to ensure a positive NPV after a 2-year period with 50% cost savings (Table 16). While this is useful for initial analyses, the sensitivity analysis provides decision-makers with criteria for evaluating investment opportunities, ensuring that solutions will have a positive NPV based on cost savings and investment value (Figure 15). Last, the breakeven analysis (Figure 16) extended these findings, showing that longer breakeven lengths (years until a positive NPV is reached) warranted higher investment amounts, albeit at the tradeoff of quick returns. The investment analysis highlights the importance of aligning digitalization efforts with organizational investment strategies and risk tolerance levels.

In summary, the prioritization analysis employed in this work provides a robust methodology for evaluating digitalization opportunities, ensuring that resources are allocated to projects with the highest potential impact. These findings help identify a more efficient, digitally enhanced nuclear plant while offering flexibility to decision-makers based on their financial strategies and risk tolerance.

4. Interview Assessment

4.1 Best Practices for Interview Protocol

To complement the quantitative findings from the survey assessment, a digitalization deep dive was conducted on-site at the plant in the form of multiple 1-hour interview sessions. A set of questions was prepared beforehand but the research team could ask additional unplanned questions during the semistructured interviews (Taherdoost, 2022). This interview format allows us to gain information about participants' perceptions, beliefs, and attitudes regarding the research topic, in their own words. Semistructured interviews are commonly used to collect qualitative data (DeJonckheere & Vaughn, 2019).

The first step in conducting effective interviews is to develop an interview protocol: introductions of both the research team and research participants, a description of the research goals, planned questions, and potential ethical concerns (i.e., anonymity of the participant, confidentiality of responses, and participant withdrawal at any time without penalty). It is also suggested that researchers explicitly inform participants that there are no right or wrong answers, and that responses will not be judged. Thus, it is preferrable that researchers maintain a neutral stance and not make statements that suggest either agreement or disagreement.

When it comes to creating interview questions that provide researchers with quality data, many of the same principles used to generate survey questions apply. For example, question wording should be short, straightforward, and not leading (neutral phrasing); the interview length should be reasonable; and participant motivation to answer honestly must be considered (Taherdoost, 2022; Turner, 2010). As with the survey development, several techniques to increase motivation were used: providing the purpose of the research, providing an incentive (in this case, candy and chocolate), and communicating that responses will help others. Attempting to develop rapport with the participants to allow them to feel more comfortable and be more open in their responses is a unique part of the in-person interview format (McGrath et al., 2019). Demonstrating active listening and showing empathy are also shown to increase participant motivation (Abbe & Brandon, 2014).

Open-ended questions are commonly used in interviews because they allow participants to share more detailed information (Dunwoodie et al., 2023). Notwithstanding, should interviewees go off on a tangent, the interviewer should gently redirect them back to the topic at hand. At the conclusion of the interview, the interviewer should ask participants if there is any other information they would like to add (Taherdoost, 2022).

4.2 Method Development

4.2.1 Participants

N = 37 participants took part in the interviews in groups of one to eight in 10 different sessions over 2 days. When possible, plant employees were grouped by department, but due to scheduling conflicts there were instances when employees from different departments were present within the same time slot. Participants were recruited and scheduled by the plant's innovation director. Not all departments were represented. The research was approved by the INL IRB, and all respondents indicated consent to the research (IRB approval INL000179).

4.2.2 Questions Selection

The first set of questions was designed to elicit critical feedback about the survey (Table 17). The development of a valid survey assessment that can produce reliable, rapid results regarding the digitalization status of an NPP represents the main research efforts of the year. Lessons learned from this work will be used to evolve the assessment in an iterative fashion. Thus, the plant visit gave researchers a valuable opportunity to collect information in real-time from the survey respondents and evaluate the survey's psychometric properties (i.e., construct validity). Importantly, we were also able to learn about likes, dislikes, and barriers to engagement. Questions were short, straightforward, and neutral.

Table 17. Survey validation questions.

Interviewees	Q#	Question
Survey takers	1	Show of hands, how many of you took the survey?
	2	For those with your hands up, how many completed it on your phone?
	3	For those who did, what motivated you to fill it out?
	4	What barriers were there that made it difficult to finish (i.e., for those that started but couldn't finish)?
	5	What did you like about it? For example, multiple choice and not typing answers, it was quick, etc.
	6	What did you not like about it?
	7	In your opinion, what was missing from it?
Survey non-takers	8	What barriers were there to starting the survey in the first place?
	9	How can we make it easier/more accessible?
	10	Did anyone work together on the survey?

The second set of questions was designed to elicit in-depth digitalization feedback about activities performed by each department the research team met with. Specifically, these interview questions were developed to first invite participants to freely describe their work processes, building trust and rapport. When pain points were uncovered, spontaneous follow-up questions—as part of the semistructured interview format—could be asked that dug deeper into the source of frustration. Examples included "Can you explain further?" or "Can you give an example?" In this way, the interview questions attempted to produce qualitative findings that would complement the quantitative survey results, together providing a comprehensive digitalization status of the organization with areas for improvement. Table 18 highlights the bank of general questions that was developed that the research team could draw from. When querying software, individuals were asked about software specifically named in the survey responses.

4.2.3 Protocol

The research team to visit the site consisted of four members: two human factors scientists, a mechanical engineer, and a nuclear power SME. Each team member had previously undergone a 30-minute training in best practices when conducting interviews. The plant's innovation director arranged the interview sessions in advance of the team's arrival and invited individuals from as many departments as possible. The research team specifically requested to meet with individuals from information services because of their central role in digitalization, as well as field workers because of their underrepresentation in the survey sample. Employees arrived at the meeting room at their allocated time and sat at a large boardroom-style table with the research team and the plant's innovation director.

The interview sessions consisted of the following approximation (although sometimes they varied): 10 minutes of introductions, informed consent, and the purpose of the meeting; 15 minutes of survey validation questions; 20 minutes of digitalization process questions; 10 minutes of no questions (participants telling the research team whatever they wished). Participants were then thanked for their time and furnished with the business card of the digitalization lead. One individual from environmental could stay only 30 minutes. Plant employees introduced themselves by first name only, and these names were not recorded. As with the survey, all responses were anonymous.

Table 18. Digitalization process questions.

Q#	Question
1	What are the core functions of your group?
2	How many people are in each position in your group?
3	Do you feel that it takes too many software programs to perform some of the processes?
4	Respondents per activity—good representation?
5	How much training do you get on software?
6	Are you required to use off-the-shelf or self-created software to perform your duties?
6a	Does this option work for you or would you rather have tailored software?
7	Do you feel your company tries to give you the most up-to-date digital tools to help you with your job?
8	Are valuable reports available and are ad hoc reports easy to run or can you get customized data by yourself?
9	Do you report issues when you identify them?
10	Can you provide any insights on software utilized by your department for specific job functions?

4.3 Results

4.3.1 Survey Validation Findings

4.3.1.1 Survey Takers

Approximately 11 of the 37 interviewees stated that they took the survey. All completed it alone, and none used their phone. The main motivation to engage with the survey was to help the innovation director, who made the request. This theme emerged across departments, and it was understood that the research team’s internal champion was popular among employees and was a critical factor in our successful response rate. Other converging motivators were to help the plant improve, that it served as a means to send feedback to the organization, and that the survey came from INL. Interestingly, no one cited the Starbuck’s gift card as an incentive; in fact, the opposite was true. Several interviewees perceived this reward as suspicious and a potential cybersecurity phishing threat (i.e., to some it looked fake). The research team learned that the gift card acted as a deterrent to employees of a municipal NPP.

Positives of the survey included that it was short, that there was a good balance of open-ended and multiple-choice questions, and that reminders were sent.

Although one of the chief positives was that the survey was short, some noted that it was too long. Some cited the wording of the questions as not being specific enough, or as being too specific, and as being redundant or nonapplicable in places. Other negatives were that the response format was too restrictive and did not include an “other” category. Not only was the gift card perceived to be a phishing threat, but some employees had ethical concerns about accepting gifts and were put off for that reason. Moving forward, significant efforts should be made to convey to plant employees that it is safe to click the survey link. Even though the email request came from the plant’s innovation director, with internal announcements and reminders, the strict safety culture of NPPs was in full effect such that some potential respondents refused to click the external link to the survey website.

4.3.1.2 Those Who Did Not Take the Survey

Of those who did not take the survey, one of the main barriers to engagement was that the email invitation was not sent to all employees, so some individuals were not aware of its existence (e.g., the maintenance department). Another chief barrier was the timing of the survey; many individuals cited a busy week with too high a workload, including other staff surveys that were sent out the same week. Although for most of the survey it was possible to navigate backward, once the activity selection was made and a customized set of questions delivered, one could no longer navigate backward, and some individuals did not like that.

Last, several people suggested making the survey more accessible: being informed that the survey could be taken on one's phone (the survey was designed for this capability, but this was not made clear to the target participants); inviting people to gather in a social setting to participate at a designated, protected time (especially for the craft staff); getting people talking about it; and having the invitation come from each department's supervisor.

4.3.2 Digitalization Process Findings

Responses from the interviewees were recorded by at least three research team members at any one time, including the SME. To increase inter-rater reliability, a research assistant examined the data across all notetakers and identified converging information. These findings were discussed and verified by the interview team.

Table 19. Main findings generated from interview responses.

Department	N	Main findings
Tech. Support/Administration	4	• Many processes involve paper documents • Several types of documents must be manually scanned • Digitizing old records would make searching for records/information easier
System Engineering	3	• A lot of information is already digitized • Data accessibility is poor
Training	4	• 50% of what is done is on paper • Poor training on software programs • Procedure for getting signatures inefficient
Information Services	8	• Some activities are on paper • Information gathering and retrieval is a challenge
Design Engineering	3	• Not a lot of paper used • Limited training for advanced functions • Hardware limitations
Regulatory Affairs	1	• Workers doing tasks that used to be done by another department • Finding information can be difficult • LDCN [licensing design change notice] should be digitized
Work Management	4	• Several homegrown tools • Finding information can be difficult • Biggest challenge in completing work is in parts area
Maintenance	5	• Digitalization would help with tags tied to tools • Wi-Fi not available everywhere; it would be helpful if it were
Security and Training Support	4	• Many "mostly" paper processes in security • Manually entering data very time-consuming
Chemistry and Environmental	1	• Forms printing, duplication, signing, scanning

The high-level takeaways were borne from the main findings for each department present at the on-site interviews (Table 19). Extrapolating across all interviews, repeating themes emerged across departments. These findings represent interdepartmental digitalization concerns that span the breadth of the organization. There are four high-level digitalization takeaways for the plant:

1. A significant amount of time is dedicated toward printing then filling out paper documents, scanning them, and then uploading these electronically. Employees expressed a desire for “better interconnectedness” between the vast data reserves in the plant that they contend with.
2. Obtaining signatures is time-consuming because often workers must use different programs, such as Word and Adobe, to complete the task.
3. Even when a document is available in digital format, due to issues such as inadequate optical character recognition conversion, workers struggle to find specific information inside it. Consequently, at times employees spend a significant amount of time searching for desired information.
4. Often, the training provided for using the software programs is inadequate.

4.3.2.1 Expert Recommendations

From the main interview findings, the research team’s SME led efforts to generate improvement opportunities that would best serve the plant. The interview findings were filtered through his years of experience to develop digitalization recommendations. Many of the recommendations involve quick, simple, and cost-effective changes that would directly address pain points uncovered during the assessment.

For concerns related to *poor data accessibility, difficulty finding information, and challenges gathering and retrieving information*, the following opportunities were created:

- More object database connectivity read-only access to the Asset Suite data tables and other program tables would help individuals more easily write ad hoc reports and macros.
- More Adobe Acrobat Pro licenses would improve PDF use capabilities and save time.
- Increase data cleanup and building routines to harmonize equipment data would help engineers more quickly and accurately evaluate plant data, which would improve trending thereby reducing unplanned corrective work orders. Data sources used by engineers include eDNA Enterprise Data Management, Electronic Shift Operations Management System (eSOMS), condition reports, action requests and the inventory parts catalog.
- Use AI for text searches would allow employees to better review plant inventory data. This would also help to reduce inventory growth and stranded inventory through reduction of duplicate stock codes.

For concerns related to *inefficient procedures for getting signatures*, *certain types of documents needing to be manually scanned,* and *printing, duplicating, signing, and scanning forms*, the following opportunities were created:

- More Docusign licenses would help when approval is needed for PDF forms. This would reduce the amount of printing, signing, and rescanning for signature approval. (Note: in some cases, plant processes may still require a manual signature for document approval. As a result, manual document creation, printing, signing, and scanning back in may still be necessary.)

For concerns related to *limited training for advanced functions*, the following opportunities were created:

- More training on existing software and report-writing tools.
- Electronic expense report training combined with Docusign would save time for approximately one-third of plant employees. Either they do it themselves or they give it to admin. to take care of.

For concerns related to *manually entering data being very time-consuming* and *some activities being on paper*, the following opportunities were created:

- Digitize security rounds and fire watches by adding them into eSOMs would speed up the approval process.

For concerns related to *digitizing old records would make searching for records/information easier*, the following opportunities were created:

- Scan the backlog into microfiche, then catalog it into a controlled docs/records module in Asset Suite for better accessibility.

For concerns related to *hardware limitations*, the following opportunities were created:

- More RAM for engineering computers, especially those that must review detailed drawings that are not in their native format (i.e., high-resolution PDF files).

For concerns related to *there being several homegrown tools*, the following opportunities were created:

- Acquisition of a customized user interface (i.e., front ends) for high-use applications to improve user-friendliness and generate productivity improvements.

Finally, although not produced directly from employee feedback, improvement opportunities were identified in that the plant may not be taking full advantage of available external resources that can increase plant performance. These were:

- Leverage guidance in the Electric Power Research Institute's Plant Obsolescence Management System documentation (POMS; Tannenbaum & Sisk, 2009).
- Providing greater search capabilities for external operating experience beyond the Institute of Nuclear Power Operations' Industry Reporting and Information System (IRIS) data and records could help identify similar issues. These include the Nuclear Regulatory Commission's information notices (NRC, 2024), and the World Association of Nuclear Operators' trends and performance monitoring system (WANO, 2024).

5. Main Discussion

5.1 Purpose and Main Findings

The purpose of this research effort was to develop an assessment instrument to take stock of the digitalization status of a utility's work processes, identify target candidates for improvement within a digitalization plan, and provide a benchmark for any future initiatives. Uncovering process inefficiencies across a broad swath of employees and across a broad swath of process health indicators provides critical insights to decisions that will affect a plant's bottom line. The work processes identified in this effort were filtered through a rigorous TERA evaluation that generated success metrics for each potential initiative, highlighting those that could gross the highest ROI across the plant (e.g., Action Items Tracking). The survey results provide a panoply of health indicators about individual work processes that can be used individually or in any desired combination given a plant's constraints, motivations, and capabilities.

State-of-the-art survey best practices were rigorously applied to the instrument's creation, validation, and deployment. Working closely with a utility partner, the survey created was rapid, user-friendly, and customized to each employee by department and position. The organization's innovation director championed the assessment, as did the plant's public affairs department and chief nuclear officer. Together these efforts culminated in a 35% response rate and a 25% completion rate. It should be noted that an online survey response rates >30% is deemed excellent (Le Masson, 2023).

Content validity of the survey's subject matter was acquired from staff at a different nuclear facility, as well as from four nuclear experts, each retired from different NPPs. Process names were carefully selected to reflect standard NPP vernacular that would be as recognizable as possible to the greatest number, increasing external validity. This served to create an instrument that is both specific enough to be relevant to our partnering utility, but broad enough to be applicable to any existing U.S. NPP. This is important given that each U.S. NPP is at a unique point in its digitalization journey, and the assessment must be flexible enough to faithfully capture a plant's status while being relevant and applicable to different plants.

Follow-up in-person interviews at the plant provided important critical feedback regarding areas for survey improvement and barriers to engagement, and provided individuals an opportunity to express any work process concerns in their own words. State-of-the-art interview best practices were applied, including those related to building rapport, question formatting, and allowing time for participants to lead discussions. The on-site interviews complemented the survey approach for three reasons: (1) Interview feedback indicated that some individuals prefer to share in person and face-to-face rather than through online means. (2) Follow-up questions based on participant responses afforded us an opportunity to dig deeper than would otherwise have been possible. (3) Repeated themes not specifically tied to any one process emerged that allowed the research team to suggest potential low-cost cross-functional solutions that may positively impact several processes (e.g., investing in Docusign software).

5.2 Limitations and Lessons Learned

Notwithstanding, these research findings must be considered within the context of some important limitations. As with any assessment, there is measurement error. Those inherent to all self-report online survey research include respondent bias, participants not being able to ask clarifying questions, and a lack of controlled environment (i.e., not knowing if the respondents are distracted, paying attention, etc. (Andrade, 2020). The following considerations are unique to this research effort, and each is treated as a lesson learned that will be applied to future iterations of the assessment instrument.

Content:

1. The questions were not benchmarked to give respondents the same point of reference. For example, when asked to rate effectiveness, providing an example of ideal effectiveness for a given process would help respondents to compare and rate accordingly. This would not only help standardize responses across participants, but it could also serve to educate plant employees as to what is possible or currently in use at other plants. Oftentimes, NPPs operate in information silos. The assessment instrument could additionally act to enlighten plant employees of more efficient digitalized processes nationwide, should they exist.
2. Every technology and digitalization assessment measure necessarily takes a human-centric approach. This is inherent to survey or interview research. Interviewing plant staff is a typical strategy researchers take when trying to understand modernization needs. Future works should additionally incorporate objective digitalization indicators that complement employee experiences, such as plant performance indicators (see Section 5.3).
3. Activity selection. The research team faithfully adhered to survey best practices, including not overburdening respondents, which is known to result in early termination (Rolstad et al., 2011). Therefore, not all work processes that an employee performs were sampled. Participants selected the activities they deemed important to increase survey ownership. However, the reasons that participants chose to report certain activities over others may have biased the results (e.g., biased participants toward providing feedback on the most problematic activities).
4. Training and proficiency levels with digital software may have impacted user-friendliness ratings. Future research can incorporate a measure of software usage to take this into account.
5. Anonymity was a method used in the survey that was not possible with the in-person interviews. Anonymity was emphasized, and respondents did not provide any personally identifiable information (note – there may have been a perceived lack of anonymity based on requests for department and position). While survey anonymity has been shown to decrease social desirability pressures, this does not automatically lead to greater accuracy. In a series of studies Lelkes et al.,

(2012) tested this premise and reported that complete anonymity instead *compromises* accuracy. This is because lack of respondent accountability produces less thoughtful answers, lower cognitive engagement and reduced motivation to provide correct information.

Deployment:

6. Not all positions were representatively sampled (e.g., N = 6 field workers) because the survey was made available to a limited sample only. This may have affected internal validity for some processes (i.e., the extent to which the observed results reflect the truth) and resulted in low estimated TERA labor costs for activities associated with some positions, such as Tool Checkout (N = 1), because dozens of employees are expected to perform this activity daily. To overcome this, the research team should be involved in sampling to ensure correct procedures.
7. Respondents were not made aware that they could complete the survey on their cell phones. This may have impacted response rate, and importantly, making this clear might have provided more opportunities for engagement for employees who do not routinely sit at a desk.
8. Activities were presented alphabetically because the software did not allow for randomized presentation. This may account for the high data collection within Action Items Tracking and would have impacted data collection for participants who terminated the survey early. Ideally, activity presentation should be counterbalanced.

Regarding the interviews, plant staff indicated room for improvement retrospectively. Feedback included sending the questions in advance so that employees had time to prepare more thoughtful answers, asking more balanced questions (i.e., drawing out more positive comments rather than leading with concerns), and providing more time for employee-led discussion. Longer sessions with fewer departments may be a more optimal strategy moving forward.

5.3 Future Directions

Moving forward, the digitalization assessment tool will evolve in an iterative fashion incorporating lessons learned from this year's efforts. The survey provides an opportunity for a large number of plant employees to rate process health indicators and indicate their digital quality of life at work. The data produced is quantitative and lends itself to statistical analyses. The interviews allow face-to-face interactions with a small number of employees, and they capture rich, qualitative data comprising digitalized concerns. These methods produce human-centric data, and future research should assess other objective inputs that supplement this perspective to provide a comprehensive digitalization status of an organization. The following suggestions represents potential data sources to add to the digitalization assessment.

- *Plant KPIs*. Having objective KPIs for the plant and processes is important because they provide points of comparison for the survey findings. For example, if a plant's performance is poor or completion rates for a certain activity are low, but the respondents rate high digitalization, then the disparity between these factors may change the overall perspective of how well digitalized processes are helping the station. KPIs are also important for gauging how a plant's digitalization status compares to other NPPs. If known, this perspective may influence satisfaction with digitalized quality of life at work.
- *Software deep dive*. The software that an NPP uses to perform its core functions may create restrictions for digitalization opportunities because of a poor user interface, the way data are captured, the way data are processed and evaluated once entered, and limits to reporting or downloading information. For example, in the current plant assessment, individuals created very capable macros and programs from old technology to bridge the gaps between two of the main programs that are needed to create and execute a work schedule. The survey tool currently assesses some but not all of these software considerations.

- *Benchmarking.* Continuous benchmarking with other utilities is important because comparisons can be made between the latest digital tools available and those currently used by the organization under evaluation. The process should be active and ongoing because digitalized innovations are continuously being implemented. Benchmarking also provides a point of reference for the researchers so that findings can be contextualized and standardized within a broader industry perspective. It also provides plant employees with the opportunity to understand their digitalization status next to the best possible options in the nation. It would be of benefit to the nuclear power industry if the LWRS digitalization research team could initiate and manage the benchmarking process, evaluate the digitalized status of all U.S. plants, and distribute results. This would provide information about what digitalized solutions are currently being used for major business processes, what key features make them effective, and any drawbacks.
- *Data review.* Reviewing the captured raw process data for completeness, accuracy, and quality is important when assessing an organization's digitalization status. This is because good-quality data are the bedrock of helpful and relevant insights generated from digitalization that can support good business decisions. The need for data review aligns with digitalization Guiding Principle 3, Establish Data Governance. The survey had two questions related to digital programs but did not specifically capture data quality. These questions are suggested for future work:
    - Do the data provided to you from the software facilitate the best decision-making?
    - Are the data necessary to perform this activity complete?
    - Are the data necessary to perform this activity accurate?
    - Are the data produced from this activity compatible with other data sources?
    - Can KPIs be easily created from the data? (The more steps it takes to "interpolate" the data or manipulate them, the more opportunity for error).
    - Do the data help ensure the highest level of regulatory compliance?
- *Process review*. It is important to periodically evaluate and take stock of the processes that drive data capture to look for outdated or outmoded ways the software and hardware are used (i.e., this is just the way it has always been done). For example, because of ancient regulatory interfaces, departments such as environmental and licensing endure constraints in how data can be reported to regulators. However, it is possible that format requirements have changed, been reduced, or even been lifted altogether, providing an opportunity to migrate to digital applications that best support business decisions. A process should be routinely reviewed for efficiency as a function of regulatory requirements, and this review should be factored into its digitalized status.

Beyond the possibility of increasing the number of data inputs to the digitalization assessment, future works in this research space will include adapting the tool to identify motivators and barriers to modernization more broadly, including AI adoption. There is currently much interest in growing AI technologies within the nuclear power industry, and its deployment within coming years is anticipated to be prolific. Great care must be taken to evaluate the ways the technology impacts not only the process outcomes, but the digital quality of life of the people using it, and other process changes up and down the organization, including those for senior leadership. This is necessary because within the industry AI solutions have been applied absent guiding principles for implementation, and they did not lead to better outcomes (Hall et al., 2024). Instead, it led to process disruptions and a loss of business intelligence that ultimately hurt the plant's bottom line. Importantly, the technology's impact must be assessed at implementation, three months and six months in, and even years later to gain a full understanding of its influence on a plant's digitalized processes. Further, unlike this year's effort that focused on one plant at one utility, future works will evaluate the assessment tool at the fleet level.

6. Conclusions

The goal of this year's research was to create an assessment tool that would provide a rapid, efficient, and effective digitalization status report of a plant's work processes. A survey tool was developed that is customized, inexpensive, and user-friendly. Best practices in survey development and deployment were rigorously applied, resulting in an excellent response rate (35%) representing 167 employee perspectives. The data collected was health indicators for a collection of work processes performed at the plant, including duration, effectiveness, and digital status. These data were used to identify optimal candidates for a potential digitalization initiative that yields the highest payback in terms of increased process efficiencies. These data can also be processed and analyzed by the plant's senior leadership according to their organizational priorities, business considerations, and desired end state. On-site interviews were conducted to validate the instrument's psychometric properties to the extent possible. Evidence supports good construct and external validity. With more applications, we can test the instrument's reliability.

The results are intended to provide a technical basis for where a digitalization effort can have the greatest impact in service of ION's strategic priorities. Having tools like this at ION's disposal will be invaluable to the process of supporting industry transformation. Using a data-driven approach to begin the ION journey embodies the principles of ION. Sharing the data and knowledge gained from the digitalization assessment across all organizational levels helps align visions and understandings across roles. This alignment helps plant employees to innovate which reflects the ION ethos.

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Appendix A
Processes identified during survey development

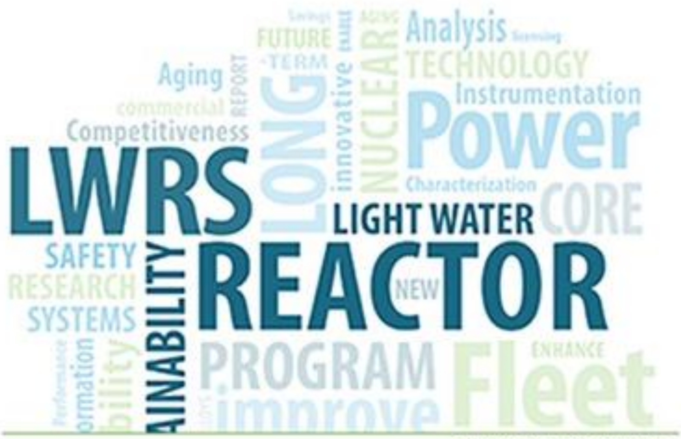
Main Processes	Subprocesses	N_{start}	N_{finish}
Accounting	Budget Management	17	16
CAP	Action Items Tracking	134	111
	CAP Operability Review	1	1
	CAP Program Administration	16	16
	External Operating Experience Use	56	53
	Investigation and Evaluation Process Administration	3	2
	OPEX Program Administration and Trending	1	1
	Reporting of Conditions, Equipment, Facility Issues	69	68
Contractor / Vendor	Vendor Audits and Assessments	2	2
Design Change	Modifications, Engineering Changes	15	15
Dose/Contamination	Dose Recording and Reporting	1	1
	Plant Rad Monitors	2	2
	Plant Radiological Surveys	3	3
	Rad Shipping	4	4
	Radiologically Protected Area Access	13	13
Emergency Preparedness	Remote Monitoring and Sampling	4	4
Inventory/Procurement	Ordering of Supplies/Materials/Parts	35	34
Maintenance Work	Measurement and Test Equipment	0	0
	Physical Plant Work	2	2
	Tool Checkout	1	1
	Work Package Closeout	0	0
	Work Package Creation	1	1
	Work Package Use	0	0
Master Equipment List	Equipment Failure Evaluation	6	5
	Plant Database Management and Security	4	4
	Plant/Component Health	5	5
	Surveillance Management	2	2
	Technical Specification Review	17	17
Personnel/HR	Employee Observation and Coaching	46	44
	Employee Timekeeping	23	22
	Job Briefings	15	14
	Plant and Department Meetings	21	21
Procedure	Procedure Use and Revision	90	87
Projects	Plant Projects Management	14	12
Security	Plant Access Processing	4	4
	Safeguards Information Administration	1	1
	Security Equipment and Zone Management	2	2
	Security Rounds	3	3
Tag Out	Clearance and Tagging	3	3
Training	Training and Qualification Verification	68	67

Work Management Schedule	Outage Schedule Use and Update	6	6
	Work Management Performance Indicators	5	5
	Work Schedule Use and Update	47	47
Department Specific	Confined Space	0	0
	Controlled Documents/Records Management	20	20
	Critical Digital Asset Administration	5	5
	Operator Rounds, Log Keeping, Turnover	2	2
	Plant Audits and Assessments	5	5
	Plant Drawings and References	21	20
	Regulatory Interface/Commitment Tracking	4	4
	Sampling and Monitoring	3	3

Appendix B
Presurvey announcement

4/24/2024

INL research helps identify nuclear efficiency gains



Idaho National Laboratory graphic

[redacted]

[redacted] is partnering with the Idaho National Laboratory (INL) on an important initiative to enhance the sustainability of the U.S. nuclear fleet.

As part of the Department of Energy's Light Water Reactor Sustainability Program, INL is conducting research on plant modernization to identify strategies that can enhance plant sustainability through digitalizing products or process.

[redacted] is one of the plants participating in the research. As part of our participation, we will receive access to industry survey results and innovative solutions identified by INL at no cost.

The project will unfold in two phases:

1. [redacted] will distribute an email survey from INL to select [redacted] and corporate employees the week of April 29. The survey will ensure proposed solutions are aligned with user needs and broader plant modernization objectives.
2. INL team members will be on site June 4-5 to collect more data through in-person interviews. The goal is to identify initiatives with the most significant potential to enhance process efficiencies.

The insights gained from these activities will inform a targeted digitalization plan, with success metrics to support a robust business case. [redacted] leadership will receive the final plan by Aug. 30.

This strategic initiative not only benefits [redacted] but also provides valuable insights to the wider industry, reinforcing the role of nuclear power in a sustainable energy future.

For questions, contact [redacted] or visit the INL website.

Appendix C
Survey email invitation

[redacted] is partnering with the Idaho National Laboratory (INL) on an important initiative to enhance the sustainability of the U.S. nuclear fleet as discussed in last week's [redacted] News article.

As part of the Department of Energy's Light Water Reactor Sustainability Program, INL is conducting research on plant modernization to identify strategies that can enhance long-term plant sustainability through digitalizing products or processes.

This survey is key to identifying the challenges that need to be addressed, and should take less than 10 minutes to complete!

Follow this link to the secure INL website to take the survey ->
https://inlhrfedramp.gov1.qualtrics.com/jfe/form/SV_0xFQM8hgpZLD7Rs
**** Please complete the survey by Friday, May 3rd. ****

The insights gained from these activities will inform a targeted digitalization plan, with success metrics, to support a robust business case. [redacted] will receive a copy of the final plan by Aug. 30.

We really appreciate your support of this effort!!

For questions, contact [redacted]

[redacted]