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Strategies to Control Costs at U.S. Commercial Nuclear Power Plants

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Abstract

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MBA, Strayer University (Jack Welch Management Institute), 2018

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Abstract

Commercial nuclear power plants in the United States are not cost competitive because of high operating and maintenance costs and historically low natural gas prices, resulting in the potential for premature plant closure of up to 25% of the operating power plants by 2025. Premature plant closure could impact the consumer through higher electricity rates, increased air pollution, and electric grid instability from increased renewable usage. Grounded in the behavioral decision theory, the purpose of this qualitative single case study was to explore successful strategies nuclear leaders used to control costs and ensure competitiveness. Data were collected through semistructured interviews with eight nuclear leaders in the Eastern United States, organizational business plans, change management plans, and innovation process documents. Data were analyzed using thematic analysis. Four themes emerged: management engagement is required to sustain long-term change that controls cost, leaders emphasize the use of technology that drives cost-effective solutions, leaders seek organizational cost initiatives that provide greater efficiencies and opportunities, and leaders must engage and empower the workforce to achieve business excellence. A key recommendation is for nuclear leaders to place the same level of emphasis on cost control strategies as they place on nuclear safety. The implications for positive social change include the potential for sustaining a viable noncarbon emitting energy source that mitigates the carbon impacts to climate change and does not emit air pollutants during operation.

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Section 1: Foundation of the Study

Background of the Problem

From the infancy of the U.S. commercial nuclear industry, predictions of the benefits and dire warnings of the pitfalls of nuclear energy have emerged (Malone et al., 2017; Sovacool et al., 2014). Malone et al. (2017) outlined a national narrative in the United States supporting the use of nuclear power and promoting the technology as a universal and inexpensive energy solution. However, Clemmer et al. (2018) suggested that nuclear power has not been cost effective and is challenged by high operating costs when compared to natural gas pricing. Overall, construction and operating costs in the U.S. nuclear industry have never reached a competitive advantage, threatening the long-term viability of the sector (Gilbert et al., 2017; Lang, 2017).

Nuclear industry detractors and some industry experts have long argued commercial nuclear industry costs are not competitive and environmentally sound alternatives exist (Kemfert et al., 2017). Rising operating costs, as compared to fossil fuel-based generation sources such as natural gas, results in noncompetitive electricity delivery from nuclear power plants (Energy Information Administration, 2018; Sokolski, 2010). Blumsack (2018) identified two U.S. nuclear power plants operating in an unregulated market and were marked for early closure because of a lack of competitiveness. Furthermore, nuclear industry supporters do not routinely consider the long-term environmental impact of nuclear waste, and the positive contribution of renewable energy sources (Suna & Resch, 2016). Thus, nuclear industry leaders must

understand the long-term industry cost drivers and implement effective cost-control strategies to mitigate potential noncompetitive practices.

Problem Statement

Closure of viable U.S. nuclear power plants may potentially raise customer costs and increase air, water, and carbon pollution affecting human health (Haratyk, 2017). U.S. nuclear power plant operating costs are not competitive, which could result in the premature closure of 25% of operating U.S. nuclear power reactors by 2025 (Energy Information Administration, 2018; Nuclear Energy Institute, 2018). The general business problem is nuclear power plants' operating costs are not competitive, which has caused the premature closure of operating nuclear reactors, resulting in lost revenue and increased capital expenditure for replacement generation sources. The specific business problem is some U.S. nuclear industry leaders do not have effective cost-control strategies to ensure competitiveness.

Purpose Statement

The purpose of this qualitative single case study was to explore the effective cost-control strategies U.S. nuclear industry leaders use to ensure competitiveness. The targeted population consisted of nuclear leaders and business professionals, working at different power plants within the same organization, at three nuclear power plant sites located in the eastern United States who have demonstrated successful cost-control strategies and are knowledgeable of industry business practices through long-term involvement in the U.S. commercial nuclear industry. The implications for positive social change include the continued supply of sustainable carbon-free base-load generation,

which mitigates the adverse effects of climate change and prevents air and water pollution from fossil-fueled energy sources.

Nature of the Study

I used the qualitative methodology for this study. Qualitative researchers seek to understand a phenomenon through personal interactions with knowledgeable contributors (Marshall & Rossman, 2011). I chose a qualitative method because of the need to interact with nuclear professionals who have demonstrated successful cost-control strategies and have experience with plant operations and budgeting. A quantitative researcher utilizes statistical data to test hypotheses about the characteristics or relationships of variables (Saunders et al., 2015). I rejected the quantitative method because using statistical data to test hypotheses about the characteristics or relationships of variables was not a goal of my study. Mixed-methods studies consist of qualitative and quantitative methodologies implemented through an analysis of statistical data (Yin, 2018). I rejected the use of a mixed-methods study, as extensive statistical data analysis was not appropriate for my study.

I used a single embedded case study design. In a case study design, the researcher asks what, how, and why questions and explores a phenomenon through multiple data types and sources (Baxter & Jack, 2008). The case study design was appropriate for my study because, through personal interaction and observations, I desired to understand the strategies nuclear professionals use to control costs. Moreover, per Yin (2018), the single embedded case study design was appropriate instead of a multiple case study design as

each power plant organization's staff operated to common procedures and work practices governed by a single overall organizational authority.

Phenomenological researchers strive to understand the personal meanings of events through the lived experiences of the research participants (Bliss, 2016). A phenomenological design was not appropriate for my study as my goal was to understand the strategies used for cost controls and not the personal meanings of the lived experiences of the participants. Ethnographic researchers immerse themselves in an organization's or group's culture to study the interactions among groups and the meanings of their actions (Palmer et al., 2018). Since I did not intend to immerse myself in the culture to study group interactions, the ethnographic design was not appropriate for my study.

Research Question

The central research question was: What strategies do nuclear leaders use to control costs and ensure competitiveness?

Interview Questions

1. What strategies do you use to control costs and ensure competitiveness in your organization's nuclear power plant(s)?
2. How do you use decision input and processes for cost control and competitive outcomes of your power plant(s)' costs?
3. What were the key barriers to implementing your organization's strategies for controlling costs to ensure competitiveness?

4. How did your organization address the key barriers to implementing its cost control strategies?
5. How, if at all, do you address potential cognitive biases when planning for cost control and competitive outcomes?
6. How, if at all, do you use information processing to make choices for cost control and competitive outcomes in your organization's nuclear power plant(s)?
7. What additional information can you add to help me understand the strategies your organization uses to control nuclear power plant costs to ensure competitiveness?

Conceptual Framework

I used behavioral decision theory (BDT) as the conceptual framework for this study. BDT accounts for riskless and risk-based decisions accounting for uncertainties in decision outcomes and the limited information available to the decision-maker (Simon, 1955). According to BDT, how an individual arrives at a decision is characterized by (a) decision inputs, (b) task characteristics, (c) choice framing, (d) decision processes, (e) decision strategies, (f) probability assessments, (g) cognitive processes, (h) cognitive biases, (i) judgmental heuristics, (j) data completeness, (k) individual differences, (l) information processing, and (m) decision support. Simon (1955) also considered the differences between a single static choice and a dynamic sequence of choices to determine an outcome, concluding the simplest choice was dynamic in nature, and acknowledging the complexity of decision-making. Through the BDT lens, I explored the

strategies nuclear industry leaders used to make complex decisions required for balancing the business aspect of utility operations with the nuclear safety requirements of the industry.

Davis-Sramek et al. (2018) applied the principles of BDT to understand the processes leaders used to make supply chain carrier selections. Davis-Sramek et al. concluded the individual preferences in the screening process resulted in varying decision strategies to select carriers. Davis-Sramek et al. added that individuals establish personal preferences through business and personal relationships and positional longevity. Fatke (2015) analyzed the influence of voter priming related to voter decisions, expanding the evidence of subconscious priming related to behavior. Fatke determined voting environments such as a church or school may affect the decision process. Moreover, Fatke concluded multiple-choice inputs, such as a two-party system, also influenced outcomes. The results of the studies by Davis-Sramek et al. and Fatke indicated the developed preferences and subconscious tendencies influence a leader's decisions, which could relate to the decision strategies U.S. nuclear industry leaders use relative to balancing cost-related decisions and the safety aspect of nuclear plant operations.

Operational Definitions

Capacity Factor: Capacity factor is actual output of a power plant compared to the theoretical output over a period of time, expressed as a percentage (U.S. Nuclear Regulatory Commission, 2020a).

Negative Learning: Negative learning is a phenomenon associated with nuclear technology implementation while experience increases with a construction process the cost rises instead of falls as is expected (Rangel & Leveque, 2015).

Assumptions, Limitations, and Delimitations

Assumptions

Research assumptions are truths considered as factual though not substantiated (Loring et al., 2016). My first assumption was cost controls for nuclear power plants were an essential factor for competitiveness. Secondly, I assumed that respondents were knowledgeable in the area of this research study and could effectively communicate their strategies. My final assumption was that participants were truthful in their responses.

Limitations

Limitations are potential weaknesses in the research, which could impact the results of the study (Dowling et al., 2018). The first limitation was the sample is from a single organization; thus, the research results may not apply to the broader nuclear community. Next, the use of interviews and archival documents to acquire data eliminated the use of potentially relevant information, which could have addressed the research question.

Delimitations

Delimitations establish the scope or the boundaries of the study (Yin, 2018). The first delimitation was the population in this study was limited to the management of a single organization whose leaders managed operating nuclear power plants in the eastern

United States. The final delimitation was the use of BDT as the conceptual framework lens to analyze the study data.

Significance of the Study

Contribution to Business Practice

The purpose of this study was to explore the strategies nuclear industry leaders use to ensure their plants' competitiveness. O'Brien (2018) posited that ineffective cost controls in the nuclear industry could lead to a lack of competitiveness, compared to other forms of energy production, forcing the premature closure of viable nuclear power plants. Averting premature plant closures should eliminate the need for replacement power sources, which increases the cost from unnecessary construction of fossil or renewable generation (Hong et al., 2018; Woo et al., 2018). Moreover, replacement fossil power generation sources are natural gas-based sources, which can expose the consumer to unpredictable electricity prices from the historically volatile natural gas market (Haratyk, 2017). Based on the results of this study, nuclear industry leaders might gain insights, which could lead to reduced costs and improved fiscal performance.

Nuclear leaders have historically implemented measures resulting in improved power plant operation, maintenance, and support activities (U.S. Nuclear Regulatory Commission, 2018a). However, identifying effective cost control strategies does not appear as an industry priority in metrics for assessing the health of a nuclear industry organization (Nuclear Energy Institute, 2017). Implementing effective cost-control strategies could allow nuclear leaders to mitigate noncompetitive plant operating costs.

Nuclear leaders who adopt a learning mentality and rigorously implement cost-savings measures could increase competitiveness.

Implications for Social Change

The implications for social change include providing leaders with effective strategies to manage power plant costs to maintain carbon-free power delivery sources in operation. Delivering power through noncarbon emitting sources may mitigate the effects of climate change (Morgan et al., 2018). Additionally, access to energy is vital for developing countries addressing quality of life concerns (Ali & Megento, 2017). Achieving reliable and sustained energy delivery requires diversified energy sources that supplement and then replace fossil fuels (Clemmer et al., 2018). Nuclear power is a noncarbon emitting energy source, which does not contribute to air and water pollution (De Blasio & Nephew, 2018). The use of nuclear power could mitigate the effects of climate change protecting the environment and improve human health.

Nuclear power plants are a nonpolluting source of energy (Massachusetts Institute of Technology, 2018; Mertz, 2018). Existing nuclear power plants may displace or reduce the need for fossil fuel-powered generation sources. Therefore, averting further nuclear power plant closures may prevent increases in air pollution from nitrogen- and sulfur-oxides and particulate compounds (Lang, 2017; Lombaard & Kleynhans, 2016). Reduction of air pollutants has a positive impact on public health, lowering the mortality rate of the affected population improving quality of life, especially for children (Lester, 2016; Perera, 2017). Controlling nuclear power plant costs may sustain the current

nuclear reactor fleet and increase the probability of plant new construction, benefitting society by maintaining a carbon-free power generating source.

A Review of the Professional and Academic Literature

Introduction

The purpose of this qualitative single case study was to explore the effective cost-control strategies U.S. nuclear industry leaders use to ensure competitiveness. Therefore, this literature review included an examination of nuclear industry cost factors and the historical source material necessary to address the research question. Moreover, the reference material also contained the information to substantiate the conceptual framework of the study. The results of the study may address the gaps in the literature associated with the strategies for effective cost controls in operating commercial nuclear power plants located within the United States. The primary sources of the research material included results from online search engines and databases, including Google Scholar, Microsoft Academic, ProQuest, Thoreau, Science Direct, Emerald Management, Sage, and EBSCOhost. I used peer-reviewed and nonpeer-reviewed journals, business textbooks, and government documents for information regarding the area of research. Keywords used to retrieve the search material included: *nuclear power cost escalation curse, economics of nuclear power, nuclear power plants, nuclear power reactors and cost overruns, prospects for nuclear power, nuclear power policy commitments, nuclear power deployment speed, cost of nuclear electricity, nuclear plants busbar costs, nuclear power construction costs, nuclear power reactors financial risk, cost-control strategies, cost-saving strategies, manufacturing industry, oil and gas industry, cost-competitiveness*

measures, *nuclear power plant waste*, *nuclear waste management*, *nuclear power plant O&M costs*, *nuclear power plant spent fuel*, and *nuclear spent fuel management*. The literature review contains information gathered from 100 sources, of which 70 (70%) were peer-reviewed and 69 (69%) were published between 2017 and 2021. The literature review also includes four seminal books (4%) and nine government publications or regulations (9%). The remaining literature consists of industry related trade and historical material, relevant to the research question, which provides background information on the U.S. nuclear industry.

The literature review contains a discussion of the conceptual framework, competing theories, literature related to the U.S. commercial nuclear industry, and literature related to cost controls in related industries. In addition to the material from U.S. sources, the nuclear industry material reviewed also includes data from other countries, such as South Korea, France, and the United Kingdom related to U.S. nuclear power plant operations, philosophies, and cost. The resource material from countries outside the United States was also required because of a lack of extant literature specific to cost-control strategies in the U.S. nuclear industry for normal operation and maintenance activities.

Behavioral Decision Theory

BDT, proposed by Simon (1955) and enhanced by Simon (1959), was the conceptual framework used to develop this study. BDT is a methodology a researcher may use to evaluate the uncertainties in decision outcomes (Simon, 1955). Simon proposed a rational decision maker, with the appropriate level of computing skills, should

make a rational choice based on the available data. The decision maker processes information based on an accurate definition of the problem and an understanding of their own personal preferences and individual biases (Stingl & Geraldi, 2017). Pandey and Jessica (2019) posited that a decision maker develops behavioral biases because of a lack of understanding of the process or decision consequences. Simon further asserted, although biases could exist, each decision maker is a rational being who approaches and processes decisions in a realistic manner with those decisions bounded by human computing skills.

Simon (1955) proposed that a decision maker might create mental processing shortcuts in their determining process based on personal experiences. Lau and Levy (1998) further described the shortcut process as the individual establishing rules that account for trade-offs in the final value assessment according to the goals of the outcome. However, Edwards (1954, 1961) posited that decision makers do not always exercise a reasonable approach to decisions as they do not properly assess conflict and in some cases do not maximize utility. Simon (1955, 1959) noted that an individual maximized utility in their decisions.

Simon (1955) postulated that decision-making theory may also apply to the organizational or group level. Jones (2017) proposed that public policy decision making is rooted in a collective or organizational process. Simon added an approximation fundamental to apply to the group decision-making dynamic. Jones summarized Simon's position and proposed macro or public policy decision making requires an understanding of human nature and interactions yielding a collective decision outcome. Approximation

is the concept that a decision outcome is good enough if the outcome meets the needs of the broader organization (Simon, 1955). Simon elaborated to accomplish the function of approximation, organizational decision makers must simplify the related assumptions because of the possibility of limited knowledge and abilities within the group. Simon (1959) expanded on the concept of group decisions and added that utility, from the theoretical perspective of the organization group, is to maximize profit. However, Simon (1959) emphasized that most group decision making, as a practical business objective, sought to establish an acceptable profit that met business goals.

BDT is divided into a normative and a descriptive model. The normative model is based on the need for a researcher to understand what a decision maker should do (Simon, 1959). Lau and Levy (1998) elaborated on the normative model, explaining that a researcher gathers as much data as practical and explores alternative actions, while evaluating self-preferences, which should reduce personal bias. The researcher then weighs the risks and gains to determine a conclusion that yields the best value of all possible outcomes related to the input factors (Lau & Levy, 1998). Budescu and Bo (2015) described weighing of risks and gains as the judgement of the decision maker, which a typical individual may not assess in the most effective manner. Jones (2017) added that individuals were mistake prone and subject to mistake repetition. Simon (1955) also proposed that a normative theorist relies upon the assumptions for the behavioral aspect of the decision maker is they act rationally and within the confines of a competitive economic environment.

The descriptive model of BDT is defined as the need of a researcher to understand how the decision maker acts, not to predict the outcome of their action. Simon (1959) proposed the descriptive theorist must address the mechanisms and processes to come to a full understanding of decision-making actions rather than theorized decision results. Roberts and Wernstedt (2019) observed that Simon's conclusions focused on decision mechanisms individuals can execute. The descriptive aspect of BDT provides the basis of the understanding in the normative model and would not be widely used as a stand-alone mechanism (Simon, 1959). Simon (1955) suggested the elements required to arrive at a decision outcome are characterized by (a) behavior alternatives, (b) behavior alternative subsets, (c) possible future state of affairs, (d) the pay-off, (e) information as to which outcome may occur, and (f) information as to the probability a particular outcome may ensue.

Behavior Alternatives

Behavior alternatives are the choices available to the decision maker. The decision maker determines the choices based on the information available or through an investigation of all possibilities (Simon, 1955). However, Simon (1955) posited the decision-maker's investigation could have physical and fiscal limitations, which prevents obtaining enough data to expand choice options and potential variants.

Behavior Alternatives Subsets

Behavior alternative subsets are choices within the larger choice the decision maker uses to enhance the decision scope. Simon (1955) summarized that subsets are the result of extended investigations into an individual choice, which may result in additional

available options for the decision point. Simon also posited the decision maker could limit the scope of decision options and proposed the available options are actual or perceived. Simon went further and proposed the decision maker initiates the expansions or detractions consciously or subconsciously as part of the decision process.

Possible Future State of Affairs

The possible future state of affairs are the potential results of the decision process. The decision maker determines the potential outcomes based on the available information and the expected utility obtained associated with the outcome (Simon, 1955). Edwards (1961) elaborated on this concept providing a decision maker chooses based on several options that culminate in a single choice, not a sequence of choices to a final decision. Edwards noted any predictive model was an approximation as any decision is a series of sequential choices rather than a static individual choice. In addition, Lau and Levy (1998) proposed that a decision maker evaluates the future state based on the context of the situation in conjunction with the utility and available information.

The Pay-off

The pay-off is the value the decision maker places on the outcome. Simon (1955) compared the decision process based on the outcome related to a maximum benefit and simply a benefit that met a certain positive threshold or the utility of the outcome. Utility is the desire to have the best possible result based on the input choices and the available information (Simon, 1955). However, Simon acknowledged the decision maker of a group in an organizational setting could choose based upon an outcome result that meets their needs, and not maximum utility (Simon, 1955). Simon posited that group decision

dynamics are both empirically and observationally logical. Edwards (1961) proposed the pay-off is objective or subjective based on whether the outcome is a physical measure or is satisfied through the measured utility of the individual or the group. However, Edwards noted a researcher may struggle to measure utility because of the subjective nature and a lack of agreement on how to perform the measurement.

The Information as to Which Outcome May Occur

The information as to which outcome may occur is the general data supporting the likelihood of one particular outcome over other potential outcomes (Simon, 1955). Simon (1955) added the determining factor is primarily based on the behavior alternatives, which lead to the potential outcomes. Lau and Levy (1998) proposed that time pressures could result in the decision maker limiting the data collection period, which could limit available data and possible outcome alternatives.

The Information as to Which Outcome May Ensue

The information as to which outcome may ensue is the detailed data set related to each behavior alternative (Simon, 1955). Simon (1955) elaborated that information is specific to the elements that make up each individual choice and subset. Weiss et al. (2010) termed this likelihood as subjective probability and added context for the decision was dependent on the circumstances at the time when the decision maker made the decision.

A researcher uses the aspects of BDT to explain the actions of an individual decision maker and for groups within organizations (Simon, 1955, 1959). Pandey and Jessica (2019) utilized the principles of BDT to analyze the behavior of investors in the

real estate market. Pandey and Jessica evaluated investor satisfaction based on rational decisions and the prospect the outcome was good enough to meet their needs. Davis-Sramek et al. (2018) utilized the descriptive function of BDT to understand the relationship between leaders in trucking companies and supply chain organizations. Davis-Sramek et al. found that trucking company managers primarily base their decisions on the economic impact to the business, which is consistent with the satisfactory utility decision aspect proposed by Simon (1955). Wood et al. (2019) sought to explain a business leaders' decision to change product direction if aspirations and results do not match. Wood et al. found that a leader introduces a pivot (i.e., change in process direction) in a new venture because the outcome is not well understood from the onset of the process, which is consistent with the probability a particular outcome may ensue tenet of Simon (1955).

I chose BDT as the conceptual framework for my doctoral study and applied the normative and descriptive model as I evaluated the research data. The combination of understanding how the decision-maker should act (normative model) and the mechanisms they use to arrive at their decisions (descriptive model) closely aligned with the need to understand the reasons behind actual decision results. Understanding the decision makers actual behavior and comparing actual behavior to predicted behavior was the purpose of this research and the approach I utilized to analyze the collected data.

Competing Theories

Expected Utility Theory

Expected utility theory (EUT), posited by Friedman and Savage (1948), established a risk-based decision model applying the concept of economic utility. Friedman and Savage described economic utility as a decision maker seeking to obtain the best outcome from the various inputs and possible outcomes presented. Friedman and Savage proposed to obtain the desired utility an individual is willing to accept risk in areas that could result in high gains and were more reluctant to accept similar risks when potentially exposed to a high loss. The assertion an individual could compromise and accept a marginal utility, that is a lesser outcome from a gain perspective, could potentially influence the risk-taker and their decisions (Friedman & Savage, 1948).

Friedman and Savage (1948) provided examples of the risk-reward aspect as it applied to individual decision making that balanced the need to prevent catastrophic losses through a minimal initial sacrifice such as an insurance premium. Friedman and Savage also submitted a monetary gain, such as the prospect of a windfall from a lottery, is offset by the minimal risk such as the cost of the ticket. In either case, the rational decision maker would choose an outcome based on maximum utility, or best possible outcome, at the least risk to the individual (Friedman & Savage, 1948).

Prospect Theory

Prospect theory (PT) posited by Kahneman and Tversky (1979) proposed an enhancement to EUT by Friedman and Savage (1948). Kahneman and Tversky advanced EUT by demonstrating individuals over-weighted probability assertions and the effects of

certainty and provided validation through statistical analysis. Kahneman and Tversky analyzed the three tenets of EUT (a) expectation, (b) asset integration, and (c) risk aversion to demonstrate human tendencies did not follow EUT predictions.

Kahneman and Tversky (1979) posited that a reflection effect and a certainty effect explained the inconsistencies in EUT outcomes. Kahneman and Tversky proposed a certainty effect, the influence of assurance in the outcome of a decision as opposed to a decision in favor of a low probability outcome, is contrary to the conclusions postulated by Friedman and Savage (1948). Kahneman and Tversky added a decision maker has the tendency to avoid risk when presented with an extreme negative outcome, which is consistent with the Friedman and Savage description of the decision makers desire to purchase insurance to avert loss.

Cumulative Prospect Theory

Cumulative prospect theory (CPT), proposed by Tversky and Kahneman (1992), is an enhancement of PT accounting for the cumulative effect of input choices related to a decision. Tversky and Kahneman (1992) proposed that a decision maker does not evaluate choices on an individual basis; however, the decision maker has the tendency to group several choices and make decisions based on the cumulative impact of those choices. A researcher uses CPT to assess the risk associated with making decisions that have multiple inputs with potential multiple outcomes including some outcomes that have extreme negative consequences (Tversky & Kahneman, 1992). Tversky and Kahneman also addressed an individual's behaviors related to loss aversion. An analysis by Glöckner and Betsch (2008) furthered the efforts by Tversky and Kahneman adding the

predictive nature of CPT surpassed probability heuristics (shortcuts) when the decision maker is presented with multiple decision inputs.

In addition to the cumulative nature of decision inputs, Suter et al. (2016) attempted to broaden CPT by proposing the concept of an affect-rich consequence. Affect-rich consequence is the explanation of the impact on decisions when the magnitude of gain or loss is extreme (Suter et al., 2016). Suter et al. also posited the consequences of a decision, especially when the results may be negative, has a greater impact on the decision process than a potentially large positive outcome. Suter et al. argued that consequences other than monetary gain or loss, such as those related to personal health, were more impactful when viewed from a negative aspect than a positive one. Häckel et al. (2017) also proposed that decisions could result in an extreme negative outcome were of greater concern to the decision maker than those of a positive outcome.

U.S. Commercial Nuclear Industry

Nuclear Industry Background

The U.S. commercial nuclear industry evolved through the expansion of the World War II Manhattan Project established to develop the first atomic bomb (De Blasio & Nephew, 2018). President Harry Truman proposed a peaceful use of atomic energy in a policy address in 1945 resulting in the Atomic Energy Act (AEA) of 1946 (Dalvesco, 2017; De Blasio & Nephew, 2018). President Dwight Eisenhower proposed additional policy considerations expanding the AEA, proposing U.S. leaders share nuclear technology with the remainder of the world, and establishing a vision of the delivery of clean and cheap electricity from nuclear improving human life and health (Dalvesco,

2017; Malone et al., 2017). To implement the U.S. domestic portion of Eisenhower's proposal, the administration established the Atomic Energy Commission (AEC), providing the initial oversight for the U.S. nuclear industry and the construction of the first commercial reactors (Malone et al., 2017; Riznic & Duffey, 2017).

As reactor development and deployment increased in the United States, dedicated oversight for commercial reactors began in the early 1970's with the creation of the U.S. Nuclear Regulatory Commission (NRC; Riznic & Duffey, 2017). The NRC assumed the duties of the AEC, inheriting the responsibilities for approving new reactor designs, licensing new construction reactors for operation, and providing general industry oversight (Riznic & Duffey, 2017). Wang et al. (2017) proposed that NRC efforts also included a focus on maintaining nuclear power plant safety as plants operated near the general public. However, increased NRC efforts to improve safety, even thru enforcement and fiscal sanctions, did not prevent the poor operational and maintenance practices and human performance errors that resulted in the 1979 accident at Three Mile Island (TMI; Riznic & Duffey, 2017). The NRC instituted the regulatory framework to correct the behaviors that resulted in the nuclear accident at TMI leading to the establishment of the Institute of Nuclear Power Operations (INPO; Riznic & Duffey, 2017).

Following the accident at TMI, the NRC and leaders in the nuclear industry sought to improve human performance by instituting a dedicated oversight body. To accomplish this function, leaders in the nuclear industry established INPO to add an industry-based oversight organization for nuclear operators to promote excellence in

nuclear industry operations and emergency preparedness (Riznic & Duffey, 2017). INPO leaders, initially derived from industry and academic experts, focused efforts on improving operator training through extensive monitoring of plant personnel, improvements to simulators and simulator training, and improved reactor operating procedures (Leslie, 2020; Perry, 1981). In addition, INPO leaders sought to improve emergency response actions and coordination efforts between government and nuclear utility operators to enhance public safety in the event of a future reactor accident (Perry, 1981; U.S. Nuclear Regulatory Commission, 2018b).

The efforts of INPO and NRC leaders, as result of TMI initiatives, in coordination with nuclear industry utility leaders resulted in improved operational performance and reactor plant availability (Knapp & Pevec, 2018). The improved performance was a result of industry leaders embracing the proposed emphasis on maintenance of safety related components over cost concerns, which enhanced the material condition of the operating fleet of nuclear power plants (O'Brien, 2018; U.S. Nuclear Regulatory Commission, 2018a). Moreover, O'Brien (2018) found that industry operators accepted the approach to excellence by emphasizing conservatism and minimizing high-risk behaviors in plant operations and maintenance activities.

The improvements in plant operating philosophies have resulted in industry capacity factor increases to an average of approximately 92% (Blumsack, 2018; Kessides, 2012). Having the nuclear unit more reliable by preventing unnecessary shutdowns and outage time improves cost and competitiveness. The initial postTMI

initiatives were successful strategies in some areas and resulted in cost-control improvements.

Reactor Designs

U.S. nuclear power plant designs fall into four basic categories: (a) demonstration reactors, (b) commercial reactors constructed prior to the TMI accident in 1979, (c) commercial reactors that completed construction following the TMI accident in 1979, and (d) next generation reactors (Lovering et al., 2016; Portugal-Pereira et al., 2018). Demonstration reactors are of low power design, less complex, and are not built to take advantage of the economies of scale, as they were not mass-produced (Portugal-Pereira et al., 2018). Lovering et al. (2016) described a demonstration reactor as a one of a kind, was not commercialized, and was primarily used as a test platform to serve in the advancement of nuclear science. Moreover, Lovering et al. (2017) went further and described demonstration reactors as those used for experimentation and testing and were not necessarily connected to the electrical grid. Within the demonstration category, gas-cooled reactors, breeder reactors, and liquid metal reactors make up the majority of these types and were developed by the government and private interests (Riznic & Duffey, 2017).

Commercial reactors constructed before and completed after the nuclear accident at TMI were of utility-scale and in most cases of high-power design with complex safety systems and constructed in enough numbers to achieve economies of scale (Lovering et al., 2016). Designs of the postTMI reactors, although similar, had additional safety systems and industry lead oversight when compared to earlier reactors (Portugal-Pereira

et al., 2018). In addition, preTMI reactors required backfitting to either improve existing safety systems or add additional safety features to improve plant response and aid the operator in the event of a nuclear accident (Riznic & Duffey, 2017). Further postTMI NRC efforts directed owners of preTMI power plants to perform additional inspections and provide retrofits of existing reactors to meet new and improved safety standards (Sovacool et al., 2014).

Following the TMI construction era, improved reactor designs have emerged with the promise of adaptability and streamlined construction. The new reactor designs include the Generation 3/3+, Generation 4, and the unique subset category of Small Modular Reactors (SMRs) (Kessides, 2012; Portugal-Pereira et al., 2018). The adoption of these new technologies and implementation of the new design power plants is in question (Riznic & Duffey, 2017). Huhtala and Remes (2017) identified only two new construction reactor licenses granted in the United States consisting of the Generation 3/3+ reactors with no expected timeframe for construction of any subsequent reactor designs. However, the NRC approved one new SMR design in 2020 (Office of Nuclear Energy, 2020a). A conglomerate, including the Flour company and the Utah Associated Municipal Power Systems (UAMPS), is investigating the feasibility of a new SMR project in the Idaho National Laboratory; however, they have yet to submit a construction application to the NRC (M. Ho et al., 2019; Utah Associated Municipal Power Systems, 2020).

Industry Cost Factors

Impacts to Construction Costs. The elements of nuclear power plant construction include the engineering design, environmental impact assessment, site preparation, plant assembly, initial plant testing, and regulatory factors, all of which have the potential to affect the time to complete the project (Portugal-Pereira et al., 2018). M. Ho et al. (2019) found that up to 80% of the lifetime cost of operating a commercial nuclear power plant is the result of the construction process. A presentation and assessment of the details of construction cost factors follow.

Engineering Design. Knapp and Pevec (2018) posited that engineering design contributes to cost increases in nuclear power plant construction. One factor is either the desire of the utility or pressure from the regulator to add innovative technologies or improve the safety design of the construction project (Knapp & Pevec, 2018). Design changes in-process causes rework of existing systems and may yield unintended consequences as system compatibility issues surface, increasing cost pressures (Kessides, 2012). In addition, construction delays from redesigns also idles the workforce increasing costs (Massachusetts Institute of Technology, 2018). Changes to safety systems might also increase regulatory scrutiny as the plant could deviate from the approved design and potentially lead to discovery situations, which could result in fiscal sanctions and rework of systems to meet regulatory standards (Kessides, 2012).

Lovering et al. (2016, 2017) identified that a lack of standardization of power plant design in the United States. As each power plant was arguably a custom build, including some plants constructed at the same site, utility leaders could not achieve

economies of scale and positive learnings from the previous construction project, which contributes to escalated costs (Matsuo & Nei, 2019). Overall, the results of U.S. reactor construction have shown to increase construction times for subsequent plants, including plants of the same design, indicating negative learning in the process, again increasing costs (Lang, 2017).

Gilbert et al. (2017) discussed that commercial power plant designs, even though seemingly complete at construction start, typically required changes beyond improvements or regulatory intervention. Although power plant leaders may anticipate a simple change, the timeline for regulatory approval and the engineering assessment to ensure conflicts do not exist may impact the construction schedule and introduce delays increasing cost (Kessides, 2012). Portugal-Pereira et al. (2018) proposed that a lack of completion of the plant design and poor engineering planning contributes to construction delays and results in increased costs. Massachusetts Institute of Technology (2018) proposed the design of the plant must be complete to support construction activities as the plant progresses, which limits preconstruction costs while waiting for a portion of the design that does not impact initial construction activities.

The nuclear industry was unable to achieve economies of scale, resulting in significant cost increases and construction cancellations (Gilbert et al., 2017). Loss of economies of scale in the United States was because of loss of workforce continuity, lack of design standardization, and increased regulatory presence (Lovering et al., 2016; Sovacool et al., 2014). Lovering et al. (2017) did note certain reactor designs did achieve economies of scale with the associated cost reductions, though Lovering et al. (2017)

noted a threshold does exist above which the utility could experience a long-term economic loss. Reactor sizes contributing to utility losses were above a power output threshold that were not right sized for the intended use, the intended service area, or the true needs of the utility (Lovering et al., 2017).

Lovering et al. (2016) proposed that although nuclear industry leaders did not achieve the promises of economies of scale and had instances of negative learnings during the construction process, industry leaders did not see escalated schedule extensions and increased costs beyond inflation. Portugal-Pereira et al. (2018), Gilbert et al. (2017), Lang (2017), and Knapp and Pevec (2018) found the U.S. nuclear industry did show an increase in schedule delays and increased cost. Gilbert et al. (2017) formally replied to Lovering et al. (2016) and provided arguments against the findings, to which Lovering et al. (2017) defended their original conclusions. I would submit that although the arguments of Lovering et al. (2016, 2017) are worth considering because of the information contained in their study, the arguments by Gilbert et al. (2017) and industry evidence from Massachusetts Institute of Technology (2018) demonstrate escalation of the overall cost of U.S. nuclear plant construction. Construction cost escalation is the primary concern in assessing the viability of any new nuclear project in the United States.

Environmental Impact and Site Preparation. Massachusetts Institute of Technology (2018) found that one factor affecting power plant construction cost was the work required to prepare the site for the construction project including the initial environmental permitting process. Challenges to permitting a commercial nuclear power plant increases construction risk, potentially increasing cost because of delays awaiting

decision results (M. Kim et al., 2017) Moreover, M. Kim et al. (2017) found that risk is country specific and most heavily weighted in environmental, public opinion, and political factors.

An analysis by Hong et al. (2018) indicated the impact to the environment from a commercial nuclear power plant was not as significant as the impact from fossil fuel energy sources, including potential pollutants entering the air and water. Huhtala and Remes (2017) found that public perception of the risks and rewards of nuclear power when referenced to environment issues were the least of all nuclear power plant concerns, including handling of nuclear waste. However, Vainio et al. (2017) found that public perception of the potential impact from long-term nuclear plant operations was environmentally detrimental and outweighed the mitigating benefits of nuclear power over climate change.

Plant Assembly. Plant assembly is the process of taking the individual commodities (piping, electrical, concrete) and connecting them together to form the basic power plant and support systems. A skilled and effective workforce is key to executing the process, which maintains the construction schedule and prevents delays (Markard et al., 2020). Appropriate work force training, planning, and supervisory oversight provide the elements for successful construction implementation, which prevents unnecessary rework that increases cost (Massachusetts Institute of Technology, 2018). Moreover, minimizing delays through task preparation and effective process management techniques are integral parts of the construction process (Lovering et al., 2016). Massachusetts Institute of Technology (2018) identified the lack of proper planning

practices, work execution, and supervisory oversight as the key points of failure of construction projects in the United States.

The daily process execution by the workforce determines project productivity, which could have a negative impact to schedule leading to delays and cost escalation (Gilbert et al., 2017). Sovacool et al. (2014) proposed that cost overruns during plant construction are a result of project delays. The failure to control schedule is the most critical aspect of the long-term cost to build and ultimately to operate U.S. commercial nuclear power plants (Sovacool et al., 2014). Koomey et al. (2017) found that U.S. nuclear plant construction delays resulted in significant project cost increases in all eras. In addition, Freedman and Perry (2010) found that improper construction techniques and installations resulted in substantial cost overruns and project delays for new build projects.

Initial Plant Testing. The NRC requires all licensed plants undergo an extensive testing regimen or a detailed analysis of each safety aspect to ensure proper plant construction and safety system operation (U.S. Nuclear Regulatory Commission, 2020). The testing of plant components is required to validate the operational status of the plant; however, Riznic and Duffey (2017) outlined the safety systems that are not required and installed on fossil-fueled power plants add to the total cost of construction for nuclear power plants. A regulatory entity does not exist to ensure a fossil-powered plant is built to specification; therefore, a nuclear power plant has a significant long-term disadvantage from a construction duration perspective based on regulatory presence and the associated technical inspections and testing (Portugal-Pereira et al., 2018).

Regulatory Factors. The regulatory presence at a U.S. commercial nuclear power plant has cost factors that are not present in fossil fuel generation sources (Batkins, 2016). Lombaard and Kleynhans (2016) shared that nuclear industry experts see over-regulation as an area of concern for the industry, and in some cases limits power production and places upward pressure on costs. Kessides (2012) found the time for the regulator to review the process leading up to construction approval increased by a factor of four from the 1960's to the 1980's impacting up-front costs. Massachusetts Institute of Technology (2018) proposed that flexibility in the regulatory approval process for minor plant changes could result in cost savings by preventing impact on a plant construction schedule.

The TMI accident prompted additional oversight by the NRC through an increased presence of inspectors and intervention in daily reactor construction operations (Sovacool et al., 2014). In addition, the NRC imposed additional inspection activities and a review of safety features not previously required in the plant design (Sovacool et al., 2014). Construction and operating costs and safety concerns threaten the longevity of the existing fleet of U.S. reactors and limits viable construction options (Clemmer et al., 2018).

Operating Costs. The elements of nuclear plant operating costs include permanent plant staffing, routine and corrective maintenance, the security force, and the reactor fuel. The four factors contribute up to 20% of the total lifetime cost of a commercial nuclear power plant (M. Ho et al., 2019). Plant Operations and Maintenance costs (staffing, maintenance activities, and security functions) account for 66% of total

costs, and reactor fuel accounts for 34% of the total costs to operate the plant on an annual basis (World Nuclear Association, 2017). Although a large amount of data exists on the breakdown of nuclear power plant costs, other than initiatives such as Delivering the Nuclear Promise (DNP), the extant literature is limited regarding the measures to control or actually reduce costs.

DNP is a Nuclear Energy Institute (NEI) initiative, executed by commercial nuclear industry leaders, to evaluate areas of commercial nuclear operations and determine the availability of cost-cutting measures (Nuclear Energy Institute, 2020). NEI leaders found potential areas of savings and divided those into areas of mandatory and voluntary implementation based on the needs of the utility and technical evaluations of the NEI membership (Nuclear Energy Institute, 2020a). NEI leaders estimate the commercial nuclear industry has saved approximately $1.6 Billion in operating costs and $130 Million in NRC licensing fees since program inception in 2014 (Nuclear Energy Institute, 2020b). An outline of the areas associated with industry operating costs continue in the following paragraphs.

Staffing. Unlike fossil-fueled power plants, the nuclear industry has specific staffing levels required by the NRC to ensure a minimum number of qualified personnel in the case of an emergency situation (U.S. Nuclear Regulatory Commission, 1980). In addition, nuclear power plant personnel have specific restrictions that limit the number of hours a person may work in a given time period (U.S. Nuclear Regulatory Commission, 2009). Nuclear power plant personnel must also undergo extensive checks to ensure they are mentally and physically fit to work in a commercial power plant (U.S. Nuclear

Regulatory Commission, 2008). The final element is a more stringent training regimen when compared to other forms of power generation, including extensive initial training programs that could take up to two years for a senior operator and bi-annual requalification programs that operate continuously over the career of each operator (U.S. Nuclear Regulatory Commission, 2018a). The limited amount of time personnel can work combined with additional training time increases the number of employees to train and operate the plant and manage the programs that govern the regulatory requirements, which can increase operating costs (Office of Nuclear Energy, 2020). In the case of operations personnel, Clemmer et al. (2018) found that fixed operating costs, which includes staffing, is a key factor resulting in unprofitability for some operating U.S. nuclear power plants.

Maintenance. Surveillance testing and corrective maintenance activities of an operating nuclear power plant comprise about 80% of the workforce effort on a routine basis (Al Rashdan & St. Germain, 2019). In addition to routine maintenance, increased costs to purchase and maintain additional safety equipment to comply with NRC directives following the Fukushima accident has added to the cost struggles of some U.S. nuclear power plants (Greco & Yamamoto, 2019). However, efforts by leaders at the NEI, through DNP, have resulted in improvements in maintenance practices providing industry cost savings (Nuclear Energy Institute, 2020).

Security. Nuclear power plant security consists of an armed force that protects the nuclear power plant from an adversarial threat (Krane et al., 2016). The security force is in addition to the plant operating and maintenance staff and are generally contract

personnel, trained by utility employees (Batkins, 2016). Batkins (2016) and Massachusetts Institute of Technology (2018) provided that security costs, included the escalated costs following the terrorist attacks on 9/11/2001, pose a significant financial burden on operating nuclear power plants when compared to the requirements placed on fossil power plants. The costs include pay and benefits of the workforce, the training time and materials, the cost of NRC inspections, and the management and oversight for the utility (Batkins, 2016). Security related costs add approximately $8.6 million annually to the budget of each operating nuclear power plant, a cost that is not incurred by similar fossil or renewable fuel powered facilities (Batkins, 2016).

Fuel. The fuel used in today's commercial reactors is primarily Uranium, specifically Uranium 235, which makes up 0.7% of naturally occurring Uranium (Energy Information Administration, 2020). Natural Uranium is an abundant element that has a favorable power density when compared to fossil fuel and renewable energy sources (Energy Information Administration, 2020). The energy produced in one pencil eraser sized fuel pellet of uranium being equivalent to one ton of coal or 17,000 cubic feet of natural gas (Nuclear Energy Institute, 2020c). Moreover, to produce the equivalent amount of energy as an operating nuclear power plant an equivalent photo-voltaic solar system would occupy up to 1000 times the land mass and an equivalent wind farm could occupy up to 8000 times the land mass (McCombie & Jefferson, 2016). However, naturally occurring Uranium is unsuitable for use in a commercial light-water reactor, requiring processing to use as a viable fuel source.

Nuclear fuel for light water reactors is primarily made up of low-enriched Uranium (LEU), which is a concentration of between 3 and 5% Uranium 235 (Energy Information Administration, 2020). The nuclear fuel process consists of the mining of natural Uranium, conversion of natural uranium into a gas, enriching the natural Uranium as required for utility needs, and finally fabricating the enriched Uranium into a structural element that is loaded into the reactor (Energy Information Administration, 2020). Following mining, the natural Uranium is separated from other materials and sent for conversion. Conversion is the chemical process of changing the natural Uranium from a solid into Uranium-Hexafluoride gas. The Uranium-Hexafluoride gas allows for the use of centrifuges to concentrate (enrich) the Uranium 235 to the required level for a commercial reactor. The final part of the enrichment process consists of conversion of the Uranium-Hexafluoride gas back into solid form for fabrication. The fabrication process involves forming the enriched Uranium into pellets and inserting the pellets into tubes, which forms the fuel rod. The final step is includes arranging the fuel rods into a 17 by 17 matrix forming the fuel assembly. Each assembly is then structurally and mechanically bound together to form a rigid structure that is inserted into the reactor (Energy Information Administration, 2020).

Most U.S. commercial reactors operate on an 18- or 24-month refuel cycle (Office of Nuclear Energy, 2020b). The reactor is taken offline and shut down for maintenance and refueling at the end of the operating period. The refueling portion of the shutdown entails replacing one-third of the existing fuel with new fuel. Once reactor maintenance and refueling is complete, the operating staff places the plant back online and the plant

should remain in operation for an 18- to 24-month cycle resulting in an industry average capacity factor of approximately 92% (Blumsack, 2018; Kessides, 2012).

The efforts to control costs and the associated strategies, other than DNP implemented through the NEI, are primarily a utility-by-utility endeavor that have very little documentation. Utility leaders maintain cost and cost measures as proprietary information and are reluctant to share sensitive data. The objective of this doctoral study was to seek out those effective strategies and add to the public discourse.

Industry Cost Impact

The total cost of nuclear plant construction and operation places nuclear power plants at a cost disadvantage when compared to other power sources such as natural gas (Blumsack, 2018; Gattie et al., 2018). The impact on nuclear plant survivability based on competitiveness is more pronounced in deregulated markets (Blumsack, 2018; Haratyk, 2017; Kemfert et al., 2017). Moreover, Kemfert et al. (2017) proposed that in the world history of nuclear power no plant has achieved competitiveness without government or public subsidies, indicating a nuclear power plants true noncompetitive nature. Lovins (2017) also noted that government subsidies support noncompetitive nuclear power plants at the expense of other energy sources. Barkatullah and Ahmad (2017) proposed that future cost control measures may not be sufficient to ensure nuclear industry competitiveness without direct government intervention or subsidies.

Nuclear Industry Leadership and Culture

Leadership standards in the U.S. commercial nuclear industry derive from established regulatory requirements, the guiding philosophies proposed by INPO, and the

global perspective proposed by the World Association of Nuclear Operators (WANO). NRC initiatives are required via regulation and enforced through on-site inspectors and periodic reviews by regional and national inspection teams (Barbour & Gill, 2017). INPO and WANO initiatives are not regulatory-enforced requirements but are voluntarily accepted performance measures by the nuclear industry that enhance the regulatory requirements and are in place to improve plant operations in order to achieve operational and fiscal excellence (Hudson et al., 2012).

Nuclear Regulatory Commission Requirements. The policies of the NRC establish the initial level of principles followed by leaders of nuclear utilities. The NRC emphasizes any leadership attribute that provides for a culture of safety, which ensures protection of plant personnel and the general public (U.S. Nuclear Regulatory Commission, 2014). To achieve a safety culture within the organization, the NRC places an emphasis on improved plant performance through the evaluation of risk-based decision making by plant operators, minimizing of plant trips, and reduction in significant events at plant sites (U.S. Nuclear Regulatory Commission, 2018). The NRC places a senior resident and, in most cases, an additional resident inspector at each plant site to enforce safety standards through monitoring plant operations (Barbour & Gill, 2017; U.S. Nuclear Regulatory Commission, 2018). The primary mission of the NRC inspectors at each site is to ensure the reduction in plant events and understanding the risk of day-to-day processes to ensure the protection of public health and safety, which is translated to utility leadership philosophies (Barbour & Gill, 2017).

Institute of Nuclear Power Operations Measures. Establishing and implementing leadership standards beyond the regulatory requirements of the NRC is the function of INPO in the United States (Burchill, 2019; Perry, 1981). Following the accident at TMI, the presidential commission found that utility leaders emphasized cost control measures and sacrificed some aspects of plant safety to accomplish the goal (The President's Commission on the Accident at TMI, 1979). INPO leaders directed efforts refocusing nuclear industry leaders and utility executives to provide for excellence in power plant operations and to ensure future industry leaders remain focused on the nuclear safety aspect of plant operations (Hansen, 2008). Focus on nuclear safety ensures public safety is of primary concern for plant operators, contrary to the attitudes shared by the industry prior to the accident at TMI (Mertz, 2018).

World Association of Nuclear Operators Initiatives. INPO philosophies and standards transferred globally when WANO formed in 1989 following the Chernobyl nuclear accident (Horan, 1989; Hudson et al., 2012). Simončič (2019) provided that WANO responsibilities mirrored those of INPO, specifically the philosophies of operator excellence, safety as the overriding factor over cost, and the need to ensure substantive emergency response measures. However, INPO maintains primary jurisdiction for matters inside the United States, with WANO acting as a partner for inspections and assessments (Institute of Nuclear Power Operations, 2020; World Association of Nuclear Operators, 2020).

The regulatory impact from an NRC, INPO, and WANO perspective are relevant to my study. Utility leaders must account for the regulatory evolution of the industry and

the burden the additional bureaucracy creates from a cost perspective. The on-site presence of the NRC and the associated cost coupled with the assessments and peer-reviews of INPO and WANO all add to the operating cost of the plant, which are ultimately transferred to the consumer.

Nuclear Energy Benefits and Concerns

Jenkins et al. (2020) posited the benefits of nuclear power outweigh the cost, requiring actions to limit the environmental impact of the energy source. The benefits of nuclear power include limiting of air and water pollution, carbon dioxide reduction, and minimal waste when compared to fossil fuel generation sources such as coal (Ford et al., 2017; S. S. Ho et al., 2019; K. Kim, 2019). The environmental and fiscal concerns are used to substantiate an argument against nuclear power include long-term waste disposal, substantial upfront costs, and local contamination at or near the plant site (S. S. Ho et al., 2019).

Environmental benefits of nuclear power include reduced carbon emissions as compared to fossil fuel power plants (S. S. Ho et al., 2019). Operating nuclear power plants provide approximately 20% of the total electrical power and 60% of the carbon-free electrical power in the United States (Murphy & Berkman, 2017). Displacing electricity generation from fossil fuel sources reduces the impact of climate change because of the overall reduction in carbon emissions (Barron & Hill, 2019; Sadekin et al., 2019). Moreover, nuclear power plants do not emit atmospheric or water pollutants such as nitrogen- and sulfur-oxides, particulate matter, or heavy metals such as mercury,

which have been shown to have a detrimental impact on human health especially in impoverished nations and children (S. S. Ho et al., 2019; Perera, 2017).

The primary environmental concern regarding the use of nuclear power in the United States is the inability of the federal government to determine an acceptable high-level waste disposal method to manage spent nuclear fuel (Von Roten et al., 2017). S. S. Ho et al. (2019) discussed the concerns over radioactive waste also contribute to rejecting nuclear power as an energy source. However, Lombaard and Kleynhans (2016) noted the risk associated with the environmental impact of waste is outweighed by the positive benefits of nuclear power. In addition, other concerns such as water use in the generation cycle, potential contamination of groundwater from tritium, and other industrial factors add to the environmental concerns and provide a negative assessment towards nuclear power as an energy solution (Lombaard & Kleynhans, 2016).

S. S. Ho et al. (2019) identified upfront costs, government experience, and public trust and acceptance as potential shortfalls to establishing and potentially maintaining a nuclear presence. The risks associated with high construction costs and the potential for nuclear accidents have resulted in public reservations for nuclear plant expansion and in some cases demands for premature plant closure (S. S. Ho et al., 2019). The citizens of countries that rely on nuclear power and the benefits nuclear power brings to society are demanding that viable power plants close to prevent future crises (Roth & Jaramillo, 2017). Additionally, the citizens of countries that could benefit from clean energy provided by nuclear power and the positive economic impact from construction and

operations are rejecting nuclear power because of a lack of confidence in their government's ability to regulate the industry (S. S. Ho et al., 2019).

The long-term management of nuclear waste and spent nuclear fuel is an additional area of concern in the United States. The U.S. Congress passed legislation in 1982 assigning management responsibility of spent nuclear fuel to the Department of Energy (DoE) (Jenkins et al., 2020). The legislative action required the DoE to identify and implement a geological repository to accept spent nuclear fuel and other nuclear wastes (U.S. Environmental Protection Agency, 1982). Jenkins et al. (2020) proposed that a lack of a long-term storage facility in the United States makes the commercial nuclear industry vulnerable to the effects of climate change in some parts of the country.

An additional factor affecting the acceptance of nuclear power is the public's perception of the risk associated with nuclear plant operations and deployments when compared to the actual risks. Abdulla et al. (2019) found that public tendencies leaned towards reduced nuclear power presence because the risk exceeded the reward. H. J. Kim and Song (2018) found that public trust in nuclear power waned even when industry and government officials implemented education programs in South Korea. Lorenz et al. (2016) found that risk made nuclear power less desirable from a public perspective and the higher operating risk resulted in increased costs when compared to other power sources. Increased operational risk and negative public perception could force viable power plant closures and hamper future construction efforts.

Summary

Leaders in the U.S. commercial nuclear industry seek excellence in all aspects of operations and maintenance (Hudson et al., 2012; Institute of Nuclear Power Operations, 2020). To achieve equal financial success, as compared to operational success, the NEI outlined and industry leaders implemented the DNP initiative to uncover cost reductions to improve competitiveness (Nuclear Energy Institute, 2020). Nuclear Energy Institute (2020b) shows DNP initiatives have led to industry cost savings; however, the extant literature does not address the efforts of utility leaders within a particular company to control costs outside of DNP efforts. The focus of this doctoral research study was to attempt to ascertain and understand the effective strategies utilized by industry leaders to achieve competitiveness.

Transition

In Section 1, I provided the arguments to support a case study on effective cost control strategies for U.S. nuclear power plants and provided the analysis methods I used to address the research question. Through a review of the professional and academic literature, I outlined the use of both the descriptive and normative models of behavioral decision theory as the conceptual framework for the study and identified expected utility theory, prospect theory, and cumulative prospect theory as competing theories. I also included a review and analysis of nuclear industry literature that began with a history of the industry, reactor design comparisons, industry construction costs, regulatory impacts to plant operations (NRC, INPO, and WANO), plant operating costs, and the guiding principles of nuclear industry and utility leaders. Section 2 includes further elaboration on

the chosen qualitative research method, the single case study design, and the manner in which I protected the rights of the individual. Additionally, I included the methodology to establish the population of the study, a detailed description of the data collection, organization, and analysis methods, and the safeguards put in place to ensure the reliability and validity of the results of the study.

Section 2: The Project

Section 2 serves as an expansion of the chosen qualitative research method and the single case study design. In this section, I also outline the role of the researcher, the qualifications of the research participants, and provisions required to protect the anonymity of the research participants. Section 2 also includes details of ethical research considerations, data collection methods, and data analysis and organization process. I concluded this section with the details on the methods for achieving validity and reliability.

Purpose Statement

The purpose of this qualitative single case study was to explore the effective cost-control strategies nuclear leaders used to ensure competitiveness. The targeted population consisted of nuclear leaders and business professionals at nuclear power plants located in the Eastern United States who were knowledgeable of industry business practices through long-term involvement in the U.S. commercial nuclear industry. The implications for positive social change include the continued supply of sustainable carbon-free base-load generation that mitigates the negative effects of climate change and prevents air and water pollution from fossil-fueled energy sources.

Role of the Researcher

I was the primary research and data collection instrument for this qualitative case study. According to Clark and Vealé (2018), the researcher is the primary data collection instrument for qualitative research. In qualitative case studies, the researcher immerses themselves in data collection and analysis (Stewart, 2016; Yin, 2018). Thus, I collected

all data associated with this qualitative case study through semistructured interviews and a review of archival documents.

I am a 31-year veteran of the nuclear power industrial complex, including 24 years in the U.S. Navy nuclear power program and 7 years in the U.S. commercial nuclear industry. I am currently the representative for a nuclear power plant joint owner at a U.S. commercial nuclear power plant where I have the responsibilities of (a) managing finances, (b) providing operational feedback, and (c) interfacing with regulatory authorities. My expertise and experience in the nuclear field allowed me to establish a level of credibility, which resulted in an increased willingness for open sharing of information from the participants. I did not have a personal or professional relationship with any of the participants in my study and did not include any potential participant from the facility where I am employed.

The *Belmont Report* includes the standards of respect, beneficence, and justice to which all researchers must adhere (U.S. Department of Health & Human Services, 1979). The researcher safeguards respect for the individual by ensuring their on-going informed consent during the research process (Anabo et al., 2019). Beneficence is the philosophy that a researcher will not perform an action resulting in harm to the participant (Anabo et al., 2019). Anabo et al. (2019) described justice as a fair burden and reward distributed to the research participants. Researchers must utilize the *Belmont Report* principles to assure adherence to ethical practices (Brothers et al., 2019). I adhered to the *Belmont Report's* ethical practices and protected the research participants using the protocols outlined in this study.

I was the primary data collection instrument with a professional connection to the commercial nuclear industry; therefore, I had to address potential personal biases. Personal biases may reduce the validity and reliability of the results of qualitative research (Mohajan, 2017). Avoiding personal interactions leading the participant to a preconceived outcome reduces potential avenues of researcher bias (Saunders et al., 2015). To mitigate potential bias, I used an interview protocol (see Appendix) through which I took a scripted approach to each interview that minimized my personal interjections. Moreover, I analyzed all information through an open-minded approach to new information that contradicted my viewpoint.

Castillo-Montoya (2016) posited that a reliable interview protocol enhances the quality of the data obtained in interviews. Furthermore, Saunders et al. (2015) outlined the need for the researcher to establish an interview guide that will help ensure the interview has purpose and direction. A researcher utilizes an interview protocol to maintain consistency in data collection between multiple participants (Skillman et al., 2019). I used an interview protocol (see Appendix) that ensured my interview process remained aligned with the research purpose, which maintained consistency in data collection.

Participants

The population consisted of eight leaders who had operational experience in nuclear power plants in the eastern United States and who (a) possessed at least 15 years of commercial nuclear industry experience, (b) had at least 5 years of experience associated with budget and spending decisions, and (c) made routine spending decisions

to control costs within budgeted constraints. I obtained access to participants who met the selection criteria through consultation with the human resources (HR) department of the target organization. An HR authorized representative identified and provided email contact information for all potential participants who met the selection criteria. I used the contact information to solicit participation by providing them with (a) an outline of the study, (b) the selection criteria, and (c) instructions to contact me directly if they were interested in participating and met the selection criteria.

Pinnegar and Quiles-Fernández (2018) proposed that a relationship between the scholar and the participant is a fundamental part of the research process. A working relationship helps to build trust and may lead to a more robust discussion and disclosure of information (Saunders et al., 2015). Furthermore, professional similarities between the researcher and the participant may result in a more open and honest disclosure of information during the interview (Harvey, 2017). As I am involved with U.S. nuclear industry operations, I have experience in operational and business decision-making that may translate into an initial level of trust and robust discussions between myself and the participant. I established a researcher-participant relationship by beginning with an open and honest disclosure of all the processes of the study beginning with the initial introductions and concluding with the actual interviews.

Research Method and Design

Research Method

Researchers use qualitative, quantitative, and mixed methods to study phenomena (Saunders et al., 2015). A qualitative method allows the researcher to understand the

meaning of a process within a specific context (Barnham, 2015). A qualitative researcher also uses multiple data sources to understand and explain a phenomenon within context (Mohajan, 2018). Additionally, a qualitative methodology allows a researcher to explore multiple perspectives affecting a similar challenge (Manhas & Oberle, 2015). The qualitative method was most appropriate for this study as I utilized multiple data sources to understand the strategies nuclear leaders use to control costs.

Quantitative researchers test a theory or a hypothesis using numerical or statistical data (Saunders et al., 2015). In quantitative research, a scholar uses specific preplanned data to test a preconceived hypothesis (McCusker & Gunaydin, 2015). Moreover, quantitative researchers seek to explain a phenomenon and prove a hypothesis through a statistical relationship between variables (Barnham, 2015). Thus, a quantitative method was not appropriate for my study because neither testing a hypothesis or an analysis using multiple variables was necessary to address the research question.

Mixed-methods researchers integrate the aspects of qualitative and quantitative research into a single study to provide a richer understanding of a phenomenon (Saunders et al., 2015). Maxwell (2016) posited that mixed-methods research includes the statistical analysis of numerical data coupled with observations to fully explain events. However, Sahin and Öztürk (2019) concluded mixed methods are only required if a single methodology cannot address the research question. Thus, a mixed method was not appropriate for my study because a statistical analysis of numerical data was not necessary to address the research question.

Research Design

I chose a single case study design for this research. Researchers use a case study design to understand a phenomenon within a specific context (Guetterman & Fetters, 2018). Yin (2018) suggested that a case study design is appropriate when a researcher desires to gather information regarding an on-going process. A case study design was most appropriate for this study because I desired to understand the meanings of the decisions governing cost-control strategies within a nuclear operating context.

A researcher uses an ethnographic design to understand the complexities of an open-ended event through direct observation of the community (Palmer et al., 2018). Moreover, Eisenhart (2017) posited that an ethnographic researcher immerses themselves in the culture through extensive face to face observations of the participants in a study. I rejected an ethnographic design for this doctoral study because an understanding of the cultural aspect of individuals through extensive observation was not required to address the research question.

Scholars use a phenomenological design to understand an individual's perception of a lived experience (Noon & Hallam, 2018). The researcher may use a phenomenological design to understand the philosophical aspect and meaning of a specific incident (Mohajan, 2018). Moreover, the phenomenological design allows the researcher to explore the differences between the interpretation of individual experiences and a group perspective (Saunders et al., 2015). I rejected the phenomenological design for this study because an understanding of the lived experiences of the participants was not required to address the research question.

Data saturation is the point in the data collection process when the scholar does not gain new information (Moser & Korstjens, 2018). According to Lowe et al. (2018), a researcher achieves data saturation when data collection does not reveal any new themes and supports the conclusions of the researcher. Furthermore, Yin (2018) suggested that obtaining data from multiple sources increases the depth of a qualitative study and helps the researcher to establish evidence to support the study's conclusions. I achieved data saturation through eight semistructured interviews as no new responses or themes emerged and I used data triangulation techniques, through the use of the current nuclear business plan, change management plan, and improvement strategy documents, which validated the interview responses.

Population and Sampling

A population is made up of individuals who have the knowledge that allows a researcher to address the research question (Malterud et al., 2016). The population for this study consisted of leaders in the U.S. commercial nuclear industry in the Eastern United States who (a) possessed at least 15 years of commercial nuclear industry experience, (b) had at least 5 years of experience associated with budget and spending decisions, and (c) who made routine spending decisions to control costs within budgeted constraints.

Onwuegbuzie and Collins (2017) emphasized a researcher must ensure the sampling method provides participants who can address the research question. I chose the purposeful sampling technique for this doctoral study. Purposeful sampling allows the researcher to select participants based on their knowledge and skills related to the subject

under exploration (Demirok et al., 2019; Wilson, 2016). Moreover, a researcher uses purposeful sampling to identify subject matter experts (Falk et al., 2016). I utilized the purposeful sampling technique for this doctoral study, which allowed the specific selection of experts within the nuclear field.

Yin (2018) posited that a researcher should have a sample size sufficient to address the research design within a given context and to allow replication of the results of the study. Furthermore, Moser and Korstjens (2018) proposed a qualitative researcher collects data until they achieve data saturation. Saunders et al. (2015) submitted a researcher should expect a sample of at least five qualified participants before reaching data saturation. I collected information through semistructured interviews and reviewed the current nuclear business plan, change management plan, and improvement strategy documents until no new themes or interpretive information emerged.

Castillo-Montoya (2016) identified the need to establish a proper setting to ensure a successful interview. Establishing a safe and convenient interview setting is an important aspect of data gathering (Saunders et al., 2015). To ensure a meaningful and open conversation, an interview should take place in a private and comfortable area (Cridland et al., 2015). I conducted interviews using Microsoft Teams video conferencing software and allowed the interviewees to select a secluded space that met each individual's privacy and comfort needs. The familiar setting for each person allowed for an open and honest conversation and enhanced data collection.

Oltmann (2016) posited that interviews conducted via internet-based video technologies are a viable substitute for on-site face-to-face interviews providing both

researcher and interviewee safety and comfort. Hanna (2012) provided the use of internet-based video technologies (e.g., Webex, Skype, or Zoom) reduced travel, which minimizes environmental impact, and does not reduce the effectiveness of the interview. Tuttas (2015) suggested the use of an internet-based video technology for interviews may increase access to participants in a study through elimination of geographical restrictions. I conducted interviews via the Microsoft Teams video conferencing platform, which met the needs of each participant and the researcher.

Ethical Research

The researcher must protect the individual through a dedicated process that ensures confidentiality (Greenwood, 2016; Nair & Ibrahim, 2015). Informed consent ensures the participant is knowledgeable of the research requirements through all stages of the study and willingly provides permission to engage in study activities (Thomas & Pettitt, 2017). Morse and Coulehan (2015) provided the researcher must ensure the privacy of study participants. Prior to commencing interviews, I used an informed consent process to ensure participants understood the scope of the study, my obligations to protect their privacy and confidentiality, and their rights to withdraw. Additionally, I obtained each participant's electronic acknowledgement via email to ensure they understood the informed consent process.

The informed consent process included instructions regarding voluntary participant withdrawal for any reason up to the completion of the member checking. No participant desired to withdraw from the study once selected. Additionally, I did not provide any incentives for participation in the study.

To ensure an understanding of my ethical research obligations, I completed the Collaborative Institutional Training Initiative (CITI) program course (#35134311). In addition, before collecting data, I obtained approval from the Walden University Institutional Review Board (IRB; approval number 03-23-21-0985009, expiration March 22, 2022) to ensure my research met the ethical standards and U.S. federal regulations, as defined in the *Belmont Report*. Following IRB approval and participant pool selection through HR, I emailed each participant (a) a formal invitation, which includes a summary of my credentials; (b) information regarding the study, and (c) the informed consent requirements. To ensure each participant understood my ethical obligations, I required a return confirmation email from each participant attesting they understood the requirements and obligations of the informed consent form before beginning the initial interview.

Maintaining a participant's privacy includes preventing information exposure that may result in unwanted contact from undesirable entities or a disruptive financial impact (Yin, 2018). Therefore, I identified each participant with the alphanumeric code P1, P2, etc. Furthermore, to ensure participant privacy, the keys that associated individual names with the respective alphanumeric code are maintained on a password protected flash drive. The flash drive and all other research material will remain in a locked storage under my control for 5 years following completion of the study.

Data Collection Instruments

The researcher is the primary data collection instrument (Karagiozis, 2018). In qualitative studies, the researcher collects, analyzes, and assigns meaning to the data

(Stewart, 2016). Moreover, the researcher is responsible for content analysis of any collected data (Prasad, 2019). Austin and Sutton (2014) identified interviews as a valid data collection method, which relies upon the researcher as the primary data collection and analysis instrument. To determine the meaning underlying the strategies nuclear leaders use to manage costs, I collected all data through internet-based video technologies, electronic document submission by each leader, and reviewed all archival documents.

Semistructured interviews also provide a method for the researcher to gain insight into a participant's experiences and the meaning of the phenomena (Ahmad et al., 2019). Semistructured interviews provide a technique that allows a researcher to begin with an outline of interview questions, while allowing the flexibility for the researcher to explore a deeper meaning through follow up and probing questions (Austin & Sutton, 2014). The researcher conducts semistructured interviews in a conversational manner to elicit responses to fulfill the research objectives (Cridland et al., 2015). I used semistructured interviews to gain an understanding of the methods, knowledge, and experiences of the participants of the study.

Castillo-Montoya (2016) proposed an interview protocol strengthens the reliability and quality of a qualitative study. Moreover, the researcher uses the interview protocol to focus on the aspects of the research topic instead of the mechanics of the interview (Cridland et al., 2015). Ford et al. (2017) concluded an interview protocol provides for consistency between interviews. The interview protocol contains (a) the interview questions, (b) amplifying information to explain the meaning of questions, and

(c) post-interview procedures. I used an interview protocol (see Appendix) as an outline for each interview to ensure a structured and consistent process.

I used member checking of the initial interviews to ensure I understood the intention of each participant's responses to the interview questions. Jackson et al. (2007) identified member checking as a process that may help the researcher ensure they understand the intent of the participant's responses to the interview questions. Vance (2015) asserted that member checking allows the researcher to ensure their interpretation of interview responses are accurate. Milosevic et al. (2015) posited that member checking increases interview data reliability and validity. Following each interview, I summarized the individual interview responses and provided the summaries to each participant for validation via email. I repeated the interview/summary process until the participant agreed with the summary and did not provide any new information.

Data Collection Technique

Following Walden University IRB approval, I began the data collection process. Yin (2018) posited that a researcher may use interviews and archival documents to gather information related to a phenomenon. Multiple sources of information will help ensure data saturation through triangulation, enhancing study validity (Hennink et al., 2019; Renz et al., 2018). I used semistructured interviews as the primary means of data collection coupled with a review of archival documents of the target organization.

Following participant consent, I conducted video conference semistructured interviews with the Microsoft Teams video conferencing platform using open-ended questions through a standardized interview protocol (see Appendix). Yin (2018) indicated

an advantage of the interview is the researcher can target a specific topic and obtain the essence of the participants' understanding. In addition, Cridland et al. (2015) noted interviews are an important part of data collection in qualitative studies. Hanna (2012) described the video conferencing interview as a method that allowed for better access and eliminated physical interactions placing the interviewee at ease. However, Yin (2018) cautioned that interviews might result in disadvantages through improper questioning techniques and interviewer biases. To mitigate interviewer bias and minimize the potential of improper questioning, I used an interview protocol (see Appendix) to aid in the conduct of each interview.

Interviews consisted of a series of initial open-ended questions, followed by probing questions to engage the participant, which allowed for exhaustive information sharing with the researcher. Saunders et al. (2015) proposed open-ended questions are "how" and "why" questions allowing the participant to develop their answers and provide an extensive response. Johansson (2019) submitted open-ended questions could lead to an increased understanding of a phenomenon by the researcher. An open-ended questioning technique could also yield a more thoughtful response (Attali et al., 2016). The open end-ended questioning technique was the inquiry method I used to execute the interviews for this qualitative single case study.

To ensure the accuracy of the information provided by the participants, I performed an audio recording of each interview. Recording each interview ensured the accuracy of the information obtained from the participant (Neal et al., 2015). Marchand et al. (2020) argued that recording an interview allows the researcher to focus on the

participant and their responses. Furthermore, recording of interview data enhances the trustworthiness of the research (Bazzano et al., 2019). My primary audio recording device was my personal cellphone with a supplemental power pack, and my backup device was a Sony BX-140 audio recorder. After recording each individual interview, I used the transcription feature of Google Dictate to transcribe the audio files into a Microsoft Word document.

Tindall et al. (2015) posited that recording data throughout the research process provides for a greater understanding of the information. Peker et al. (2019) concluded taking notes during interviews allows the researcher to capture additional details enhancing the study. Furthermore, notetaking during each interview allows the researcher to capture context, which may not be evident in the audio recording (Goertzen, 2017; Sutton & Austin, 2015). To ensure I captured the non-verbal information associated with the participants, I took notes and recorded my observations from each interview.

The final aspect of data collection for this doctoral study was the review of archival documents. Yin (2018) submitted archival documents could provide collaboration for other research processes. Including archival documents in the data collection process may yield an increase in the legitimacy of the research results (Singh, 2017). Furthermore, Brown et al. (2017) found that archival documents may improve the understanding of a research phenomenon. Yin (2018) asserted archival documents are, in some cases, difficult to retrieve and could have limited access because of privacy concerns. I used the current nuclear business plan, change management plan, and

improvement strategy document in conjunction with semistructured interviews to complete this doctoral study.

Member checking allows the participant to scrutinize the interview results ensuring the researcher has captured the true meanings of the participant's interview responses (Iivari, 2018). Cridland et al. (2015) proposed participant interaction and involvement, and validating the meaning of interview responses, could benefit study results. Moreover, Iivari (2018) discussed the need for a researcher to capture the intent of the data through member reviews of interview results. I implemented member checking by summarizing all interview results and presenting the summary to each participant for evaluation. After presenting the interview summary to each participant, I provided and opportunity for each participant to review the material and then scheduled a follow-up interview to review comments and concerns and address any follow-up questions. Presenting the summary for evaluation and conducting a follow-up interview ensured I captured the essence and intent all interview responses.

Data Organization Technique

Qualitative researchers capture information and use data organization methods to ensure the validity of the research results (Burton & Galvin, 2019). A reflective journal is a method that may enhance the data collection process as the researcher records insights during the individual interviews (Saunders et al., 2015). Reflective journaling allows for recording thoughts and observations, which promotes a critical analysis of the information following data collection (Woronchak & Comeau, 2016). Moreover, a reflective journal provides the researcher with an opportunity to record pertinent

information that could enhance understanding of a large amount of data (Hughes, 2016). I used reflective journaling to record my thoughts and impressions during the interviews and during the review of each recorded video, capturing the essence of the information.

During the interview process, I assigned an alphanumeric code (P1, P2, etc.) to each participant to establish confidentiality. Kovshoff et al. (2016) stated the use of unique alphanumeric indexes assists the researcher with data organization. Additionally, Lahman et al. (2015) asserted a unique naming criterion adds to the confidentiality of the study participant's responses. Furthermore, a coded naming convention allows for correlating journal entries with transcript documents and analysis software to maintain data integrity (Kovshoff et al., 2016). The alpha-numeric code provided participant confidentiality and ease of data recall throughout the data collection and evaluation process.

The researcher must safeguard all study materials, including handwritten journal entries, electronic recordings and transcripts, and the analysis software database. Jao et al. (2015) emphasized the need to protect data from inadvertent disclosure. I safeguarded electronic and hardcopy data through personal possession while in use and through locked means when not in use. I stored all electronic data on a password protected flash drive during the study and will maintain the data following completion of the study. I will maintain all electronic and hardcopy data in a locked storage container for 5 years following completion of the study, after which all hardcopy records will be shredded, and the flash drive will be formatted.

Data Analysis

For qualitative research, data analysis consists of an in-depth review of the information collected as part of the study (Farquhar et al., 2020). Watkins (2017) mandated the scholar should perform a rigorous analysis of all research data. To enhance the validity of a qualitative study, the researcher can use multiple data sources to corroborate the information (Farquhar et al., 2020; Yin, 2018). Yin (2018) outlined a 5-step methodology to systematically analyze data and ensure validity. The data analysis method includes (a) compiling the data, (b) disassembling the data, (c) reassembling the data, (d) interpreting the data, and (e) drawing conclusions from the data. I performed a detailed analysis of the data collected through semistructured interviews and the information contained within the nuclear business plan, change management plan, and improvement strategy document, which ensures the validity of the study.

Compiling the Data

Compiling the data consisted of gathering information through semi-structured interviews, collection of archival documents, and organizing the information. Yin (2018) described the process as collecting and organizing the data for analysis. Additionally, data organization includes evaluating and scrutinizing the raw data to ensure it is adequate to answer the research question (Belotto, 2018). I stored the raw data transcripts and archival documents in a dedicated file structure in native formats (Microsoft Word or Adobe data files) in preparation for traditional manual analysis and upload into NVivo 12.

Qualitative researchers validate information through triangulation (Farquhar et al., 2020). Yin (2018) proposed data triangulation is the use of multiple data sources, which contributes to the integrity of the research results. Johnson et al. (2017) described data triangulation as the use of multiple data sources to verify the authenticity of the information. Therefore, triangulation provides for a greater assurance that research results are valid and trustworthy (Abdalla et al., 2018). Fischer and Van de Bovenkamp (2019) posited the use of interviews and archival documents as methods to increase validity through data triangulation. I used data triangulation, consisting of the information gathered from semistructured interviews and the data from review of archival documents, to ensure the validity of this study.

Disassembling the Data

Yin (2018) described data disassembly as reducing the data into manageable segments to which a researcher may attach labels for regrouping. A qualitative researcher establishes codes to group data into manageable sets of information for further consideration (Woods et al., 2016). Data analysis is a process a researcher uses to code qualitative data (Houghton et al., 2017). Coding data is the collation of related information based on an established framework (Belotto, 2018; Scharp & Sanders, 2019). Additionally, Maher et al. (2018) proposed a combined approach to coding data through a traditional process and the use of a software platform. I used a combination of traditional analysis and software-based analysis to code the data.

Belotto (2018) proposed the use of Microsoft Word to break down and organize data for evaluation. Following member checking, I used the native Microsoft Word file of

each participant's interview to structure interview responses based on initial codes derived from the research question and the purpose of the study. Additionally, I performed manual coding for all archival documents. Saunders et al. (2015) posited the data coding process is a recurring process as the researcher codes and reviews data. As I reviewed the initial coded data from the interview and archival documents, I added new codes as required to logically group data for further evaluation. Following manual coding and data structuring using Microsoft Word, I loaded all codes into the NVivo software and uploaded the interview for software analysis. Zamawe (2015) described data analysis software as a viable means to assist qualitative researchers in identifying themes in complex data sets. The functionality of software data analysis aided the evaluation process through ease of data search and manipulation function (Saunders et al., 2015). Once codes were assigned and the data was arranged into related groupings, I reconstructed the related data into relevant themes for evaluation.

Reassembling the Data

Yin (2018) posited that data reassembly is the process of grouping themes to form a narrative for further analysis. Saunders et al. (2015) proposed the researcher must immerse themselves in the data to derive themes and determine viable relationships. Additionally, qualitative researchers may use data analysis software as an aid to discover themes from qualitative data (Yin, 2018). Zamawe (2015) described data analysis software as a viable means to assist qualitative researchers in identifying themes in complex data sets. Harrati et al. (2018) proposed qualitative data analysis software increases the accuracy of the results of a study. In addition, Houghton et al. (2017)

emphasized the researcher must participate in the data analysis to ensure the correct interpretation of the raw data. Following the traditional and software-based coding assignments, I utilized the search functionality of Microsoft Word and the NVivo software to highlight related information for review and grouping into appropriate themes. As I identified themes, I grouped theme-related data together electronically to establish and maintain alignment for further analysis.

Interpreting the Data

Data interpretation is a logical grouping of thematic data for consideration (Yin, 2018). Saunders et al. (2015) proposed the researcher interprets thematic data to determine primary and secondary themes, considers regrouping and combining themes, to ensure the analysis addresses the research question. Belotto (2018) emphasized the need for the researcher to address the research question as a part of the data interpretation process. I utilized the final four themes to establish a narrative that addressed the research question through conclusions based on the design of the study and the conceptual framework.

Drawing Conclusions from the Data

Renz et al. (2018) posited that data conclusion is the point a qualitative researcher generates inferences from the final thematic data. Yin (2018) described the data conclusion process as understanding the sense behind the data. Additionally, Maher et al. (2018) provided the conclusions of a study are dependent on the researcher's ability to apply context to the data. I completed the analysis through a contextual evaluation of the data utilizing the conceptual framework as the guiding lens.

The conceptual framework is the structure a scholar uses to develop the research and explain the phenomenon under investigation (Gregory, 2020). Gupta et al. (2017) described the conceptual framework as the structure the researcher applies to derive meaning from the research data. The conceptual framework, supported by the literature review, maintains the scope of the research, and provides the guiding principles to address the research question (Saunders et al., 2015). I used BDT as the lens to analyze the findings of this study.

Reliability and Validity

Reliability

In case study research, reliability refers to the processes and documentation required for another researcher to replicate the results (Yin, 2018). Jackson et al. (2007) described reliability as a rigorous and ethical data collection and evaluation process that minimizes biases. A researcher achieves reliability if future research, with similar data and context, yields equivalent conclusions (Ali & Yusof, 2011). The researcher is responsible for outlining the data collection process, the faithful recording of information, and providing methods to ensure the information is true and accurate (Yin, 2018).

A researcher may use member checking to enhance reliability by verifying the absence of errors in data (Milosevic et al., 2015). Saunders et al. (2015) described member checking as a validation of the participant's intent regarding the provided information. Moreover, Lincoln and Guba (1989) posited that member checking is a test of the researcher's interpretation of the collected data. I developed a data summary based on the responses to the individual interviews, email each participant and provided them

the opportunity to comment and provide corrections as required, which I used for my data analysis.

Dependability

An additional aspect of reliability is dependability. Korstjens and Moser (2018) described dependability as a process that can withstand auditable scrutiny. Moreover, Birt et al. (2016) concluded dependability has a time-based aspect and contextual relationship. A scholar establishes dependability through overlapping verification methods and meticulous documentation (Ali & Yusof, 2011). I executed an interview protocol (see Appendix) that contained the questions that each participant addressed, which helped improve the quality of the study and ensure dependability (Yeong et al., 2018). The structured interview protocol, recording participant interview responses, and documenting observations through a reflective journal are the primary methods I used to ensure the dependability of the results of this study.

Validity

Bennett and McWhorter (2016) described validity as trustworthiness in the research results. Validity is the assurance the study results are accurate (Saunders et al., 2015). Furthermore, validity is the credibility, transferability, and confirmability of the research results (Ali & Yusof, 2011). I established validity through member checking, reflective journaling, and retention of records.

Credibility

Credibility is the assurance the study results are a trustworthy representation of the phenomenon under evaluation (Matamonasa-Bennett, 2015). Iivari (2018) pointed out

ensuring factual and correct data establishes credibility. Lahman et al. (2015) defined credibility as the proper representation of the material in a study. Member checking is a common practice a researcher may use to ensure credibility. A researcher uses member checking to allow the participant to review the interview material to verify the researcher captured the true meaning of their responses (Saunders et al., 2015). Providing the opportunity for each participant to critique and correct the information ensures the outcome of the study is truthful (Birt et al., 2016).

Transferability

Transferability occurs when a future researcher finds the body of research useable in another context (Saunders et al., 2015). The content of the study is transferable if the material product of the research applies to another area of study (Matamonasa-Bennett, 2015). Furthermore, to achieve transferability, appropriate information must exist for a future researcher to determine extended applicability (Lahman et al., 2015). Capturing the research information through reflective journaling, audio recordings, and response synthesis, and incorporating the results of archival document reviews provided the required thick descriptions and study transferability (Korstjens & Moser, 2018).

Confirmability

Confirmability is the exclusion of bias in the research results (Lahman et al., 2015). Haven and Van Grootel (2019) stated confirmability coincides with auditable results. Confirmability is the concept of eliminating a researcher's partiality (Rapport et al., 2015). I ensured confirmability through the record-keeping process and data saturation via semistructured interviews and the review of archival documents.

Data Saturation

Saunders et al. (2015) asserted that data saturation occurs when the researcher obtains limited new information through the data collection progression. Data saturation is the point the researcher does not receive any new information regarding the subject (Lowe et al., 2018). Guest et al. (2020) posited that data saturation is the point a researcher does not gain an additional understanding of the research phenomenon. Moreover, Moser and Korstjens (2018) concluded the scholar has a sense of conclusion at the point of data saturation. To reach data saturation, I conducted semistructured interviews with nuclear industry leaders and reviewed archival documents until no new themes occurred.

Transition and Summary

Section 2 included an elaboration on my role as the researcher, a review of the methodology to identify the participants of the study and the research method and design. Additionally, Section 2 included the determining factors for participant population and sampling, my responsibilities for ethical research practices, the process of data collection and analysis, and the safeguards to ensure reliability and validity of the results of the study. In Section 3, I discuss the findings of the study, the applications to professional practice, and the social change implications. I also identified actionable results and areas of further research.

Section 3: Application to Professional Practice and Implications for Change

Introduction

The purpose of this qualitative single case study was to explore the effective cost-control strategies U.S. nuclear industry leaders use to ensure competitiveness. Eight leaders with operational nuclear power plant experience who were actively engaged in budgetary decision making participated in the study. I used the responses from semistructured interviews, and the information gathered from organizational documentation to address the research question.

Presentation of the Findings

The central research question for this study was: What strategies do nuclear leaders use to control costs and ensure competitiveness? I performed semistructured interviews with open-ended questions (see Appendix) and analyzed organizational documents to obtain the data for this study. The analysis included the assignment of codes and development of themes using Microsoft Word and Microsoft Excel with validation through NVivo 12. The four main themes that emerged were (a) management engagement is required to effect long-term change that controls costs, (b) leaders should emphasize the use of technology that drives cost-effective solutions, (c) leaders need to seek organizational cost initiatives that provide for greater efficiencies and opportunities, and (d) leaders must engage and empower the workforce to achieve business excellence.

Theme 1: Management Engagement is Required to Sustain Long-Term Change That Controls Cost

The use of effective management practices and the understanding of the need to make business changes to nuclear operations may contribute to the ability of the organization to implement and sustain effective cost-control solutions. Improper or poor management was a contributing factor in the premature closure of at least one operating U.S. nuclear power plant (Clemmer et al., 2018). Failure of plant managers to address environmental concerns and a lack of confidence in the stability of decommissioning finances eroded public confidence in some nuclear power plant operations and led to premature plant closure (Greco & Yamamoto, 2019). However, improved plant capacity factors have demonstrated the resolve of some nuclear industry leaders in addressing long-standing operational issues (Kessides, 2012). P1, P2, P3, P4, and P8 described the need for senior manager involvement to sustain change activities and stated the driving force for change within the organization came from senior leaders. P2 stated, “It is very much a corporate strategy. This comes all the way down from the top.” P8 stated, “there was a clear understanding at the leadership level that we needed to lower our operating and maintenance cost, that we had to do that to stay competitive and stay in the game.”

To improve business outcomes, an organization requires change agents to identify areas for improvement. Lee et al. (2018) emphasized that leaders who institute continuous improvement initiatives can increase efficiencies and improve performance. Riznic and Duffey (2017) proposed that positive change is required to reduce organizational cost and improve competitiveness. P2, P3, P4, P7, and P8 stated the need

to seek opportunities to change processes reducing costs. P4 stated, “it's looking for those opportunities and getting the buy-in and being able to act on it.” P2 stated, “Changing culture is slow, but we've been working on it and we've seen a lot of progress.” P1 and P3 noted that technical experts are not necessarily financial experts requiring management effort to improve performance. P1 stated,

> The human strategy is the calculation of our costs and competitiveness that is so far removed by the day-to-day activities of the normal nuclear worker that unless we make a specific concerted management effort to connect the importance of meeting budget with eventually being cost-competitive with natural gas that people just go about their day and don't even think about it.

P5 observed the need for coaching decision-makers on financial priorities and budget, stating,

> When you hear them talking about operational information you can either bring up something then to make sure that they're thinking about it the correct way on the financial side, or you can go back to them off-line to the people that are the decision-makers to make sure that they understand the financial impacts as a top priority.

Change agents must identify barriers to proposed changes and institute process to address the barriers for successful implementation. Lee et al. (2018) stressed the need to identify barriers and provide solutions to ensure positive change. All participants described some type of barrier to change existing within the company or from external forces. P1, P3, P4, and P8 identified department-level supervision or workers at

individual sites as an internal barrier. P1 stated, “The bottom levels have more inertia and they're totally willing to make a 12-hour work order last 12 hours and then get good results.” P3 identified some in-use processes as significant barriers, stating “there is a level of granularity and often a number of do-loops and redos inherent to the processes that at a minimum slows the process down and at times are unnecessarily costly.” P1, P2, P3, P4, P6, and P8 addressed change barriers with solutions to affect change initiatives. The comments by each participant spoke to effective communications with P2 stating, “Just making sure people understood what we were doing and why we were doing it, so people could embrace that change, and we see culture changing because of that.” P6 stated, “when you come up with a new technology you have to take the time to show people what you are doing, what you are going to do, and what the results will be.” In Table 1, I illustrate the frequency with which participants mentioned that management engagement is required to sustain long-term change that controls cost.

Table 1

Management Engagement (Frequency)

Participant	Interview questions	Total number of references
P1	3, 4, 5, 7	10
P2	1, 3, 5	16
P3	1, 3, 4, 5, 6, 7	21
P4	1, 3, 5, 6, 7	29
P5	3	3
P6	3, 4, 7	8
P7	1, 3	2
P8	3, 5, 6	12

Archival Document Review

P1, P2, P3, P4, and P8 proposed the need for senior manager involvement in change processes, which is one of the guiding principles contained within the nuclear business plan (archival document). The business plan contains the actions required for engagement of senior leaders at all levels of the organization to drive and sustain initiatives that support change and increase competitiveness. P1, P2, P3, P4, P5, and P8 described the need to address change barriers and implement processes that reduce or control costs. P1, P2, P3, P6, and P8 described defined processes within the organization that guide employees through work activities and control change implementation. The corporate change management procedure (archival document) outlines the processes and

requirements for organizational change. P3 referenced change management procedures as a defined corporate process for effective change implementation, stating,

> If you keep it to the facts, a change management plan based on facts, I have found that to be more effective than talking about why we are going to do this, but how we are going to do this.

Theme 2: Emphasize the Use of Technology That Drives Cost-Effective Solutions

Adopting innovative technologies that address high-cost functions may reduce resources and introduce long-term cost savings. The use of autonomous systems reduces processed waste cost with potential broader applications to other areas of the industry (Aitken et al., 2018). Markard et al. (2020) submitted that advancement of technology is a sustaining industrial factor. P1, P2, P3, P4, P6, P7, and P8 identified innovation resulting in advancement in the use of technology as a driver for cost improvements. P1 stated, "We're trying to use better tools and techniques" and "we're trying to use technology, we're trying to use remote sensors more than ever before." P4 stated, "being able to utilize technology for remote monitoring, or drones - all kinds of stuff." P2, P4, P6, and P8 shared that technology advancement reduced resources from the point of time constraints or a physical reduction in staffing, reducing cost. P2 stated, "depending on the initiative there could be costs as some things have soft cost savings instead of hard cost savings, such as saving an employee's time." However, to implement changes and advance technological solutions to solve problems requires a significant investment by the company. P6 and P8 observed the impact of technology costs and the impact on implementation, with P6 addressing the need for company leaders to understand the

overall benefit and return on investment of the technology. P6 stated, “we had to figure out what was going to be the most beneficial for us and which as going to deliver the product we were looking for” and “not only do we look at the implementation cost we also look at the return on investment.”

Industry-related organizations have initiated programs that identify cost-savings measures available for implementation by company leaders. Leaders at the NEI sought to assist plant operators in improving the efficiencies of nuclear power plants (Nuclear Energy Institute, 2020b). P1, P2, P4, P7, and P8 identified DNP as the starting point for company initiatives to reduce cost. P7 stated, “That helped us to decrease the number of maintenance actions we do from daily to weekly. That was part of the Delivering the Nuclear Promise Initiative (DNP) taken by the industry to help control costs.” P2 stated, “Things were started through initiatives by the Nuclear Energy Institute (NEI) as part of deliver the nuclear promise, which had the purpose of making the nuclear industry more efficient and cost competitive.” P2, P3, P4, and P6 also discussed the company innovation initiative with the purpose of expanding DNP principles throughout the organization. P2 stated, “the innovation project is basically an enabler to eliminate work, improve processes, buy smart, as well to do innovation in order to make our nuclear sites more cost effective and efficient.” In Table 2, I illustrate the frequency with which participants mentioned emphasizing the use of technology that drives cost-effective solutions.

Table 2

Emphasize the Use of Technology (Frequency)

Participant	Interview questions	Total number of references
P1	4, 7	5
P2	1,2, 3, 7	13
P3	1, 4, 7	3
P4	1, 2, 3, 6	14
P5	N/A	N/A
P6	1, 2	10
P7	1, 3, 4, 7	13
P8	2, 3, 5, 6, 7	9

Archival Document Review

P2, P3, P4, and P6 identified the company innovation process as a driver for process improvement and adoption of technology. The company innovation process (archival document) provides for a disciplined approach from the proposal of an improvement initiative through a follow-up evaluation of the level of success of the project. The innovation process is planned and implemented through teamwork, collaboration, and communication. The innovation process is initiated through a challenge, an individual, or business unit, and is team led throughout with the goal of embracing change and turning ideas into action. P2 stated, “The process is about changing the culture in order to have people think differently, embrace the change, and turning ideas into action.”

Theme 3: Seek Organizational Cost Initiatives That Provide for Greater Efficiencies and Opportunities

The ability of an organization to apply costs throughout a nuclear fleet structure or between a nuclear organization and nonnuclear entities within the same company may achieve economies of scale and reduce costs. Hansen (2008) found that a conglomerate of utilities and single-unit nuclear sites effectively pooled resources and utilized economies of scale to control costs. P2, P4, P5, and P8 described the benefits of fleet applications or the provision for leveraging cost across non-nuclear business units. P4 stated, “We're also leveraging the spend that we have in our fossil and hydro business. Solar, wind, whatever, if it's some commodity need we will leverage that spend try to derive the benefits from that.” P5 stated, “When you look at something at the higher level from the fleet, you can do the best you can to look across even within your own fleet.” To understand processes and determine viable solutions to business problems, successful leaders use tools such as benchmarking to seek best practices (Oliveira et al., 2019). P1, P3, P6, P7, and P8 defined the use of benchmarking internal or external nuclear organizations or internal nonnuclear units seeking best practices. P8 stated, “we constantly benchmark our stations and fleet against industry-best performers to identify and implement improvements in equipment, processes, procedures, etc.” P1 described the willingness of nuclear industry leaders to share ideas, stating “we have an incredible culture of sharing good ideas and information” and “Throughout the operating nuclear power reactors there is very little withholding good ideas.”

Corporate-level oversight and training initiatives that target process improvement may provide for effective and streamlined operations. P4 and P8 indicated the corporate oversight provided for efficient operations. P8 stated,

> Generally everything that we do is covered by one of these peer groups and it's their role and responsibility to be sure we have good sound procedures and practices and policies and they're repeatable and we use them every time … it's absolutely critical that we have a structured methodical, repeatable approach to doing things.

P3 described their Six Sigma training and black belt certification as a valuable tool for understanding methods and strategies to improve processes, stating "the processes that I learned there, particularly process mapping and efficiency tools that I learned there, have been of great value." In addition, P2 and P6 indicated that training is a valuable employee tool as new processes or equipment is introduced to the company. P6 stated, "I think to overcome the fear of change we try to at least put together fair training on how to use a tool or what is the tool going to do", with P2 adding, "new piece of equipment that requires training they would go through the normal company process." In Table 3, I illustrate the frequency with which participants mentioned the need to seek organizational cost initiatives that provide for greater efficiencies and opportunities.

Table 3

Organizational Cost Initiatives (Frequency)

Participant	Interview questions	Total number of references
P1	1, 3, 4, 6	13
P2	1, 2	11
P3	1, 4, 5, 6, 7	12
P4	1, 2, 5, 6, 7	20
P5	1, 2, 4, 5, 6, 7	6
P6	1, 2, 6	13
P7	1, 2, 3, 5, 6	11
P8	1, 2, 5	15

Archival Document Review

P1, P3, P6, P7, and P8 identified the use of benchmarking as a significant factor for determining effective and efficient strategies that may reduce cost. The nuclear business plan (archival document) outlines the need to perform benchmarking to collect information regarding successful operational and business practices. The business plan specifically requires the use of external sources for the information. The use of benchmarking initiatives provides leaders an opportunity to find best practices and efficiencies that may not exist in the organization (Oliveira et al., 2019). P3 stated, “It is the efficiency we learned and also the cost savings that trial and error would bring if we didn’t benchmark are the real cost savings there.”

Theme 4: Leaders Must Engage and Empower the Workforce to Achieve Business Excellence

Employees who have an interest in business operations and are engaged by leaders feel empowered to drive sustainable performance (Tian & Zhang, 2020). P1, P2, P3, P5, and P8 discussed actions that empowered employees to promote successful outcomes. P8 stated, “Having the workforce engaged in the solution creates an ally for change.” P2 stated, “people know that they have a voice that they can come up with an idea that people in the company as a whole are willing to listen, to help, and have a better life.” P1, P2, P4, P5, and P8 proposed the need to build relationships is an important factor for achieving excellence. Establishing relationships leads to trust and positive outcomes (Marchand et al., 2020). P2 stated, “Relationships matter in terms of people feeling comfortable with who you're dealing with.” P5 stated, “If you have established a relationship with them where they're kind of seeing you as a partner in the decisions.” P1, P4, P5, and P8 mentioned the need to build relationships not only with internal organizations but also with external organizations as well. P5 stated, “the key is being a partner with the operational side” and P1 stated, “we all do see each other as cooperative partners and not competitors.” P2, P6, and P8 discussed the need to communicate the positive aspect company initiatives to employees and P1, P3, P5, P7 shared the need for communicating financial information to the technical groups to ensure better understanding of financial matters within the technical departments. P2 stated, “you try to get communication out, so people understand the reason why being more competitive from a whole world market in a sense.” P1 stated, “a 2021 goal has to do with

communicating different things that lead to people having some kind of impact on our cost competitiveness," and P7 elaborated on the actions of the financial organization communicating budgetary status, stating "we would have meetings with our finance people, I think it was once a quarter, so they kept you on track for spending. I think that helped you with cost control." In Table 4, I illustrate the frequency with which participants mentioned that leaders must engage and empower the workforce to achieve business excellence.

Table 4

Leaders Must Engage and Empower the Workforce (Frequency)

Participant	Interview questions	Total number of references
P1	1, 2, 4, 5, 7	12
P2	1, 3, 4, 5, 7	13
P3	1, 2, 3, 5, 6, 7	13
P4	2, 3, 4	7
P5	1, 2, 3, 4, 5, 6, 7	19
P6	3, 4	7
P7	1	4
P8	2, 3, 4, 5, 6, 7	12

Archival Document Review

P1, P2, P3, P5, and P8 discussed empowering employees to achieve sustained success. The need to empower employees to achieve excellence in the nuclear organization is common element throughout the nuclear business plan (archival

document). Empowered employees are more likely to engage in innovation activities that improve processes (Karnouskos, 2017). P2 stated,

> I think it's really looking at the people aspect of it changing the culture letting people know that they have a voice that they can come up with an idea that people in the company as a whole is willing to listen.

P8 stated, “Having the workforce engaged in the solution creates an ally to making the change.” P3 stated, “People’s opinions are important, people’s experiences are important.”

Findings Related to Behavioral Decision Theory

Simon (1955) developed BDT to understand the rational behaviors leading to economic decisions and the information required to make those decisions. Simon (1959) elaborated on the shift between the decision-making characteristics of the individual and decision making at the firm or business level, noting the impact of the business environment on organizational-level decision making. Five (62%) participants stated the primary concern of the leaders in the organization was the safe and reliable operation of the power plant and that cost decisions are secondary considerations. Additionally, three (37%) participants mentioned the NRC, INPO or environmental organizations as the key factors affecting the business environment. The strict regulatory environment of the NRC and the pursuit of excellence enforced by INPO leads to a business environment that limits the organization in some cost savings measures (Lombaard & Kleynhans, 2016). The impact of the regulatory environment on business cost decisions aligns with Simon’s proposal regarding the business environment affecting decision making.

Decision makers must address the risk (pay-off) of decision outcomes as a part of the broader decision process (Simon, 1955). In the absence of perfect foresight, the decision maker must provide provisions to deal with uncertainty in the business environment (Simon, 1959). Decision makers must understand and evaluate the available information and balance the risk and reward of the decision outcome (Budescu & Bo, 2015; Lau & Levy, 1998). Four (50%) participants described the industry as risk adverse throughout decision processing. However, one (12%) participant outlined successful methods to understand the risk and outlined the methods to address risk and introduce cost savings measures. Budescu and Bo (2015) provided the information available to decision makers and the context of the decision allowed for a maximum utility outcome with acceptable risk. The requirement for nuclear industry leaders to evaluate risk that effects decision outcomes align with the pay-off tenet of BDT.

Organizational decisions are typically made in a group dynamic and are based on the cognitive abilities and limitations of the individuals in the group (Simon, 1955). Simon (1955) proposed organizational decision outcome resulted from trade-offs within the group as individuals yielded to achieve the greatest good for the organization. Group, or collective, decision making is enhanced by effective communication within the group dynamic (Jones, 2017). Four (50%) participants described the company innovation initiative, which is a team led process using a group decision-making and evaluation dynamic. One (12%) participant identified funding review boards and the plant health process, which utilize the group decision and evaluation dynamic. One (12%) participant described the corporate level peer group, made up of individual site experts, who provide

oversight to ensure repeatable and sound practices throughout the organization. Seven (87%) participants mentioned the need for effective communication throughout processes and initiatives within the organization. The use of group decision making and the need for effective communication aligns with the group decision dynamic described by Simon.

Applications to Professional Practice

Successful strategies that control cost and provide competitive energy delivery may benefit the broader commercial nuclear industry. Commercial nuclear industry leaders might apply the research findings from this study within their organization to improve financial performance reducing costs. To achieve cost controls, nuclear leaders could implement measures to, ensure management engagement, provide for innovation initiatives, utilize technology solutions to reduce or improve resource utilization, simplify processes, increase efficiencies, and empower employees.

Management performance is a key factor in sustaining any business initiative. In response to questions 3, 5, 6, and 7, six participants emphasized the connection between management and change initiatives within the organization. Lee et al. (2018) proposed leaders must seek continuous improvement to drive organizational performance. Chan et al. (2021) found that successful leaders exhibit characteristics that allow for abandoning existing business methods for new initiatives that provide the best chance of sustainable long-term performance. Leaders must address obstacles in operations and implement process improvements to achieve a competitive advantage.

The implementation of technology solutions to business problems may improve business operations. In response to questions 1, 2, 3, 4, 6, and 7, seven participants

mentioned the use of technology or innovation activities to improve processes. Merk et al. (2017) found that innovation resulted in increased affordability and improved use of resources in nuclear power plants. Innovation can reduce the operational challenges associated with commercial nuclear power plants reducing costs (Aumeier & Allen, 2018). Leaders must seek options that use innovative and technology driven solutions to current business problems that hinder cost controls.

The ability to implement organizational level cost solutions may yield cost savings. In response to questions 1, 2, 5, and 6, three participants revealed the benefits of corporate or fleet cost sharing that resulted in savings opportunities. Economies of scale, such as in multi-reactor locations, result in costs savings as compared to a single-reactor site (Krautmann & Solow, 1988). Hansen (2008) proposed that sharing resources and costs across multiple business units has a positive impact on the long-term cost of plant operation. Leaders should explore opportunities to distribute costs across all business units within an organization to leverage economies of scale and improve competitiveness.

An engaged and empowered workforce may improve business practices that reduce costs and leads to competitive advantage. In response to questions 1, 2, 3, 4, 5, and 7, seven participants discussed the importance of an engaged and empowered workforce to seek best practices, which would support initiatives championed by company leaders. Engaging and empowering employees who are knowledgeable and well-trained provides the best opportunity for innovation in the workplace (Karnouskos, 2017). Leaders who establish a positive work environment can enable innovation through employee empowerment (Tian & Zhang, 2020). Leaders should establish the work

environment that results in increased employee engagement and innovation, which could reduce costs through efficiency and performance improvement.

Implications for Social Change

Nuclear power plants are a nonpolluting energy source that does not contribute to air and carbon pollution during operations. An impact of nuclear plant closures is an increase in carbon emissions with the associated climate affects unless the plants are replaced by renewable energy sources (Haratyk, 2017). Particulate air pollution from fossil power plants contributes to poor health in adults and children (Perera, 2017). The continued operation of nuclear power plants and the potential for construction of new plants could improve quality of life for impoverished people groups and mitigate the effects of air and water pollution.

Some nuclear power plant closures and potential closures are the result of cost factors that make nuclear plants noncompetitive. Operation and maintenance costs of commercial nuclear power plants have risen 20% since 2002, while natural gas prices have decreased, resulting in an ever-increasing noncompetitive environment for nuclear (Davis & Hausman, 2016). However, nuclear power plant operations have improved markedly since 2002 with an industry average capacity factor of 92% as compared to 37% (solar) and 27% (wind). The data from this study may provide nuclear leaders with strategies that could reduce plant operating costs and increase competitiveness, resulting in sustainable carbon-free energy delivery.

Recommendations for Action

High operating costs coupled with low gas prices and falling renewable prices have resulted in nuclear power plants losing competitive advantage (Davis & Hausman, 2016; Haratyk, 2017). Moreover, the current operating nuclear fleet in the United States is subject to further cost increases from regulation and replacement of aging equipment (Davis & Hausman, 2016). The key to sustainable and competitive operations is the adoption of standardized process and implementation of process improvement tools (Ferreira et al., 2020). Based on the research findings, I recommend the following actions:

- Nuclear leaders must place the same level of emphasis on cost control strategies as they do on nuclear safety.
- Senior leaders should establish training or mentoring programs for all employees on fiscal responsibility and the benefits to the company.
- Organizational leaders should implement training programs that enhance employee process improvement skills and teach critical thinking (e.g. Lean Six Sigma).
- Senior leaders should encourage and provide adequate resources to pursue cost-savings measures.
- Senior leaders must seek and adopt best operational and financial practices inside and outside the nuclear industry to improve competitiveness.
- Senior leaders should push down cost savings goals and strategies, in terms of the department-level mission, to the lowest levels of the organization.

I will pursue opportunities to share my research findings in nuclear industry publications and through internal industry advocacy and support groups. Nuclear industry trade organizations, such as the NEI, have the purpose of seeking out and recommending best practices through industry-wide initiatives (Nuclear Energy Institute, 2020a). The findings of this research may assist nuclear leaders in managing the financial aspects of plant operations while maintaining nuclear safety.

Recommendations for Further Research

The findings of this qualitative single case study may contribute to the existing research on nuclear industry cost-control strategies. For businesses to continue operations in a competitive environment, leaders must seek best practices and implement changes to achieve positive results (Ferreira et al., 2020). Leaders in the broader nuclear industry must adapt to market changes and implement strategies that sustain the organization or risk premature plant closure (Haratyk, 2017).

A limitation of this qualitative case study was the population from a single organization. Future researchers could broaden the scope to include multiple companies with larger reactor fleets, expanding into different regions in the United States. Moreover, additional research could include a focus on the different perspectives between senior leaders and department workers to determine the barriers to sustainable change.

An additional limitation of this qualitative single case study was the use of interviews and archival documents to obtain data. To enhance the validly of the study, I could have used a mixed-methods approach. Sahin and Öztürk (2019) proposed the use of mixed methods provides for a more thorough response to the research question. The use

of mixed methods would have allowed the use of numerical data to validate participant responses.

Reflections

Through a qualitative single case study, I sought to identify and understand the successful strategies nuclear leaders use to control costs in their organization. I conducted semistructured interviews through video conferencing and communicated with the participants exclusively via electronic means. I would suggest the lack of personal interaction, although convenient from a time and expense standpoint, limited some aspects of data gathering from a personal engagement perspective. However, I believe the procedures utilized throughout the study led to a successful process.

Participants were forthcoming, open, and honest, and shared personal experiences that corroborated their insight and the principles of the organization. Seven (87%) participants emphasized the need for engagement by senior leaders to sustain change. However, participants also identified barriers to change in the lower levels of the organization indicating a need for leadership emphasis in this area. I would submit an opportunity exists for leaders to address the financial aspect of the business with all levels of the organization.

A nuclear organization is governed by strict operating procedures and is highly regulated to ensure nuclear safety (De Blasio & Nephew, 2018). As a member of the nuclear community, I understand the need for the emphasis on safety and strict process controls but had not observed an effort by the utility to emphasize change and improvements. The initiatives shared by the participants and the reviews of the archival

documents revealed a strong adoption of change philosophies at management level, which indicated leadership dedication to cost reductions.

Conclusion

The purpose of this qualitative single case study was to explore the effective cost-control strategies U.S. nuclear industry leaders use to ensure competitiveness. I interviewed eight nuclear leaders in the Eastern United States who had operational nuclear power plant experience and made routine budgetary decisions. To collect data, I used semistructured interviews and information obtained from the nuclear business plan, change management plan, and innovation process documents. Four themes emerged through data analysis including management engagement is required to sustain long-term change that controls cost, emphasize the use of technology that drives cost-effective solutions, seek organizational cost initiatives that provide for greater efficiencies and opportunities, and leaders must engage and empower the workforce to achieve business excellence. The overarching theme is a concerted effort is required, for all levels of the leadership team, to unify the workforce and aggressively identify and implement cost savings measures for the benefit of the organization. I suggest the findings of this study address some gaps in the extant literature regarding cost control strategies in operating commercial nuclear power plants.

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Appendix: Interview Protocol

Introduction: Welcome the participant and explain the scope of the interview is to collect data regarding the main research question.

1. Introduce self to participant.
2. Verify the participant is located in a private comfortable setting.
3. Verify the participant has read and understands the informed consent form and recommend they retain an electronic copy.
4. Turn on recording device.
5. Follow procedure to introduce participant with pseudonym/coded identification; note the date and time.
6. Begin the interview with question #1; follow through to final question.
7. Follow up with additional questions.
8. End interview sequence; discuss member-checking with the participant.
9. Thank the participant for their part in the study. Reiterate contact numbers for follow up questions and concerns.
10. End protocol.

Main Research Question: What strategies do nuclear leaders use to control costs and ensure competitiveness?

Interview Questions

1. What strategies do you use to control costs and ensure competitiveness in your organization’s nuclear power plant(s)?
2. How do you use decision input and processes for cost control and competitive

outcomes of your power plant(s)' costs? ("decision input and processes" mean inputs and processes other than those you have established)

3. What were the key barriers to implementing your organization's strategies for controlling costs to ensure competitiveness?
4. How did your organization address the key barriers to implementing its cost control strategies?
5. How, if at all, do you address potential cognitive biases when planning for cost control and competitive outcomes? ("cognitive biases" would include personal preferences or establishes procedures that may influence decision-making)
6. How, if at all, do you use information processing to make choices for cost control and competitive outcomes in your organization's nuclear power plant(s)?
7. What additional information can you add to help me understand the strategies your organization uses to control nuclear power plant costs to ensure competitiveness?