Assessing the Influence of a Continuous Improvement Process

on a Nuclear Safety Culture

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ABSTRACT

The commercial nuclear power industry has been challenged by economic demands resulting in the creation of organizational strategies to reduce operating costs. One strategy included implementation of a Lean Continuous Improvement Process (LCIP). Application of this strategy could affect key nuclear organizational factors, including the nuclear safety culture. This quantitative research examined the influences of implementing a LCIP on a nuclear safety culture. Based on a review of the literature, the operational indicators of quality and production (cost) were correlated to six nuclear safety culture indicators. Data were gathered from the management systems at an experimental and a control commercial nuclear power plant located in a common industry alliance and regulatory region in the United States. When evaluated independently, the results of the correlation analyses indicated significant correlation existed between cost/productivity ($p < 0.01$) and two culture indicators (material unavailability and schedule errors) and between quality ($p < 0.05$) and one culture indicator (schedule errors). The results of the ANOVA analyses indicated significant differences for material unavailability ($F = 19.99$) and schedule errors ($F = 19.93$) by plant (experimental vs. control). Recommendations were provided for application of the research findings, including the development of a plant-specific integrated continuous improvement plan and improved targeting of projects that extend beyond simply reducing costs. Future research was recommended on response strategies related to economic pressures, modeling operational costs relative to a nuclear safety culture through the use of other indicators and direct observations, and assessing vertical interactions of other cultural factors and organizational changes relative to a nuclear safety culture.

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CHAPTER 1: INTRODUCTION

Designed, built, and operated to produce electricity, commercial nuclear power plants consist of complex technologies operating in a complex regulatory environment. The technical challenges inherent in the design are confronted by economic demands, mainly due to changes in the circumstances of the energy industry (Itoigawa, Wilpert & Fahlbruch, 2005). The nuclear power industry has been challenged by changing circumstances, including governmental pressures to deregulate energy markets, increases in company mergers, organizational cost-saving strategies, and the replacement of aging technical components with newer and more costly technologies (Itoigawa et al., 2005). Competitive business pressures appear to have been compelling the nuclear power industry to improve delivered value and the processes that deliver value.

Nuclear industry leaders have been exploring different methodologies for achieving a desired state of improving value creation and reducing production wastes and costs (MacAvoy & Rosenthal, 2005). Some continuous improvement methodologies focus on value creation and waste and cost reduction through improvement initiatives (Womack & Jones, 2003; Baghel, 2005). As nuclear power plant operating companies adjust business models to meet economic challenges, a fundamental principle of safe and reliable plant operations - nuclear safety culture - could be affected. Implied in the concept of nuclear safety culture is the idea that it is applicable to every employee in the nuclear organization, from the board of directors to individual contributors. Nuclear safety is the first shared organizational value adopted at a commercial power plant and is considered a collective responsibility and priority of all employees (Institute of Nuclear Power Operations, 2004, 2009a).

The purpose of this chapter is to provide the background for the research, a statement of the problem addressed by the research, and the purpose and nature of the study. A theoretical framework for the study is provided that outlines the basic concepts of a nuclear safety culture and continuous improvement processes. The research questions and hypotheses and the significance of the study are established in this chapter. Definitions of nuclear and continuous improvement process terms are provided to assist the reader's understanding of terminology used in this study.

Background

Nuclear power is a complex technology for electrical power generation. Commercial nuclear power plants consist of redundant systems that force a nuclear reactor shutdown when temperatures and pressures exceed design basis limits (McAvoy & Rosenthal, 2005). These systems are designed to prevent core damage and resultant potential radiological hazards to the surrounding environments. The technical challenges created by a need to ensure safe operations and to prevent the introduction of radioactive materials into the external environment have been a necessary element in the commercial nuclear industry since its beginnings (McAvoy & Rosenthal, 2005). Researchers have observed that this complex technology is being confronted by additional challenges and demands, including increased competitiveness among nuclear operating companies, intensified cost-saving strategies, and the replacement of original technical components due to natural aging with newer and more costly technologies (Itoigawa et al., 2005).

Although commercial nuclear power plants in the United States (U.S.) historically have had a reasonable record of safe operations (Langston, 2005; U.S. Nuclear Regulatory Commission, 2009a), events in the global nuclear industry have influenced the conceptualization of nuclear safety cultures. The industry had its first significant safety culture incident in 1979 as a result of an accident at the Three Mile Island Nuclear Power Plant in the United States (Institute of Nuclear Power Operations, 2004). The importance of maintaining strong cultural attributes related to nuclear safety were reinforced after the 1986 event at the Chernobyl Nuclear Power Plant in Ukraine (International Atomic Energy Agency, 1988). According to industry researchers, one critical factor essential to a strong nuclear safety culture was a nuclear business acumen, which included the ability to manage the unique interaction among technology, economics, human factors, and safety in a changing nuclear business environment (Wilpert & Itoigawa, 2001).

Researchers have identified continuing economic challenges to the commercial nuclear industry. After the Three Mile Island Nuclear Power Plant accident in 1979 the U. S. Nuclear Regulatory Commission mandated additional and more expensive nuclear safeguard systems to prevent a future incident (Wilpert & Itoigawa, 2001). As nuclear power plants began to age, stress induced corrosion cracking and boric acid degradation appeared in safety-related components which contributed to additional maintenance and inspection expenses and sometimes required additional capital to replace degraded components (McAvoy & Rosenthal, 2005). During financial and market fluctuations of the late 1990s, U.S. nuclear plant owners began to search for additional competitive business advantages (Itoigawa et al., 2005). Since the late 1990s, four U.S. nuclear plants have experienced extended shutdowns because of economic pressures resulting in nuclear safety issues (Institute of Nuclear Power Operations, 2003).

Because of regulatory rule changes, increasing operating costs, aging equipment and technologies, and changing market environments, nuclear power plant owners have been searching for ways to improve the processes that deliver value while simultaneously controlling production costs (MacAvoy & Rosenthal, 2005). Further, when applying processes to improve value and control costs, key organizational factors could be affected, specifically allocation of resources and work. Corcoran (2010) implied that application of improvement processes could affect the nuclear power plant's institutions by which the work organizations perform its activities involved with nuclear safety. Although a Lean Continuous Improvement Process may improve the production value and the value creating processes at a nuclear power plant, the effect on a nuclear safety culture is unknown.

Problem Statement

Researchers in other studies concluded that overemphasis on controlling production costs and improving the bottom line had compromised safety margins and degraded the broader safety culture of some nuclear organizations (Itoigawa et al., 2005). In two different studies of the most significant nuclear power incidents in the United States, analysts at the Institute of Nuclear Power Operations (2002a, 2003) concluded that in 20% of the cases studied pressure by nuclear plant leaders to continue plant operations had reduced the focus on nuclear safety and in 75% of the *leader pressure* cases, the pressure by nuclear plant leaders was economic in nature. In a competitive environment, pressure to continue operating a nuclear power plant may be a contributor to future significant events (Institute of Nuclear Power Operations, 2002a).

Organizational causes for nuclear power plant events and extended plant shutdowns have been examined (Itoigawa et al., 2005), and in recent years researchers have conducted studies to examine precursors to these organizational causes. These precursors typically have included various dimensions of leadership and organizational behaviors (International Atomic Energy Agency, 2002, 2005). There has been limited research on the dimensions of a nuclear safety culture when confronted by opposing economic forces. Different strategies are being implemented in the commercial nuclear power industry to confront the competitive business pressures of reducing operational costs (Itoigawa et al., 2005). One strategy is the use of a Lean Continuous Improvement Process. The problem addressed by this quantitative research is that no previous research was located that studied the influences of implementing a Lean Continuous Improvement Process on a nuclear safety culture and the effect of these influences was unknown.

Purpose

Given the scarcity of research that has examined the influence of continuous improvement processes on a nuclear safety culture, the purpose of this quantitative research was to examine the relationships between a continuous improvement process which focused on reducing process wastes and operating costs (i.e., Lean Continuous Improvement) and the nuclear safety culture at a nuclear power plant. The relationships between a Lean Continuous Improvement Process and six key nuclear safety culture indicators were assessed. The framework for a Lean Continuous Improvement Process (the independent variable) was based on two of the operating results established by Utah State University (2008): quality and cost/productivity. The framework for a nuclear safety culture (the dependent variable) was based on six indicators derived from a set of indictors for determining changes in a nuclear plant's organizational performance (Institute of Nuclear Power Operations, 2001): maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions.

The data were collected from an experimental and a control commercial nuclear power plant in the United States. The data collection period extended over five months. Based on operating histories at the experimental and control plants, issues aligned with the six cultural indicators selected for this study have the highest incidence of reporting during times of high work activity levels and infrequent evolutions, such as during preparations for and during refueling outages, installation of modifications, and tests and experiments. Thus, the most practical time period to conduct the study was in the summer as the plants prepared for fall refueling outages and tested plant systems due to increased ambient temperatures. Each indicator was represented by ratio data. The trended data from both the experimental and the control plants were then statistically compared.

Theoretical Framework

A brief literature review is provided to outline the basic concepts of a nuclear safety culture and continuous improvement processes relative to organizational cultures. Different methodologies used for analyses of safety cultures are discussed. The need for additional studies in the field of a nuclear safety culture in competitive business environments is identified and discussed.

Although organizations have used continuous improvement processes to increase productivity, flexibility, responsiveness, and customer service by changing and reshaping organizational cultures, there has been no common formula (Shafritz & Ott, 2001). Many organizations have noticed measurable improvements from implementing a continuous improvement process, yet often these improvements have primarily occurred in the areas of cost reduction and increased efficiency (Evans & Lindsay, 2005). Some organizational cultures may not be compatible with a continuous improvement process; other organizational cultures may be influenced in unintended ways when implementing a continuous improvement process (Kujala & Lillrank, 2004).

The concept of a nuclear safety culture was developed by researchers in the aftermath of a nuclear accident at the Chernobyl Nuclear Power Plant in Ukraine (International Atomic Energy Agency, 1988). On April 26, 1986, reactor number four at the Ukrainian Chernobyl Nuclear Power Plant exploded, which resulted in the top being torn from the reactor and exposing the nuclear core (Medvedev, 1990). Large geographical areas were badly contaminated, dozens of people died, and 336,000 people were evacuated and resettled (Medvedev, 1990). Although the severity of the Chernobyl Nuclear Power Plant accident may have been the catalyst for studies of a nuclear safety culture concept, the industry had its first significant safety culture incident in 1979 as a result of the accident at the Three Mile Island Nuclear Power Plant in the United States (Institute of Nuclear Power Operations, 2004). As explained by Itoigawa et al. (2005), the accident at the Three Mile Island Unit 2 Nuclear Power Plant near Middletown, Pennsylvania, resulted in a partial meltdown of the reactor core. The researchers determined the accident was caused by a combination of personnel errors, design deficiencies, and component failures. The extensive literature on these two nuclear accidents, however, has dealt almost exclusively with technical, radiological, and environmental issues.

Researchers for the International Atomic Energy Agency (1988, 1991) studied the concept of a nuclear safety culture after the Chernobyl accident and developed common terms, definitions, and methods for assessment. Analysts at the Institute of Nuclear Power Operations (2003, 2004) studied nuclear power plant events and problems relating to shortfalls in a nuclear safety culture. Perin (2005) argued that a nuclear power plant culture embodies several different cultures of control based on different methods of risk assessment. For example, the commercial nuclear industry culture is organized around a structured logic of command and control which requires tradeoffs with a parallel logic of problem identification and diagnosis. The two different intra-cultural logics have not aligned in an environment of intense pressures relative to schedule, electricity output, and reduction of operating costs.

Dimensions of a nuclear safety culture may be defined by multiple attributes and measured through multiple methods (Corcoran, 2010; International Atomic Energy Agency, 2002). Researchers have typically employed questionnaires and surveys to measure the attributes of leadership; worker and manager attitudes, beliefs, values, and behaviors; and, perceptions of risk, stress, and decision-making, all of which have some relevance to worker performance and the safety culture (Corcoran, 2010; Findley, 2004; Itoigawa et al., 2005; Reiman, 2007). Other researchers have studied safety culture attitudes, values, and beliefs in other high-risk industries (Burns, 2005; Helmreich & Merritt, 1998; McDonald, 2006; Reason, 1997).

A nuclear safety culture may also be defined by specific observable physical attributes (Corcoran, 2010; Institute of Nuclear Power Operations, 2009a). Observations of human actions and physical objects, such as the quality of physical goods and archival records, have been employed in some continuous improvement and safety culture studies (Helmreich & Merritt, 1998; Keating, Olivia, Repenning, Rockart, & Sterman, 1999). Human observations have frequently been used in nuclear power plant studies because the situation and resultant behaviors are not easily predictable (Corcoran, 2010; Institute of Nuclear Power Operations, 2006).

Nuclear safety culture researchers have focused on the individual worker's commitment and performance based on attitudes, work approaches, and communication systems (Reason & Hobbs, 2003; Reiman, 2007). Reason and Hobbs (2003) concluded that the most common worker errors at nuclear power plants were caused by failure to do something that should have been done rather than doing something incorrectly. Some nuclear safety culture researchers have studied other dimensions of the complex and dynamic interrelationships within the organizational cultures at nuclear power plants. Findley (2004) and Matthews (2006) found that organizational priorities were not always properly balanced between safety and production and often safety cultures were constrained when production factors became priorities over prevention factors. Reiman (2007) studied the maintenance organizations at three European nuclear power plants and concluded that nuclear safety was affected if the demands of the organizational task were not aligned with the dynamics of the organization's culture.

Researchers have stated a common parallel underlying extended shutdowns of U.S. nuclear power plants appeared to be the tension between increasing economic and production pressures and diminishing safety culture margins (Institute of Nuclear Power Operations, 2003; Itoigawa et al., 2005). For example, in 1996, the U.S. Nuclear Regulatory Commission directed Northeast Utilities to shut down the three nuclear reactors at the Millstone Nuclear Power Plant in Connecticut. Contributing to the shutdown was diminishing safety culture margins exacerbated by competitive advantage strategies (McAvoy & Rosenthal, 2005). The U.S. Nuclear Regulatory Commission directed closure of the Maine Yankee Nuclear Power Plant in 1997 because of cost-cutting measures at the expense of safety considerations (Jackson, 1997). A significant operating event occurred in 2002 at the Davis Besse Nuclear Power Plant when the reactor pressure vessel head began to leak radioactive coolant (U.S. Nuclear Regulatory Commission, 2002). Analysts at the Institute of Nuclear Power Operations (2002b) concluded a major contributor to this event was a shift in focus at all organizational levels from implementing high safety standards to justifying minimal safety standards. These analysts stated that a reduction in standards resulted from excessive focus on meeting short-term production goals.

Within the high-risk industries of aviation and space operations, medical surgery, chemical processing, and offshore drilling, more safety culture studies have been conducted than in the nuclear industry. Researchers have traced various efficiency and cost containment influences as sources of accidents (Columbia Accident Investigation Board, 2003; Helmreich & Merritt, 1998; McDonald, 2006; Vaughan, 1996). Based on the accidents studied, a parallel was evident among increasing production pressures and schedule conflicts and diminishing safety culture margins.

Although not focused on high-risk industries and the concept of safety culture, some researchers have specifically examined the influence of continuous improvement processes on organizational structures and cultures (Boggs, 2004; Benavent, 2006). A common theme was identified in some of these studies. Despite the demonstrated benefits of continuous improvement processes, many companies have instead realized business performance shortfalls. One reason for the organizational impacts was the negative influence on an organization's culture when employees view the efforts to improve value through waste removal and cost reductions as stressors (Chakravorty, 2010).

Perin (2005) argued the need for more understanding of relationships among various kinds of knowledge for reducing uncertainties affecting nuclear safety cultures. Itoigawa et al. (2005) proposed additional research into the economic factors challenging commercial nuclear power plants. Corcoran (2010) stated that the concept of a nuclear safety culture could benefit from more research and reflection.

There has been limited research on the dimensions of a nuclear safety culture when confronted by opposing economic forces. Different strategies are being implemented in the commercial nuclear power industry to confront the competitive business pressures of reducing operational costs (Itoigawa et al., 2005). One strategy is the use of a Lean Continuous Improvement Process. No research was located that studied the influence of a continuous improvement process on the respective safety culture. This research was conducted to bridge a gap in knowledge and to supplement the body of knowledge on nuclear safety cultures.

Research Questions and Hypotheses

This research examined the effects of a Lean Continuous Improvement Process on a nuclear safety culture at a commercial nuclear power plant in the United States. As an aid to understanding the research questions, constructs for the research were developed. The framework for a Lean Continuous Improvement Process (the independent variable) was based on two business operating results. The framework for a nuclear safety culture (the dependent variable) was based on six indicators derived from a set of indictors for determining changes in a nuclear plant's organizational performance (Institute of Nuclear Power Operations, 2001). Correlating changes in organizational performance to changes in organizational culture has a basis in previous research (Cameron & Quinn, 2006; Schein, 2004). Based on these factors and concepts, the following research questions and hypotheses were developed for this study. The results of this study responded to these research questions.

Ql: What relationships, if any, exist among the two Lean Continuous Improvement Process operating results (quality and cost/productivity) and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions)?

Hl_0: There is no correlation between quality and cost/productivity and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions).

$H1_A$: There is a correlation between quality and cost/productivity and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions).

Q2: What differences, if any, exist on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental)?

$H2_0$: A difference does not exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental).

$H2_A$: A difference does exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental).

Nature of the Study

The approach of this quantitative research was to apply an independent variable (a Lean Continuous Improvement Process) to the dependent variable of a nuclear safety culture at a commercial nuclear facility in the United States to study correlations among two production factors and six nuclear safety culture variables. To ensure probabilistic equivalence, both the experimental and control plants were assigned from a common pool of nuclear power plants located in the same Nuclear Regulatory Commission inspection region and the same geographical area, were members of a common industry alliance, had a recognized strong nuclear safety culture, and had similar organizational and professional cultures. The independent variable was applied simultaneously to the population of workforce groups at the experimental plant, thus there was no assignment of participants to groups and pretest measurements were not possible. The research design was, therefore, a post test-only control group design.

Relationships between a Lean Continuous Improvement Process and a nuclear safety culture were assessed to answer the research questions. The independent variable of a Lean Continuous Improvement Process (i.e., the applied program) reflected the techniques used to reduce process wastes and costs, create value, and improve workflow. The effect construct was the concept of a nuclear safety culture, expressed in this research by six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions). Based on previous studies (Institute of Nuclear Power Operations, 2001), the six cultural indicators set forth for this research were related to other performance measures and, therefore, had both high content and face validity. Thus, these indicators provided adequate metrics and correlated with other measures of the same construct.

The research strategy was similar to Reiman's (2007) nuclear power plant studies with the exception that the cultural indicator strategy for this research consisted of reviewing and categorizing data within the plants' incident reporting, or corrective action reporting systems, excluding materials related to proprietary, personal, and security safeguards information. A research instrument was not necessary for this study. Nuclear power plant corrective action systems are computerized to support collecting, sorting, and analyzing performance trends. Standardized trending criteria and codes, classified by issue types, were used and tabulated in a Microsoft Excel spreadsheet. A standardized coding structure ensured consistency in the coding process. Data for the operational, or productivity, indicators were provided by the experimental and control nuclear power plants.

Tabulated data were entered into SPSS® version 15.0 for Windows and descriptive statistics were conducted. To examine the first research question, 12 Pearson *r* correlations were conducted to assess if statistically significant relationships existed between a Lean Continuous Improvement Process and the six cultural indicators. To examine the second research question, a Multivariate Analysis of Variance (MANOVA) and an Analysis of Variance (ANOVA) were conducted on the six cultural indicators by group (experimental and control).

The study extended over the five months preceding the planned refueling outages for both the experimental and control plants. The collection period was started on May 1, 2009, and terminated on September 30, 2009. Results of this study are detailed and discussed in Chapter 4.

Significance of the Study

Competitive economic pressures on business organizations with commercial nuclear power plant assets have created stress on plant operations and maintenance budgets. These pressures have resulted in cost-cutting measures that could be risky, including deferred maintenance on plant equipment, reduced training, excessive reductions in down time for refueling outages, and staff reductions (Wilpert & Itoigawa, 2001). Many of these practices have been documented in the literature. Nuclear industry analysts identified knowledge deficits in the industry on nuclear safety culture concepts and began to study the factors affecting a nuclear safety culture. One of these studies was conducted by analysts at the Institute of Nuclear Power Operations (2004) and resulted in eight principles for a strong nuclear safety culture (see Appendix C for a summary of these eight principles). Principle 2 (Leadership commitment to nuclear safety) and

Principle 4 (Decision making reflects nuclear safety first) were considered important for this quantitative research. Attributes within these two principles implied that an emphasis on production (in other words, a focus on plant generation output) could potentially undermine a nuclear safety culture.

Academic researchers and more reflective industry analysts identified gaps in knowledge and understanding of the interrelated dimensions of a nuclear safety culture and have proposed additional research. For example, Itoigawa et al. (2005) proposed additional research into the economic factors challenging commercial nuclear power plants. Perm (2005) concluded that the existence of a cultural logic of questioning and discovery, as delineated by the Nuclear Regulatory Commission and the Institute of Nuclear Power Operations, contradicted the cultural logic of control predominate in the daily operations and management of a nuclear power plant. Perm's conclusion seems to indicate that Nuclear Safety Culture Principle 6 (A questioning attitude is cultivated) is inconsistent with the nuclear industry command and control function when faced with pressures regarding schedules, outputs, and costs. Perm (2005) also proposed additional research to develop greater understanding of the relationships between these two cultural logics. Corcoran (2010) concluded that the industry's understanding of a nuclear safety culture could benefit from additional research and reflection.

The significance of this quantitative study was to examine a segment of the debate on a nuclear safety culture during a climate of economic pressures and uncertainties. Many approaches have been used to support nuclear power plant performance in an uncertain environment. This study focused on one approach -a Lean Continuous Improvement Process - and its application to a nuclear power plant. Other industries have used this approach to improve processes that create value by reducing process wastes and operational costs. No previous research could be found relative to implementation of a Lean Continuous Improvement Process at a commercial nuclear power plant.

Correlating plant operating results post implementation of a Lean Continuous Improvement Process to plant indicators common in the industry provided a methodology to identify if relationships existed between the operating results and the plant indicators. If relationships existed between plant operational data and the selected plant performance indicators, and if these relationships could be compared to another plant's operational data and the same plant performance indicators, the research questions would be answered and the nuclear safety culture body of knowledge would be increased. Since economic pressures and uncertainties will continue for the foreseeable future, commercial nuclear power plants will continue to seek new approaches for improving processes and solving problems.

The significance of this study also provided new insights for improving leader actions for maintaining a strong nuclear safety culture. Schein (2004) discussed the importance of the leader in managing and nurturing the desired culture. Detert, Schroeder, and Mauriel (2000) suggested that additional research was needed to identify organizational cultural maintenance issues after implementation of new business approaches. This study was designed to fill some of this gap and provide additional insights for nuclear power plant leaders trying to maintain a strong nuclear safety culture when reacting to economic pressures and uncertainties.

Definitions

Nuclear and Lean Continuous Improvement Process terms are defined as used in the context of this research. Words used in a unique way for the subject of this research are defined. The following definitions are provided to assist the reader with an understanding of terminology related to this research.

Capability Factor. Capability factors are defined as the ratio of the available energy generation over a given time period to the reference energy generation over the same time period, expressed as a percentage (Institute of Nuclear Power Operations, 2009b).

Continuous Improvement. Continuous improvement is defined as a quality methodology that requires processes and performance to be continuously reevaluated and improvements identified and implemented. The continuous improvement process is an ongoing evaluation and change of processes, products, programs, and services to make them work better (Evans & Lindsay, 2005).

Event. Event is defined as an outcome, condition, or eventuality that occurred during some activity and resulted in challenges to safe plant operations (Adams, 2007).

High-Risk. High-risk is defined as a hazardous activity or business venture where the risk to human life is an essential part of the operation and a proper balance between production and safety is required (Collins, 2005).

Lean Continuous Improvement. Lean continuous improvement is defined as a continuous and systematic approach to identifying and eliminating waste and non-value-added activities throughout the entire value chain to improve cycle times, reduce response times, and simplify the design and functioning of processes, products, and services (Womack & Jones, 2003). A model of the Lean Continuous Improvement Process is provided in Figure 1.

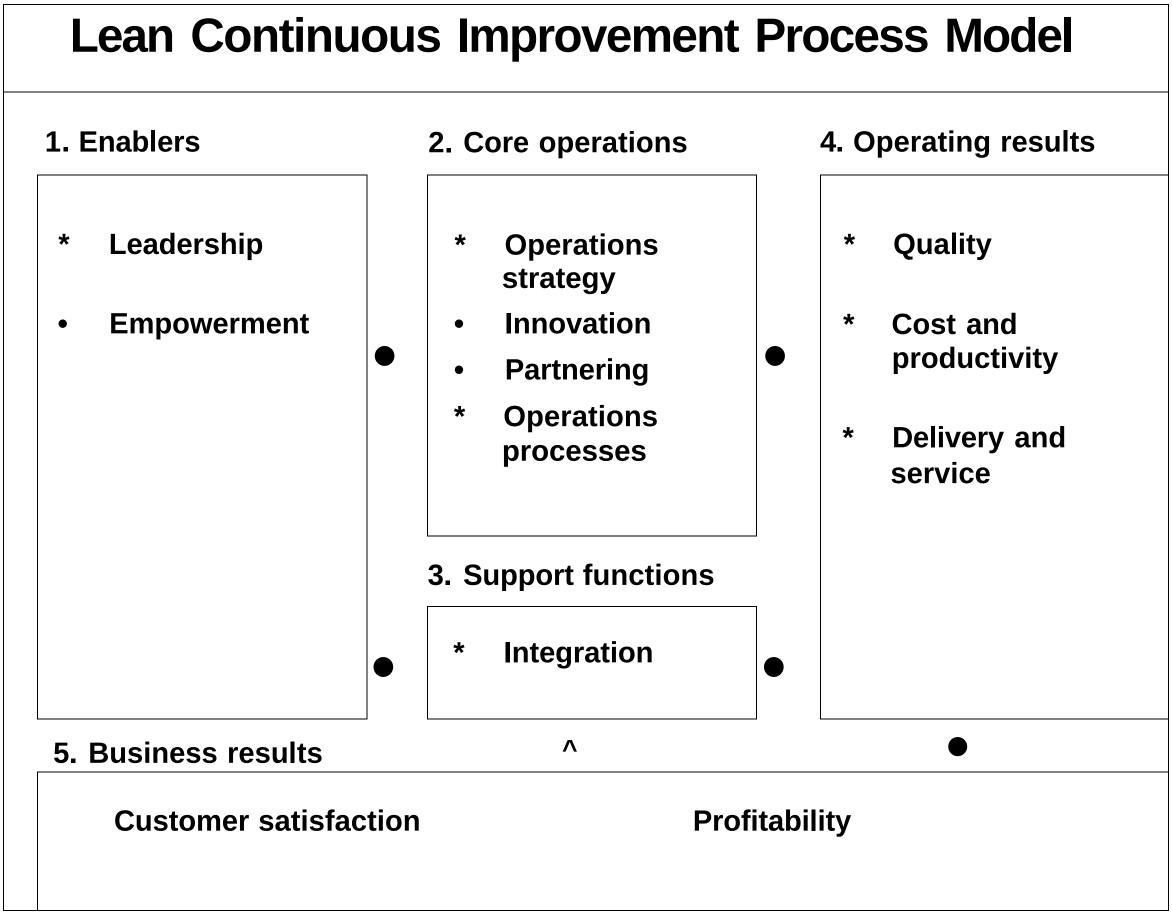

Figure 1: Model of the Lean Continuous Improvement Process. The model depicts the interrelationship of key process variables that lead to business results. (Note: Adapted from "The Shingo Prize for Operational Excellence," by Utah State University, September 2008.)

Nuclear Safety Culture. Nuclear safety culture is defined as a nuclear organization's values and behaviors - modeled by its leaders and internalized by its members - that serve to make nuclear safety its overriding priority (Institute of Nuclear Power Operations, 2004).

Quality. Quality is defined as the totality of characteristics that bear on the ability of the organization to satisfy stated and implied needs (Gryna, Chua, & DeFeo, 2006). Quality for a nuclear power plant is defined as a station capability factor.

Standard Nuclear Performance Improvement. Standard nuclear performance improvement is defined as an integrated approach to ensure business results are achieved through effectively monitoring performance, identifying shortfalls in the desired performance and specific actions, and implementing solutions and change to correct shortfalls and improve performance (Institute of Nuclear Power Operations, 2005).

Waste. Waste is defined as anything that adds cost or time without adding value. There are seven fundamental wastes: unnecessary transportation, excessive inventory, unnecessary motion, unnecessary waiting, overproduction, overprocessing, and defects (Junewick, 2002).

Value. Value is defined as a numerical quantity measured, assigned, or computed to reflect the ratio of quality over a given period of time to the reference cost over the same period of time, expressed as a percentage (Gryna et al., 2006).

Summary

The technological complexities inherent in nuclear power plants to prevent reactor core damage and potential radiological hazards, while ensuring continual operations to support electricity generation, have been challenged by economic pressures to improve the processes that deliver value by reducing production wastes and operating costs (Itoigawa et al., 2005). Researchers have stated a common parallel underlying extended shutdowns of U.S. nuclear power plants appeared to be the tension between increasing economic and production pressures and diminishing safety culture margins (Institute of Nuclear Power Operations, 2003; Itoigawa et al., 2005).

One strategy for creating value and reducing production wastes and costs is the use of a Lean Continuous Improvement Process, but the effect of applying a Lean Continuous Improvement Process to a nuclear safety culture was unclear. Researchers have identified differing perspectives and frameworks for continuous improvement. Although organizations have used continuous improvement processes to increase productivity, flexibility, responsiveness, and customer service by changing and reshaping organizational cultures, there has been no common formula (Shafritz & Ott, 2001). Many organizations have noticed measurable improvements from implementing a continuous improvement process, yet often these improvements have primarily occurred in the areas of cost reduction and increased efficiency (Evans & Lindsay, 2005). Some organizational cultures may not be compatible with a continuous improvement process; other organizational cultures may be influenced in unintended ways when implementing a continuous improvement process (Kujala & Lillrank, 2004).

The concept of a nuclear safety culture is complex and somewhat difficult to comprehend. In fact, the literature on safety culture has demonstrated that the concept includes many interrelated components and members of many organizations (Itoigawa et al., 2005). Given the interrelationship of economic forces on the operations of a commercial nuclear power plant, one would expect that the introduction of a process to improve a plant's ability to create value and contain operating costs would be included in studies of the relationships of economic issues to nuclear safety. Despite the significance of reliable and safe technical systems for nuclear electrical generation and the potential influence of production priorities with a focus on cost containment, there has been relatively little research on the various dimensions of a nuclear safety culture when affected by opposing economic-based factors.

Organizational causes for nuclear power plant events and extended plant shutdowns have been examined in the literature (Itoigawa et al., 2005), and in recent years researchers have conducted studies examining precursors to these organizational causes. These precursors typically have included various dimensions of leadership and organizational behaviors. Several event investigations at U.S. nuclear power plants have uncovered organizational flaws. Although researchers have traced various efficiency and cost containment influences as causes of events, no research was located that studied the influence of a continuous improvement process on the respective safety culture.

Organizational culture and nuclear management researchers have not adequately studied the effect of implementing a Lean Continuous Improvement Process on the safety culture of a commercial nuclear power plant. The literature on nuclear power plant accidents has dealt almost exclusively with technical, radiological, and environmental issues. This research attempted to bridge a gap in knowledge and to supplement the body of knowledge on nuclear safety culture.

Within the next chapter of this dissertation, a review of organizational culture, continuous improvement, and relevant safety culture literature has been provided. Since organizational culture and nuclear management literature have not adequately addressed the effect of continuous improvement processes on a nuclear safety culture, this review included literature in the area of a nuclear safety culture and safety cultures in other high-risk industries, wherein the latter often focused on industrial safety cultures. As such, Chapter 2 has been divided into five subsections of prior studies to assist in comprehension of the material: an overview of organizational culture, an overview of continuous improvement processes, an overview of a continuous improvement culture, a safety culture relative to a nuclear power plant safety culture, and a safety culture relative to other high-risk industries.

CHAPTER 2: LITERATURE REVIEW

Studies assessing safety cultures have been conducted by government, academic, and industry organizations. These studies were considered as the foundational bases for this research. Researchers and theorists have studied organizational culture concepts, continuous improvement processes, and the effects of continuous improvement processes on organizational cultures. These themes were considered relevant for this research. The dimensions that shape and define any organizational culture have been viewed as difficult to establish and the result of a long process of implementation by all members of the organization (Schein, 2004). As an example of an influencing dimension, Shafritz and Ott (2001) observed that organizations have used continuous improvement processes to increase productivity, flexibility, and responsiveness by changing and reshaping organizational cultures.

Within this section of the dissertation, a review of organizational culture, continuous improvement processes, and relevant safety culture literature is provided. Since organizational culture and nuclear management literature have not adequately addressed the effect of continuous improvement processes on a nuclear safety culture, this review included literature in the area of a nuclear safety culture and safety cultures in other high-risk industries, wherein the latter often focused on industrial safety cultures. There are some similarities in key principles for both nuclear and industrial safety cultures (Reason, 1997).

As such, this section has been divided into five subsections of prior studies to assist in comprehension of the material: an overview of organizational culture, an overview of continuous improvement processes, an overview of a continuous improvement culture, a safety culture relative to a nuclear power plant safety culture, and a safety culture relative to other high-risk industries.

Organizational Culture

Organizational culture has been conceptualized in the literature as a set of intangible attributes, such as values, beliefs, assumptions, behaviors, perceptions, and norms, synergistically working with tangible attributes, such as customs, traditions, rituals, and shared group meanings (Shafritz & Ott, 2001). Some theorists have defined organizational culture as shared meanings that group members assign to organizational concepts and frameworks that are held in common. A definition of this type would include Schein's (2004) assertion that the culture of a group includes patterns of assumptions held in common that the group learned as it matured. Hofstede (2010) defined organizational culture as the collective programming of the mind distinguishing the members of one group from another. Others have defined organizational culture as the shared meanings, behaviors, and assumptions aligned with the differences in meanings, behaviors, and assumptions. For instance, Schneider (1990) maintained that shared group behaviors and assumptions that prevail across the work environment would be countered by individual behaviors and assumptions.

Other dimensions and attributes for organizational culture have been conceptualized in the literature. Cameron and Quinn (2006) summarized the works of some culture researchers, specifically the 1992 studies conducted by Martin. Martin proposed three dimensions to an organizational culture - integration, differentiation, and fragmentation - that supposedly co-existed in all organizations. The integration dimension was similar to Schein's conceptualization that organizational culture was a set of shared meanings. The differentiation dimension was similar to Schneider's conceptualization that organizational cultures were defined by the differences and conflicts between subgroups within the organization. The fragmentation dimension was based on the assumption that organizational cultures were ambiguous and unknowable. Cameron and Quinn (2006) argued that culture cannot be described as an attribute of an organization since it was the inherent in the organization itself. Wagner and Hollenbeck (2005) summarized other perspectives and dimensions, including Hofstede's culture dimensions of power distance, uncertainty avoidance, individualism, and masculinity and Ernst's perspective of an organizational culture grid, wherein people orientation (i.e., participative leadership) and response to the environment were the key cultural dimensions. Kotter and Rathgeber (2005) argued that congruence was a key dimension within organizational cultures.

Hofstede (2010) documented that organizational cultures differ mainly at the level of practices. Examples of practices included symbols and rituals, process-oriented versus results-oriented perspectives, open systems versus closed systems, and tight versus loose controls. According to Hofstede (2010), since organizational cultures were rooted in practices, they were somewhat more manageable than national cultures which tended to be rooted in values. Based on additional studies, the cultural dimensions of power distance, uncertainty avoidance, individualism, and masculinity were amended to include a fifth dimension of long-term versus short-term orientation (Hofstede & Hofstede, 2004). A long-term orientation indicated values of efficiency, stewardship, and perseverance, with an organizational mindset of safeguarding the organization or group.

A short-term orientation indicated values of sustaining tradition, protecting a group's reputation, and meeting obligations. Although these two orientations have some relevance to functions within business organizations, application of orientation to business cultural practices was not clear.

The classical conceptualization of culture was viewed as a process within a non-equilibrium state and included diagnosis as a key component for understanding an organization's culture and eventually changing the culture to a desired state (Seel, 2000). Seel argued that organizational culture should be considered an emergent result of conversations and negotiations between members of an organization. The implications of this viewpoint were that organizational cultures should be described by participative and collaborative inquiry rather than diagnosis. Seel applied Schein's approaches to organizational culture to the argument - if a culture is co-created by the collective membership of the organization, then these members should jointly inquire into it.

In an effort to identify the specific constructs used by researchers to describe the larger concept of organizational culture, Detert, Schroeder, and Mauriel (2000) performed a qualitative content analysis of the literature. The results of the analysis indicated a small number of constructs were common in the majority of existing culture research. These constructs included ideas held within organizations about the basis of truth and rationality, the nature of time and the time horizon, stability relative to change and innovation, orientation to work, isolation relative to cooperation, and orientation and focus (internal versus external focus). The last construct was of interest from a continuous improvement perspective. It included ideas about whether the organization assumes it controls, or is controlled by, its external environment, wherein the focus would be either on improving processes in the organization or on improving its standing in the industry (Detert et al., 2000).

Culture in groups and organizations has been difficult to define in unambiguous terms (Schein, 2004). Cameron and Quinn (2006) maintained that the broadness and inclusiveness of organizational culture have resulted in the many different conceptualizations. As noted by Cameron and Quinn, since the concept is comprised of a set of complex, interrelated, and ambiguous factors, it would be impossible to include every relevant factor when assessing organizational culture. Reason (1997) observed that a continuing controversy among social scientists was whether a culture is something an organization *has* or whether it is something an organization *is.* Reason viewed culture as a hidden force that unified an organization by providing meaning, direction, and mobilization. Although operationally culture has been defined as shared values, beliefs, assumptions, and norms, these concepts are seldom documented yet learned by living in an organization and becoming a part of it (Frick, 2007).

Different conceptualizations of organizational culture may have been developed due to differences in actual organizational cultures. As stated by Shafritz and Ott (2001), each organizational culture is different because what has worked repeatedly for one organization may not for another, which results in changes to basic assumptions. These researchers maintained that an organization's culture is shaped by many factors, including the societal culture in which it resides and its technologies, markets, and competition. Further, some organizations have many subcultures that exist in different geographical areas (Shafritz & Ott, 2001).

Other factors that shape an organization's culture include the structural foundations of the organization, which may be ordered by the regulatory environment, and the internal integration necessary for group functioning and adaptation to changing environments (Cameron & Quinn, 2006). Schein (2004) maintained that when the intangible aspects of culture are applied to organizations engaged in producing goods and services, the term organizational culture must be broadened to include the tangible aspects of structure and patterning. Yukl (2002) stated that structure would be used to stabilize an organization and the organizational structure included systems, processes, policies, rules, and the way the organization functions. According to Schein, patterning and integration would be used to bind the various intangible elements of culture into a coherent whole. Schein viewed patterns as derived from accumulated learning as an organization solves its problems, while integration was viewed as derived from various subcultures, such as professional and national subcultures.

Other dimensions have been proposed to classify organizational cultures by types. Schein (2004) presented these other dimensions as universal typologies. According to Schein, the value of typologies was to provide useful categories for sorting out the complexities of organizational realities. The basic typology focused on assumptions about individual participation and involvement in the organization. The next level of typology focused on assumptions of corporate character and culture. A more difficult typology was described as intraorganizational. Schein viewed the intraorganizational typology as difficult because work arrangements within many organizations were based on a combination of the work to be done and the occupational reference groups performing the work.

Thus, organizational culture includes formal structural relationships and problem solving approaches and informal assumptions and group interconnections (Wagner & Hollenbeck, 2005). Based on the various conceptualizations of organizational culture, a formal definition of organizational culture was developed by Schein (2004) that included the various factors that shape a culture. (This definition of organizational culture has been used in the nuclear power industry to conceptualize a nuclear safety culture.) The culture of an organization was defined as a pattern of shared assumptions that the organization learned as it solved the problems encountered with internal integration of its members and external adaptation to its surroundings. Schein added to this definition that the organization's culture has worked sufficiently well to be considered valid to be taught to new organizational members as the correct way to perceive, think, and feel relative to the problems of integration and adaptation.

Schein (2004) distinguished between underlying beliefs and espoused values, wherein the values may or may not be consistent with the beliefs. For example, an organization might espouse that quality is the primary objective for its products, but the underlying belief might be that any defects in the products would be marketed anyway at a discounted price. The underlying beliefs of the organization's culture would be the learned responses to problems encountered in the external environment and problems encountered with internal integration.

Another way of conceptualizing organizational culture is as a composite of interacting subcultures that have specific characteristics and a sense of identification (Wagner & Hollenbeck, 2005). As noted by Wagner and Hollenbeck, subcultures may be classified in several ways, including occupational and professional skills and generational and national diversities. Individuals in the same subcultures would tend to think and act more similarly than would people from other subcultures. These organizational subcultures resulted in diverse networks of meaning yet were homogenous with the organization's overall culture.

Cameron and Quinn (2006) identified four major organizational culture types. The first major culture type described was the hierarchy culture, characterized by a formalized and structured workplace, procedures that govern work people perform, and effective leadership to organize and coordinate. The long-term concerns of hierarchy organizations were viewed as stability, predictability, and efficiency, thus requiring formal rules and policies. The second major culture type - the market culture - evolved as organizations encountered new competitive challenges. The market culture was described as a results-oriented organization, orientated to the external environment instead of internal matters. According to Cameron and Quinn, the market organizational culture does not rely on rules and procedures, and has a set of core values focused on competitiveness and productivity. The third major culture type was described as a clan culture, characterized by an emphasis on loyalty and tradition, teamwork, participation, and consensus. The last major culture type was described as an adhocracy culture, characterized by a dynamic, entrepreneurial, and creative workplace. This type organization was viewed as committed to experimentation, innovation, and change. Organizations develop a major culture type dependent on the industry, stage of organizational life cycle, and leadership style (Cameron & Quinn, 2006).

Schneider (1990) considered organizational cultures strong when all levels of the organization shared the same goals and values. In strong organizational cultures, people throughout the organization at all levels understood what they were supposed to do because a few guiding principles were clearly established (Reason, 1997). Not all organizational cultures, however, would be desirable. Organizational researchers have described a number of negative or dysfunctional cultural dimensions (Hofstede, 2010; Reason, 1997; Wagner & Hollenbeck, 2005). Dysfunctional dimensions of culture included paranoid, bureaucratic, and political factors. Another type of dysfunctional culture was described as anxiety-avoidance. Although dysfunctional and counter cultural behaviors and practices have been observed wherein organizational cultures were disrupted, Mann (2005) observed that counter cultures typically disrupted other organizational factors as well and the topic was broader in scope than simply culture.

Researchers of organizational cultures have discussed actions necessary for maintaining the culture and reshaping or changing the culture. Some researchers concluded that organizational cultures were maintained through constancy of business purpose for improvement, unity of organizational members through participation and ownership of work, intimacy among organizational members through sharing, and integrity in work practices (Smith, 2006). Some researchers have considered cultures in any group setting as dynamic - naturally evolving through various kinds of incremental changes (Trice & Beyer, 1993). Trice and Beyer stated that attempts to maintain an organization's culture involved adjustments in ideas, practices, and structures that could be considered changes, yet concluded that true organizational change referred to something more deliberate, drastic, and profound than incremental adjustments in the culture. Trice and Beyer maintained that cultural changes involve a break with the past and continuity in organizational cultures is disrupted. Three different types of culture change efforts in organizations were described - revolutionary efforts to change the cultures of complete organizations, efforts confined to change subunits within organizations, and efforts that are gradual and incremental with the intent to eventually change an entire organization's culture (Trice & Beyer, 1993).

Other researchers have considered organizational culture changes as predictable patterns (Cameron & Quinn, 2006). Cameron and Quinn maintained that organizational cultures change as the organization moves through its life cycle stages. According to this theory, in the earliest stages of the organization's life cycle organizations have adhocracy cultures. As the organization matures and develops, the culture evolves into a clan culture, followed by a hierarchy culture and finally a market culture. Although this theory of predictability may be somewhat narrow for high-risk industries such as nuclear power energy, Cameron and Quinn qualified the theory that culture changes in mature organizations (typically those classified as hierarchy cultures) have occurred in less predictable patterns. This theory indicated that culture changes involving hierarchy cultures should be managed consciously.

According to Seel (2000), the purpose of describing an organization's culture should be because of some need to change the culture or to determine if the culture needs to be changed. The implications of this viewpoint were that cultural description did not precede cultural change since organizational members participated in describing the culture. Seel argued that the process of discovery and inquiry fostered organic change that evolved rather than the classical mandate approach.

Yukl (2002) stated that an organization's culture could be influenced by what leaders communicate as priorities, values, and concerns and by the ways leaders react to critical incidents and crises. Organizational leaders also have a role in maintaining and shaping culture by communicating the desired end-state of results (Yukl, 2002). Schein (2004) maintained that leaders must first understand the organization's culture before attempting to alter the culture. According to Schein, organizational leaders create a group's culture through primary and secondary embedding mechanisms. Primary mechanisms included what leaders measure, how leaders react, how resources are allocated, and how leaders model and coach desired behaviors. Secondary mechanisms included organizational designs, systems, procedures, and rituals.

Some theorists have argued that the prevailing cultural values would lead organizational members to rely on specific sources of guidance to make sense of what is happening around them, and that reliance on particular sources of guidance would influence the individual and the organization's cultural foundations (Smith, Peterson, & Schwartz, 2002). For instance, organizational actions for improving competitiveness in response to changing business environments and customer demands have resulted in changes to organizational cultures (Smith et al., 2002). Organizations have also used continuous improvement processes to increase productivity, flexibility, responsiveness, and customer service by changing and reshaping organizational cultures (Shafritz & Ott, 2001). Some theorists, however, have considered a continuous improvement culture as a subset of the larger organizational culture and not a significant influencing factor (Juran, 1995).

Researchers in sociology and psychology have provided other perspectives on organizational cultures. One example relevant to this dissertation included the concept of cross-cultural interactions. Bochner (2003) discussed the psychological processes that occur between individuals and groups who differ in their cultural backgrounds. The researcher indicated that people working in similar disciplines inhabit a culturally homogeneous space in that they have comparable values, beliefs, and technical languages. Bochner contended that the interaction of one culture with another could have potentially adverse reactions. Relevant to this dissertation were the aspects of a culture of continuous improvement interacting with a culture of nuclear safety. Based on the cross-cultural research results, the two organizational culture types would not inhabit a culturally homogeneous space.

Although major change efforts have been shown to help some organizations adapt to changing environments and improve overall performance, DeFeo and Barnard (2005) observed that most organizational change initiatives have failed to produce desired results. DeFeo and Barnard (2005) maintained that the fundamental flaw in most change strategies was a focus on the change and the results rather than developing an understanding of how the organizational culture would react to the change. Similarly, Kotter (1996) concluded that few organizational change initiatives have successfully helped organizations improve performance. According to Kotter, when improvement initiative changes have not produced the desired results, the interdependence of new practices with existing organizational cultures had not been factored into change plans and the changes were not anchored in the existing organizational culture.

Measurement indicators for an organizational culture and changes within an organizational culture have been difficult to establish because the basic defining dimensions of an organizational culture are not directly observable (Schein, 2004). This measurement problem may exist because researchers have concluded that a given organizational culture is defined in the organization's formal structures and processes, symbolic systems, products or services, and actions of the group membership. As observed by Itoigawa et al. (2005), based on these defining dimensions, organizational culture cannot be quickly changed at management's desires. These researchers concurred with Schein that organizational culture is the end-state of a long process of implementation by all group members in which they define and construct their system of meanings. Schein (2004) stated that empirical measurement of organizational cultures was difficult because the concept includes shared group rather than individual values, assumptions, and beliefs.

From the literature, it can be concluded that organizational culture has been conceptualized in various ways because the culture of an organization has been defined by both mechanistic and organic dimensions and because every organizational culture is different. Empirical measurement of the concept has been difficult for researchers because of these competing dimensions. Researchers have identified that some organizational cultures have been shaped by a distinctive subculture, such as a professional or industrial subculture, due to the nature of the business. Furthermore, an organization's culture has been influenced by other factors, including implementation of processes with the purpose of improving the organization. Organizational cultures can be changed yet some changes have not been as expected. Although major change efforts have been shown to help some organizations adapt to changing environments and improve overall performance, many organizational change initiatives have failed to produce desired results when the interdependence of new practices with existing organizational cultures had not been adequately considered.

Continuous Improvement Process

The continuous improvement process has been conceptualized in the literature from various perspectives and within different frameworks. Basic continuous improvement has been generally defined as reduction of complexity and variation (Wescott, 2006). Beyond this basic definition, various dimensions, attributes, and approaches for continuous improvement frameworks have been proposed in the literature. McCann (2007) maintained that any continuous improvement approach consists of four fundamental steps - standardize the process, improve the process, innovate the process, and repeat the first three steps again. Wescott (2006) stated that the basic framework of any continuous improvement process was the operational work process. According to this viewpoint, the work process has to be definable (inputs and outputs must be understood), predictable (expected process outcomes are known), and repeatable (the outcomes can be reproduced each time the process is used). Researchers have been in general agreement that continuous improvement processes, whether defined as Total Quality Management, Six Sigma, Lean Production Systems, or any combination of these, include ongoing evaluation and change of processes, products, programs, and services to make them function better. Each continuous improvement framework, however, has some contrasting approaches to accomplishing the end objective of superior product and service quality (Evans & Lindsay, 2005).

Some researchers have argued that an effective and sustainable continuous improvement project has to focus on three system types within any organization - the formal systems, the informal systems, and the intangible systems (Aiken, 2006). Formal systems are characterized by written documentation, whereas informal systems are characterized as supplemental to the formal systems and the way required outputs are actually achieved. Aiken (2006) characterized intangible systems as the knowledge and culture of the organization that inform workers of limitations and conditions of the work environment.

Evans and Lindsay (2005) stated that before a continuous improvement process can provide effective results, an organization must first understand the basis, nature, and differences of the various processes and then develop an approach tailored to the individual organization. Each organization has unique characteristics, visions, and strategies for market integration and any single specific continuous improvement approach may be difficult to align with the purpose of the organization (Evans & Lindsay, 2005). Okes (2007) stated that an organization should consider the total economic value of a continuous improvement process before inserting the process into the organizational culture. As viewed by Okes, the economic value of a particular continuous improvement process was dependent on the organizational benefits obtained compared to the costs incurred. In other words, organizational leaders should receive an acceptable return on investment.

Researchers have generally maintained that organizations should take a holistic and integrated approach to continuous improvement practices and techniques. As stated by George (2002), the organization must be customer-focused, process-centered, and driven to excellence throughout all levels of the organization. The process-centered orientation included a sequence of steps one must follow to implement the continuous improvement approach and a series of performance metrics to determine the extent of the improvement required to carry out the process (Wescott, 2006).

Pioneers in the continuous improvement process movement, specifically Deming (1986) and Juran (1995), viewed quality as a continuous improvement cycle vital for organizational sustainability in competitive international markets; emphasized the importance of partnerships among management and workers and the company and external stakeholders; and recognized the difficulties associated with changing organizational cultures. Deming (1986) maintained that continuous improvement consisted of a cycle of planning, taking action, and reviewing the results of the action for product and service quality through reduction in uncertainty and variation at all functional levels within an organization. The concept of variation was based on the degrees of difference which exist in all processes and systems.

In Deming's view, continually higher levels of improvement would lead to higher levels of productivity because of fewer defects and errors and, therefore, better use of resources and lower production costs. Deming's approach was not focused on change within existing processes and management systems. Rather, Deming stressed radical changes in entire perspectives of management (Evans & Lindsay, 2005). Deming (1986) argued that best efforts by everyone and support by top management were not sufficient for the transformation in management styles necessary to improve American industry. To support the argument, Deming had proposed 14 points for transforming management and the organization. Two of these points have important relevance to the commercial nuclear power industry in the 21^{st} century. Deming's first point was to create a constancy of purpose for continual improvement of products, processes, and services while allocating resources to provide for long range needs rather than only short-term profitability. Deming's seventh point was to institute leadership aimed at helping workers to do a better job and at focusing on quality rather than numbers.

Juran (1995) defined continuous improvement as product performance that resulted in customer satisfaction and freedom from deficiencies. Juran's view of continuous improvement was similar to Deming's view in that quality and performance excellence were achieved through a framework of interdependent functions that constantly cycled through a sequence of continuous improvement activities. Consistent with Deming's approach to continuous improvement, Juran maintained that top-level management must be committed to quality and continuous improvement and that control techniques were essential to hold the gains after improvement projects were completed.

The cornerstone processes in the Juran approach to continuous improvement included quality planning, quality control, and quality improvement breakthrough (Juran, 1995). Quality planning included the activity of developing quality goals and all the processes involved in preparation to meet quality goals, whereas quality control was the operational method for assuring that processes worked as they were designed to work and that target levels of performance were being achieved (Juran, 1995). Juran specified a structured approach for breakthrough improvement that focused on studying symptoms, diagnosing causes, and applying remedies. According to Juran (1995), a continuous improvement approach should be directed for adaptation within an organization's current business approaches without major changes in strategic approaches. In contrast to Deming, Juran did not propose a major cultural change in the organization, but rather viewed continuous improvement as working within the current systems (Evans & Lindsay, 2005).

One of the pioneers of quality and continuous improvement, Kaoru Ishikawa, argued that 95% of an organization's problems could be solved through knowledgeable application of a select number of process tools (American Society for Quality, 2009). Ishikawa maintained that continuous quality improvement extended beyond models and methods to using appropriate techniques at the appropriate time to improve processes and performance (American Society for Quality, 2009). The foundational seven continuous quality improvement tools included histograms, control charts, Pareto analyses, cause and effect diagrams, check sheets, scatter plots, and stratification. The American Society for Quality (2009) indicated the power of these seven continuous improvement tools was the universal application to any problem and the versatility of use. It appears that this viewpoint may be limited in scope. Based on other researchers' viewpoints, the power of these seven continuous improvement tools may be in application of the tools and in the results for decision making processes. Even then, the use of seven basic tools to resolve most modern business problems may be rather simplistic without consideration of other complex organizational issues such as culture.

During the last 20 years, many theorists and practitioners have devised different approaches for improving product and process quality, some of which were simply reframing of earlier approaches. For instance, Total Quality Management (TQM) was championed as a continuous improvement approach that would change the organization's culture by first reshaping the production systems of the organization (Evans & Lindsay, 2005). The TQM approach to continuous improvement evolved from earlier conceptualizations of total quality control (Gryna et al., 2006). Deming (1986) defined a production system as the operational work structure, documented in technical and managerial procedures, which was used to guide the coordinated actions of people, machines, and information to assure customer satisfaction and economies of production. The foundation of TQM included use of the scientific method for solving problems and involvement by all stakeholders in achieving desired quality levels: the workers, the managers, the suppliers, and the customers (Evans & Lindsay, 2005). When the TQM movement was seen as not meeting organizational needs for continuous improvement, partially due to misapplication of the approach, new theories, often based on previous approaches, began to emerge (Evans & Lindsay, 2005).

The Theory of Constraints (TOC) approach to continuous improvement evolved from systems-thinking theorists. The TOC approach was based on the concept that a system was limited in achieving its maximum capability by a small number of constraints, wherein the goal of the organization was to identify and exploit these constraints so that throughput could be maximized and inventories and operating costs could be minimized (Breyfogle, 2010a). Breyfogle noted that the operational performance of an organization was a result of the integration of its processes, not of individual steps and procedures in isolation. Thus, the output of an organization was a function of its constraints. According to this approach, continuous improvement activities should focus on the integrated organizational system so the entire organization is optimized.

Contemporary researchers have maintained that concepts of continuous improvement processes should be broadened to include analyses of chronic causes of poor performance to eliminate process waste and variation, while adding value to the processes. For instance, Gryna et al. (2006) advocated a process-oriented continuous improvement approach, wherein if the organization resolved the chronic causes of process problems the product or service would take care of itself, and any results achieved would lead to continually improved processes. In the 1980s, Motorola Corporation proposed that both managerial and statistical techniques should focus on reducing variation in processes and initiated the Six Sigma Continuous Improvement Process (George, 2002).

The Six Sigma Continuous Improvement Process has been described as a business improvement approach used to find and eliminate causes of defects and errors with a focus on business outputs that are critical to customers and a clear financial return for the organization (Evans & Lindsay, 2005). Deming (1986) had used the statistical term sigma - the standard deviation of measurements around the process mean - to denote variation in a process. The Six Sigma Continuous Improvement Process was based on statistical measures to express the rate of defects introduced by a process or built into a product. For a process to be considered six-sigma capable there would be six standard deviations (3.4 errors or defects per million opportunities) between the process mean and either specification limit (Evans & Lindsay, 2005). In contrast to other continuous improvement approaches, each six-sigma improvement initiative was expected to contribute specific amounts to operating profits each year (Wescott, 2006). Six Sigma was the first continuous improvement approach that indicated a level of investment to a clear profit return (George, 2002).

Although the financial results aspects of the Six Sigma Continuous Improvement Process have been considered by some organizations to be difficult to implement, George (2002) concluded the standardized process was similar to Juran's breakthrough approach. According to George, the Motorola Corporation had recognized that there was a pattern to process improvements that could be summarized as five phases for solving problems: define, measure, analyze, improve, and control. George maintained that organizations had to understand the phased approach to solving problems and the process tools for successful implementation of the Six Sigma Continuous Improvement Process.

While the Six Sigma Continuous Improvement Process has been characterized in the literature as a statistical precision process, the Lean Continuous Improvement Process has been conceptualized in the literature as a quicker process with a focus on doing ipore work with less equipment, money, time, human effort, and space (Womack & Jones, 2003). Liker (2004) maintained that the Lean Continuous Improvement Process (originally termed lean production) referred to approaches developed by the Toyota Motor Corporation that focused on the elimination of waste in all forms. The original lean concepts were formulated in the 1920s and 1930s yet not fully implemented until the 1950s (Arthur, 2005). According to Liker, waste included defects requiring rework or scrap, unnecessary processing steps, unnecessary movement of materials or people, waiting time, excess inventory, and unnecessary or untimely production. Arthur (2005) observed that the key points of Lean Continuous Improvement - improved quality and productivity and reduced cost - were derived from producing small batches of a given product without any inventories of partially finished goods. Although the concepts were developed for manufacturing businesses, Arthur maintained that a Lean Continuous

Improvement Process applied to any business, whether manufacturing, service, or administration. It was not readily apparent that these concepts would apply equally as well to a business producing a bulk commodity such as electricity. Further, a nuclear power plant performs best when operating at 100% power, which obviates the concept of batch production.

Some writers have indicated a Lean Continuous Improvement Process has often been encumbered with misconceptions about the applicability and desired results of the process. Miller (2007) documented some of the common misconceptions. For example, a common problem has been consideration of *lean* as a set of tools rather than a set of behaviors working within a process. The misconception most applicable for the nuclear industry may be that *lean* can be implemented primarily for cost reduction. Miller stated that a Lean Continuous Improvement Process was more about making work easier so that work can be spent on the most important issues for the business.

The emphasis on waste reduction has been emphasized in definitions of a Lean Continuous Improvement Process. For instance, Womack and Jones (2003) defined a Lean Continuous Improvement Process as a constant effort to improve cycle times, reduce response times, eliminate production and process wastes, and simplify the design and functioning of processes, products, and services. Lareau (2000) defined *lean* as a process philosophy with three purposes: to eliminate wasted time, effort, and material; to reduce cost while improving quality; and to provide customers with products and services made to fit their needs. Evans and Lindsay (2005) summarized the Lean Continuous Improvement Process as a continuous and systematic approach to identifying and eliminating waste and non-value added activities throughout the entire value chain of an organization.

Womack and Jones (2003) summarized the Lean Continuous Improvement Process as a series of principles - specify value for each product, identify the value stream for each product, allow value to flow through the work processes, let customers pull value from the producer, and seek perfection in all processes and activities. Arthur (2005) noted that by clearly understanding these principles, and then tying them together, organizational managers could successfully implement a Lean Continuous Improvement Process. The first two principles for a Lean Continuous Improvement Process indicate that organizational leaders should understand the concepts of value and the value stream when implementing the process. Arthur (2005) argued that value must be defined by the customer, not the company, and that the value stream includes every activity required to deliver a product or service. Since most business organizations have grouped work in functional organizational silos the definition of value and value stream has often been skewed by each silo (Arthur, 2005). While each functional silo attempts to optimize its own operation, waste is created by failing to optimize the overall flow of products and services (McCann, 2007).

Some aspects of the five principles for a Lean Continuous Improvement Process have been difficult to uniformly define in unambiguous terms. For example, Womack and Jones (2003) defined value as a capability provided to a customer at the right time at an appropriate price as defined by the customer. Other researchers have maintained that value was defined as quality (as perceived by a customer) divided by price (Gryna et al., 2006). As viewed by Juran (1995), product or service value included two components:

freedom from deficiencies and conformance to requirements. Another example of ambiguity included the term perfection. Womack and Jones (2003) defined perfection as the complete elimination of waste so that all activities along a value stream create value. Others have disagreed with the perfection aspect of lean production since workers and materials always introduce some forms of variation into a process (Deming, 1986).

Another perspective of the Lean Continuous Improvement Process was developed by Utah State University (updated September 2008) through the Shingo Prize for Operational Excellence. Developers of the Shingo Prize (named after Shigeo Shingo, a Japanese industrialist and innovator) stated the mission of the prize was to build operational excellence in organizations through the promotion of lean principles, lean systems of management, and the wise application of lean tools and techniques across the entire organization. The perspective of the Shingo Prize development team was that each organization had four core operations - operations strategy, innovation, partnering, and operations processes - and one support function of integration. According to the development team, when lean tools and techniques were applied with lean principles and management systems to core operations the results are improved quality, cost and productivity, and delivery and service (Utah State University, 2008).

Breyfogle (2010b) maintained that the continuous improvement philosophies and tools should be integrated throughout an organization. According to this viewpoint, the organization should determine which metric to be improved and then decide the best approach for improvement. For example, if an organization needed to improve cycle time, Lean Continuous Improvement Process tools such as value stream mapping may be the best approach. If, however, an organization needed to reduce process or product defects, the statistical analysis techniques of Six Sigma may be the best approach.

Commercial nuclear power industry leaders and researchers have viewed continuous improvement processes somewhat differently than other industries. At the beginning of nuclear power energy generation in the U.S., regulators at the Atomic Energy Commission and nuclear power plant owners were primarily concerned with assuring safe plant operation without consideration of the management controls necessary to ensure quality in achieving safe operation of these technically complex facilities (Langston, 2005). Problems encountered during early commercial nuclear facility design and construction prompted regulators and owners to realize the importance and interrelationship of quality assurance to nuclear safety (Langston, 2005). Current regulatory emphasis has been on the operations, maintenance, and security of existing nuclear power plants rather than construction (Nuclear Regulatory Commission, 2006a). One concern implied by Langston was misapplication of continuous improvement processes without the knowledge of nuclear quality assurance standards could result in problems as observed over 20 years ago. As noted by this researcher, no new nuclear reactors have been ordered for over 20 years and many of the skilled technical and quality workers have left the industry.

Continuous improvement in the commercial nuclear power industry has been viewed as part of an integrated set of processes for improving performance of the operation and support of nuclear power plants, designed to facilitate management of change (Institute of Nuclear Power Operations, 2005). The Institute of Nuclear Power Operations (2005) defined performance improvement as a philosophy which assumes that further improvements are always possible and that processes and performance should be continuously reevaluated and improvements identified and implemented. Nuclear power plant performance improvement processes include a core set of sub-processes, such as problem identification, causal analyses, benchmarking and operating experience, and self-assessments. The performance improvement framework at nuclear power organizations, however, must focus primarily on safe nuclear power operations. Some aspects of the nuclear power plant improvement framework have resulted in less than desired business improvement results (Corcoran, 2010).

Given the limiting conditions and situations of a particular organization, differing individual and organizational perspectives have resulted in implementing differing approaches to continuous improvement. Implementation of differing perspectives and frameworks for continuous improvement, however, has been viewed as difficult by some organizations. Some practitioners have observed that organizations must expend considerable amounts of detailed planning, discipline, and attention to detail to successfully implement Six Sigma or Lean Continuous Improvement Processes (Gryna et al., 2006). Although many organizations have noticed measurable improvements from implementing a continuous improvement process, these improvements have primarily occurred in the areas of cost reduction and increased efficiency (Evans & Lindsay, 2005).

Continuous Improvement Culture

Different types of continuous improvement cultures have been discussed in the literature. For instance, Juran (1995) provided illustrations of negative and positive quality improvement cultures. A negative quality improvement culture was illustrated by a paint manufacturer. Company management had pressured the fabrication line to meet production quotas, wherein workers resorted to hiding paint that did not meet specification instead of correcting the defective process. A positive quality improvement culture was illustrated by hotel workers taking extraordinary steps to please a customer by improving service processes. Juran (1995), however, considered a continuous improvement culture as a subset of the larger organizational culture and not an influencing factor. Cameron and Sine (1999) discussed research on four different quality improvement cultures. One culture was described as negative, in that no improvement was emphasized by management. Other improvement cultures were described as those which emphasized error detection, those which emphasized error prevention, and those which emphasized creative improvements.

Organizational cultures may be influenced adversely when implementing a continuous improvement process. For example, many organizations have morphed continuous improvement processes, such as Lean and Six Sigma, into hybrid continuous improvement processes thus confounding the intent of the processes and creating misconceptions of the value and potential benefits of continuous improvement (Bhalia, 2010). For effective and sustainable business results, Bhalia recommended that organizational leaders learn the cultural mindsets and behaviors expected of the processes before implementing the processes.

Organizations have used continuous improvement processes to increase productivity, flexibility, responsiveness, and customer service by changing and reshaping organizational cultures (Shafritz & Ott, 2001). To understand how a culture may be influenced by a continuous improvement process, several concepts have been discussed in the literature. Cameron and Sine (1999) recommended that goals and measurements be established and supported by visible upper management leadership. Gryna et al. (2006) recognized that although employees should be developed and empowered, participation was a key driver to successful cultural transformation. Other researchers observed that organizations that consider continuous improvement a cultural norm have approached the continuous improvement process as a set of values and as an organizational ideology rather than a set of tools and techniques (Boggs, 2004). George (2002) provided data that demonstrated that continuous improvement processes often failed to deliver desired business results because the organization did not perceive the process as a culture - the way the organization operated. George concluded that Lean and Six Sigma Continuous Improvement Processes were instruments for transformational change and organizational culture development.

An ideal continuous improvement culture includes shared and compatible cultural elements and strong interrelationships among basic continuous improvement assumptions (Kujala & Lillrank, 2004). Boggs (2004) stated that the organization should be aware of the existing cultural values and norms and have prepared the culture for implementation of a continuous improvement process. Boggs' conclusions were consistent with Schein's assertions that organizational leaders must be aware of the underlying organizational culture and the assumptions of the group on which new solutions and practices would be imposed.

Some researchers have observed that organizational cultures may not always be compatible with a continuous improvement process (Kujala & Lillrank, 2004). As noted by Kujala and Lillrank, some organizations have not been able to create a continuous improvement culture because the organizational culture did not have the required shared values. These shared values included honesty, trust, and receptivity to new ideas. Cultural incompatibility has been refuted by other studies. For instance, Boggs (2004) stated that organizational managers often set forth a path for failure when implementing a continuous improvement framework with expectations of immediate cultural changes by emulating successful organizations. Researchers have maintained that a continuous improvement culture must have worker engagement and ownership to be successful (Gryna et al., 2006).

Womack and Jones (2003) observed that organizations have positively influenced work environments, processes, and cultures when continuous improvement processes have been implemented. Although positive changes were celebrated in the observations, the researchers noted that the direction of the change depended on the objective of process implementation and the tactics employed by management. Yukl (2002) stated that when organizations introduce different ideologies into an existing culture, influence approaches should include consideration of consistency with the prevailing social norms and role expectations, appropriateness of the objective, and the anticipated level of resistance.

The influence of continuous improvement processes on organizations has been examined in the literature (Benavent, 2006; Keating et al., 1999; Liker, 2004; Mann, 2005; Pemberton, 2005). These studies provided additional organizational culture insights. Lean and Six Sigma consultants have recognized the importance of institutionalizing continuous improvement processes within an organization. Spackman (2009) argued that Lean and Six Sigma continuous improvement processes change organizational foundations and must be institutionalized through visible commitment by the organization's leadership and the initial planning efforts prior to deployment of the processes. Spackman emphasized the processes must be embedded in everything the company does and then encoded into the organization where the processes become the culture. Key steps in the embedding process included linkage of the continuous improvement plan to the organization's strategic business plan, integration of the linked plans throughout the entire organization, and allocation of appropriate resources to implement the linked plans. Aiken (2006) provided organizational examples where cultural challenges inhibited implementation of a Lean Continuous Improvement Process. These organizations improved trust relationships between workers and management, empowered the workers to implement the process, and readjusted organizational focus from financials to organizational performance. As a result, cultural challenges were reduced and as performance improved the financials improved, with an average of 21% in cost reduction for the organizations studied (Aiken, 2006).

Despite the demonstrated benefits of continuous improvement processes, many companies have instead realized business performance shortfalls. One reason for the organizational impacts was the negative influence on an organization's culture when employees viewed the efforts to improve value through waste removal and cost reductions as stressors (Keating et al., 1999). Chakravorty (2010) studied continuous improvement programs at large companies over a five-year period. The research indicated that when confronted with increasing stress over time, continuous improvement programs often failed to provide sustainable changes. Chakravorty equated continuous improvement programs in organizations to material fatigue failures, wherein the material progresses through stretching and yielding phases when pulled with increasing force before failing entirely. Methods have been proposed to remove stress to employees and the organization. For example, De Koning and De Mast (2007) maintained that precision and clarity about implementing the continuous improvement process and about the desired results and potential unintended consequences should be defined and understood prior to implementation.

Thus, although organizations have used continuous improvement processes to increase productivity, flexibility, responsiveness, and customer service by changing and reshaping organizational cultures, there has been no common formula. Many organizations have noticed measurable improvements from implementing a continuous improvement process, yet often these improvements have primarily occurred in the areas of cost reduction and increased efficiency. Some organizational cultures may not be compatible with a continuous improvement process; other organizational cultures may be influenced in unintended ways when implementing a continuous improvement process. Researchers of Malcolm Baldrige Quality Award winners concluded that each had a unique continuous quality improvement engine that was used to drive the improvement efforts in the organization (Evans & Lindsay, 2005). The researchers stated that the organization used the continuous quality improvement engine and customized the improvement efforts to the organizational culture, thereby minimizing influences to the culture.

Nuclear Power Plant Safety Culture

Since the creation of nuclear technologies during World War II, nuclear industry leaders and regulatory bodies have struggled with the question of how safe is safe enough (Dahlgren, Lederman, Palomo, & Szikszai, 2001). Safety is a common goal for organizations involved in designing, operating, and regulating nuclear installations, yet the concept of safety has not been easy to define (Dahlgren et al., 2001). A general understanding has evolved over time as to what attributes a nuclear power plant should have in order to operate safely. Practitioners and researchers, however, continue to develop and understand one key attribute - a nuclear safety culture.

The concept of a nuclear safety culture was developed by researchers in the aftermath of a nuclear accident at the Chernobyl Nuclear Power Plant in Ukraine (International Atomic Energy Agency, 1988). On April 26, 1986, reactor number four at the Ukrainian Chernobyl Nuclear Power Plant exploded, which resulted in the top being torn from the reactor and exposing the nuclear core (Medvedev, 1990). Further explosions and the resulting fire sent a plume of highly radioactive fallout into the atmosphere and over an extensive geographical area. Large geographical areas were badly contaminated, dozens of people died, and 336,000 people were evacuated and resettled (Medvedev, 1990).

Nuclear industry leaders viewed the accident at the Chernobyl Nuclear Power Plant as a reminder of the risks and hazards of nuclear technology (Medvedev, 1990). Further, this accident showed the importance of maintaining strong cultural attributes related to nuclear safety (International Atomic Energy Agency, 1988; Institute of Nuclear Power Operations, 2004). According to Medvedev, the accident was caused by poor group relationships among plant organizations, weak communications, and pressures to continue with a planned test despite a known flawed design. Kapitza (1993) observed that the safety of any hazardous enterprise is determined by the human factor, such that human attitudes and behaviors have to be factored into every stage of the enterprise, from conception and design to construction and operation. Kapitza maintained that the lack of a nuclear safety culture mindset was the root cause of the Chernobyl accident.

Although the severity of the Chernobyl Nuclear Power Plant accident may have been the catalyst for studies of a nuclear safety culture concept, the industry had its first significant safety culture incident in 1979 as a result of the accident at the Three Mile Island Nuclear Power Plant in the United States (Institute of Nuclear Power Operations, 2004). Even though there were no deaths or injuries attributed to the accident, this event was the most serious in U.S. commercial nuclear power plant operating history (Institute of Nuclear Power Operations, 2004). The accident at the Three Mile Island Unit 2 Nuclear Power Plant near Middletown, Pennsylvania, resulted in a partial meltdown of the reactor core. The accident was caused by a combination of personnel errors, design deficiencies, and component failures (Itoigawa et al., 2005).

The extensive literature on these two nuclear accidents, however, has dealt almost exclusively with technical, radiological, and environmental issues. Researchers for the International Atomic Energy Agency (1988, 1991) studied the concept of a nuclear safety culture after the Chernobyl accident to develop common terms and definitions and methods for assessment. These researchers defined a nuclear safety culture in more holistic terms that included all factors and groups that influence safety at nuclear power plants. Similar to Schein's definition of organizational culture, the initial nuclear industry definition of nuclear safety culture included the concepts of characteristics and attitudes of both the organizations and the individuals.

Some researchers and practitioners have argued that a focus on characteristics and attitudes had confined discussions over nuclear safety culture to the mental-cognitive area of attitudes and noted that attitudes and actions do not correlate well (Wert, 2003: Wilpert & Itoigawa, 2001). Other researchers, most notably at the Institute of Nuclear Power Operations (2004), explored nuclear safety cultures and the various factors affecting the diverse dimensions of a safety culture in order to diagnose the current safety culture at nuclear plants and to establish a common reference framework and common terminology. Later conceptualizations of nuclear safety culture included the behaviors and actions that support a desired nuclear safety culture (Institute of Nuclear Power Operations, 2009a). These researchers used industry experiences and data developed by others, often based on nuclear power plant events, to build a body of knowledge that was not previously well defined.

As stated by Wilpert and Itoigawa (2001), some theorists have maintained that a safety culture is the organizational culture of industries that are high-risk in nature. Some researchers have concluded the concept of nuclear safety culture has not been well defined. For instance, Sorensen (2002) concluded that the mechanism by which safety culture affects the safety of nuclear power plant operations was not well established. Sorensen observed that statistical evidence linking specific attributes of a safety culture with the safety of nuclear power plant operations was limited. According to Sorensen, these limitations were caused by investigators of nuclear power events constructing new frameworks for each event rather than building on what had been studied previously.

Irrespective of the continuing debate about nuclear safety culture, the original concept as defined by the International Atomic Energy Agency (1988; 1999) included a set of critical factors and organizational members that are foundationally important. Critical factors included training, goals, and policies. One critical factor that has influenced nuclear safety cultures, termed nuclear business acumen, included the ability to manage the unique interaction among technology, economics, human factors, and safety in a changing nuclear business environment. In a subsequent study, twelve organizational factors were identified as most important for nuclear safety: external influences, goals and strategies, management functions and overview, resource allocation, human resource management, training, coordination of work, organizational knowledge, proceduralization, organizational culture, organizational learning, and communications (Nuclear Energy Agency, 1999). Each of these factors was considered to be interrelated, wherein one could influence another.

Researchers at the International Atomic Energy Agency (1999) stated the organizational membership included several levels, specifically the level of management, the level of individuals, and the extra-organizational level of suppliers and government agencies. Similar to Schein's definition of organizational culture, membership in a nuclear safety culture was viewed as comprehensive so that a pattern of shared basic assumptions of external adaptation and internal integration could work synergistically to solve common problems, with nuclear safety the overriding priority. As noted by the International Atomic Energy Agency (1991), nuclear safety is achieved when every member of the group is dedicated to the common goal.

In subsequent studies, researchers have identified that a safety culture can be strengthened over time (International Atomic Energy Agency, 1998, 2002). The International Atomic Energy Agency stated that three stages exist in a nuclear safety culture's transformation. The first stage was viewed as a compliance safety culture, driven by following government rules and regulations. In the first stage, researchers considered the nuclear safety culture as a minimalist culture, barely ensuring that nuclear safety is the overriding priority of the operating company. The second stage was viewed as a goal oriented safety culture, wherein the nuclear operating company established safety performance goals with the stated purpose of meeting those goals. In the second stage of a nuclear safety culture, the safety performance goals were established to exceed government rules and regulations. The third stage was viewed as a continuous improvement safety culture, wherein nuclear safety had become institutionalized throughout the organization and internalized throughout all individuals. In the latter stage, researchers considered nuclear safety culture to be self-sustaining and more in line with Schein's conceptualization of organizational culture. Suggestions were provided by the International Atomic Energy Agency to develop and improve a nuclear safety culture.

The U.S. Nuclear Regulatory Commission recognized the importance of nuclear power plant owners and operators in establishing and maintaining a strong nuclear safety culture, which was defined as a work environment where management and employees are dedicated to putting safety first (Nuclear Regulatory Commission, 2006a). As a result, the regulatory reactor oversight process was revised to more fully address safety culture. As described by the Nuclear Regulatory Commission (2006a), a nuclear safety culture included 13 components: decision-making, resources, work control, work practices, corrective action program, operating experience, self and independent assessments, environment for raising safety concerns, preventing perceptions of retaliation, accountability, continuous learning environment, organizational change management, and safety policies. The first nine safety culture components were considered as cross-cutting components in that they were aligned with the existing inspection process for human performance, problem identification and resolution, and a safety conscious work environment.

It is noteworthy that the Nuclear Regulatory Commission (2006a) referenced the International Nuclear Safety Advisory Group's definition of a nuclear safety culture - the assembly of characteristics and attitudes in nuclear power organizations and all individuals in the nuclear power organizations which establishes that nuclear plant safety issues receive the attention warranted by their significance (International Atomic Energy Agency, 1988). This definition excluded the organizational concepts of values and behaviors. Corcoran (2010) observed that this definition excluded the organizational concepts of norms, institutions, and physical items and that the concept of characteristics was unclear, thus open to interpretation.

Corcoran (2010) observed that Nuclear Regulatory Commission reports of applications of a nuclear safety culture were rare and that the components identified by the Nuclear Regulatory Commission were not mutually exclusive. For example, a safety culture finding by a regulatory inspector could be categorized in more than one component, resulting in over-reporting or under-reporting of nuclear safety culture problems in the industry and creating database integrity issues. If the components were mutually exclusive then each norm, institution, and physical item of a safety culture would fit in only one component. Corcoran further argued that the components were not jointly exhaustive in that they did not appear to cover the totality of a nuclear safety culture.

Although researchers and analysts have approached the concept of nuclear safety culture differently, most have concluded that while nuclear power is a complex technology, the use of nuclear power has proved to be a safe and efficient method for electrical power generation (Wilpert & Itoigawa, 2001). Commercial nuclear power plants consist of redundant systems that force nuclear reactor shutdown when temperatures and pressures exceed design basis limits (McAvoy & Rosenthal, 2005). The technical challenges created by a need to ensure safe operations and to prevent the introduction of radioactive materials into the external environment have been a necessary element in the commercial nuclear industry since its beginnings.

Some researchers have observed that this complex technology is being confronted by business pressures, such as deregulation of the electric power industry, to reduce operating costs (Itoigawa et al., 2005). Economic pressures have been shown to cause a reshaping of power plant policies and the fallible human workers (Itoigawa et al., 2005). Further, when applying processes to control operational and maintenance costs, key organizational factors defined by the Nuclear Energy Agency (1999) could be affected, specifically allocation of resources and work. There have been nuclear power events and accidents that have had significant impacts on safe plant operations. In studies of the most significant nuclear power incidents in the United States, analysts at the Institute of Nuclear Power Operations (2002a, 2003) concluded that in 20% of the incidents, economic pressures had reduced the focus on nuclear safety.

In 1996, the Nuclear Regulatory Commission directed Northeast Utilities to shut down the three nuclear reactors at the Millstone Nuclear Power Plant in Connecticut (McAvoy & Rosenthal, 2005). Northeast Utilities, along with most other electric utilities in the 1980s, developed strategies for gaining a competitive advantage among numerous generation companies and brokers in a pending deregulated environment (McAvoy &

Rosenthal, 2005). Competitive advantage would be based on the relative cost of power generation, and nuclear power generation was perceived by some electric utilities as a disadvantage without a significant focus on cost containment. Market pricing of electricity does not allow for direct cost recovery, thus nuclear power plant management has the responsibility for cost reduction. When management responds inappropriately to the pressures of continuing operations and reducing operating costs, nuclear safety risks become more evident (Wilpert & Itoigawa, 2001). Of the variable costs at nuclear plants, Operations and Maintenance (O&M) costs have the greatest capability for control by plant management but have the greatest potential for degrading the safety culture if deferred or reduced (McAvoy & Rosenthal, 2005). Reducing O&M costs to improve profitability was considered a risky strategy when coupled with incentives to take shortcuts (McAvoy & Rosenthal, 2005).

In 1997 the U.S. Nuclear Regulatory Commission directed that utility management close the Maine Yankee Nuclear Power Plant because of cost-cutting measures at the expense of safety considerations (Jackson, 1997). Jackson noted that the Maine Yankee plant had economic pressure to be a low-cost energy producer, which limited the resources available for corrective actions and plant improvements. The plant's formula for operational survival was based on low cost and high production.

A significant operating event occurred in 2002 at the U.S. Davis Besse Nuclear Power Station when degradation of the reactor pressure vessel head resulted in radioactive coolant leakage (Nuclear Regulatory Commission, 2002, 2008). The Institute of Nuclear Power Operations (2002b) studied this event and concluded a major contributor to the reactor vessel head degradation was a shift in focus at all organizational levels from implementing high safety standards to justifying minimal safety standards. This reduction in standards resulted from excessive focus on meeting short-term production goals. Analysts concluded that corporate incentive programs, in combination with other incentives such as rewards for meeting or exceeding refueling outage goals, had led to the deferment of emergent work and repairs that did not directly affect power generation (Institute of Nuclear Power Operations, 2002b). The U.S. Nuclear Regulatory Commission (2008) concluded safety culture weaknesses at the Davis-Besse Nuclear Power plant were one of the root causes of the reactor vessel head degradation event.

The Palo Verde Nuclear Generating Station, the largest nuclear plant in the United States, was a recent U. S. nuclear plant to have nuclear safety culture problems. In 2007, the U.S. Nuclear Regulatory Commission downgraded the safety rating of the plant because of continuing programmatic concerns. Causes for the safety downgrade included limited resources, inadequate corrective action resolutions, inadequate communications, and inadequate procedures - all indicators of nuclear safety culture issues (Nuclear Regulatory Commission, 2004, 2006b). As noted in the press, the power plant owners had focused on ensuring constant electricity was placed on the power grid and generating profits for owners (Schaffer, 2007)

Despite the documented results of economic pressures and challenges on nuclear power plants, few studies of economic effects on a nuclear safety culture could be found in the literature. Researchers and analysts have documented regulatory and business decisions that indicate economic considerations have contributed to revisionist conceptualizations of a nuclear safety culture. The literature has included evidence that supports the concept of inadequate business acumen contributing to economic pressures and thus influencing a nuclear safety culture. (The International Atomic Energy Agency used the term business acumen to describe the ability to manage the unique interaction among technology, economics, human factors, and safety in a changing nuclear business environment.)

For instance, after the Three Mile Island Nuclear Power Plant accident in 1979, in which there were radiological releases from the nuclear containment into surrounding environments, the Nuclear Regulatory Commission mandated additional and more expensive nuclear safeguard systems to prevent a future incident (Wilpert & Itoigawa, 2001). Another instance in the literature involved the concern of aging in nuclear power plants, where stress induced corrosion cracking and boric acid degradation appeared in safety-related components which contributed to additional maintenance and inspection expenses, and sometimes required additional capital to replace degraded components, for power plant owners (McAvoy & Rosenthal, 2005). These additional costs contributed to a mindset in the commercial nuclear industry that increasing costs would continue to be problematic but would be offset by increasing revenues (McAvoy & Rosenthal, 2005).

Other instances cited in the literature involved the financial and market fluctuations of the late 1990s. U.S. nuclear plant owners began to search for additional competitive business advantages (Itoigawa et al., 2005), and four U.S. nuclear plants have experienced dramatic extended shutdowns because of nuclear safety issues. A common theme underlying these extended shutdowns was that, over time, problems occurred as a direct result of the nuclear safety culture at the plants (Institute of Nuclear Power Operations, 2004).

The protective environment after the September 11, 2001, terrorist attacks resulted in the creation of additional rules and oversight. Expenditures for support functions critical to both the nuclear and protective safety of nuclear power plant operations increased. In 2005, researchers observed that a small percentage of total operations and maintenance costs in commercial nuclear power plants were allocated to labor performing the functions necessary to actually operate the plants (Itoigawa et al., 2005).

Nuclear safety culture analysts and researchers have frequently focused on the individual worker's commitment and performance based on attitudes, values, work approaches, and communication systems (Hansen, 2008; Institute of Nuclear Power Operations, 2006; Kajder, 2005; Reason & Hobbs, 2003). Some of these cultural themes were directly related to a parallel between increasing economic and production pressures and diminishing safety culture margins. Reason and Hobbs (2003) concluded that the most common worker errors at power plants were caused by failure to do something that should have been done rather than doing something incorrectly. These researchers argued that different forms of errors resulted in different outcomes. Based on these studies, a set of error precursors was developed for the industry's nuclear safety language, including documentation and procedure problems, time pressure, poor housekeeping and tool control, inadequate communication and coordination, fatigue, inadequate knowledge and experience, and personal beliefs such as illusions of invulnerability (Reiman, 2007).

Some nuclear safety culture researchers have studied other dimensions of the complex and dynamic interrelationships within the organizational cultures at nuclear facilities. Matthews (2006) reviewed safety culture practices at Department of Energy nuclear sites and concluded that organizational priorities were not always properly balanced between nuclear safety and production. Examples provided in the study included rewards applied when work milestones were achieved in comparison to no penalties applied when nuclear safety was compromised or when nonconformances were rationalized as minor with few corrective actions taken.

Meredith (2003) used data derived from studies conducted by governmental agencies, independent agencies, and industry research to study compliance levels with nuclear safety agreements. The purpose of this research was to explain variations in compliance with international nuclear safety agreements, for which the conclusion was that economic priorities determined the levels of compliance with standards. Findley (2004) studied group differences in industrial safety cultures within a segment of the commercial nuclear power plant industry and concluded that safety cultures were constrained when production factors became priorities over prevention factors.

Some contemporary researchers have studied the concept of a nuclear safety culture within the frameworks of risk demands and sub-culture alignments. Perin (2005) argued that a nuclear power plant culture embodies several different cultures of control based on different methods of risk assessment. The research findings indicated three different logics within a comprehensive culture of control. For example, the commercial nuclear industry culture is organized around a structured logic of command and control which requires tradeoffs with a parallel logic of problem identification and diagnosis. The two different intra-cultural logics have not aligned in an environment of external pressures relative to electricity production and reduction of operating costs. Given Perin's conclusions, the issue in the nuclear power industry today is not just whether the plant should shutdown safely when warranted but, equally important, what it will it cost to shutdown (in terms of purchasing power from alternative sources, annual performance bonuses, and so forth). Reiman (2007) studied the maintenance organizations at three European nuclear power plants and concluded that nuclear safety was affected if the demands of the organizational tasks were not aligned with the dynamics of the organization's culture. Thus, according to Reiman (2007), nuclear safety is at its highest levels when critical and instrumental task demands, combined with demands for working practices, were aligned with the cultural elements of structure, internal integration, and conceptions concerning the work.

Although the organizational culture and nuclear management literature has included a few studies of economic effects on a nuclear safety culture, researchers have not adequately studied the effect other types of cost reduction strategies have had on a nuclear safety culture. For instance, some continuous improvement strategies emphasize cost reductions through implementation of various techniques. Researchers have not studied the effect on a nuclear safety culture when a continuous improvement process that emphasizes control of production wastes and costs has been implemented. There may be valid reasons for this deficiency in knowledge. Because the basic defining dimensions of a culture are not directly observable, valid indications and measurements of these dimensions are difficult to establish (Schein, 2004).

Schein (2004) observed other difficulties in studying any group culture. The dimensions that define the culture of a particular organization were the result of a long process of negotiation and implementation among all members of the organization. The membership lists for organizational cultures at nuclear power plants are complex and include critical extra-organizational members that interrelate with plant personnel: corporate owners of the power plant (which may or may not include electric utility companies), national and local regulators, and contracting firms (Itoigawa et al., 2005). Such complex interrelationships may have influenced studies conducted in the field of nuclear safety culture.

The high technical standards of the industry may also have influenced studies conducted in the field of nuclear safety culture. Some researchers in the industry have argued that these technical standards imply that only through optimizing the human dimension can cost-efficient improvements be achieved at nuclear power plants (Wilpert & Itoigawa, 2001). Other researchers in the industry have argued that an ultimate proof of the practical relevance of a safety culture as a useful industrial concept was missing (Wilpert & Itoigawa, 2001). Quality, availability, and competitiveness might provide valid criteria for the practical relevance of a safety culture.

Organizational causes for nuclear power plant events and extended plant shutdowns have been examined (Itoigawa et al., 2005) and in recent years researchers have conducted studies to examine precursors to these organizational causes. These precursors typically have included various dimensions of leadership and organizational behaviors (International Atomic Energy Agency, 2002; Institute of Nuclear Power Operations, 2009a). Economic dimensions have received less attention in nuclear power plant research, and a nuclear safety culture within an environment of a Lean Continuous Improvement Process has not been studied.

Other High-Risk Industry Safety Cultures

As defined by the U.S. Occupational Safety and Health Administration (2009), industrial safety cultures included shared beliefs, practices, and attitudes that existed at a business. An organization's safety culture was viewed as the end result of a number of factors, including management and employee norms, assumptions and beliefs, and attitudes; policies and procedures; actions and lack of actions to correct unsafe behaviors; employee training, involvement, and motivation; and production and efficiency factors. According to the U. S. Occupational Safety and Health Administration (2009), peer coaching at all levels and employee awareness of changing conditions and situations at job locations were observed at organizations with strong occupational safety cultures.

Researchers in the field of general occupational safety have maintained that safety accidents are typically caused by failure of attitudes, failure of technical training, failure of safety training, or combinations of any of these three causes (Burns, 2005; Roughton and Crutchfield, 2008; Williams, 2002). Burns (2005) stated that the primary focus of industrial safety programs should be on changing employee behaviors and attitudes. Burns maintained that although many researchers have argued that trust was important in modeling safety cultures, attitudes about trust, whether implicit or explicit, were equally important. Roughton and Crutchfield (2008) maintained that fundamental principles for preventing industrial safety accidents included establishing a positive culture where individuals understood job hazards and were not punished for reporting accidents and near misses. According to Roughton and Crutchfield, a positive safety culture included rewarding safe workers, sharing information about accidents and near misses, and assessing the potential hazards of a job while planning the work. Williams (2002) stated that a positive safety culture should start with management behaviors.

Hansen (2006) stated that a strong organizational safety strategy included meaningful measurement, employee participation, shared values, positive recognition, process improvement, continuous improvement, and alignment. According to Hansen, since the work processes contributed to most occupational accidents the safety goals should be challenging yet causing incrementally improving processes. Further, Hansen maintained that safety values should be on the same level as production values and aligned with all organizational members.

Within the complex, high-risk industries of aviation and space operations, medical surgery, chemical processing, and offshore drilling, more safety culture studies have been conducted than in the nuclear industry. Most contemporary researchers have studied the attributes of leadership; worker and manager attitudes, beliefs, values, and behaviors; and, perceptions of risk, stress, and decision-making, all of which have some relevance to safety cultures (Columbia Accident Investigation Board, 2003; Helmreich & Merritt, 1998; McDonald, 2006; Mearns, Whitaker, & Flin, 2003; Roughton & Crutchfield, 2008; Vaughan, 1996). Although no research could be identified that had studied the influence of a continuous improvement process on the respective safety culture, various efficiency and cost containment influences have been traced as sources of accidents. Based on the accidents studied, a parallel was evident among increasing economic and production pressures and schedule conflicts and diminishing safety culture margins.

Mearns et al. (2003) stated there is little evidence to link weaknesses in safety at the organizational level with individual accidents; however, the researchers noted case studies of major disasters have linked weaknesses in safety culture with organizational accidents. Reason (1997) maintained that work-related values, behaviors, and perceptions at industrial plants are universal, but are influenced in varying degrees by corporate and organizational cultures. Helmreich and Merritt (1998) compared and contrasted the high-risk industries of aviation and emergency medical operations in the context of organizational, professional, and national cultures. Survey results of physicians and nurses in anesthesia, surgery, and intensive care units were compared with equivalent cockpit crew members in commercial aviation. The researchers observed that some organizational events and incidents occurred when organizational focus noticeably shifted from implementing high standards to meeting short-term goals. As implied by Helmreich and Merritt (1998) these short-term goals were often based on resource or economic conditions and were evident in organizational cultures irrespective of the influences by national or professional cultures.

The January 26, 1986, Space Shuttle *Challenger* disaster was an organizational accident caused by production influences. Vaughan (1996) concluded that over time production pressures became institutionalized at the National Aeronautics and Space Administration (NASA). It was theorized that,a work group culture had evolved wherein technical deviations were normalized when the work groups encountered consistent contributing factors of economic and scheduling pressures.

The February 1, 2003, Space Shuttle *Columbia* disaster was an organizational accident with similar preconditions to the *Challenger* disaster. NASA management had to devise a new business approach when the United States government reduced the national space budget by 40% during the period of 1992 to 2000 (Columbia Accident Investigation Board, 2003). While the intent of the new approach was to improve efficiency and effectiveness, the result was a decrease in resources. Under funding pressure, NASA management began outsourcing much of its work to contractors and simultaneously began reducing the scope of its operational, or institutional, safety program (Columbia Accident Investigation Board, 2003). It was assumed that NASA's ownership of operational safety could be reduced because the contractors would assume the responsibility for safety. Investigators at the Columbia Accident Investigation Board concluded that organizational streamlining and downsizing conveyed an additional message to workers that efficiency was an important goal. Combined with the reductions that decreased the safety focus, efficiency was viewed by employees as more important than safety.

Reason (1997) studied safety accidents in aviation, petrochemical, offshore oil, and transportation industries. Reason concluded that significant accidents in some high-risk industries could be repeated in other high-risk industries because of flaws in causal analyses that led to a misguided focus on technical failures rather than organizational weaknesses as learning organizations. Thus, some safety critical organizations had not been effectively solving underlying safety culture problems and, in turn, were not effectively learning from accidents and incidents whether small or large in magnitude. Based on the accidents studied, a parallel was evident between increasing economic and production pressures and diminishing safety culture margins.

According to Reason (1997), the components of a safety culture included an informed culture, a reporting culture, a just culture, a learning culture, and a flexible culture. An informed culture was described as leadership-based, in that those responsible for managing the organizational system had current knowledge about the human, technical, organizational, and environmental factors that determined the safety of the organization as a whole. Reason (1997) maintained that leaders must understand and acknowledge that people were usually not the instigators of accidents or incidents and that they usually inherited bad situations that had been developing over a long period. A reporting culture was described as a climate in which workers were prepared to report their errors and near-misses. Reason viewed a just culture as a way of thinking that promoted a questioning attitude, was resistant to complacency, was committed to excellence, and included accountability at all levels of the organization. A learning culture was described as a willingness to draw the right conclusions from its safety information system and to implement major reforms. Reason viewed the last component as a culture where the organization was able to reconfigure itself during times of environmental changes or attacks.

Mearns et al. (2003) concluded from studies of offshore oil and gas operations that safety cultures were affected by the convergence of several hazardous factors, including the potential for fire, explosion, and other accidents, work stress, priorities of continuing operations, and the isolation of installations. In the first year of the research, production and schedule pressures were not considered significant contributors to a negative safety culture. In the second year of the research, the researchers found that continued production and schedule pressures had caused these factors to become significant contributors to a negative safety culture.

McDonald (2006) summarized the results from a series of studies concerning aircraft workers. This researcher observed that technicians routinely did not follow procedures, rationalizing their actions by stating they had developed faster, better, and safer ways of performing the tasks than those described in approved procedures. For many of the aircraft companies studied, professional cultures were found to be inconsistent with organizational cultures, leading to inconsistencies between established requirements and the need for flexibility to meet the changing production schedules of the operational environment (McDonald, 2006).

Within the complex, high-risk industries of aviation and space operations, medical surgery, chemical processing, and offshore drilling, contemporary researchers have studied the attributes of leadership; worker and manager attitudes, beliefs, values, and behaviors; and, perceptions of risk, stress, and decision-making, all of which have some relevance to safety cultures. Researchers have documented that a strong organizational safety strategy should include meaningful measurement, shared values, continuous improvement, and alignment. Although researchers have traced various efficiency and cost containment influences as causes of accidents, none have studied the influence of a continuous improvement process on the respective safety culture. Based on the accidents studied, a parallel was evident among increasing economic and production pressures and schedule conflicts and diminishing safety culture margins.

Summary

From the literature, it can be concluded that an organizational culture has been conceptualized in various ways because the culture of an organization has been defined by both mechanistic and organic dimensions and because every organizational culture is different (Cameron & Quinn, 2006; Seel, 2000; Schein, 2004; Trice & Beyer, 1993). Empirical measurement of the concept has been difficult for researchers because of these competing dimensions. Researchers have identified that some organizational cultures have been shaped by influencing factors, including implementation of processes with the purpose of improving the organization (Cameron & Quinn, 2006; Schein, 2004)..

Researchers have identified differing perspectives and frameworks for continuous improvement (Evans & Lindsay, 2005; Wescott, 2006). Although organizations have used continuous improvement processes to increase productivity, flexibility, responsiveness, and customer service by changing and reshaping organizational cultures, there has been no common formula (Shafritz & Ott, 2001). Many organizations have noticed measurable improvements from implementing a continuous improvement process, yet often these improvements have primarily occurred in the areas of cost reduction and increased efficiency (Evans & Lindsay, 2005). Some organizational cultures may not be compatible with a continuous improvement process; other organizational cultures may be influenced in unintended ways when implementing a continuous improvement process (Keating et al., 1999; Kujala & Lillrank, 2004). The Lean Continuous Improvement Process concepts were derived for producing batches of product lines without resulting inventories of partially finished goods (Arthur, 2005). It is not readily apparent that these concepts would apply equally as well to a business producing a bulk commodity such as electricity. Further, a nuclear power plant performs best when operating at 100% power, which obviates the concept of batch production.

A nuclear safety culture has been conceptualized in the literature as either a subset of the organizational culture or a unique subculture that resides along with the organizational culture (Wilpert & Itoigawa, 2001). The term is complex and somewhat difficult to comprehend. In fact, the literature on safety culture has demonstrated that the concept includes many interrelated components and members of many organizations

(Institute of Nuclear Power Operations, 2009a; International Atomic Energy Agency, 1999). Given the interrelationship of economic forces on the operations of a commercial nuclear power plant, one would expect that the introduction of a process to improve a plant's ability to create value and contain operating costs would be included in studies of the relationships of economic issues to nuclear safety. Despite the significance of reliable and safe technical systems for nuclear electrical generation and the potential influence of production priorities with a focus on cost containment, there has been relatively little research on the various dimensions of a nuclear safety culture when affected by opposing economic-based factors.

Organizational causes for nuclear power plant events and extended plant shutdowns have been examined in the literature, and in recent years researchers have conducted studies examining precursors to these organizational causes (Itoigawa et al., 2005). These precursors typically have included various dimensions of leadership and organizational behaviors. Several event investigations at U.S. nuclear power plants have uncovered organizational flaws (Institute of Nuclear Power Operations, 2004). Since the late 1990s, four U.S. nuclear plants have experienced extended shutdowns because of nuclear safety issues (Institute of Nuclear Power Operations, 2004). A major contributor to some extended plant shutdowns was a shift in focus from implementing high safety standards to justifying minimal safety standards, resulting from an excessive focus on meeting short-term production goals. Within other complex, high-risk industries researchers have studied the attributes of leadership; worker and manager attitudes, beliefs, values, and behaviors; and, perceptions of risk, stress, and decision-making (Columbia Accident Investigation Board, 2003; Helmreich & Merritt, 1998; McDonald, 2006; Meams et al., 2003; Roughton & Crutchfield, 2008; Vaughan, 1996). Although researchers have traced various efficiency and cost containment influences as causes of accidents, none have studied the influence of a continuous improvement process on the respective safety culture.

The effect of continuous improvement processes on a nuclear safety culture has not been adequately addressed in the literature. Although continuous improvement processes may improve the production value and the value creating processes at a nuclear power plant, the effect on nuclear safety culture is unknown.

Provided within the next chapter of this dissertation are the methods and procedures used to address the research questions. Included in the next chapter are the rationales for the research design and instrumentation used, methods of data analyses, and limitations/delimitations of the research. A discussion of ethical assurances is also included in this chapter.

CHAPTER 3: RESEARCH METHOD

The problem addressed by this quantitative research is that no previous research was located that studied the influences of implementing a Lean Continuous Improvement Process on a nuclear safety culture and the effect of these influences was unknown. Researchers in other studies concluded that overemphasis on controlling production costs and improving the bottom line had compromised safety margins and degraded the broader safety culture of some nuclear organizations (Itoigawa et al., 2005). In two different studies of the most significant nuclear power incidents in the United States, analysts at the Institute of Nuclear Power Operations (2002a, 2003) concluded that in 20% of the cases studied pressure by nuclear plant leaders to continue plant operations had reduced the focus on nuclear safety and in 75% of the *leader pressure* cases, the pressure by nuclear plant leaders was economic in nature. As observed by analysts at the Institute of Nuclear Power Operations (2002a) pressure to continue operating may be a notable contributor to future significant events.

Organizational causes for nuclear power plant events and extended plant shutdowns have been examined (Itoigawa et al., 2005), and in recent years researchers have conducted studies to examine precursors to these organizational causes. These precursors typically have included various dimensions of leadership and organizational behaviors. There has been limited research on the dimensions of a nuclear safety culture when confronted by opposing economic forces. Different strategies are being implemented in the commercial nuclear power industry to confront the competitive business pressures of reducing operational costs (Itoigawa et al., 2005). One strategy is the use of a Lean Continuous Improvement Process. No previous research could be found relative to implementation of a Lean Continuous Improvement Process at a commercial nuclear power plant. Given the scarcity of research that has examined the influence of continuous improvement processes on a nuclear safety culture, the purpose of this quantitative research was to examine the relationships between a continuous improvement process which focuses on reducing process wastes and operating costs (i.e., Lean Continuous Improvement) and the nuclear safety culture at a nuclear power plant. The relationships between two operating results from a Lean Continuous Improvement Process and six key nuclear safety culture indicators were assessed.

As an aid to developing and understanding the research questions, constructs for the research were developed and are restated herein. The framework for a Lean Continuous Improvement Process (the independent variable) was based on two of the operating results established by Utah State University (2008), as depicted in Figure 1: quality and cost/productivity. The framework for a nuclear safety culture (the dependent variable) was based on six indicators derived from a set of indictors for determining changes in a nuclear plant's organizational performance (Institute of Nuclear Power Operations, 2001): maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions. Correlating changes in organizational performance to changes in organizational culture has a basis in previous research (Cameron & Quinn, 2006; Schein, 2004). Based on these factors and concepts, the following research questions and hypotheses were developed for this study. The results of this study responded to these research questions.

Ql: What relationships, if any, exist among the two Lean Continuous Improvement Process operating results (quality and cost/productivity) and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions)?

$H1_0$: There is no correlation between quality and cost/productivity and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions).

$H1_A$: There is a correlation between quality and cost/productivity and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions).

Q2: What differences, if any, exist on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental)?

$H2_0$: A difference does not exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental).

$H2_A$: A difference does exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental).

The purpose of this section of the dissertation is to provide the methods and procedures used to address the research questions, the rationale for the research design and instrumentation, methods of data analyses, and limitations of the research. A discussion of ethical assurances is included in this section. The desired result of this study was to bridge a gap in the existing knowledge for determining precursors to nuclear safety events and to supplement the body of knowledge on a nuclear safety culture.

Research Methods and Design

This quantitative research was based on application of a program (Lean Continuous Improvement Process) to the dependent variable of a nuclear safety culture. Data were derived from two normally distributed populations (i.e., the workforce at an experimental nuclear power plant and the workforce at a control nuclear power plant), wherein the focus was in determining differences in six indicators for the treatment and control groups. For purposes of this research, the experimental nuclear power plant was delineated as Plant A and the control nuclear power plant was delineated as Plant B. Both plants were located in the same U. S. Nuclear Regulatory Commission Inspection Region. Since the experimental plant sponsored program application and implementation, pretest measurements were not available to the researcher. The quasi-experimental design was, therefore, a posttest-only control group design to determine the effect of the treatment (a Lean Continuous Improvement Process). Posttest only designs have been demonstrated to be strong against single group threats to internal validity and strong against most multiple-group threats to internal validity (Trochim, 2001).

A nuclear safety culture was operationally defined by six indicators as defined by the Institute of Nuclear Power Operations (2001). As shown in Figure 1, the Lean Continuous Improvement Process Model, three operating results are derived from implementing the model: quality, cost and productivity, and delivery and service. The interrelationship of the operating results with the six indicators of a nuclear safety culture is depicted in Figure 2. For purposes of this study, the operating results were assumed to have a direct relationship with the six nuclear safety culture indicators and an indirect relationship with the business results desired by the nuclear plant.

Lean CI Process Operating Results

3

Indicators of Changes in Nuclear Safety Culture

- Quality
- Cost/Productivity
- Delivery/Service

- Maintenance rework
- Longstanding equipment problems
- Resource unavailability
- Material unavailability
- Schedule errors
- Inadequate corrective actions

Indirect Effect

Direct Effect

Nuclear Plant Business Results

Safe Operations
Reliable Operations
Profitable Operations

Figure 2: Interrelationship of Lean Continuous Improvement Process operating results with indicators of changes in nuclear safety culture and nuclear business results.

Data for the safety culture indicators were gathered from the nuclear power plants' corrective action reporting systems, excluding documentary materials related to proprietary, personal, and security safeguards data. Researchers have documented similar approaches for cultural studies in other high-risk industries (Reason, 1997). Helmreich and Merritt (1998) indicated that for such measures to be valid and reliable, the incident reporting system must be robust and placed in a context that supports and encourages full participation by workers and others within the organization. Nuclear power plants in the United States have incident reporting systems (i.e., corrective action systems) that allow nuclear plant workers to report problems, concerns, or questions, including when rules have been violated, without fear of reprisal or retaliation, as required by the Code of Federal Regulations, Title 10, Part 50.7. As indicated by the Nuclear Regulatory Commission (2009a), U.S. nuclear power plant incident reporting systems provide relatively accurate and complete data on power plant issues and concerns, including worker performance. Data for the operational, or productivity, indicators were provided by the experimental and control nuclear power plants.

Schein (2004) noted the basic defining dimensions of an organizational culture were not directly observable, thus valid indications and measurements of these dimensions were difficult to establish. Although there are a variety of quantitative and qualitative methods available to measure the psychological, behavioral, and situational aspects of safety cultures in high-risk industries, methods to measure work process aspects of safety cultures are limited (Cooper, 2000). As indicated in the review of the literature, various aspects of safety culture have been examined through observations and assessments of management and control records. Employee attitudes, values, and beliefs can be measured by a survey, but only through observations of worker performance or through reviews of event records are the application of these cultural aspects confirmed (Roughton & Mercurio, 2002).

Analyses consisted of a two-group, posttest-only quasi-experimental design. Ratio-scaled data were used to test the hypotheses about the mean. Data were entered into SPSS® version 15.0 for Windows and descriptive statistics were conducted on demographic data. Descriptive statistics included means and standard deviations for continuous (interval or ratio) data. Standard deviation measures statistical dispersion, or the spread of values in a data set (Gryna et al., 2006).

To examine hypothesis 1,12 Pearson *r* correlations were conducted to assess if statistically significant relationships existed between quality and cost/productivity with the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions). Analysts have used correlation as a statistical measure when the research purposes were concerned primarily with finding out whether a relationship existed between continuous variables and with determining the magnitude of a relationship (Aczel & Sounderpandian, 2006). Given that all variables were continuous data and the researcher had established the hypotheses to assess the relationships, or how the distribution of the *z* scores varied, Pearson *r* correlations were considered to be the appropriate statistic (Aczel & Sounderpandian, 2006). Cohen's standard was used to evaluate the correlation coefficient, where 0.2 represents a weak association between the two variables, 0.5 represents a moderate association, and 0.8 represents a strong association (Howell, 1992).

To examine hypothesis 2, a Multivariate Analysis of Variance (MANOVA) was conducted on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental). The assumptions of normality and homogeneity of covariance were evaluated. A MANOVA test was used to determine whether mean differences among groups on a combination of dependent variables were likely to have occurred by chance (Tabachnick & Fidell, 2001). The MANOVA test was used to create a linear combination of the dependent variables and to determine whether there were group differences on the set of dependent variables. The MANOVA was broken down by each dependent variable and resulted in an analysis of variance (ANOVA) test, an appropriate statistical analysis when the purpose of the research is to assess if mean differences existed on one continuous dependent variable between two or more discrete groups (Tabachnick & Fidell, 2001). The ANOVA uses the *F* test, which is the ratio of two independent variance estimates of the same population variance (Aczel & Sounderpandian, 2006). Researchers use the *F* test to make the overall comparison on whether group means differ. If the obtained *F* is larger than the critical *F*, then the null hypothesis will be rejected.

Power analysis computer software was used to estimate the key parameters for the optimal design and statistical methodology. Using the computer software G*Power® Version 3.0.10, the program input consisted of the specification of an *F* test statistic with an a of 0.05, a power (1-P) of 0.95, and two levels of the independent variable (treatment and control). A power of 0.95 was selected to increase the probability of rejecting a false null hypothesis given the scope of the research. A sensitivity analysis was performed using the specified program inputs. The computer software determined the effect size as 0.36. For the MANOVA test with repeated measures between factors the computer software specified a total sample size of *n* greater than 74 was needed to achieve stated research goals. For the ANOVA test the computer software specified a total sample size of *n* greater than 102 was needed to achieve stated research goals. Sample-size issues, however, were not the most important parameter given the nature of the study. As noted by Lenth (2001), sample-size issues are usually more important when the consequences of an over- or undersized study could affect the outcome of the study, when it takes considerable time and expense to collect data, or when ethical issues are significant. Size of the study relative to outcomes, collection times, and ethical issues had negligible impact on this study.

Participants

The experimental nuclear power plant was selected because the plant leadership had a desire to implement a Lean Continuous Improvement Process to improve performance and reduce process wastes and operating costs. The control nuclear power plant was selected because it has a similar plant design, it is located in the same geographical region of the United States, and it is a member of a common nuclear industry alliance. These similarities minimized the confounding influences of extraneous subculture variables during the experiment. Access to the two populations and the two plants' corrective action systems were obtained through each plant's senior management team. The researcher had made previous inquiries with the subject nuclear power plants and experienced no difficulties in gaining access to study each plant's systems.

Human subjects were not directly involved in data collection or analysis. Source documentation within the corrective action systems at both the experimental and control plants were analyzed during this study. Although workforce populations were included in the study, they were not considered participants. These workforce members were not specifically selected for this study and did not participate in any part of this study.

Materials and Instruments

A research instrument was not necessary for this study. Data for the safety culture indicators were gathered from the experimental and control nuclear power plants' corrective action (incident) reporting systems, excluding proprietary, personal, and security safeguards documentary materials. Approval to use these reporting systems was appropriately obtained (see Appendix A). Data for the operational, or productivity, indicators were provided from management review packages at the experimental and control nuclear power plants.

Nuclear power plant corrective action systems are computerized to support collecting, sorting, and analyzing performance trends. Instrumentation included a standardized collection of trending criteria and codes, classified by issue types as described in Appendix B and tabulated in a Microsoft Excel spreadsheet. A standardized coding structure ensured consistency in the coding process. Use of common trending codes resulted in identification of changes in frequency of occurrence of a given parameter or a change in operational performance levels across a wide range of areas at low detection thresholds (Institute of Nuclear Power Operations, 2007). Unique designators (i.e., codes) were applied by a trending group at each nuclear power plant in accordance with standard methodologies.

Operational Definition of Variables

The research involved measurement of the application of two Lean Continuous Improvement Process operating results (the independent variable) to six indicators of nuclear safety culture (the dependent variable) using ratio data. The dependent variable of the nuclear safety culture was operationally defined by six indicators of changes in organizational and cultural performance, as defined by the Institute of Nuclear Power Operations (2001). The Institute of Nuclear Power Operations (INPO) considered two of the indicators (maintenance rework, longstanding equipment problems) to be performance level indicators reflective of current human and equipment performance. Three of the indicators (material unavailability, schedule errors, and inadequate corrective actions) were considered by INPO to be process level indicators reflective of current processes and programs designed to perform and control key work activities. The final indicator (resource unavailability) was considered by INPO to be a fundamental level indicator underlying factors that may influence performance. Each indicator was represented by ratio data (rate per 10, 000 person-hours worked). Data were collected from the incident reporting systems from the experimental and control nuclear power plants.

The independent variable of a Lean Continuous Improvement Process was operationally defined by two lean process operational indicators (quality and cost/productivity) as defined by Utah State University (2008). Quality for a nuclear power plant was expressed as a station capability factor. This indicator reflects effectiveness of nuclear power plant programs and practices in producing electrical generation and how well nuclear power plants are operated and maintained. Capability factors are defined as the ratio of the available energy generation over a given time period to the reference energy generation over the same time period, expressed as a percentage (Institute of Nuclear Power Operations, 2009b). Data were collected from the experimental and control plants' management review packages. The formula for this factor is expressed as:

Indicator value = [(REG - PEL - UEL - OEL)/REG] x 100%, where

REG = reference energy generation for the period

PEL = total planned energy losses for the period

UEL = total unplanned energy losses for the period

OEL = total outage extension energy losses for the period

Cost/productivity for a nuclear power plant was expressed as the operations and maintenance (O&M), excluding fuel, costs in U.S. dollars per megawatt-hour. Due to plant-specific variations in how these direct and indirect costs are determined, the O&M costs per megawatt-hour were calculated by both the experimental and control plants. Although nuclear power plant calculations for O&M costs are complex and include different variables, the constants required by oversight groups, such as state Public Utility Commissions, and the relative inelasticity of the values for the study period ensured constant values.

Data Collection, Processing, and Analysis

The researcher inquired of the subject plants as to quantities and trend types of incident reports experienced during different times of the year. Based on the responses obtained and personal knowledge of commercial nuclear power plant operations, issues aligned with the six cultural indicators selected for this study appeared to have the highest incidence of reporting during times of high work activity levels and infrequent evolutions, such as during preparations for and during refueling outages, installation of modifications, and tests and experiments. Thus, the most practical time period to conduct the study was in the summer as the plants prepared for fall refueling outages, installed modifications, and tested plant systems due to increased ambient temperatures.

Based on the common codes for each of the six indicators for a nuclear safety culture, as shown in Appendix B, appropriate plant incident reports from both the experimental and control plants were identified and subsequently evaluated to validate the coding and related trends. Data analysis provided indication of both positive and adverse trends aligned with the indicators of changes in a nuclear safety culture. Subsequent to data validation and analysis, implementation steps included transference of the relevant corrective action program data to Microsoft Excel templates and development of macros to sort, count, and analyze the data. Although not a strong statistical tool, Excel templates enhanced with additional statistical processes are useful workbooks for basic statistical analyses performed on field data (Aczel & Sounderpandian, 2006).

For the six nuclear safety culture indicators, data were collected from the plants' corrective action systems based on standardized trend codes (see Appendix B). For the two operational indicators, data were collected from the experimental and control plants' management review packages. Processing consisted of identifying the relevant information on the established indicators, transferring data to Microsoft Excel spreadsheets, and performing statistical tests for the indicators. Data were transferred into SPSS® version 15.0 for Windows and descriptive statistics were conducted. Pearson *r* correlations were conducted for the first set of hypotheses to assess if statistically significant relationships existed between quality and cost/productivity with the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions).

To examine the second set of hypotheses, a Multivariate Analysis of Variance (MANOVA) was conducted on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental). A MANOVA test was used to determine whether mean differences among groups on a combination of dependent variables were likely to have occurred by chance. The MANOVA was broken down by each dependent variable and resulted in an analysis of variance (ANOVA).

Methodological Assumptions, Limitations, and Delimitations

Relevant to this research was whether a continuous improvement process that emphasizes process waste elimination and cost reduction had an effect on the nuclear safety culture at a commercial nuclear power plant. To ensure probabilistic equivalence, both the experimental and control plants were assigned from a common pool of nuclear power plants located in the same Nuclear Regulatory Commission inspection region and the same geographical area, were members of a common industry alliance, had a recognized strong nuclear safety culture, and had similar organizational and professional cultures (Utilities Service Alliance, 2009). An assumption of this study was that data collected from the experimental nuclear power plant (Plant A) and the control nuclear power plant (Plant B) were normally distributed.

The program was applied simultaneously to the population of workforce groups at the experimental power plant, thus there was no sub-assignment of participants within the power plant group. Due to the nature and distribution of the workforce populations at both the experimental and control nuclear power plants, the plants were equivalent and random assignment included entire workforce populations. It was not possible to administer the program to randomly selected subgroups within the nuclear workforce population at either the experimental plant or the control plant.

As noted by Schein (2004), the basic defining dimensions of an organizational culture are not directly observable, thus valid indications and measurements of these dimensions are difficult to establish. Although there are a variety of quantitative and qualitative methods available to measure the psychological, behavioral, and situational aspects of safety cultures in high-risk industries, methods to measure work process aspects of safety cultures are limited (Cooper, 2000). As indicated in the review of the literature, various aspects of safety culture have been examined through observations and assessments of management and control records. Employee attitudes, values, and beliefs can be measured by a survey, but only through observations of worker performance or through reviews of event records are the application of these cultural aspects confirmed (Roughton & Mercurio, 2002).

Observations of work processes, however, have some limitations due to spatial arrangements, observer bias, and behavior alterations by respondents. Data gathered from plant event records minimized spatial and respondent behavior limitations and analysis by a single researcher mitigated researcher bias concerns. Gathering data from plant event records is an unobtrusive measurement process and does have a limitation relative to researcher control over the types of data collected (Trochim, 2001). Analysis techniques of content analysis through standardized coding applications were used to mitigate most other forms of bias. The use of the standardized codes listed in Appendix B encapsulates human judgment in assigning the codes to power plant event records, which can only be addressed through a qualitative observational study.

A significant regulatory environmental factor occurred during application of the treatment. The regulatory activity included new regulations for employee work hours and affected both the experimental and control plants. Regulatory activity was considered a delimitation for this study. It was assumed that industry factors would not affect the validity of this study at a nuclear power plant in the United States since all subjects involved in the study were equally exposed to the effect. The effect was present in all experimental conditions and had the same influence.

A limitation of this quasi-experimental design approach concerned possible selection effects where the experimental and control nuclear power plants may have been unequal on critical variables, thus resulting in posttest differences apart from the treatment. Although probabilistic equivalence was assured during the selection process, one threat to the internal validity of this study was the selection process. Pretesting was not possible for the research due to the security features for commercial nuclear power plants in the United States. In particular, selection-history, selection-maturation, and selection-regression effects could have affected this study and were not accounted for in the design. History and maturity effects are reviewed in the following discussion. A selection-regression effect occurs when there are different rates of regression to the means in the two groups (Trochim, 2001). When research groups (in the case of this research the experimental and control plants) are selected based on extreme indicators, subsequent application of indicators may move toward the group's mean. Although nuclear power plant indicators tend to be extreme indicators (e.g., plant capability factors) and the selection-regression effect was not considered in the research design, if the results of applying the treatment indicated no improvement, then it was assumed that the effect did not significantly impact validity.

The validity of this study was affected by history effects at Plant A. Organizational changes, including management changes and the engagement of a new efficiency consulting firm, occurred at the end of the data collection period. A limitation of this study is that the research did not consider the effect of organizational changes. Since the study extended over a five month period, validity was similarly affected by a maturation effect at the experimental plant. During the periods prior to and throughout this study, the workers at the power plant became more experienced in implementing a Lean Continuous Improvement Process. Since the purpose of a Lean Continuous Improvement Process is to reduce production and process wastes and costs, create value, and improve workflow, the likelihood of this maturation effect was expected to be high.

Another type of maturity effect has been described wherein organizations were unprepared for the interactions of improvement programs with other processes (Keating et al., 1999). Unintended interactions with other processes and programs represented an extraneous variable reflected as another dimension to the maturity effect that could have potentially influenced the dependent variable. A delimitation of this study is that the research findings did not account for these maturity effects because the focus was on the effect of operational indicators on specified nuclear safety cultural indicators.

Some other types of extraneous variables were assumed to not influence or affect the validity of this study. No pretesting was performed as part of this study, which would preclude a testing effect. This researcher relied upon operational data at the experimental and control nuclear power plants to examine the influence of a Lean Continuous Improvement Process on the nuclear safety culture. Since no instruments were developed to support this study, this researcher assumed that instrumentation would have no effect on validity. Due to the nature of this study, it applied to the population of workers at the subject power plant and the experimental and control groups have a similar nuclear safety culture; thus, it was assumed that the single group threats of selection effects, mortality effects, or social interaction effects did not adversely affect validity.

All measures of constructs contain some error (Gryna et al., 2006), and the measures described for this research contained some error, especially common variation error, that was not accounted for. Using more than one measure of a construct and establishing validity and reliability of the measures, however, minimized error variance (Gryna et al., 2006). Use of the six indicators established for this study assured that construct variance was larger than error variance.

Based on previous studies (Institute of Nuclear Power Operations, 2001), the indicators selected for this study were expected to consistently and dependably measure nuclear safety culture changes. Gryna et al. (2006) maintained that reliable units of measure could be based on any relevant indicator when bias was eliminated. The indicators used in this research had high test-retest reliability because the results were consistently correlated to common denominators and provided consistent true scores over repeat measurements, given the conditions did not dramatically change. Establishing ratios of key construct attributes to common denominators is one approach for ensuring measurement reliability (Gryna et al., 2006). Inter-item reliability (internal consistency) was high for these measures.

Fundamental to these indicator measures was that they provide a valid measurement of the influence of a Lean Continuous Improvement Process on a nuclear safety culture. Based on nuclear industry performance indicators, the indicator measures employed in this study were assumed to be relevant to the construct. The Institute of Nuclear Power Operations (2001) developed these indicators to measure changing plant performance, and this study evaluated changes in performance as an indicator to changes in a nuclear safety culture. Based on previous studies (Institute of Nuclear Power Operations, 2001), these indicator measures were also assumed to be related to other performance measures and assumed to have both high content and face validity. Assurance of criterion validity was established based on the nature of organizational cultures at U.S. nuclear power plants. Worker behaviors and practices are governed by formal rules and standardized operating procedures (Perin, 2005). Planning and coordination of work activities are accomplished through structured and bureaucratic reporting relationships (Perin, 2005). Thus, these indicators were expected to provide adequate measurement and to correlate with other measures of the same construct.

Construct validity was moderate during this study. Operational definitions were established through the use of six cultural indicators and generalizing across constructs was minimized. Other cultures exist within the context of a safety culture (Corcoran, 2010; Reason, 1997). Corporate and plant organizational cultures interact with and influence nuclear safety cultures. Members of a nuclear power plant culture also reside in subcultures, which may complicate the task of measuring the influence of a program on the nuclear safety culture. Organizations have informal cultures that provide a shared way of perceiving the world, and membership in the informal cultures influences work patterns, behaviors, and values (Wagner & Hollenbeck, 2005). Organizations also have professional cultures (Schein, 2004). The nuclear power generation industry has a strong and unique professional culture that can influence work patterns, behaviors, and values (Wilpert & Itoigawa, 2001). Professional cultures are shaped by history, the attributes of the professional task, the risks and responsibilities of the technology, and the characteristics of its members (Helmreich & Merritt, 1998). Although different subcultures could affect the nuclear safety culture apart from the application of a Lean Continuous Improvement Process, a limitation of this study was that other cultural influences were not accounted for because this research focused on the impact of business operational results on safety cultural indicators.

External validity may be realized when generalized across the commercial nuclear industry within the United States because of similarities in operational structures and institutions, organizational, professional and national cultures, and regulatory environments. Differences in national perceptions and conceptualizations of a nuclear safety culture in other countries could affect external validity when extrapolating results for use in the global commercial nuclear industry. Any generalizations to other industries would be limited to those which are high-risk in nature and have some sort of safety culture mindset, such as aerospace and emergency medical or rescue fields.

Threats to internal validity during this study were reasonably controlled by the nature of the study. Most extraneous variables were eliminated in this study. Other extraneous variables were either assumed to be constant throughout the study or to not influence validity.

Ethical Assurances

This research assessed the relationships on a nuclear safety culture at a commercial nuclear power plant in the United States when implementing a Lean Continuous Improvement Process. Proprietary, personal, and nuclear safeguards information was excluded from the corrective action documents reviewed. Management at the experimental and control plants granted permission to use plant data within the bounds of stated limitations (see Appendix A). Personal and social harm was avoided.

Data obtained from nuclear power plant corrective action systems based on trend codes are recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects. This research was based on the concept of grouped information, for which no identifiable private information was obtained on human subjects. Furthermore, data were not obtained through intervention or interaction with any individuals. This research project did not, therefore, meet the definition of human subject research as specified in the Code of Federal Regulations Title 45, Part 46, and was in compliance with the standards of the Northcentral University Institutional Review Board.

Summary

The approach of this quantitative research applied an independent variable (a Lean Continuous Improvement Process) to the dependent variable of a nuclear safety culture at a commercial nuclear facility in the United States to study correlations among two production factors and six nuclear safety culture variables. The control group was another nuclear power plant within a common industry alliance and in the same geographical region. The program was applied simultaneously to the population of workforce groups at the experimental power plant, thus there was no sub-assignment of participants within the power plant group. Due to the nature and distribution of the workforce populations at both the experimental and control nuclear power plants, the plants were equivalent and random assignment included entire workforce populations. It was not possible to administer the program to randomly selected subgroups within the nuclear workforce population at either the experimental plant or the control plant.

The strategy for this research consisted of reviewing and categorizing data within the plants' information reporting systems, excluding materials related to proprietary, personal, and security safeguards information. A research instrument was not necessary for this study. Nuclear power plants' information systems are computerized to support collecting, sorting, and analyzing performance trends. Standardized trending criteria and codes, classified by issue types, were used and tabulated in a Microsoft Excel spreadsheet. A standardized coding structure ensured consistency in the coding process.

Tabulated data were entered into SPSS® version 15.0 for Windows and descriptive statistics were conducted. To examine the first research question, 12 Pearson *r* correlations were conducted to assess if statistically significant relationships existed between a Lean Continuous Improvement Process and the six cultural indicators. To examine the second research question, a Multivariate Analysis of Variance (MANOVA) and an Analysis of variance (ANOVA) were conducted on the six cultural indicators by group (experimental and control). Results of this study are detailed and discussed in Chapter 4.

A limitation of this quasi-experimental design approach concerned possible selection effects where the experimental and control nuclear power plants may have been unequal on critical variables, thus resulting in posttest differences apart from the treatment. Although probabilistic equivalence was assured during the selection process, one threat to the internal validity of this study was the selection process. Pretesting was not possible for the research due to the security features for commercial nuclear power plants in the United States.

Changes in the environment occurred during this study. A significant regulatory environmental factor occurred during application of the treatment but was considered a delimitation for this study. Industry factors would not affect the validity of this study at a nuclear power plant in the United States since all subjects involved in the study were equally exposed to the effect. The validity of this study was affected by history effects at Plant A. Organizational changes occurred at the end of the data collection period. A limitation of this study is that the research did not consider the effect of organizational changes. Since the study extended over a five month period, validity was similarly affected by a maturation effect at the experimental plant. The purpose of a Lean Continuous Improvement Process is to reduce production and process wastes and costs, create value, and improve workflow. Thus, the likelihood of this maturation effect was expected to be high. Other cultures exist within the context of a safety culture (Corcoran, 2010), such as corporate and worker cultures. Although different subcultures could affect the nuclear safety culture apart from the application of a Lean Continuous Improvement

Process, a limitation of this study was that other cultural influences were not accounted for. External validity may be realized when generalized across the commercial nuclear industry within the United States because of similarities in operational designs, organizational, professional and national cultures, and regulatory environments. Differences in national perceptions and conceptualizations of nuclear safety culture in other countries could affect external validity when extrapolating results for use in the global commercial nuclear industry.

Unintended interactions with other processes and programs represented an extraneous variable reflected as another dimension to the maturity effect that could have potentially influenced the dependent variable. A delimitation of this study is that the research findings did not account for these maturity effects because the research strategy was to determine the effect of operational indicators on specified nuclear safety cultural indicators. Some other types of extraneous variables, such as testing and instrumentation effects, were assumed to not influence or affect the validity of this study.

Based on previous studies (Institute of Nuclear Power Operations, 2001), the indicators selected for this study were expected to consistently and dependably measure nuclear safety culture changes. The indicators used in this research had high test-retest reliability because the results were consistently correlated to common denominators and provided consistent true scores over repeat measurements, given the conditions did not dramatically change. Establishing ratios of key construct attributes to common denominators is one approach for ensuring measurement reliability (Gryna et al., 2006). Inter-item reliability (internal consistency) was high for these measures.

Fundamental to these indicator measures was that they provide a valid measurement of the influence of a Lean Continuous Improvement Process on a nuclear safety culture. Based on nuclear industry performance indicators, the indicator measures employed in this study were assumed to be relevant to the construct. These indicators were developed to measure changing plant performance (Institute of Nuclear Power Operations, 2001), and this study evaluated changes in performance as an indicator of changes in a nuclear safety culture. These indicator measures were also assumed to be related to other performance measures and assumed to have both high content and face validity. Assurance of criterion validity was established based on the nature of the structured and proceduralized organizational cultures at U.S. nuclear power plants (Perin, 2005).

The research methods were implemented and the findings of the study have been documented in the next chapter of this dissertation. Safety culture indicator data and operating results data were gathered from the experimental and control nuclear power plants. The research design and methodology were applied to produce the findings. Included within the next chapter of this dissertation is an evaluation of the findings.

CHAPTER 4: FINDINGS

The purpose of this study was to evaluate the effect of implementing a continuous improvement process that focuses on reducing process wastes and operating costs on a nuclear safety culture at a commercial nuclear power plant. A Lean Continuous Improvement Process (the independent variable) was determined by two fundamental business operating results: quality and cost/productivity. A nuclear safety culture (the dependent variable) was differentiated by six indicators derived from standard nuclear power plant indictors used in determining changes in a nuclear plant's organizational performance: maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions. As used in this study, changes in organizational performance were used as indicators of changes in organizational culture. The operating results of quality and cots/productivity were assumed to have a direct relationship with the six nuclear safety culture indicators.

Safety culture indicator data were gathered from the experimental and control nuclear power plants' incident/corrective action reporting systems, excluding documentary materials related to proprietary, personal, and security safeguards data. The focus of the study was to use incident/corrective action reports to determine differences in the six cultural indicators relative to the two operating results of quality and cost/productivity and by group (experimental vs. control). Operating results data were obtained from the experimental and control nuclear power plants' management indicator review systems. Collected data were manually transferred to spreadsheets using double entry to test for data entry errors. The research design and methodology were applied to produce the findings.

Results

Based on operating histories at the experimental and control plants, issues aligned with the six cultural indicators selected for this study have the highest incidence of reporting during times of high work activity levels and infrequent evolutions, such as during preparations for and during refueling outages, installation of modifications, and tests and experiments. Thus, the most practical time period to conduct the study was in the summer as the plants prepared for fall refueling outages and tested plant systems due to increased ambient temperatures.

During the analysis phase, it was necessary to expand the sample size to improve variance for testing purposes. Since the original resulting data set was too small to conduct the analysis as designed, the revised data collection period was started on May 1, 2009, and terminated on September 30, 2009, prior to commencement of refueling outages. The additional extension of the collection period still included the pre-refueling period for both the experimental and control plants.

The Lean Continuous Improvement Process operating results were calculated by the experimental and control plants. Descriptive statistics were conducted on these calculated values for the two operating results and the collected data for the six cultural indicators to determine means, standard deviations, and ranges for continuous (ratio) data. To examine the first set of hypotheses, the analyses consisted of Pearson *r* correlations to assess if statistically significant relationships existed between quality and cost/productivity with the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions). To examine the second set of hypotheses, a Multivariate Analysis of Variance (MANOVA) test was conducted on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental). A MANOVA test was used to determine whether mean differences among groups on a combination of dependent variables were likely to have occurred by chance. The MANOVA was broken down by each dependent variable and resulted in an analysis of variance (ANOVA).

Lean Continuous Improvement Process Operating Results. Quality for a nuclear power plant was expressed as a station capability factor. The purpose of this industry indicator is to monitor progress in attaining high energy production reliability. This indicator reflects effectiveness of nuclear power plant programs and practices in producing electrical generation and how well nuclear power plants are operated and maintained. Capability factors are defined as the ratio of the available energy generation over a given time period to the reference energy generation over the same time period, expressed as a percentage (Institute of Nuclear Power Operations, 2009b).

The capability factors for the subject test period were calculated by both the experimental and control plants because of the inclusion of proprietary information. As expected, since neither plant had a planned nor unplanned outage during the study period, capability factors were high. Resultant values by month are presented in Table 1.

Table 1

Quality Operating Results (Expressed as Percent Capability Factor)

p . ,	Experimental (Plant A)	Control (Plant B)
May 2009	99.97	100.00
June 2009	99.97	100.00
July 2009	99.99	100.00
August 2009	99.99	100.00
September 2009	99.99	100.00

Cost/productivity for a nuclear power plant was expressed as the operations and maintenance (O&M), excluding fuel, costs in U.S. dollars per megawatt-hour. Due to plant-specific variations in how these direct and indirect costs are determined, the O&M costs per megawatt-hour were calculated by both the experimental and control plants. Although nuclear power plant calculations for O&M costs are complex and include different variables, the constants required by oversight groups, such as state Public Utility Commissions, and the relative inelasticity of the values for the study period suggested no significant impact on the statistical tests. Resultant monthly O&M costs are presented in Table 2.

Table 2

Cost/Productivity Results (Expressed as O&M $/Mwh)

Period	Experimental (Plant A)	Control (Plant B)
May 2009	9.42	10.52
June 2009	9.08	10.13
July 2009	8.97	10.07
August 2009	9.49	10.82
September 2009	9.29	10.64

Nuclear Safety Culture Indicator Results. Data were collected from the incident reporting/corrective action systems at both the experimental and control plants. The physical count of instances for each of the six cultural indicator data sets was divided by 10,000 man-hours worked during the period to provide a representation of ratio data. As expected, total man-hours worked at the control plant (Plant B) were higher than man-hours worked at the experimental plant (Plant A) because of a larger workforce population. Based on plant capability factors during the study period, neither plant experienced any unusual maintenance or other work activities during this period, which would have caused the workforce populations to deviate from the norm.

Resultant values for the experimental plant (Plant A) are presented in Table 3. Resultant values for the control plant (Plant B) are presented in Table 4. Each nuclear safety indicator has been provided in Table 3 and Table 4 in the sequence presented in the research questions.

Table 3

Nuclear Safety Culture Indicator (Experimental Plant A)

Indicator	Period	Count	Rate
Maintenance Rework	May	5	0.117
	Jun	4	0.093
	Jul	8	0.186
	Aug	5	0.117
	Sept	5	0.117
Longstanding Equipment Problems	May	32	0.746
	Jun	29	0.676
	Jul	35	0.816
	Aug	35	0.816
	Sept	35	0.816
Resource Unavailability	May	3	0.070
	Jun	5	0.117
	Jul	4	0.093
	Aug	5	0.117
	Sept	4	0.093
Material Unavailability	May	8	0.186
	Jun	5	0.117
	Jul	13	0.303
	Aug	10	0.233
	Sept	6	0.140
Schedule Errors	May	12	0.280
	Jun	10	0.233
	Jul	15	0.350
	Aug	9	0.210
	Sept	10	0.233
Inadequate Corrective Actions	May	3	0.070
	Jun	4	0.093
	Jul	6	0.140
	Aug	7	0.163
	Sept	3	0.070

Table 4

Nuclear Safety Culture Indicator (Control Plant B)

Indicator	Month	Count	Rate
Maintenance Rework	May	11	0.188
	Jun	6	0.103
	Jul	8	0.137
	Aug	4	0.070
	Sept	5	0.0.86
Longstanding Equipment Problems	May	45	0.771
	Jun	42	0.702
	Jul	43	0.736
	Aug	43	0.736
	Sept	43	0.736
Resource Unavailability	May	7	0.120
	Jun	3	0.051
	Jul	6	0.103
	Aug	5	0.086
	Sept	4	0.070
Material Unavailability	May	2	0.034
	Jun	1	0.017
	Jul	4	0.070
	Aug	2	0.034
	Sept	3	0.051
Schedule Errors	May	10	0.171
	Jun	9	0.154
	Jul	4	0.068
	Aug	5	0.086
	Sept	7	0.120
Inadequate Corrective Actions	May	12	0.137
	Jun	10	0.171
	Jul	3	0.051
	Aug	5	0.086
	Sept	3	0.051

Descriptive Statistics. Descriptive statistics including means, standard deviations and ranges for the two Lean Continuous Improvement Process operating results (quality and cost/productivity) and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) were conducted. The results are presented in Table 5.

Table 5

Means, Standard Deviations and Range for Research Variables

	Min	Max	M	SD
Maintenance Rework	0.07	0.19	0.12	0.04
Longstanding Equipment Problems	0.68	0.82	0.76	0.05
Resource Unavailability	0.05	0.14	0.10	0.03
Material Unavailability	0.02	0.30	0.12	0.10
Schedule Errors	0.07	0.35	0.19	0.09
Inadequate Corrective Actions	0.05	0.21	0.11	0.06
Cost	8.97	10.82	9.93	0.74
Quality	99.97	100.00	99.99	0.01

Hypothesis 1. To examine hypothesis 1, 12 Pearson *r* correlations were conducted to assess if statistically significant relationships existed between the two Lean Continuous Improvement Process (LCIP) operating results (quality and cost/productivity) and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions). The results of this correlational analysis are presented in Table 6. As indicated by the results presented in Table 6, significant negative correlation coefficients existed between cost and material unavailability (r = -0.83) and between cost and schedule

errors, (r = -0.90). The results also indicated a significant negative correlation coefficient between quality and schedule errors (r = -0.65). Cohen's standard was used to evaluate the correlation coefficient, where 0.2 represents a weak association between the two variables, 0.5 represents a moderate association, and 0.8 represents a strong association (Howell, 1992). No significant relationships were found between the cost operational indicator with the cultural indicators of maintenance rework, longstanding equipment problems, resource unavailability, and inadequate corrective actions or between the quality operational indicator with the cultural indicators of maintenance rework, longstanding equipment problems, material unavailability, resource unavailability, and inadequate corrective actions.

Table 6

Correlation Coefficients between LCIP and Cultural Indicators

Indicator	Cost	Quality
Maintenance Rework	-.112	.103
Longstanding Equipment Problems	-.332	.155
Resource Unavailability	-.430	-.136
Material Unavailability	-.829**	-.499
Schedule Errors	-.898"	-.650*
Inadequate Corrective Actions	-.012	.215

Note. $^*p < 0.05$, $^{**}p < 0.01$.

Hypothesis 2. Preliminary analyses, using 12 Shapiro-Wilk tests, six for each plant, were conducted on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) to evaluate the assumption of normality. The Shapiro-Wilk tests compared the ordered sample values with the corresponding statistics from the specified distribution to test for a normal distribution. All cultural indicators were normally distributed by group except long standing equipment problems for Plant A (see Table 7). The indicator for long standing equipment problems was slightly negatively skewed. As noted by Howell (1992), non-normality has only a slight affect on a Type I error rate, even for skewed distributions, because the *F* statistic is robust with the respect to the normality assumption.

Table 7

Shapiro-Wilk Tests on Cultural Indicators by Plant

	Experimental (Plant A)		Control (Plant B)	
Indicator	Statistic	Sig.	Statistic	Sig.
Maintenance Rework	.911	.471	.935	.630
Longstanding Equipment Problems	.771	.046	.883	.325
Resource Unavailability	.959	.803	.990	.980
Material Unavailability	.957	.787	.958	.793
Schedule Errors	.875	.288	.946	.706
Inadequate Corrective Actions	.865	.248	.852	.200

To examine hypothesis 2, a Multivariate Analysis of Variance (MANOVA) test was conducted to assess if differences existed on cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by plant (A vs. B). A MANOVA test was used to determine whether mean differences among groups on a combination of dependent variables were likely to have occurred by chance (Tabachnick & Fidell, 2001). Levene's test of homogeneity of variance was not met on longstanding equipment problems and material unavailability; however, according to Howell (1992), as long as the largest to smallest group ratio is 1.5 or less, the MANOVA is robust. The results of the MANOVA, presented in Table 8, were not significant, F (6, 3) = 5.87, p = 0.087.

Table 8

MANOVA on Cultural Indicators by Plant

F	Experimental (Plant A) dfl	Control (Plant B) df2	Sig.
5.87	6	3	.087

The MANOVA test was broken down by each dependent variable and resulted in an analysis of variance (ANOVA) test, an appropriate statistical analysis when the purpose of the research is to assess if mean differences exist on one continuous dependent variable between two or more discrete groups (Tabachnick & Fidell, 2001). Individual ANOVA test statistics are presented in Table 9, which indicated that for material unavailability Plant A had a larger mean (M= 0.20, *SD* = 0.07) compared to Plant B (M = 0.04, *SD* = 0.02) and on schedule errors Plant A had a larger mean (M= 0.26, *SD* = 0.06) compared to Plant B *(M*= 0.12, *SD* = 0.04). No other significant differences were found on maintenance rework, longstanding equipment problems, resource unavailability, and inadequate corrective actions by plant (A vs. B).

Table 9

ANOVA 's on Cultural Indicators by Plant

Indicator	*F*	Sig.	Experimental (Plant A) M	Experimental (Plant A) SD	Control (Plant B) M	Control (Plant B) SD
Maintenance Rework	0.00	.995	0.12	0.04	0.12	0.05
Longstanding Equipment Problems	1.58	.244	0.77	0.06	0.74	0.02
Resource Unavailability	1.59	.244	0.11	0.03	0.09	0.03
Material Unavailability	19.99	.002	0.20	0.07	0.04	0.02
Schedule Errors	19.93	.002	0.26	0.06	0.12	0.04
Inadequate Corrective Actions	0.02	.883	0.11	0.04	0.11	0.07

Note. df= 1, 8.

Evaluation of Findings

The first research question was stated as follows: What relationships, if any, exist among the two Lean Continuous Improvement Process operating results (quality and cost/productivity) and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions)? The results of the correlational analysis indicated significant negative correlation coefficients existed between cost and material unavailability (r = -0.83) and between cost and schedule errors, (r = -0.90). As indicated by these results, the operational indicator of cost/productivity has an inverse relationship with the cultural indicators of material unavailability and schedule errors. When operating costs decreased, material unavailability and schedule errors increased.

The results also indicated a significant negative correlation coefficient between quality and schedule errors (r = -0.65), suggesting that as the operational indicator of quality increases schedule errors will decrease. No significant relationships were found between cost with maintenance rework, longstanding equipment problems, resource unavailability, and inadequate corrective actions or between quality with maintenance rework, longstanding equipment problems, material unavailability, resource unavailability, and inadequate corrective actions. Based *onp* < 0.01 for this test, relative to the indicator of cost/productivity correlated with the indicators of material unavailability and schedule errors, and/? < 0.05 for this test, relative to the operational indicator of quality correlated with the indicator of schedule errors, there is evidence to reject the first null hypothesis (There is no correlation between quality and cost/productivity and the six cultural indicators: maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) in favor of the alternative hypothesis (There is a correlation between quality and cost/productivity and the six cultural indicators: maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions).

The second research question was stated as follows: What differences, if any, exist on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental)? The results of the MANOVA test were not significant, $F(6, 3) = 5.87, p = 0.087$, suggesting that simultaneous differences between Plant A and Plant B did not exist. Individual ANOVA test statistics indicated that for material unavailability Plant A had a larger mean ($M = 0.20$, $SD = 0.07$) compared to Plant B ($M = 0.04$, $SD = 0.02$) and on schedule errors Plant A had a larger mean (M= 0.26, *SD* = 0.06) compared to Plant B (*M*= 0.12, *SD* = 0.04). Significant differences were revealed for the cultural indicators of material unavailability and schedule errors between Plant A and Plant B. No other significant differences were found on maintenance rework, longstanding equipment problems, resource unavailability, and inadequate corrective actions by plant (A vs. B).

The ANOVA test results validated conclusions derived for the first research question. Based on these results, there is evidence to reject the second null hypothesis (A difference does not exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental)) in favor of the alternative hypothesis (A difference does exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental)).

Summary

Based on the findings from this research, evidence existed to reject the null hypotheses developed for each research question. The findings indicated a correlation between quality and schedule errors and between cost and material unavailability and between cost and schedule errors. Although the findings indicated that simultaneous differences between Plant A and plant B did not exist, significant differences were revealed for the indicators of material unavailability and schedule errors between Plant A and Plant B.

Since no previous research could be found relative to implementation of a continuous improvement process that focuses on reducing process wastes and operating costs at a commercial nuclear power plant, the findings of this study identified some additional influences on a nuclear safety culture. Evidence has been presented that a nuclear safety culture may be affected when operating costs are sustained relatively low compared to other plants in the industry. Evidence was not available to determine the degree of the effect. Furthermore, these lower operating costs could be counterproductive when the unavailability of materials and errors in scheduling result in work delays, reworks, and extra transportation costs - the very items that a Lean Continuous Improvement Process targets to eliminate as wasteful activities.

Within the next chapter of this dissertation, the implications, recommendations, and overall conclusions from this research have been provided. Each research question and hypothesis has been discussed separately. Limitations and effects on the results have been discussed. Recommendations for application of research results and for future studies have been provided.

CHAPTER 5: IMPLICATIONS, RECOMMENDATIONS, AND CONCLUSIONS

The problem addressed by this quantitative research was how implementation of a continuous improvement process that emphasizes reduction in process wastes and operating costs affected a nuclear safety culture. Although researchers in other studies had concluded that overemphasis on controlling production costs and improving the bottom line had compromised safety margins and degraded the broader safety culture of some nuclear organizations (Itoigawa et al., 2005), no previous research could be found relative to the effects on a nuclear safety culture when implementing a continuous improvement process that focuses on reducing process wastes and operating costs (i.e., Lean Continuous Improvement) at a commercial nuclear power plant. The purpose of this research was, therefore, to examine the relationships between a Lean Continuous Improvement Process and the nuclear safety culture at a nuclear power plant. The intent of this research was to identify if correlations existed between two operational factors (quality and cost) and six nuclear safety culture indicators, thus providing nuclear power plant leaders additional insights for sustaining a strong nuclear safety culture.

Quantitative analysis was applied to data collected from an experimental commercial nuclear power plant and a control commercial nuclear power plant located in a common region in the United States. The design was a posttest-only control group design to determine the effect of a Lean Continuous Improvement Process on a nuclear safety culture. Pearson *r* correlations were conducted to assess if statistically significant relationships existed between quality and cost/productivity and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions). A Multivariate

Analysis of Variance (MANOVA) was conducted on the six indicators by group (control vs. experimental) to determine whether mean differences among the groups were likely to have occurred by chance. The MANOVA was broken down by each dependent variable and an analysis of variance (ANOVA) was performed to determine if group means differed.

There were some limitations that affected the validity of this study. The program was applied simultaneously to the population of workforce groups at the experimental power plant, thus there was no sub-assignment of participants within the power plant group. Due to the nature and distribution of the workforce populations at both the experimental and control nuclear power plants, the plants were probabilistically equivalent and random assignment included entire workforce populations. It was not possible to administer the program to randomly selected subgroups within the nuclear workforce population at either the experimental plant or the control plant. A limitation of this design approach concerned possible selection effects where the experimental and control nuclear power plants may have been unequal on critical variables, thus resulting in posttest differences apart from the treatment. Although probabilistic equivalence was assured during the selection process, one threat to the internal validity of this study was the selection process. Pretesting was not possible for the research due to the security features for commercial nuclear power plants in the United States. Another limitation of this study was that the researcher did not consider the effect of organizational changes, including management changes and the engagement of a new efficiency consulting firm, which affected the experimental plant at the end of the data collection period. A final limitation of this study was that other cultural influences were not accounted for. Other cultures exist within the context of a safety culture such as corporate and plant professional and organizational sub-cultures that interact with and influence nuclear safety cultures.

Ethical assurances were maintained during the research. Proprietary, personal, and nuclear safeguards information was excluded from the data reviewed. Management at the experimental and control plants granted permission to use plant data within the bounds of stated limitations. Personal and social harms were avoided. This research was based on the concept of grouped information, for which no identifiable private information was obtained on human subjects. Data were not obtained through intervention or interaction with any individuals.

The purpose of this section of the dissertation is to present the implications of the research findings, recommendations for practical applications of the study, and conclusions of the research. Each research question and associated hypothesis is discussed individually. The effects of research limitations on research results are summarized. The desired result of this study was to bridge a gap in the existing knowledge for determining precursors to nuclear safety events and to supplement the body of knowledge on a nuclear safety culture.

Implications

This research studied the implementation of a continuous improvement process that emphasizes reduction in process wastes and operating costs at a commercial nuclear power plant in the United States to determine if there was any effect on a nuclear safety culture. Previous studies had identified that overemphasis on controlling production costs had compromised safety margins and degraded the broader safety culture of some nuclear power plants (Itoigawa et al., 2005). Research on nuclear power plants and organizational economics is limited, however, and no previous research could be found relative to the effects on a nuclear safety culture when implementing a Lean Continuous Improvement Process.

The first research question was stated as follows: What relationships, if any, exist among the two Lean Continuous Improvement Process operating results (quality and cost/productivity) and the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions)? For purposes of this study, the first null research hypothesis was presented as no correlation existed between quality and cost/productivity and the six cultural indicators. As indicated by the correlational analysis, the operational indicator of cost/productivity had an inverse relationship with the cultural indicators of material unavailability and schedule errors. During the study, when operating costs decreased, material unavailability and schedule errors increased in quantity. The correlational analysis also indicated that a negative correlation existed between quality and schedule errors, suggesting that as the operational indicator of quality increased schedule errors decreased. No significant relationships were found between cost with maintenance rework, longstanding equipment problems, resource unavailability, and inadequate corrective actions or between quality with maintenance rework, longstanding equipment problems, material unavailability, resource unavailability, and inadequate corrective actions. Based *onp* < 0.01 for this test relative to the indicator of cost/productivity correlated with the indicators of material unavailability and schedule errors, and/? < 0.05 for this test relative to the operational indicator of quality correlated with the indicator of schedule errors, there was sufficient evidence to reject the first null hypothesis in favor of the alternative hypothesis that there was a correlation between quality and cost/productivity and the six cultural indicators: maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions.

The second research question was stated as follows: What differences, if any, exist on the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental)? For purposes of this study, the second null research hypothesis was presented as a difference did not exist among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental). The results of the MANOVA test were not significant, suggesting that simultaneous differences between Plant A and Plant B did not exist. Individual ANOVA test statistics indicated significant differences existed between Plant A and Plant B for the cultural indicators of material unavailability and schedule errors. For material unavailability and schedule errors Plant A had a larger mean compared to Plant B. No other significant differences were found on maintenance rework, longstanding equipment problems, resource unavailability, and inadequate corrective actions by plant (A vs. B). The ANOVA test results validated conclusions derived for the first research question. Based on these results, there was sufficient evidence to reject the second null hypothesis in favor of the alternative hypothesis that a difference existed among the six cultural indicators (maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions) by group (control vs. experimental).

There are some noteworthy implications from these research results. The research results were consistent with the quality-related literature. Juran (1995) and other continuous quality improvement researchers had observed that errors decrease as quality levels increase. Aside from the relationship of errors to quality, quality has been conceptualized in many other ways. Building on international standards, Gryna et al. (2006) conceptualized quality as the totality of characteristics that bear on an organization's ability to satisfy stated and implied needs. Based on this conceptualization, a commercial nuclear power plant must produce electricity in a safe and reliable manner (stated needs) and in a reasonably economic manner to remain in business (implied needs). When stated and implied needs were considered in terms of electricity generation, quality was defined in this study as a nuclear power plant's capability factor. This present study was consistent with the literature relative to quality levels and errors.

Another implication from the findings of this study was the relationship of cost to quality. According to the literature, implementation of a continuous improvement process should improve overall quality which should reduce overall costs of poor quality, such as the costs of defects in product. This study had some implications that although a Lean Continuous Improvement Process may reduce operational costs, it may induce negative pressures on quality levels. Analysts at the American Society for Quality (2010) have recently started exploring the possibilities of a business organization being *too lean.* Lean Continuous Improvement Processes entail certain risks such as reductions in inventories and numbers of suppliers so there is no safety stock available if problems arise with materials or the suppliers (American Society for Quality, 2010). Although not demonstrated by the findings, it can be inferred that operational quality indicators were affected by the operational cost indicators. Both operational indicators had some affect on the culture indicators of material unavailability and schedule errors.

Other implications were related to the operational cost indicator. Material unavailability is directly correlated to a nuclear power plant's Operations and Maintenance (O&M) budgets since required tools and materials are factored into operational plans. Errors in scheduling are indirectly correlated to O&M budgets since these errors are not operationally planned yet affect work that is operationally planned. Both the material unavailability and schedule errors indicators have been directly correlated to an increase in error-likely situations at nuclear power plants (Reiman, 2007). A problematic work schedule has been considered an at-risk practice when tasks are of a critical nature and workers perceive pressure existed to complete tasks according to the schedule (Reiman, 2007). Schedule errors may increase a worker's frustration, thus increasing the potential for mistakes. Unavailable materials, parts, and components for nuclear safety systems combined with work tasks scheduled at incorrect times could delay preventive and corrective maintenance on critical work tasks. Unsuitable, unavailable, or non-current materials have been demonstrated to gradually change conceptualizations about an organization's culture and legitimize activities and practices that are not conducive to a nuclear safety culture (Reiman, 2007). For example, when faced with the incompatible demands of increased productivity, work schedule problems, and unavailable or incorrect materials, parts, or components, the workforce's conceptions of a nuclear safety culture could gradually change and activities that no longer support nuclear safety could be normalized (Vaughan, 1996). Thus, over time, these performance shortfalls could become the norm in the culture.

Relative to conflicts between observed cultural attributes and the desired strong safety culture attributes, Corcoran (2010) noted conflicts between O&M budgets and safety cultures when these budgets were established by higher level groups with insufficient knowledge of safety impacts. Relationships between O&M budgets and the continuous improvement process, including implementation, may also be unclear. This current study has some implications for nuclear power plant economic models, specifically as these models relate to the budgetary process. The Standard Nuclear Performance Improvement Process is incorporated into a standard budgeting process for continuous improvement activities, wherein business plans and resources are considered relative to analysis and solution implementation phases of continuous improvement processes (Institute of Nuclear Power Operations, 2005). Relative to business planning considerations, the Institute for Nuclear Power Operations (2005) provided a caution to power plants about not factoring major improvement initiatives into operations budgets.

' A commercial nuclear power plant in the United States budgets for standard continuous improvement processes, such as benchmarking and self-assessments, and for implementing actions. As a consequence, variances in operating costs are monitored but not the costs of obtaining different levels of performance. Implementation of a Lean Continuous Improvement Process at a commercial nuclear power plant may require a different budgetary approach wherein operational budgets account for the costs of non-standard continuous improvement approaches, the costs of obtaining different levels of performance, and impacts on nuclear safety.

This research resulted in some implications relative to economic and competitive response strategies for commercial nuclear power plants. A comparison of Plant A with Plant B, both comparably sized and engineered and similar in age, culture, and technology, was appropriate for this research. Both plants implemented the Standard Nuclear Performance Improvement Process as expected by the Nuclear Regulatory Commission and the Institute of Nuclear Power Operations. Plant B implemented no alternative continuous improvement strategy yet sustained high quality levels and high ratings in operational and safety performance. Although no data were available to support a conclusion, the research findings imply that when a commercial nuclear power plant implements a Standard Nuclear Performance Improvement Process, integrated throughout the work organizations and consistent with the requirements of the Nuclear Regulatory Commission, a strong nuclear safety culture is maintained. The strategy of Plant B may be the preferred economic and competitive response strategy.

Results presented by some researchers indicated that some organizational cultures were not compatible with a continuous improvement culture (Kujala & Lillrank, 2004). As noted by Kujala and Lillrank, some organizations have not been able to create a continuous improvement culture because the organizational culture did not have the required shared values. The results of this current research found no evidence that a nuclear safety culture was incompatible with a continuous improvement culture. The current results were consistent with nuclear safety culture principles, which support the shared values of trust and receptivity to new ideas (Institute of Nuclear Power Operations, 2004).

Some researchers had observed that many companies have realized business performance shortfalls when implementing a continuous improvement process (Keating et al., 1999). Although there were insufficient data obtained during this current study to determine whether implementation of a Lean Continuous Improvement Process resulted in business performance shortfalls at Plant A, evidence indicated organizational stress factors at Plant A were increasing more than organizational stress factors at Plant B. For example, implementation of the Lean Continuous Improvement Process was confronted by organizational changes and the introduction of an efficiency consultation firm in an environment of regulatory rule changes. Chakravorty (2010) concluded that when confronted with increasing stress over time, continuous improvement programs often fail to provide sustainable changes. Stress on the organizational structure and cultural institutions and artifacts may have affected the applied program (a Lean Continuous Improvement Process) or the nuclear safety culture indicators or both.

Other research studies have indicated an effect existed wherein organizations were unprepared for the interactions of improvement programs with other processes (Keating et al., 1999). Unintended interactions with other processes and programs represented an extraneous variable that influenced other organizational processes in unintended ways. Changes were implemented at Plant A to reduce process wastes and operational costs and improve performance. Although these changes appeared successful in reducing operating costs, these changes appeared to have induced unintended changes in other business aspects of a nuclear power plant. According to the Theory of Cascading Change developed by Hannan, Polo, and Carroll (2003), organizational leaders frequently have organizational opacity resulting in a systematic misunderstanding of the interconnections among organizational work units. Change is inevitably disruptive to existing routines and practices and demands new skills and competencies (Kotter, 1996). Applying these concepts of change to a nuclear safety culture, an implication from these research results was that something as complex as a nuclear safety culture cannot be adequately managed without understanding the dynamics among the key cultural dimensions. Nuclear safety (or an event) is an emergent property of these dynamics (Reiman, 2007).

Another consideration within the nuclear safety culture concept is its preventive nature (International Atomic Energy Agency, 2002). According to Schein (2004), the organization should not wait until a culture is not healthy and then cure it by some form of intervention. Safety culture mindsets require assessment and development initiatives regularly without the typical over-reliance on nuclear safety culture indicators (Reiman, 2007). As noted in the literature, organizational cultures do not necessarily cause degradation of nuclear safety cultures, but elements of organizational cultures (e.g., counter-productive activities and inadequate practices) might contribute to declines in nuclear safety cultures and increases in resultant nuclear safety incidents (Reiman, 2007). As designed, this current study excluded the influences of organizational cultures on a nuclear safety culture. Preventive aspects of a nuclear safety culture, however, were evident during this study. Concurrent with the research method, the safety culture of Plant A was healthy prior to implementing the treatment (a Lean Continuous Improvement Process). As such, Plant A had performed regular surveys and assessments of its nuclear safety culture, which are required by the regulator. The approach was consistent with methods prescribed by Schein (2004) that organizations not wait until a culture is unhealthy and then try to cure the problem with some form of intervention.

A final consideration for nuclear power plant organizational cultures was based on studies performed by Cameron and Quinn (2006) and Perm (2005). The commercial nuclear power industry has traditionally been dominated by organizations characterized as hierarchy cultures, consisting of tight regulations and controls, standardized rules and procedures, clear lines of decision-making authority, and control and accountability mechanisms. Given that a Lean Continuous Improvement Process induces changes in organizational cultures, these changes at a nuclear power plant would tend to occur in unpredictable patterns, as defined by Cameron and Quinn (2006). Unpredictable changes in organizational cultures imply unmanaged changes and, without a congruent set of values and perspectives in the leadership team, conflicts have been exhibited that affected the functionality of a strong nuclear safety culture (Frick, 2007).

Possible implications of the unpredictability factor on a nuclear safety culture become more problematic when the logic of command and control are introduced into the equation. Perm (2005) had observed disconnects at nuclear power plants when the logic of command and control and the logic of problem identification and diagnosis encountered stress. The stress at a nuclear power plant in the 21st century includes pressures to continuously produce electricity and to reduce operating costs. According to Chakravorty's (2010) stress theory, continuous improvement programs also encounter disconnects with organizational cultures when stress was encountered. This current research provided additional insights supportive of the previous research. It could be that implementation of a Lean Continuous Improvement Process with an overemphasis on one aspect of the process - reduction of operating costs - combined with the organizational stress to *stay on line* and continuously reduce operating costs, within a period of unpredictability places additional stress on the command and control operating logic at a nuclear power plant. Furthermore, if the dominant command and control operating logic is already contrary to the logic of identifying and diagnosing problems (Nuclear Safety Culture Principles 6 and 7 - see Appendix C) then the nuclear safety culture could be adversely affected. Could the combined affects be greater than the capabilities of a nuclear power plant organization? Based on the findings of this current research, these combined forces would certainly affect a nuclear safety culture

Recommendations

A Lean Continuous Improvement Process is not a business management governance system; neither is it a set of tools. The operational excellence criteria established by Utah State University (2008) were composed of four dimensions - cultural enablers, continuous process improvement, consistent lean enterprise culture, and business results. Two of these dimensions included culture conceptualizations, wherein leadership and safety systems were considered key elements within the cultural enablers. As seen in the literature, practitioners of Lean Continuous Improvement Processes have often emphasized the cost reduction aspects at the expense of the other dimensions of the process. Implementation of a Lean Continuous Improvement Process with a focus on the *continuous improvement process* dimension without due consideration of the cultural and constancy of purpose aspects across the organization may create silos of excellence instead of centers of excellence. Such a focus may actually increase operational costs in the longer term, especially when materials and parts are not available when needed.

Nuclear business management governance systems should consider an integrated plant continuous improvement plan based on its long-range vision, business goals, plant priorities, and a systematic assessment of process and system variations, with a foundation established on a nuclear safety culture. Management systems in nuclear power plants are fundamental barriers against events and, as documented by the International Atomic Energy Agency (2003), weaknesses in management systems have caused, either directly or indirectly, the occurrence of events. Within the integrated approach, the Standard Nuclear Performance Improvement Process should be the central focus for any continuous improvement plan wherein another continuous improvement process would only complement rather than work separately from it. Further, implementation of a Lean Continuous Improvement Process at a nuclear power plant should be consistent with quality assurance requirements established by the Nuclear Regulatory Commission in Appendix B to Part 50 of Title 10, Code of Federal Regulations (1974). Included within these requirements are systems of controls and an emphasis on management oversight of the status and adequacy of the quality assurance program, especially when affected by changes.

Organizational leaders at commercial nuclear power plants should have a systematic understanding of the interconnections among organizational work units and the Lean Continuous Improvement Process. This recommendation would facilitate targeting of improvement activities and placement of the reinforcing mechanisms to safeguard a nuclear safety culture. A practical recommendation for commercial nuclear power plants would be to have a nuclear safety culture manager with these understandings. Responsibilities would include conducting literature reviews to monitor and assess ongoing industry activities and events, directing continuous improvement initiatives and change activities, managing the plant's error reduction program (i.e., the human performance program), ensuring plant operating budgets count for all aspects of continuous improvement processes, and ensuring that the nuclear safety culture is not compromised.

Targeting of improvement activities would enable a broader application of a Lean Continuous Improvement Process rather than a more constricted application toward cost reductions. For example, Gryna et al. (2006) defined two types of problems (sporadic and chronic) where the characteristics and the countermeasures for each differed. Sporadic problems tended to occur suddenly, consisted of a single cause, and the countermeasures were to restore the conditions to the previous state. Chronic problems tended to exist over longer periods of time because the resultant issues derived from chronic problems did not manifest themselves until triggered by some other condition, such as an organizational stressor. Gryna et al. viewed chronic problems as persistent throughout organizations because of the complex nature of the problems, difficulty in causal identification, and ineffective countermeasures used to solve the problems. Some applications of a Lean Continuous Improvement Process would be better designed for use on sporadic problems at nuclear power plants, where other applications would be better designed for use on chronic problems when used in conjunction with more statistically rigorous continuous improvement processes such as Six Sigma. Understanding of limitations and application of a Lean Continuous Improvement Process is important for maintaining a nuclear safety culture. Applying a Lean Continuous Improvement Process concurrently with other continuous improvement processes, including the Standard Nuclear Performance Improvement Process, is recommended.

Additional research is needed on the topics of response strategies related to economic and competitive pressures and the relationship of these strategies to a nuclear safety culture. The research findings imply that when a commercial nuclear power plant implements a Standard Nuclear Performance Improvement Process as a response strategy, integrated throughout the work organizations and consistent with the requirements of the Nuclear Regulatory Commission, a strong nuclear safety culture is maintained. Nevertheless, economic and competitive pressures will continue, possibly intensifying, as more energy is required to sustain the economic engine of growth. Although various integrations of continuous improvement strategies have been recommended in this dissertation, future research might engage in building models of various continuous improvement processes, describing best practices in a rapidly - often unpredictable -changing environment, identifying obstacles to implementation and the organizational structure, and suggesting alternative methods to ensure a nuclear safety culture is maintained.

Future research is recommended on the topics of operational costs with respect to a nuclear safety culture. The operational cost indicator had the more significant impact on the cultural indicators and may have affected the other independent variable of operational quality. Additional research should consider modeling with respect to costs (represented in U.S. dollars/megawatt-hour) and operations and maintenance cost outlays and the relationships to a nuclear safety culture

The specific methods and procedures used in this research require more empirical work. For example, by highlighting some indicators in this study as indicative of a nuclear safety culture, other possible indicators and measures were not included within the design framework. Inappropriate worker behaviors and practices might still occur that have nothing to do with a Lean Continuous Improvement Process.

The design of this study included the entire workforce populations at the experimental and control nuclear power plants. Thus, random assignment of the participants included entire workforce populations. Efforts were employed during this study to ensure probabilistic equivalency between the two groups, yet true randomness was not practical for the approach. Future research is recommended in this area wherein the researcher would use true randomization and direct observations of the workforce combined with document reviews across several nuclear power plants. Unless the future research was under the direction of the Nuclear Regulatory Commission or the Institute of Nuclear Power Operations, this recommendation may be difficult to implement due to access limitations at commercial nuclear power plants in the United States.

There were other limitations that affected this study. The approach of this current research was to model normal work practices through six indicators to represent a nuclear safety culture. This decomposition provided a method to explore a complex concept. Other cultural influences were not accounted for. Other cultures exist within the context of a safety culture such as corporate and plant professional and organizational sub-cultures that interact with and influence a nuclear safety culture. Another limitation of this study was that the effect of organizational changes was not included in the study. The vertical interactions and influences of other cultural factors and organizational changes should be included in future research. Specifically, it is recommended that research be conducted at the dyadic level to determine the effects of a continuous improvement process on both a nuclear safety culture and the organizational culture. Further, since the effect of organizational cultures on a nuclear safety culture has not been adequately studied, it is recommended that research be conducted on these dynamic cultural interrelationships. As suggested by Wilpert and Itoigawa (2001), future research should attempt to map the interfaces between organizational factors, components of performance, and a nuclear safety culture and investigate causal relationships between factors and performance.

Conclusions

Energy generation through nonrenewable fossil fuels is feasible only for the relatively near future and has limitations due to environmental problems. Studies of the renewable sources of energy (solar, wind, biomass, and hydro) indicated limitations in capabilities in meeting future energy needs (Itoigawa et al., 2005). At this time, the best alternative for meeting future energy needs may be reliance on nuclear energy. Nuclear power plants, however, must be able to compete economically while performing in a manner that convinces the public of the capability to operate safely (Wilpert & Itoigawa, 2001). As indicated in the review of the literature, the pressure for cost-competitiveness was a powerful motivator capable of altering a nuclear power plant's organization. Leaders' responses to this pressure could affect the nuclear safety culture at the plant.

Conceptualizations of a nuclear safety culture were developed in the period after the accident at the Chernobyl Nuclear Power Plant. Researchers have explored the various dimensions of a nuclear safety culture in holistic terms that included concepts of inter- and intra-organizational influences that contribute to nuclear safety. Although various influences on a nuclear safety culture have been studied, studies of stress factors such as mandates to reduce operating costs were found to be limited in number. The influences on a nuclear safety culture by programs designed to improve nuclear power plants and reduce operating costs have not been adequately studied.

No previous research could be found relative to implementation of a continuous improvement process that focuses on reducing production/process wastes and operating costs at a commercial nuclear power plant. This current research studied the implementation of a continuous improvement process that emphasizes reduction in production/process wastes and operating costs at a commercial nuclear power plant in the United States to determine if there was any effect on a nuclear safety culture. The intent of this research was to add to the existing body of knowledge on the concept of a nuclear safety culture.

The first research question and hypotheses addressed a Lean Continuous Improvement Process as a composite of two indicators and a nuclear safety culture as a composite of six indicators to determine if relationships existed between the process and the culture. For purposes of this study, the first null research hypothesis was presented as no correlation existed between quality and cost/productivity and the six cultural indicators. The correlational analysis indicated that when operating costs decreased, material unavailability and schedule errors increased in quantity. The analysis also indicated that a negative correlation existed between quality and schedule errors, suggesting that as the operational indicator of quality increased schedule errors decreased. Based on the test results relative to the indicator of cost/productivity correlated with the indicators of material unavailability and schedule errors and relative to the operational indicator of quality correlated with the indicator of schedule errors, there was sufficient evidence to reject the first null hypothesis in favor of the alternative hypothesis that there was a correlation between quality and cost/productivity and the six cultural indicators.

The second research question and hypotheses addressed the differences in the six cultural indicators between the experimental and control nuclear power plants. For purposes of this study, the second null research hypothesis was presented as a difference did not exist among the six cultural indicators by group (control vs. experimental). Individual ANOVA test statistics indicated significant differences existed between Plant A and Plant B for the cultural indicators of material unavailability and schedule errors. For material unavailability and schedule errors Plant A had a larger mean compared to Plant B. The ANOVA test results validated conclusions derived for the first research question. Based on the test results, there was sufficient evidence to reject the second null hypothesis in favor of the alternative hypothesis that a difference existed among the six cultural indicators by group (control vs. experimental).

The findings of this study identified some additional influences on a nuclear safety culture. Evidence has been presented that a nuclear safety culture is affected when operating costs are sustained relatively low compared to another equivalent plant in the industry. Furthermore, these lower operating costs could be counterproductive when the unavailability of materials and errors in scheduling result in work delays, reworks, and extra transportation costs - the very items that a Lean Continuous Improvement Process targets to eliminate as wasteful activities.

There are some noteworthy implications from these research results. This study had some implications that although a Lean Continuous Improvement Process may reduce operational costs, it may induce negative pressures on quality levels. Lean Continuous Improvement Processes entail certain risks such as reductions in inventories and numbers of suppliers so there is no safety stock available if problems arise with materials or the suppliers (American Society for Quality, 2010). Although neither demonstrated by the findings nor supported by statistical evidence, it can be inferred that operational quality indicators were affected by the operational cost indicators. Both operational indicators had some affect on the culture indicators of material unavailability and schedule errors. Unsuitable, unavailable, or non-current materials, parts, or components have been demonstrated to gradually change conceptualizations about an organization's culture and legitimize activities and practices that are not conducive to a nuclear safety culture (Reiman, 2007). Thus, over time, an implication was that these performance shortfalls could become the norm in the culture.

This research resulted in some implications relative to economic and competitive response strategies for commercial nuclear power plants. Both Plant A and Plant B implemented the Standard Nuclear Performance Improvement Process as expected by the Nuclear Regulatory Commission and the Institute of Nuclear Power Operations. Plant B implemented no alternative continuous improvement strategy yet sustained high quality levels and high ratings in operational and safety performance. Although no statistical data were available to support a conclusion, the current research findings implied that when a commercial nuclear power plant implements a Standard Nuclear Performance

Improvement Process, integrated throughout the work organizations and consistent with regulatory requirements, a strong nuclear safety culture is maintained.

Although there were insufficient data obtained during this current study to determine whether implementation of a Lean Continuous Improvement Process resulted in business performance shortfalls at Plant A, evidence indicated organizational stress factors at Plant A were increasing more than organizational stress factors at Plant B. Stress on the organizational structure and cultural institutions and artifacts may have affected the applied program (a Lean Continuous Improvement Process) or the nuclear safety culture indicators or both. Changes were implemented at Plant A to reduce operational costs, improve performance, and create value. Although these changes appeared successful in reducing operating costs, these changes appeared to have induced unintended changes in other business aspects of a nuclear power plant. Applying the concepts of change to a nuclear safety culture, an implication from these research results was that something as complex as a nuclear safety culture cannot be adequately managed without understanding the dynamics among the key cultural dimensions. Given that a Lean Continuous Improvement Process induces changes in organizational cultures, these changes at a nuclear power-plant would tend to occur in unpredictable patterns, as defined by Cameron and Quinn (2006), without a congruent set of values and perspectives in the leadership team. Possible implications of the unpredictability factor on a nuclear safety culture become more problematic when the logic of command and control in conjunction with organizational stress are introduced into the equation. The stress at a nuclear power plant in the 21st century includes pressures to continuously produce electricity and to reduce operating costs. This current research provided additional insights supportive of the possibility that implementation of a Lean Continuous Improvement Process with an overemphasis on one aspect of the process - reduction of operating costs - combined with the organizational stress to *stay on line* and continuously reduce operating costs, within a period of unpredictability places additional stress on the command and control operating logic at a nuclear power plant. Furthermore, if the dominant command and control operating logic is already contrary to the logic of identifying and diagnosing problems, then the nuclear safety culture may be adversely affected. The combined affects may be greater than the capabilities of a nuclear power plant organization. Based on the findings of this current research, these combined forces would certainly affect a nuclear safety culture.

The results of this research have provided reflections and insights for nuclear power plant leaders and additional information for the nuclear safety culture body of knowledge, but are incomplete, which has to be taken into account when using these results in broad extrapolations across the industry. Recommendations were provided for application of the research findings and for future research.

1. Nuclear business management governance systems should consider an integrated plant continuous improvement plan based on its long-range vision, business goals, plant priorities, and a systematic assessment of process and system variations, with a foundation established on a nuclear safety culture. Within the integrated approach, the Standard Nuclear Performance Improvement Process should be the central focus for any continuous improvement plan wherein another continuous improvement process would only complement rather than work separately from it. Further, implementation of a Lean Continuous Improvement Process at a nuclear

power plant should be consistent with quality assurance requirements established by the Nuclear Regulatory Commission in Appendix B to Part 50 of Title 10, Code of Federal Regulations (1974). Included within these requirements are systems of controls and an emphasis on management oversight of the status and adequacy of the quality assurance program, especially when affected by changes.

2. Organizational leaders at commercial nuclear power plants should have a systematic understanding of the interconnections among organizational work units and the Lean Continuous Improvement Process. This recommendation would facilitate targeting of improvement activities and placement of the reinforcing mechanisms to safeguard a nuclear safety culture.
3. A practical recommendation for commercial nuclear power plants would be to have a nuclear safety culture manager with these understandings. Responsibilities would include conducting literature reviews to monitor and assess ongoing industry activities and events, directing continuous improvement initiatives and change activities, managing the plant's error reduction program (i.e., the human performance program), ensuring plant operating budgets count for all aspects of continuous improvement processes, and ensuring that the nuclear safety culture is not compromised.
4. Targeting of improvement activities would enable a broader application of a Lean Continuous Improvement Process rather than a more constricted application toward cost reductions. Some applications of a Lean Continuous Improvement Process would be better designed for use on sporadic problems at nuclear power plants, where other applications would be better designed for use on chronic

problems when used in conjunction with more statistically rigorous continuous improvement processes such as Six Sigma. Understanding of limitations and application of a Lean Continuous Improvement Process is important for maintaining a nuclear safety culture. Applying a Lean Continuous Improvement Process concurrently with other continuous improvement processes, including the Standard Nuclear Performance Improvement Process, is recommended.

5. Additional research is needed on the topics of response strategies related to economic and competitive pressures and the relationship of these strategies to a nuclear safety culture. Although various integrations of continuous improvement strategies have been recommended in this dissertation, future research might engage in building models of various continuous improvement processes, describing best practices in a rapidly - often unpredictable -changing environment, identifying obstacles to implementation and the organizational structure, and suggesting alternative methods to ensure a nuclear safety culture is maintained.
6. Future research is recommended on the topics of operational costs with respect to a nuclear safety culture. The operational cost indicator had the more significant impact on the cultural indicators and may have affected the other independent variable of operational quality. Additional research should consider modeling with respect to costs (represented in U.S. dollars/megawatt-hour), operations and maintenance cost outlays, and the relationships to a nuclear safety culture
7. The specific methods and procedures used in this research require more empirical studies. By highlighting some indicators in this study as indicative of a nuclear

safety culture, other possible indicators and measures were not included within the design framework. Inappropriate worker behaviors and practices might still occur that have nothing to do with a Lean Continuous Improvement Process.

8. Future research is recommended in this area wherein the researcher would use true randomization and direct observations of the workforce combined with document reviews across several nuclear power plants. Unless the future research was under the direction of the Nuclear Regulatory Commission or the Institute of Nuclear Power Operations, this recommendation may be difficult to implement due to access limitations at commercial nuclear power plants in the United States.
9. The vertical interactions and influences of other cultural factors and organizational changes should be included in future research. Specifically, it is recommended that research be conducted at the dyadic level to determine the effects of a continuous improvement process on both a nuclear safety culture and the organizational culture. Further, since the effect of organizational cultures on a nuclear safety culture has not been adequately studied, it is recommended that research be conducted on these dynamic cultural interrelationships. Future research should attempt to map the interfaces between organizational factors, components of performance, and a nuclear safety culture and investigate causal relationships between factors and performance (Wilpert & Itoigawa, 2001).

This current research has provided some foundational understanding of how a Lean Continuous Improvement Process influences a nuclear safety culture. Additional insights have been provided to expand the current body of knowledge for a nuclear safety culture. This current study identified a relationship between cost/productivity and a nuclear safety culture. Nuclear safety should remain the nuclear power industry's most important performance measure with cost/productivity performance measures a distant second. Since this current study identified a relationship between quality and a nuclear safety culture, the latter may have some similarities to a quality assurance program. If so, then a nuclear safety culture should be an objective in the nuclear power plant's quality assurance program.

Future research needs have been identified based on the results of this current research. Application of future research, however, will require the resolution of a few problems in methodology and the support of the regulatory community. Additional scientific endeavors will require more interventions with the inter-organizational elements that contribute to a nuclear safety culture. Hypothesized dimensions of a nuclear safety culture may be more valid if tested in cooperation with practitioners within the varied sub-organizations of a nuclear power plant. These thoughts indicate that observations of actual work combined with practicable and valid metrics would include plant personnel in data gathering and subsequent analyses.

REFERENCES

Aczel, A. & Sounderpandian, J. (2006). *Complete business statistics* (6 ed.). NY: McGraw Hill.

Adams, D. (2007, November). *The importance of operating experience.* Paper presented at the annual Operating Experience Conference, San Antonio, TX.

Aiken, C. (2006). How do I create a distinctive performance culture? *McKinsey & Company Organizational Practice,* 12(3), 5-11.

American Society for Quality. (2009, January). Building from the basics. *Quality Progress 42(1),* 19-29.

American Society for Quality. (2010). Toyota: Is "leanest" best? *ASQ Weekly.* Retrieved February 20, 2010 from http://www.asq.org/media-room/news/2010/02/20100216-toyota-is-leanest-best.html?WT.mc_id=EM4636M&WT.dcsvid=1929976052.

Arthur, J. (2005). *Lean simplified: The economies of speed.* Denver, CO: Lifestar Publishing.

Baghel, A. (2005). An evaluation of continuous improvement methodologies and performance. M.A.Sc. dissertation, Concordia University (Canada), Canada. Retrieved September 11, 2007, from ProQuest Digital Dissertations database. (Publication No. AAT MR04412).

Benavent, F. B. (2006). TQM application through self-assessment and learning: Some experiences from two EQA applicants. *Quality Management Journal, 13(\),* 7-25.

Bhalia, A. (2010). Lean Six Sigma fusion and confusion. *Quality Digest.* Retrieved February 24, 2010, from http://www.qualitydigest.com/inside/quality-insider-article/lean-six-sigma-fusion-and-confusion.html.

Bochner, S. (2003). Culture shock due to contact with unfamiliar cultures. In W. J. Lonner, D. L. Dinnel, S. A. Hayes, & D. N. Sattler (Eds.), *Readings in Psychology and Culture* (Unit 8, Chapter 7). Bellingham, WA: Center for Cross-Cultural Research.

Boggs, W. B. (2004). TQM and organizational culture: A case study. *Quality Management Journal, 11(2),* 42-52.

Breyfogle, F. (2010a). Stop wasting improvement resources. *Quality Digest.* Retrieved February 14, 2010, from http://www.qualitydigest.com/inside/quality-insider-article/stop-wasting-improvement-resources.html.

Breyfogle, F. (2010b). Integrating lean and Six Sigma process improvement tools. *Quality Digest.* Retrieved February 18, 2010, from http://www.qualitydigest.com/inside/quality-insider-article/integrating-lean-and-six-sigma-process-improvement-tools.html.

Burns, C. (2005). Dual attitudes about trust in safety culture. *The Business Review, Cambridge, 4(2),* 92-98.

Cameron, K. S. & Quinn, R. E. (2006). *Diagnosing and changing organizational culture.* San Francisco, CA: Jossey-Bass

Cameron, K. S. & Sine, W. (1999). A framework for organizational quality culture. *Quality Management Journal, 6(4),* 7-25.

Chakravorty, S. S. (2010, January 25). Where process-improvement projects go wrong. *The Wall Street Journal.* Retrieved January 25, 2010, from http://online.wsj .com/article/.

Code of Federal Regulations, Title 10, Part 50, Appendix B. (1974). *Quality assurance criteria for nuclear power plants and fuel reprocessing plants.* (Regulation 10CFR50). Washington, D.C.:U.S. Government Printing Office.

Code of Federal Regulations, Title 10, Part 50.7. (1997). *Employee protection.* (Regulation 10CFR50). Washington, D.C.:U.S. Government Printing Office.

Code of Federal Regulations, Title 45, Part 46. (2007). *Protection of human subjects.* (Regulation 45CFR46). Washington, D.C.:U.S. Government Printing Office.

Collins, D. (2005). *Getting safety into the bloodstream of the organization.* Unpublished manuscript, University of New Haven.

Columbia Accident Investigation Board. (2003). *Final Report on the Columbia Space Shuttle Accident.* Author: National Aeronautics and Space Administration. Retrieved July 28, 2008, from www.caib.nasa.gov.

Cooper, M. D. (2000). Towards a model of safety culture. *Safety Science, 36(1),* 111-136.

Corcoran, W. R. (March, 2010). Safety culture: Back to the basics. *The Firebird Forum, 13(3),* 1-57.

Dahlgren, K., Lederman, L., Palomo, J. & Szikszai, T. (2001). *Safety performance indicators.* Paper presented at the annual Nuclear Safety Culture Conference, Vienna, Austria.

De Koning, H. & De Mast, J. (2007). The CTQ fiowdown as a conceptual model for project objectives. *Quality Management Journal, 14(2),* 19-28.

DeFeo, J. A. & Barnard, W. W. (2005, January). A roadmap for change. *Quality Progress, 38(1),* 24-30.

Deming, W. E. (1986). *Out of the crisis.* Cambridge, MA: Massachusetts Institute of Technology.

Detert, J. R., Schroeder, R. G., & Mauriel, J. J. (2000). A framework for linking culture and improvement initiatives in organizations. *Academy of Management Review, 25(4),* 850-863.

Evans, J. R. & Lindsay, W. M. (2005). *The management and control of quality* (6th ed.). Cincinnati, OH: South-Western College Publishing.

Findley, M. E. (2004). Group differences in safety climate among workers in the nuclear decommissioning and demolition industry in the United States. Ph.D. dissertation, The University of Tennessee, United States — Tennessee. Retrieved October 2, 2007, from ProQuest Digital Dissertations database. (Publication No. AAT 3141806).

Frick, W. (2007). *Cultural indicators of a nuclear organization.* Paper presented at the annual Strategic Teaming and Resource Sharing Assessment Conference, Salt Lake City, UT.

George, M. L. (2002). *Lean Six Sigma: Combining Six Sigma quality with lean speed.* NY: McGraw-Hill.

Gryna, F. M., Chua, R.C.N., & DeFeo, J.A. (2006). *Juran 's quality planning and analysis for enterprise quality* (5th ed.). NY: McGraw-Hill.

Hannan, M. T., Polo, L, & Carroll, G. R. (2003). The fog of change: Opacity and asperity in organizations. *Administrative Science Quarterly, 48,* 399-432.

Hansen, L. (2006, November). Benchmarking organizational safety strategy. *Professional Safety, 51*{11), 50-57.

Hansen, T. (2008, May). An approach for plants to address INPO's nuclear safety culture expectations. *Power Engineering, 112(5),* 70-76. Retrieved June 23, 2008, from Research Library database. (Document ID: 1494463671).

Helmreich, R. L. & Merritt, A.C. (1998). *Culture at work in aviation and medicine.* Burlington, VT: Ashgate Publishing.

Hofstede, G. (2010). *Culture.* Retrieved March 23, 2010, from http://www.geerthofstede.com/culture.aspx.

Hofstede, G. & Hofstede, G. J. (2004). *Cultures and organizations: Software of the mind.* NY: McGraw-Hill.

Howell, D.C. (1992). *Statistical methods for psychology* (3rd ed.). Boston: Kent Publishing.

Institute of Nuclear Power Operations (INPO). (2001, December). *Indicators of changing performance* (Report INPO 01-005). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2002a, September). *Analysis of significant events* (Report INPO 02-05). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2002b, November). *Reactor pressure vessel head degradation at Davis-Besse Nuclear Power Station* (Report SOER 02-04). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2003, December). *Analysis of recent significant events: January 2002 - September 2003* (Report INPO 03-005). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2004, November). *Principles for a strong nuclear safety culture.* Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2005, April). *Performance improvement at nuclear power stations* (Report INPO 05-005). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2006, October). *Human performance reference manual* (Report INPO 06-003). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2007, December). *Performance assessment and trending: General practices for analyzing and understanding performance* (Report INPO 07-007). Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2009a). *Principles for a strong nuclear safety culture. Addendum 1: Behaviors and actions that support a strong nuclear safety culture.* Atlanta, GA: Author.

Institute of Nuclear Power Operations (INPO). (2009b). *Plant information center.* Atlanta, GA: Author.

International Atomic Energy Agency (IAEA). (1988). *Basic safety principles for nuclear power plants* (Report 75-INSAG-3). Vienna: Author.

International Atomic Energy Agency (IAEA). (1991). *Safety culture* (Report 75-INSAG-4). Vienna: Author.

International Atomic Energy Agency (IAEA). (1998). *Developing safety culture in nuclear activities: Practical suggestions to assist progress* (Safety Report Series No.l 1). Vienna: Author.

International Atomic Energy Agency (IAEA). (1999). *Basic safety principles for nuclear power plants* (Report 75-INSAG-3, Revision 1). Vienna: Author.

International Atomic Energy Agency (IAEA). (2002). *Key practical issues in strengthening safety culture* (Report INSAG-15). Vienna: Author.

International Atomic Energy Agency (IAEA). (2003). *Nuclear power plant operating experiences from the IAEA/NEA incident reporting system: 1999-2002.* Vienna: Author.

International Atomic Energy Agency (IAEA). (2005). *Safety culture in the maintenance of nuclear power plants* (Report 42). Vienna: Author.

Itoigawa, N., Wilpert, B., & Fahlbruch, B. (Eds.). (2005). *Emerging demands for the safety of nuclear power operations: Challenge and demand.* NY: CRC Press.

Jackson, S.A. (1997). *Nuclear power in a competitive era.* Address by NRC Chairman Jackson at the National Association of Regulatory Commissioners Conference on Nuclear Energy in Competitive Electricity Markets, Fort Meyers, FL. Retrieved July 12, 2008 from www.nrc.gov.

Junewick, M. A. (Ed.). (2002). *LeanSpeak: The productivity business improvement dictionary.* NY: Productivity Press.

Juran, J. M. (1995). *Managerial breakthrough* (2nd ed.). NY: McGraw-Hill.

Kajder, C. (2005). Management perceptions of the safety culture in logistics at Sandia National Laboratories. M.S. dissertation, Central Missouri State University, United States — Missouri. Retrieved October 2, 2007, from ProQuest Digital Dissertations database. (Publication No. AAT 1425368).

Kapitza, S. P. (1993). Lessons of Chernobyl: The cultural causes of the meltdown. *Foreign Affairs, 72(3)*, 7-11. Retrieved June 23, 2008, from Research Library database. (Document ID: 414788).

Keating, E. K., Olivia, R., Repenning, N. P., Rockart, S., & Sterman, J. D. (1999). Overcoming the improvement paradox. *European Management Journal, 17*(2), 120-134.

Kotter, J. P. (1996). *Leading change.* Boston: Harvard Business School.

Kotter, J. P. & Rathgeber, H. (2005). *Our iceberg is melting: Changing and succeeding under any conditions.* NY: St. Martin's Press.

Kujala, J. & Lillrank, P. (2004). Total quality management as a cultural phenomenon. *Quality Management Journal, 11(4),* 43-55.

Langston, M.E. (2005, August). *Continuing evolution of U.S. nuclear quality assurance principles, practices, and requirements - Part I. American Society of Mechanical Engineers.* Retrieved December 12, 2009, from http://cstools.asme.org/csconnect/pdf/CommitteeFiles/16898.pdf.

Lareau, W. (2000). *Lean leadership: From chaos to carrots to commitment.* Davenport, IA: Midland Press.

Lenth, R. V. (2001). Some practical guidelines for effective sample size determination. *The American Statistician, 55,* 187-193.

Liker, J. K. (2004). *The Toyota way.* NY: McGraw Hill.

MacAvoy, P. W., & Rosenthal, J. W. (2005). *Corporate profit and nuclear safety: Strategy at Northeast Utilities in the 1990s.* Princeton, NJ: Princeton University Press.

Mann, D. (2005). *Creating a lean culture: Tools to sustain lean conversions.* NY: Productivity Press.

Matthews, D. (2006). *Integrated safety management: Foundation for a successful safety culture* (Report DNFSB/TECH-36). Washington, D.C.: Defense Nuclear Facilities Safety Board.

McCann, T. (2007, December). Integrated continuous improvement. *Peak Review, 12(4),* 9-12.

McDonald, N. (2006). Organizational resilience and industrial risk. In E. Hollnagel, D. Woods, & N. Leveson (Eds.), *Resilience Engineering: Concepts and Precepts.* Aldershot, England: Ashgate Publishing.

Mearns, K., Whitaker, S. M., & Flin, R. (2003). Safety climate, safety management practice, and safety performance in offshore environments. *Safety Science, 41,* 641-680.

Medvedev, Z. A. (1990). *The legacy of Chernobyl* NY: Norton & Co.

Meredith, S. B. (2003). Delaying disaster: The problem of nuclear safety in Eastern Europe. Ph.D. dissertation, University of Virginia, United States — Virginia. Retrieved June 16, 2008, from Dissertations & Theses: Full Text database. (Publication No. AAT 3135412).

Miller, J. (2007). *10 common misconceptions about lean manufacturing.* Retrieved March 1,2010, from http://www.gembapantarei.com/2007/06_common_misconceptions_about.html.

Nuclear Energy Agency (NEA). (1999). *Identification and assessment of organizational factors related to the safety ofNPPs* (Report NEA/CSNI/R (99)21). Paris, France: Author.

Okes, D. (2007, June). Economic case for quality. *Quality Progress, 40(6),* 32-33.

Pemberton, L. (2005). Measuring the organizational climate as perceived by leaders at higher education institutions participating in the academic quality improvement program. Ph.D. dissertation, Northcentral University, United States — Arizona. Retrieved September 2, 2007, from Northcentral University Dissertations database.

Perin, C. (2005). *Shouldering risks: The culture of control in the nuclear power industry.* Princeton, NJ: Princeton University Press.

Reason, J. (1997). *Managing the risks of organizational accidents.* Aldershot, England: Ashgate Publishing.

Reason, J. & Hobbs, A. (2003). *Managing maintenance error: A practical guide.* Hampshire, England: Ashgate Publishing.

Reiman, T. (2007). Assessing organizational culture in complex sociotechnical systems: Methodological evidence from studies in nuclear power plant maintenance organizations. [Espoo, Finland]: VTT Technical Research Centre of Finland.

Roughton, J. E. & Crutchfield, A. (2008). *Job hazard analysis: A voluntary guide for compliance and beyond.* Burlington, MA: Butterworth-Heinemann.

Roughton, J. E. & Mercurio, J. J. (2002). *Developing an effective safety culture: A leadership approach.* Boston, MA: Butterworth-Heinemann.

Schaffer, M. (2007, February 27). Nuclear station's challenges laid out. *The Arizona Republic,* pp. Al, A2.

Schein, E. H. (2004). *Organizational culture and leadership* (3^{r} ed.). San Francisco: Jossey-Bass.

Schneider, B. (1990). *Organizational climate and culture.* San Francisco: Jossey-Bass.

Seel, R. (2000). Complexity and culture: New perspectives on organizational change. *Organizations and People,* 7(2), 2-9.

Shafritz, J. M. & Ott, J. S. (2001). *Classics of organizational theory* (5^{th} ed.). Orlando, FL: Harcourt College Publishers.

Smith, P. B., Peterson, M. F., & Schwartz, S. H. (2002). Cultural values, sources of guidance, and their relevance to managerial behavior. *Journal of Cross Cultural Psychology, 33,* 188-208.

Smith, L. (2006, June). *Assessing cross-cutting issues for improving performance.* Paper presented at the annual Strategic Teaming and Resource Sharing Assessment Conference, Phoenix, AZ.

Sorensen, J. N. (2002). *Safety culture: A survey of the state of the art.* Advisory Committee on Reactor Safeguards, U.S. Nuclear Regulatory Committee. (Report NUREG/CR-6840). Retrieved October 12, 2007, from www.nrc.gov.

Spackman, L. (2009, April). Nine steps to make process improvement permanent. *Quality Progress 42(4),* 23-28.

Tabachnick, B. G. & Fidell, L. S. (2001). *Using multivariate statistics* (4^{th} ed.). Boston: Allyn and Bacon.

Trice, H. M. & Beyer, J. M. (1993). *The cultures of work organizations.* Englewood Cliffs, NJ: Prentice Hall.

Trochim, W. M. K. (2001). *Research methods knowledge base* (2^{nd} ed.). Cincinnati, OH: Atomic Dog Publishing.

United States Nuclear Regulatory Commission (NRC). (2002). *Reactor pressure vessel head degradation and reactor coolant pressure boundary integrity* (Report NRC Bulletin 2002-01). Retrieved June 12, 2008, from www.nrc.gov.

United States Nuclear Regulatory Commission (NRC). (2004, January). *Meeting summary discussing Palo Verde safety conscious work environment.* Division of Reactor Projects, U.S. Nuclear Regulatory Committee. (Report PV\2004\PV1-14-04MS-DRP). Retrieved June 12, 2008, from www.nrc.gov.

United States Nuclear Regulatory Commission (NRC). (2005). *Guidance for establishing and maintaining a safety conscious work environment* (Regulatory Issue Summary Report RIS 2005-018). Retrieved June 12, 2008, from www.nrc.gov.

United States Nuclear Regulatory Commission (NRC). (2006a). *Information on the changes made to the reactor oversight process to more fully address safety culture* (Regulatory Issue Summary Report RIS 2006-13). Retrieved September 30, 2009, from www.nrc.gov.

United States Nuclear Regulatory Commission (NRC). (2006b). *Palo Verde Nuclear Generating Station: NRC follow up supplemental inspection report* (Report EA-04-221). Retrieved June 12, 2008, from www.nrc.gov.

United States Nuclear Regulatory Commission (NRC). (2008). *Davis-Besse reactor pressure vessel head degradation: Overview, lessons learned, and NRC actions based on lessons learned* (Report NUREG/BR-0353, Revision 1). Retrieved June 12, 2008, from www.nrc.gov.

United States Nuclear Regulatory Commission (NRC). (2009a). *Problem Identification and Resolution Inspection Reports.* Retrieved February 21, 2009, from http://www.nrc.gov/reading-rm/doc-collections/.

United States Nuclear Regulatory Commission (NRC). (2009b). *Fiscal year 2008 results of the industry trends program for operating power reactors and status of the ongoing development of the program* (Report SECY-09-0048). Retrieved June 22, 2009, from www.nrc.gov.

United States Occupational Safety and Health Administration. (2009). *Creating a safety culture.* Retrieved November 22, 2009, from http://www.osha.gov/SLTC/etools/safetyhealth/mod4_culture.html.

Utah State University. (2008). *The Shingo Prize for Operational Excellence.* Author. Retrieved November 21, 2008, from http://www.shingoprize.org/.

Utilities Service Alliance. (2009). *Industry Reports.* (Available from the Utilities Service Alliance, http://www.usainc.org/)

Vaughan, D. (1996). *The Challenger launch decision: Risky technology, culture, and deviance at NASA.* Chicago: University of Chicago Press.

Wagner, J. A. & Hollenbeck, J.R. (2005). *Organizational behavior: Securing competitive advantage* (5th ed.). Cincinnati, OH: South-Western College Publishing.

Wert, J. (2003, January). *Organizational and nuclear safety culture.* Paper presented at the meeting of the American Nuclear Society, Washington, D.C.

Wescott, R. T. (2006). *The certified manager of quality/organizational excellence handbook* (3rd ed.). Milwaukee, WI: ASQ Quality Press.

Williams, J. (2002, April). Improving safety leadership: Using industrial/organizational psychology to enhance safety performance. *Professional Safety, 47(4)*, 43-47.

Wilpert, B. & Itoigawa, N. (Eds.). (2001). *Safety culture in nuclear power operations.* London: Taylor & Francis.

Womack, J. P. & Jones, D. T. (2003). *Lean thinking: Banish waste and create wealth in your corporation.* NY: Free Press.

Yukl, G. (2002). *Leadership in organizations* (5th ed.). Upper Saddle Creek, NJ: Prentice Hall.

APPENDIXES

Appendix A:

Cover Letter for Approval to Use Information at the Experimental Nuclear Power Plant and the Control Nuclear Power Plant

Date:

Dear (Nuclear Power Plant Executive),

As discussed with you previously, I am a nuclear power professional conducting research for a doctoral degree at Northcentral University. The dissertation topic is titled:

Assessing the Influence of a Continuous Improvement Process on a Nuclear Safety Culture

This research will examine the relationships between a Lean Continuous Improvement Process and six nuclear safety culture attributes based on the document INPO 01-005. The specific indicators selected for this research are as follows: maintenance rework, longstanding equipment problems, resource unavailability, material unavailability, schedule errors, and inadequate corrective actions. A goal of this research will be to bridge a gap in knowledge and to supplement the body of knowledge on nuclear safety culture.

This research will be using trend data from your plant's corrective action system and will exclude any data related to proprietary, personal or security safeguards information. Plant personnel will not be directly involved in this research and there are no surveys involved. Station capability factors and operations and maintenance costs will be used in a broad sense in order to determine correlations with the trend data. I am requesting your approval to spend some time at your nuclear power plant reviewing trend data and condition reports. Please rest assured that no unauthorized copying of data will be performed and that no information will be used for any purpose other than to provide inputs into statistical analyses. Your plant's management team would be able to counter review any information collected.

The resulting statistics will be published in the completed Northcentral University dissertation. Copies of the completed dissertation will be provided to the supporting plants.

Thank you for your time and consideration in supporting completion of this research and please contact me if you have any questions.

Sincerely,

Appendix B:

Standardized Reporting Trend Codes

Issue	Code	Description
Maintenance rework	**MAI**	Repeat maintenance on equipment because the original repair did not correct the problem or another problem was caused by the maintenance
Longstanding equipment problems	EQ5	Equipment operation has degraded and is known, yet not repaired or replaced
Resource unavailability	**D4e**	Adequate personnel resources to support work (without overtime) are not provided, approved, or funded
Material unavailability	**D4a**	Required materials and tools to support work are not available or obsolete
Schedule errors	WC2	Work is delayed or rescheduled due to inadequate coordination, scheduling, or support from other work groups
Inadequate corrective actions	**PI1**	Cause identification and /or the actions to correct the condition are inadequate, untimely, or not correctly implemented to prevent recurrence

Appendix C:

Summary of Principles for a Strong Nuclear Safety Culture

(Institute of Nuclear Power Operations, 2004)

1. Everyone is personally responsible for nuclear safety. *Responsibilities for nuclear safety are defined and understood; authorities, staffing, and financial resources support nuclear safety responsibilities.*

2. Leaders demonstrate commitment to safety. *Leaders demonstrate commitment in word and action; nuclear safety messages are communicated frequently and consistently.*

3. Trust permeates the organization. *Trust levels are high; communications are accurate and timely; employees are informed of steps taken in response to their concerns.*

4. Decision-making reflects safety first. *Decision making that supports safe, reliable plant operations are systematic and rigorous; leaders support conservative decisions.*

5. Nuclear technology is recognized as special and unique. *The special characteristics of nuclear technology are included in all decisions and actions.*

6. A questioning attitude is cultivated. *Individuals challenge assumptions, investigate items that were not expected or are discrepant, and consider potential consequences of planned actions. Individuals understand that events can occur from decisions and actions that reflect flaws in the shared assumptions and values of the organization.*

7. Organizational learning is embraced. *The organization demonstrates its capacity to learn from experience through performance improvement practices.*

8. Nuclear safety undergoes constant examination. *Nuclear safety is constantly examined through a various oversight and monitoring techniques.*