Assessing the Impact of Regulation on the Performance of Power and Pipeline Projects

by

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ABSTRACT

The International Energy Agency (IEA) anticipates the global energy demand to grow by more than 25% by 2040, requiring more than $2 trillion a year of investment in new energy supply (IEA, 2018). With power needs increasing as populations grow and climate extremes become more routine, power companies seek to continually increase capacity, improve efficiency, and provide resilience to the power grid, such that they can meet the energy needs of the societies they serve, often while trying to minimize their carbon emissions. Despite significant research dedicated to planning for industrial projects, including power generation projects as well as the pipeline projects that enable power generation and distribute power, there are still endemic cost overruns and schedule delays in large scale power generation projects. This research explores root causes of these seemingly systemic project performance issues that plague power generation projects. Specifically, this work analyzes approximately 770 power and pipeline projects and identifies how project performance indicators (i.e., cost and schedule performance) as well as planning indicators, compare in two regulatory environments, namely nonregulated and regulated markets. This contributes explicit understanding of the relationship between project performance and regulatory environment, both quantitatively and qualitatively, to the pipeline and power project planning and construction bodies of knowledge. Following an understanding of nonregulated versus regulated markets, this research takes a deeper dive into one highly-regulated power sector, the nuclear power sector, and explores root causes for cost overruns and schedule delays. This work leverages gray literature (i.e., newspaper articles) as sources, in order to analyze projects individually (most academic literature presents data about an aggregated set of projects) and understand the public perception of risks associated with such projects. This work contributes an understanding of the risks associated with nuclear power plant construction to the nuclear power plant construction body of knowledge. Ultimately, the findings from this research support improved planning for power and pipeline projects, in turn leading to more predictable projects, in terms of cost and schedule performance, regardless of regulatory environment. This enables power providers to meet the capacity demands of a growing population within budget and schedule.

I would like to dedicate this dissertation first and foremost, to myself. You are, and always have been, worth it.

Secondly, I would like to dedicate this dissertation to all the women who have been conditioned to question themselves; who exist in spaces feeling like an imposter.

You do not have to make yourself as small as possible to be accepted or respected.

"Authenticity is a collection of choices that we have to make every day. It's about the choice to show up and be real. The choice to be honest. The choice to let our true selves be seen."
– Brené Brown

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CHAPTER 1- INTRODUCTION

The International Energy Agency (IEA) anticipates the global energy demand to grow by more than 25% requiring more than $2 trillion a year of investment in new energy supply by 2040 (IEA, 2018). With power needs increasing as populations grow and climate extremes become more routine, power and pipeline companies seek methods to continually increase capacity, improve efficiency, and provide resilience the infrastructure such that they can meet the energy needs of the societies they serve, while minimizing carbon emissions. Roberts (2014) suggests that if large power projects reliably go over budget, then it may be that owners of such projects are hesitant or even unwilling to invest in such projects. In turn, this suggests that when owners *do decide to invest*, they allocate more capital than the project is expected to need, thus creating capital budgets misallocate investment dollars. Other work (e.g., (Merrow, 2003, 2011) documents similar challenges for large industrial projects in terms of cost and schedule performance. Indeed, it seems that poor project performance is an expectation on power generation projects (Bacon & Besant-Jones, 1998; EIA, 1986; IHS-Costs-and-Strategic-Sourcing, 2019; Kaplan, 2008; Mari, 2014; Benjamin K. Sovacool, Alex Gilbert, & Daniel Nugent, 2014; Thurner, Mittermeier, & Kuchenhoff, 2014).

Motivation

Many Americans are living in working class households, and are acutely attuned to the importance of affordable and reliable power for the survival and comfort of their friends and families. When pursuing a research topic, the authors personal internship experience within the power industry was used as a point of take-off to understand how to best serve the societies we live in when planning for and executing additional capacity and flexibility projects within power and pipeline industries. While regulating bodies such as FERC are in place to serve and protect customers from a monopoly's power, it has alternatively been argued that rate of return regulation encourages regulated firms, such as power and pipeline utility companies, to overcapitalize on projects that could be executed at a lesser cost. The upfront costs of these capital projects directly influence the rate that customers are charged per kilowatt hour of power. Understanding the current cost and schedule performance of these projects, the planning metrics used, and the risks associated with these projects provide a deeper understanding into how to better plan for and execute power and pipeline projects in the future.

Organization of Dissertation

Ch. 1 is a literature review that provides context for this dissertation. The author begins with a discussion of large industrial projects, or megaprojects, generally. This provides background for the specific sort of large industrial projects, namely power and pipeline projects, that this work focuses on. Finally, the author discusses specifics related to power and pipeline project markets, and one highly regulated market, nuclear power plants.

Ch. 2 looks at project performance (i.e., cost and schedule performance) of power and pipeline projects. This paper explores how capital project performance varies for power and pipeline projects in both non-regulated and regulated environments through analysis of 1,859 projects in the Independent Project Analysis, Inc. project database.

Ch. 3 looks at how power and pipeline industries plan for projects in both nonregulated and regulated environments. This paper explores how variables such as FEL score, percent time spent in planning, percent cost of planning and stakeholder engagement differs in regulated and nonregulated environments. This provides an in depth look into how power and pipeline projects plan for additional capacity and flexibility within their network.

Ch. 4 explores one highly-regulated power industry in the United States, nuclear power, and explores the risk profile of such projects. This work was informed by the previous two chapters, as the point of departure for this chapter was nuclear power plant construction projects consistently found to be over budget and completed late. Sovacool et al (2014) found that more than 25% of the worldwide nuclear reactors studied, had overruns above 179% and 1425 $/kWe; overruns afflicted greater than 97% of all nuclear projects examined. Sixty-four projects in this sample had cost overruns exceeding $1 billion, and the single highest overrun had a cost escalation of more than 1200% (Benjamin K Sovacool, Alex Gilbert, & Daniel Nugent, 2014). The author chose to study risk profiles because project risks should form the basis for project performance; thus, in exploring the risks, the author hoped to identify root causes for the project performance parameters discussed in Chapters 2 and 3.

Research Aims and Questions

The overarching aim of this research is to contribute to the construction management and engineering body of knowledge by explicitly comparing the capital project performance and planning of power and pipeline projects in both regulated and nonregulated environments. Further, the author critically assesses one highly regulated industry, nuclear power, to document risks inherent in that sector. To achieve this aim, the author takes a multi-pronged approach, rooted academic literature, but explored in both practice and non-academic literature, as described in the methodology section. From this, the following three research hypothesis are proposed: Hypothesis (1) postulates that the performance of nonregulated projects is statistically significantly different from the performance of regulated projects in the power and pipeline sectors. Hypothesis (2) postulates that the planning processes, such as stakeholder involvement, budget spent on project planning, and project definition are statistically significantly different in nonregulated pipeline and power than their regulated counterparts. Lastly, hypothesis (3) postulates that there are unique risks that are captured in nuclear power plant construction and they are unique to the time and location the plant is constructed in, as well as the reactor manufacturer the unit is constructed by.

CHAPTER 2- EXAMINING THE IMPACT OF RATE OF RETURN REGULATION ON CAPITAL PROJECT PERFORMANCE

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ABSTRACT

Current electricity demands, increased environmental requirements, and growing populations require innovation in power production and delivery. At the same time, securing capital can be challenging, particularly during economic downturns. Moreover, how capital is spent may vary in different regulatory environments. Indeed, project performance and the profitability of power and pipeline construction projects, the two most prevalent project types in the power production and delivery sector, often look different in a regulated environment than a non-regulated environment. This is hypothesized to be due to the effect produced when “fair” rate of return (RoR) regulation encourages a firm to expend more capital than is consistent with the minimization of its costs (aka the Averch-Johnson Effect). This paper explores how capital project performance varies for power and pipeline projects in both regulated and non-regulated environments through analysis of 770 projects in the Independent Project Analysis, Inc. project database. This paper presents a statistical comparison of pipeline and power project performance indicators – estimated cost index, actual cost index, cost growth, and schedule slippage – to assess the impact of RoR regulation in such projects. Results illustrate the impact of RoR regulation in the construction phase of both power and pipeline projects; in both project types, the estimated cost index, the actual cost index, and the cost growth were higher for projects subjected to RoR regulation than their nonregulated counterparts. Therefore, this paper contributes to the construction body of knowledge by explicitly documenting the impact of the Averch-Johnson effect on the construction of power and pipeline projects for utilities.

INTRODUCTION

Utility providers often struggle to deliver power and pipeline projects close to their anticipated cost and schedule targets, and this poor capital performance can be attributed to several causes. Indeed, construction research has long documented the struggles to deliver industrial (e.g., power) and infrastructure (e.g., pipeline) capital projects on time and within budget (Bingham & Gibson, 2016; P. Dumont, Gibson, & Fish, 1997; A. Griffith & G Edward Gibson, 2001; Merrow, 2003, 2011). Roberts (2014) suggests that if large power projects reliably go over budget, then it may be that owners of such projects are hesitant or even unwilling to invest in such projects; similarly, Collins et al. (2017)

document budget and schedule overruns in smaller projects. In turn, this suggests that when owners do decide to invest, they allocate more capital than the project is expected to need, thus creating capital budgets that misallocate investment dollars. This paper explores how power plant and pipeline construction projects of various sizes have performed in different regulatory environments.

Definitions

Power projects are defined as power plant construction projects, electrical distribution projects, and transmission lines (greenfield, add-on, expansion, co-located, revamp); they are a specific type of industrial project ((P. Dumont et al., 1997)). Small industrial projects are those less than $10M in total installed cost; large industrial projects are those over $10M but less than $1B (W. Collins et al., 2017); and mega industrial projects are those that exceed $1B (Merrow, 2011).

Pipeline projects are defined as any project that aids in the transportation of liquids or gasses through a system of pipes. Pipeline projects are a type of infrastructure project; small infrastructure projects are those less than $20M in total installed cost; large infrastructure projects are those over $20M but less than $1B (El Zomor, Burke, Parrish, & Gibson Jr, 2018); and mega infrastructure projects are those with costs exceeding $1B (Merrow, 2011).

Industrial Project Performance

Large industrial projects and megaprojects are characterized by “extreme complexity, substantial risks, long duration, and extensive impact on the community, economy, technological development, and environment of the region or even the whole country" (Zhai, Xin, & Cheng, 2009). A comprehensive quantitative review of very large projects, including those for energy development, concluded that they routinely failed to achieve their objectives (Merrow, 2011). These failures were driven primarily by inappropriate project definition and, in particular, by the failure to fully understand and appreciate the interaction of megaprojects and the institutions, regulations and customs of the host country (Merrow, 2003). Indeed, "data from more than 300 global megaprojects shows that 65 percent of industrial projects with budgets larger than US $1 billion in 2010 failed to meet their business objectives" (Merrow, 2011).

Power Utility Construction

The International Energy Agency (IEA) anticipates the global energy demand to grow by more than 25 percent by 2040, requiring more than $2 trillion a year of investment in new energy supply (IEA, 2018). With power needs increasing as populations grow and climate extremes become more routine, power companies seek methods to continually increase capacity, improve efficiency, and provide resilience to the power grid, such that they can meet the energy needs of the societies they serve, while minimizing carbon emissions. This is often done through either retrofitting existing power infrastructure or by building new power plants.

While the research dedicated to megaprojects and industrial construction offer significant steps forward in the understanding of large and complex construction projects, there is limited research dedicated to the unique governance processes that affect power utility construction. Bacon and Beasant-Jones (1998) wrote about power utility construction, stating: "The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical to policies for pricing electricity on the basis of economic costs, because such overruns would lead to underpricing. The financial impact of a cost overrun is the strain on the power utility and on national financing capacity in terms of foreign borrowings and domestic credit."

For instance, all across the United States, electric utilities were faced with prematurely abandoning partially completed nuclear units when, in the wake of the Three Mile Island accident, regulations began to change, leaving in-progress projects unable to move forward, in turn leading to cost overruns and schedule delays. Abandoning such projects is not without consequence – abandonment forces regulators to make decisions on the allocation of the fixed costs sunk in the abandoned projects between ratepayers and stockholders (Berry & Loudenslager, 1987); usually, ratepayers bear the brunt of the costs.

Because of the high rate of return demanded on both the debt and the equity of power generation projects, the generation costs may rise rapidly, and if wholesale prices of electricity fall below the required level to repay the investment in the new generation project, the project could turn into a financial failure. Csereklyei et al (2016) found that future financing opportunities, higher oil prices during construction, as well as a positive business climate, make it likelier for a project to be completed faster.

Infrastructure Project Performance

Similar to power generation, many of the pipelines in the United States are nearing the end of their useful life. A significant reinvestment is needed in the upcoming decades to replace or rehabilitate the pipeline infrastructure (ASCE, 2017). However, in contrast to power utility construction, there is relatively little published work that describes the impact of regulation on construction project performance. In 2010, Tonery and Perez reported on the examination of US Gas Pipeline earnings, following the Federal Energy Regulatory Commission (FERC's) proposed changes to pipeline rates under Section 5 of the Natural Gas Act (NGA). They found that regulatory uncertainty is related to *an increase* in the cost of capital, discouraging investment in FERC-regulated pipeline infrastructure, and ultimately resulting in higher prices for gas consumers. Ironically, FERC regulates infrastructure to limit gas prices for consumers (Tonery & Perez, 2010). Perrotton and Massol (2018) assessed the magnitude of Averch-Johnson distortions on both the output and the cost of the regulated firm, and found the socially desirable rate of return can be higher than the market price of capital for that industry.

Rate of Return Regulation

Regulation of coal gas and piped water projects arose as part of the contract with municipalities, who granted rights of way in exchange for quality standards and price controls on such projects. Rate-of-return, RoR, regulation evolved through a series of landmark court cases in the US to provide procedural fairness in the allocation of rents accruing to franchise monopoly investor-owned utilities (Newbery, 1997). RoR regulation is a form of regulation where a designated regulator sets prices for electricity via transmission lines or natural gas via pipelines so that the regulated firm's return on assets attains a target value in each period. Prices are set so that revenues cover not only current operating expenses but also an interest charge on the book value of the firm's operating assets. A frequently voiced claim in the industrial organization literature is that RoR regulation is inherently inefficient. Specifically, product prices are predicted to be too high relative to the levels that a welfare maximizing planner would choose (Nezlobin, Rajan, & Reichelstein, 2012).

While FERC is under a legal obligation to set a rate of return that will allow companies to attract capital and maintain their financial integrity, there is a constant and natural tension between regulators wanting to grant lower returns on equity to keep rates low for consumers and regulated companies arguing for the need for higher returns to attract investment (Tonery & Perez, 2010).

RoR regulation adjusts overall price levels according to the operator's accounting costs and cost of capital. In most cases, the regulator reviews the operator's overall price level in response to a claim by the operator that the rate of return that it is receiving is less than its cost of capital plus approved profit, or in response to a suspicion of the regulator or claim by a consumer group that the actual rate of return is greater than the cost of capital plus approved profit. Critical issues for the regulator include how to value the base, whether to add investments to the rate base as they are made or when the facilities go into service, the amount of depreciation, and whether expenditures have been prudently made and whether they relate to items that are used and useful for providing the utility service (Jamison, 2005).

Averch-Johnson Effect

Historically, the economic characteristics of railroad, electric power, telephone and oil pipeline industries have made them prime targets for RoR regulation. Economists have noted the special efficiency problems involving the profit maximizing responses of regulated firms to their particular economic environments. It has been argued by economic researchers that the techniques employed by regulatory agencies alter the effective input price conditions confronting regulated firms, in turn distorting the choices made by those firms; this is known as the Averch-Johnson Effect (Averch & Johnson, 1962) .

Gap in the Literature

While the literature documents efforts to manage power and pipeline construction projects, and explores their project performance, literature does not document research dedicated to how the capital project performance metrics of these types of projects are impacted by regulation. This paper seeks to fill that gap by addressing the following hypotheses:

H1: The estimated costs for pipeline projects are higher in regulated environments than nonregulated environments.

H2: The estimated costs for power projects are higher in regulated environments than nonregulated environments.

H3: The actual costs for pipeline projects are higher in regulated environments than nonregulated environments.

H4: The actual costs for power projects are higher in regulated environments than nonregulated environments.

H5: Cost growth is higher for pipeline projects in regulated environments than nonregulated environments.

H6: Cost growth is higher for power projects in regulated environments than nonregulated environments.

H7: Schedule growth is higher for pipeline projects in regulated environments than nonregulated environments.

H8: Schedule growth is higher for power projects in regulated environments than nonregulated environments.

Note that the authors include Hypotheses 7 and 8 for completeness; that is, to explore both the cost and schedule impacts of RoR regulation. However, there is no reason to believe that regulation would impact schedule directly; indeed, the Averch-Johnson effect only discusses costs.

METHODOLOGY

This section discusses data sources for this study, as well as the data analysis approach.

Data Source

The dataset for this study was drawn by the authors from an existing database of 20,000+ capital projects maintained by Independent Project Analysis (IPA). IPA works with facility owner organizations that are responsible for developing and executing power and pipeline projects, among others. Their data collection process involves face-to-face interviews with project teams using a structured questionnaire. The questionnaire is designed to gather information related to the project objectives and scope, technology, project management practices, estimated and actual costs, planned and actual schedule, and other project information. The data is translated into a structured database, which is used in individual project evaluations and project system benchmarking (Independent Project Analysis). Typically, the interviews are conducted at the time of project authorization, when funds are allocated for the project, and at the end of the project, after mechanical completion and startup (see Figure 1). Statistical analysis techniques, including t-testing and multi-variate regressions, were used to test the research hypotheses.

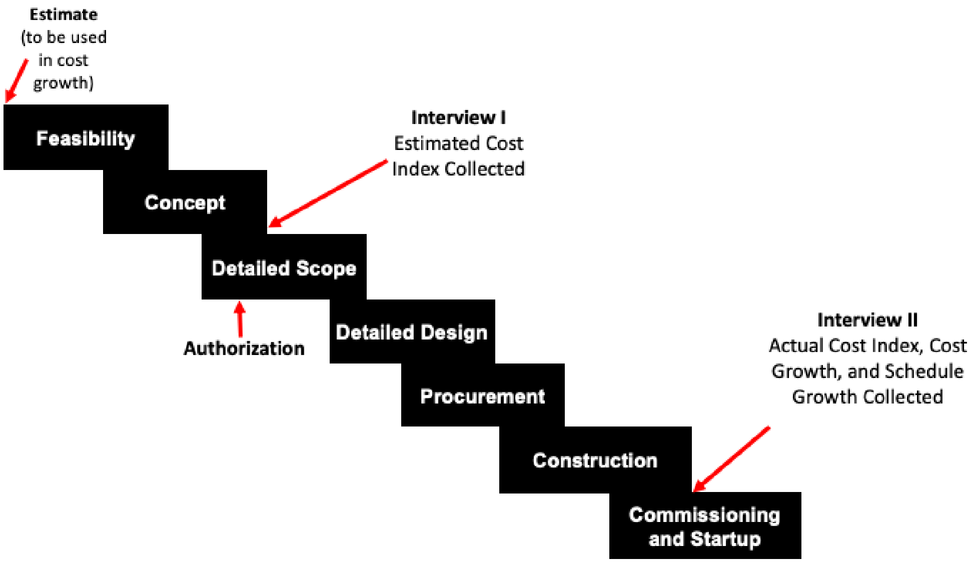

Figure 1: Timeline of Data Collection (Adapted from CII Project Timeline)

Descriptive Statistics of Project Types in Study Dataset

The dataset used for this paper comprises both pipeline and power projects constructed in the US after 2000 to support consistency. The authors categorized the projects in the dataset as “regulated” if the companies completing the projects were subject to RoR regulation, and non-regulated if not. Table 1 lists the numbers and project types in the dataset.

Table 1: Descriptions and Descriptive Statistics of Project Types included in Study

Project Type	Description	Pipeline Projects Frequency (#projects)		Power Projects Frequency (#projects)	
		n_{reg}	n_{nonreg}	n_{reg}	n_{nonreg}
Greenfield	constructed on a new, undeveloped	21	108	13	4

	site or area with an existing site				
Add-On	constructed within an existing facility where the process did not previously exist	20	72	24	25
Expansion	constructed to increase the capacity of an existing facility of the same type at the same site	12	60	6	13
Co-located	located adjacent to an existing facility, but standalone except for possible utilities	8	38	9	23
Revamp	rebuilds or a refurbishment to an existing facility	60	114	34	58
Other	projects that do not fit in any of the previously described categories.	17	22	3	6
Total		138	414	89	129

The Power Dataset is made up of 218 projects that range in capacity from <10MW to >10,000MW. These projects are comprised of multiple feedstocks, such as wind, solar, hydro, and coal fired; the sample also includes cogeneration, transmission lines, and electrical distribution-type projects. These projects represent data from 57 facility owner organizations and range in completed project size from $69.3 Thousand USD to $2.05 Billion USD. One hundred and twenty-nine (129) of the power projects were regulated, while 89 projects were not regulated.

The pipeline dataset includes 552 projects that range in length from 1km to 1200 km, diameters ranging from 5.08 to 142.24 centimeters, and water depths ranging from 1 to 2895 meters. These projects comprise both offshore and onshore pipeline. These projects represent data from 51 facility owner organizations and range in completed project size from $337.7 Thousand USD to $2.05 Billion USD. One hundred and thirty-eight (138) of the pipeline projects were regulated, while 414 projects were not regulated.

Data Analysis

For regulated and nonregulated power and pipeline projects, the authors tested the correlation between regulation and: (1) estimated cost, (2) actual cost, (3) cost growth, (4) schedule growth. To do so, the authors used the Estimated Cost Index (ECI) as a proxy for estimated cost and the Actual Cost Index as a proxy for actual cost (referenced in the research hypotheses) and as described in the next section. The authors calculated cost growth using estimated actual costs for each project. Similarly, the authors calculated schedule growth using estimated and actual durations for each project. These metrics are described in the following subsections; Figure 1, present earlier, illustrates when each metric is assessed or calculated. Calculations are described in the subsections defining each metric. Note that for each metric considered, the number of projects included in the analysis varies according to available data. As such, the authors list the number of projects considered in the particular analysis (e.g., n nonregulated pipeline projects, n regulated pipeline projects, etc.).

Estimated Cost Index

The ECI is the estimated cost performance of a project as compared to other projects of similar scope in the dataset. It is calculated prior to detailed design (see Figure 1) after in person interviews with the project team.

This metric measures the relationship between the authorization cost estimate and IPA's benchmark of the average cost of like projects. It is, therefore, a measure of the conservatism or aggressiveness of the authorization estimate, Since the cost data is gathered from different states, companies, and years, this aggregate data is often in many different forms and requires adjustment before being used for comparison analysis or as a basis for projecting future costs. Cost data are adjusted in a process called normalization, stripping out the effect of certain external influences. The objective of data normalization is to improve data consistency, so that comparisons and projections are more valid and other data can be used to increase the number of data points. While the specific normalization factors are proprietary to IPA, Equation 1 shows the general form of the Estimated Cost Index

$$ECI = \frac{Estimated\ Cost * Location\ Factor * Size\ Factor * Time\ Factor * Other\ Factors}{Average\ Normalized\ Estimated\ Cost\ of\ Project\ of\ Similar\ Scope\ in\ Dataset}$$

Equation 1: Estimated Cost Index

“Similar scope” in Equation 1 is determined by the type and size of project. For instance, an 10MW electrical distribution project would be compared to other electrical distribution projects up to 25MW in the database, while a power plant would be compared to other power plants in the database appropriately scaled.

The ECI is then compared to the average estimated cost value of electrical distribution projects in the dataset and benchmarked. The benchmark is then used to analyze cost performance and estimate how the project will perform at completion. An estimated cost index of 1.0 indicates that the project is estimated to cost the same as others in IPA’s dataset of similar scope, while a value of 1.1 or 0.9 indicates the project is estimated to be 10 percent more costly, or 10 percent less costly, respectively, than other projects of similar scope.

Actual Cost Index (ACI)

ACIs are used by IPA to communicate relative cost performance of final construction costs as compared to the IPA benchmarks, using Equation 2. Note all project costs are normalized to 2003 US dollars, using the process described for the estimated cost index. The ACI for a particular project is calculated by dividing the actual (normalized) cost of the project by the average actual (normalized) cost for projects with similar scopes, resulting in a unitless index (Equation 2). The actual cost index is calculated after commissioning and startup, using data from a second in-person interview.

$$ACI = \frac{Actual\ Cost * Location\ Factor * Size\ Factor * Time\ Factor * Other\ Factors}{Average\ Normalized\ Actual\ Cost\ of\ Project\ of\ Similar\ Scope\ in\ Dataset}$$

Equation 2: Actual Cost Index Calculation

Similar to the ECI, this metric is intended to indicate and predict *actual* cost performance at the outset of a given project, through comparison to an IPA benchmark. The actual cost index is then used to analyze cost performance, and normalized final project costs are added to IPA's dataset of final project costs to keep the dataset current.

Cost Growth

Cost growth is calculated by dividing the total final project cost by the estimated project cost in uniform currency and multiplying by 100 to convert into percent growth (Equation 3). IPA collects estimated and actual (final) project costs and uses these to calculate cost growth.

$$Cost\ Growth\ (\%) = \frac{Actual\ Cost - Estimated\ Cost}{Estimated\ Cost}$$

Equation 3: Cost Growth Calculation

Schedule Growth

Schedule growth is calculated by dividing the total final project duration by the planned project duration cost in uniform units (e.g., months, days) and multiplying by 100 to convert the ratio into a percentage (Equation 4). IPA collects estimated and actual (final) project durations and uses these to calculate schedule growth.

$$Schedule\ Growth\ (\%) = \frac{Actual\ Duration\ (days) - Estimated\ Duration\ (days)}{Estimated\ Duration\ (days)}$$

Equation 4: Schedule Growth Calculation

Statistical Analysis

For each metric, the authors calculated mean values and standard deviations for: (1) nonregulated pipeline projects, (2) regulated pipeline projects, (3) nonregulated power projects, and (4) regulated power projects. These means and standard deviations were then compared to illustrate the difference between regulatory environments for all metrics considered. The analysis was completed in Stata. The authors used t-tests and Mann-Whitney U Tests for each of the metrics considered to determine whether a difference in the means of regulated and non-regulated projects were statistically significant (Sheskin, 2007). Both the t-test and the Mann-Whitney U Test compare the means of two samples, with the null hypothesis being that the means are the same. The t-test is appropriate for data that behave normally. If the assumption of normality was not confirmed by Stata, the authors conducted a Mann-Whitney U Test to compare the means between regulated and non-regulated projects. For both t-test and U-Test analyses, a p-value of .05 was selected as the comparison test, indicating that the metric was statistically significant at a 95 percent confidence level. In other words, tor the purposes of this analysis, all p-values less than or equal to .05 indicate statistical significance.

Graphical Representation of Data

Given that the authors want to compare the means, they selected a graphical representation of data that illustrates how means differ between two samples. Figure 2 shows such a plot. The horizontal lines in the plot illustrate the mean and vertical lines represent one standard deviation from the mean. The p-value is listed in the upper right corner of each chart. Boxplots are a commonly used method for graphically summarizing the distribution of a data set (Morrison). While these charts are not boxplots, they are similar to boxplots in that they show the mean and a single standard deviation.

RESULTS & DISCUSSION

This research found that RoR regulation had a significant effect on the cost performance of power and pipeline projects in the 770 projects studied. The following subsections illustrate the impact of regulation on the estimated cost index, the actual cost index, cost growth, and the schedule performance. The subsections also revisit the research hypotheses.

Estimated Cost Index

Figures 2 and 3 illustrate the comparison of ECIs on nonregulated vs. regulated pipeline and power projects, respectively, Figure 2 supports testing H1, that the estimated costs for pipeline projects are higher in regulated environments than nonregulated environments. This was found to be true in the analysis with statistical significance ($p=.0031$). Figure 3 supports testing H2, that the estimated costs for power projects are higher in regulated environments than nonregulated environments. This was found to be true in the analysis with statistical significance.

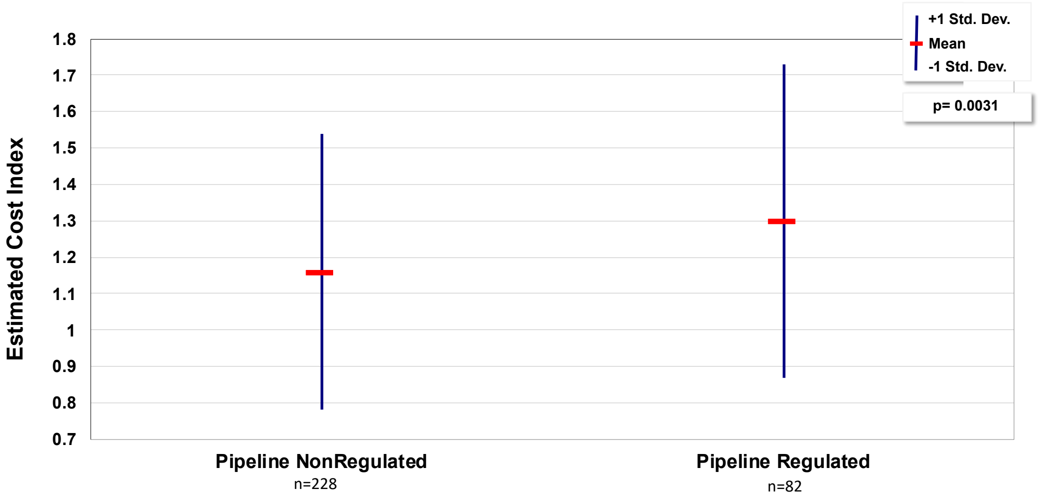

Figure 2: Comparison of the Estimated Cost Index for Nonregulated and Regulated Pipeline Projects

As shown in Figure 2, mean estimated costs in pipeline projects are higher than for their nonregulated counterparts. Pipeline projects constructed by organizations that are not subject to rate of return (RoR) regulation have an estimated cost index of 1.15, while projects constructed by organizations subject to RoR regulation have an estimated cost index of 1.29. This indicates nonregulated projects at the project planning stage are estimated to be 15 percent more expensive than the average benchmark within IPA's database of projects. Regulated projects of similar scope would have estimated costs 29 percent higher than that same benchmark.

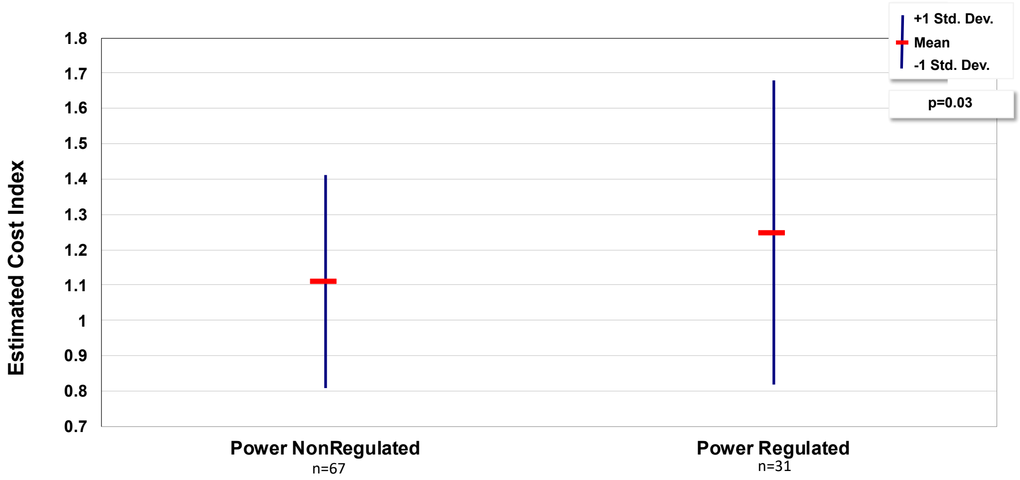

Figure 3: Comparison of the Estimated Cost Index for Nonregulated and Regulated Power Projects

As shown in Figure 3, power projects constructed by organizations that are not subject to RoR regulation have an estimated cost index of 1.11 while projects in regulated environments had a mean estimated cost index of 1.25. This indicates that nonregulated power projects are estimated 10 percent more expensive than the average benchmark within IPA database of projects. Regulated projects, further, are estimated to be 25 percent more expensive than the average benchmark.

When planning for additional capacity within a pipeline company, predictability matters for future forecasts of profitability and reliability. Given that RoR regulators set rates based on the estimated capital costs of a utility, elevated price points for capital projects allow for power and pipeline utilities to have contingency within a project budget. Conversely, if costs are determined to be too high, or considered not prudent by the regulating body, the project may be de-scoped, or, in extreme cases, rejected altogether. This analysis shows that regulated projects of similar scope to nonregulated projects are estimated at higher costs. These costs are passed down to the customer who ultimately pays the rate for projects that could be executed at lower costs.

Actual Cost Index

Figures 4 and 5 illustrate the comparison of ACIs on nonregulated vs. regulated pipeline and power projects, respectively. Figure 4 supports testing H3 that the actual costs for pipeline projects are higher in regulated environments than nonregulated environments. This was found to be true with statistical significance. Figure 5 supports testing H4 that the actual costs for power projects are higher in regulated environments than nonregulated environments. This was found to be true with statistical significance.

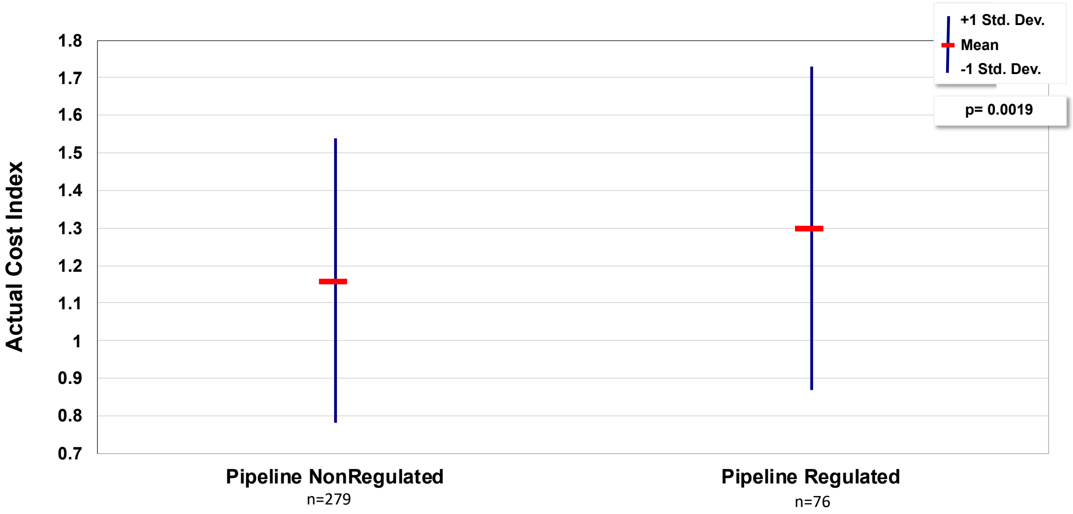

Figure 4: Comparison of the Actual Cost Index for Nonregulated and Regulated Pipeline projects

As shown in Figure 4, mean actual costs in pipeline and power projects are higher than their nonregulated counterparts. Pipeline projects constructed by organizations that are not subject to rate of return (RoR) regulation have an actual cost index of 1.07, while projects constructed by organizations subject to RoR regulation have an estimated cost index of 1.17. This indicates that nonregulated projects at completion (see Figure 1) are estimated to be 7 percent more expensive than the average benchmark within IPA database of projects. Meanwhile, regulated projects of similar scope would be estimated 17 percent more expensive than the average benchmark. The actual cost indices for pipeline projects improved their performance from estimate to actual cost. This indicates that the teams, upon receiving information of their projected performance at authorization, worked to improve project definition such that the project final outcomes were more favorable.

The standard deviations shown in Figure 4 illustrate the predictability of actual cost within pipeline and power projects in different regulatory environments. Note nonregulated projects have a standard deviation of 0.32 and regulated projects having a standard deviation of 0.35, suggesting similar predictability in both regulatory environments.

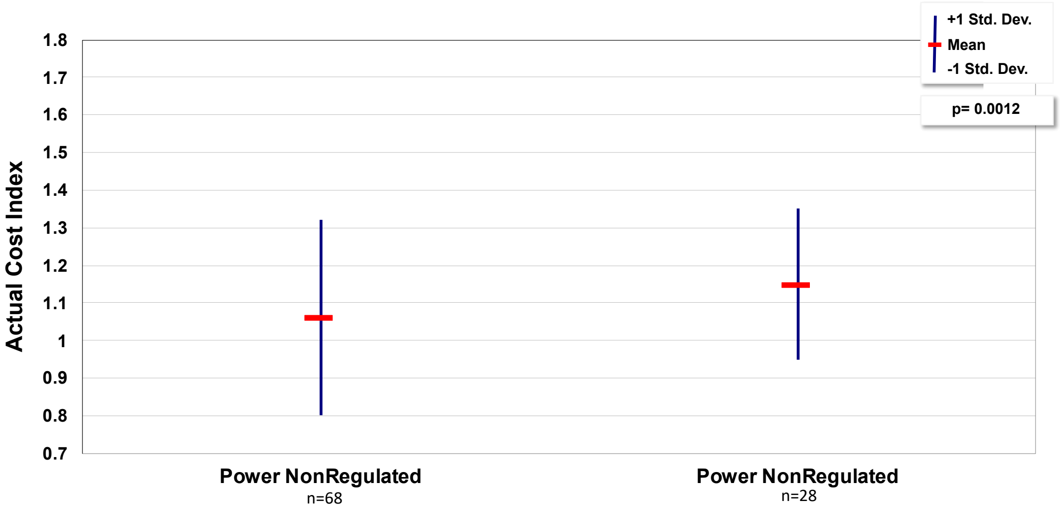

Figure 5: Comparison of the Actual Cost Index for Nonregulated and Regulated Power projects

As shown in Figure 5, power projects constructed by organizations that are not subject to RoR regulation have an estimated cost index of 1.06 while projects in regulated environments had a mean estimated cost index of 1.15. This indicates that nonregulated power projects are estimated 6 percent more expensive than the average benchmark within IPA database of projects. Regulated projects, further, are estimated to be 15 percent more expensive than the average benchmark.

Interestingly, the predictability within the power projects within the dataset is similar to that of pipeline projects. The standard deviation of nonregulated power projects was 0.26 while the regulated power projects had a standard deviation of 0.20.

The actual costs indices for both power and pipeline projects decreased from the estimated cost indices. It can be inferred that from estimated to actual costs, project performance improved. This was to be expected, as IPA provides their customers metrics to improve project outcomes based on industry averages and expectations. By analyzing the projects at authorization, IPA provides their customers opportunities to adjust their behavior and operations prior to execution. However, this analysis shows that regulated projects of similar scope to nonregulated projects are still completed at higher costs than their nonregulated counterparts. Also, given that rates are set based on the estimate, customer prices reflect the higher estimated costs for projects, even when the projects realized costs savings between the estimate and actual costs. That is, the customers were unable to capture the benefits of improved project performance.

Cost Growth

Figures 6 and 7 illustrate the comparison of the cost growth on nonregulated vs. regulated pipeline and power projects, respectively. Figure 6 supports testing H5, that cost growth is higher for pipeline projects in regulated environments than nonregulated environments. This was found to be false without statistical significance. Figure 7 supports testing H6, that cost growth is higher for power projects in regulated environments than nonregulated environments. This was found to be true with statistical significance.

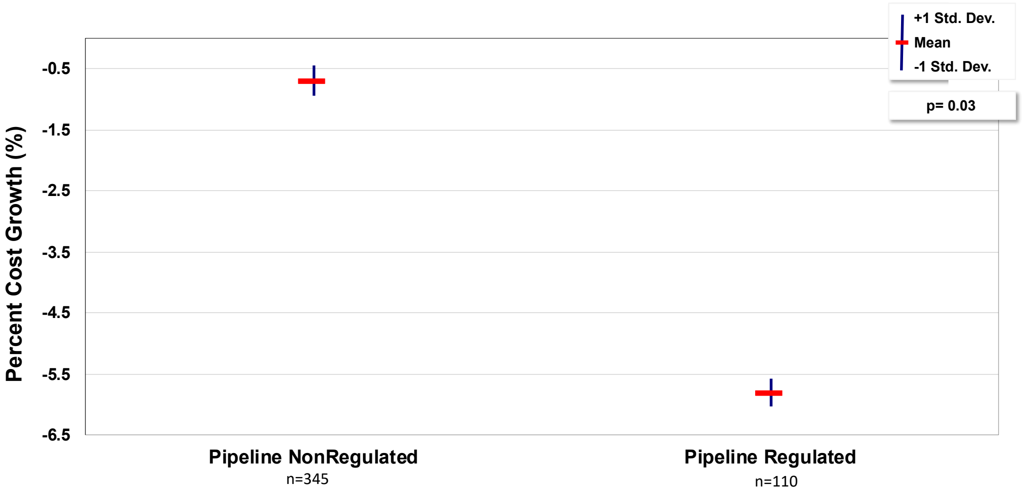

Figure 6: Comparison of Cost Growth for Nonregulated and Regulated Pipeline Projects

As shown in Figure 6, cost growth in regulated pipeline projects are lower than their nonregulated counterparts. Pipeline projects constructed by organizations that are not subject to RoR regulation have a cost growth of -0.7 percent, showing there is cost savings on nonregulated pipeline projects. Regulated pipeline projects have -5.8 percent cost growth, showing even more cost savings than their nonregulated counterpart. Overall, pipeline projects on average see cost savings, with regulated projects seeing more cost savings than their nonregulated counterparts. This result reinforces our earlier finding that the cost estimates tend to be padded at authorization.

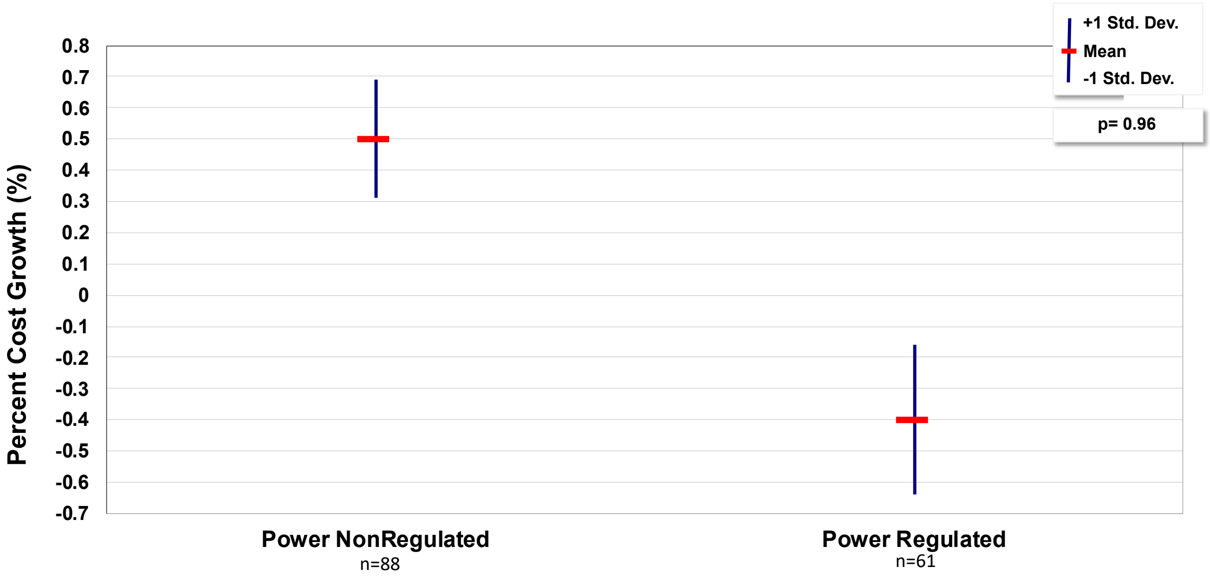

Figure 7: Comparison of Cost Growth for Nonregulated and Regulated Power Projects

As shown in Figure 7, power projects constructed by organizations that are not subject to RoR regulation have cost growth of 0.5 percent while their regulated counterparts see on average a 0.4 percent cost savings (i.e., -0.4 percent cost growth). There is a standard deviation of 0.25 and 0.23, for nonregulated pipeline and regulated pipeline projects, respectively; illustrating similar predictability of cost growth in both regulatory environments. One explanation for this is that these projects have an extensive safety net in their estimates to limit need for additional funding on these projects. The more likely implication of this difference, however, is that padding cost estimates is lucrative for utilities subject to RoR regulation; in fact, padding the estimate is rational behavior that is predicted by the Averch-Johnson effect.

The standard deviation on cost growth within power projects is similar to the pipeline project spread. The standard deviation of nonregulated power projects was 0.19 while the regulated power projects had a standard deviation of 0.24. Power and pipeline projects, regardless of regulation will demonstrate minimal to no cost growth. Thus, in both project types, costs seem predictable, given the "tight" standard deviation bars on Figure 6.

Additionally, while three of the four considered cases show cost savings, the nonregulated companies would be able to pass construction savings on to their consumers or their shareholders. By contrast, in regulated environments, cost savings would be reinvested within the organization, but the savings would not impact the rates charged to consumers. In regulated pipeline projects, in particular, it seems that nearly all projects report cost savings – this may be due to difficulties in securing right-of-ways that may result in including relatively high contingencies in the estimates. Moreover, it is possible that due to regulation, it is not possible to change the scope of the project during construction; hence, contingencies are realized as "cost savings" rather than changes in scope.

Projects in nonregulated environments are not only estimated lower than their regulated counterparts, they are executed at lower costs (as evidenced by the comparison of actual cost indices in Figure 4). In fact, the data illustrates that higher estimated costs lead to higher completed costs. Thus, it is unsurprising that the data did not illustrate cost growth for pipeline and power projects. That is, data does not show that costs *grew,* per se; rather, they were always expected to be higher for regulated projects compared to their nonregulated counterparts.

Schedule Growth

Figures 8 and 9 illustrate the comparison of schedule performance on nonregulated vs. regulated pipeline and power projects, respectively. Figure 8 supports testing H7 that schedule growth is higher for pipeline projects in regulated environments than nonregulated environments. This hypothesis was rejected in favor of the null hypothesis (i.e., that there is no difference between the schedule growth for pipeline projects in regulated environments compared to those in nonregulated environments). Figure 9 supports testing H8, that schedule growth is higher for power projects in regulated environments than nonregulated environments.

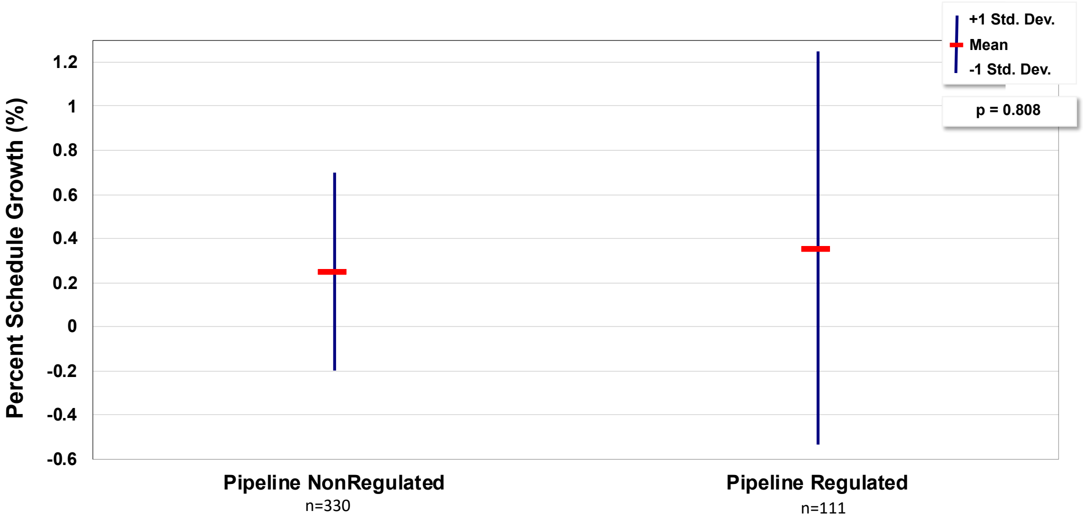

Figure 8: Comparison of Schedule Growth (as a percentage) for Nonregulated and Regulated Pipeline Projects

As shown in Figure 8, schedule growth in regulated pipeline projects is higher than in their nonregulated counterparts. This value however, is not statistically significant, producing a p-value of 0.81. Pipeline projects constructed by companies that are not subject to RoR regulation have a schedule slip of 0.25 percent showing there is very little schedule growth on nonregulated pipeline projects. Regulated pipeline projects have 0.45 percent schedule growth, illustrating these, too, experience very little schedule growth.

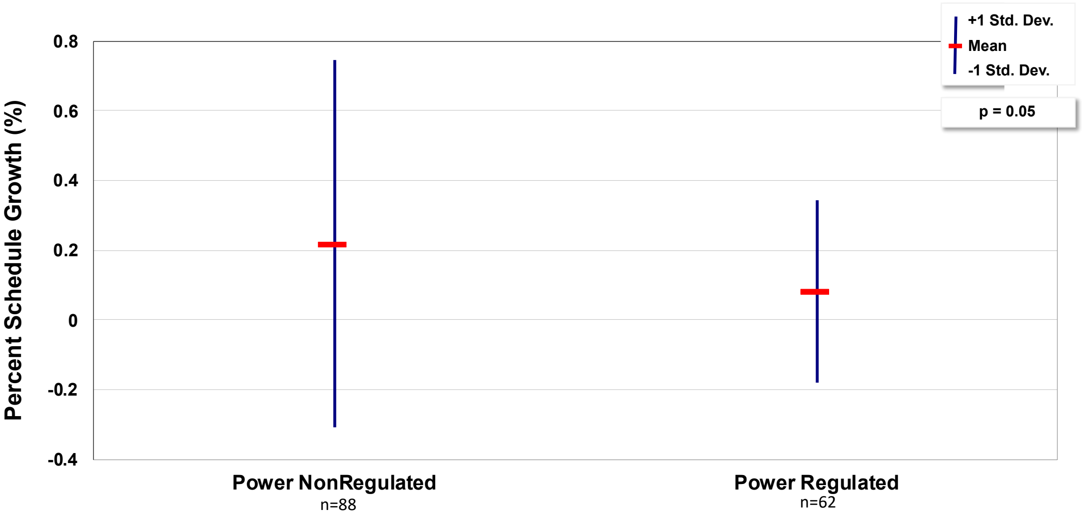

Figure 9: Comparison of Schedule Growth (as a percentage) for Nonregulated and Regulated Power Projects

Figure 9 shows that power projects constructed by companies that are not subject to RoR regulation have schedule growth of 0.2 percent while their regulated counterparts have 0.08 percent schedule growth. This result is statistically significant (p-value = 0.05).

For most capital projects, cost growth and schedule growth go together. Often higher cost and cost growth are driven by slips in schedule. Thus, for the regulated power projects, the fact that they cost more and display more cost growth makes their lack of great schedule slip surprising – the authors suggest future research explores this result in more detail.

CONCLUSION

The Averch-Johnson Effect hypothesized that RoR regulation incentivizes companies to over capitalize on their projects, leading to higher rates that ratepayers must absorb. Project performance and the profitability of power and pipeline construction projects often look different in a regulated environment than a non-regulated environment. This paper further affirmed the Averch Johnson Effect through analysis of 770 pipeline and power projects studied. Across power and pipeline projects, nonregulated environments resulted in lower cost estimates and lower final costs. Cost growth was not found to plague either industry, suggesting that cost estimates are a good indicator of what the final cost of a project will be.

Ironically, RoR regulation, originally developed to protect consumers from price gouging to fund new projects, seems to have resulted in the opposite. Indeed, in pipeline and power projects subject to RoR regulation, estimated and actual costs are higher than similar projects in nonregulated environments. Moreover, in regulated environments, rates are set **prior to** project execution to fund the project, and there is no mechanism to pass cost savings on to consumers. By contrast, in nonregulated environments, where rates are set to cover project expenditures following project completion, cost savings *can* be passed on to consumers.

FUTURE RESEARCH

This research lends itself to further investigation on the business cases for power and pipeline projects in both regulated and nonregulated environments to understand the relationships and processes that lead to apparent overcapitalization. The authors suggest a multiple case study analysis that compares the planning and budgeting processes of regulated and nonregulated power and pipeline projects.

ACKNOWLEDGEMENTS

This research was partially supported by Independent Project Analysis, Inc. (IPA). We thank our colleagues from IPA who provided insight and expertise that greatly assisted the research. All opinions, findings, and conclusions presented in this paper are those of the authors and do not necessarily reflect the views of IPA.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

CHAPTER 3-EXAMINING THE IMPACT OF RATE OF RETURN REGULATION ON CAPITAL PROJECT PLANNING

ABSTRACT

As the United States' population grows and power delivery needs continue to expand, utility companies are presented with a unique opportunity to improve reliability, increase capacity, and provide innovations to power and pipeline production and delivery infrastructure. While there is research dedicated to the impacts of regulatory environment on project performance and profitability of power and pipeline projects, there has been no research dedicated to identifying the differences in planning processes for such projects. This paper explores how capital project planning varies for power and pipeline projects in both regulated and nonregulated environments through an analysis of 770 projects in the Independent Project Analysis (IPA), Inc. project database. This paper presents a statistical comparison of pipeline and power project planning indicators – Front End Loading (FEL) Score, budget spent on front end planning, and stakeholders engaged in front end planning – to understand the impact of regulatory environment on project planning. Results suggest that for some planning indicators studied, regulated projects outperform nonregulated projects and for other indicators, the reverse is true. In particular, results show that regulated pipeline projects have better project definition at the time of project authorization than nonregulated pipeline projects, based on FEL score; the reverse is true for power projects. Regulated pipeline and power projects spend more budget on front end planning than nonregulated pipeline and power projects. Lastly, key stakeholders are represented in both regulatory environments with little difference between nonregulated and regulated environments in both pipeline projects but that power projects in regulated environments engage the key stakeholders for more time.

DEFINITIONS

Sherman (2020) defines pipeline and power projects as follows:

> *Pipeline projects are defined as any project that aids in the transportation of liquids or gasses through a system of pipes, Pipeline projects are a type of infrastructure project; small infrastructure projects are those less than $20M in total installed cost; large infrastructure projects are those over $20M but less than $1B (El Zomor et al., 2018); and mega infrastructure projects are those with costs exceeding $1B (Merrow, 2011).*
>
> *Power projects are defined as power plant construction projects, electrical distribution projects, and transmission lines (greenfield, add-on, expansion, co-located, revamp); they are a specific type of industrial project (CII, 1999). Small industrial projects are those less than $10M in total installed cost; large industrial projects are those over $10M but less than $1B* (W. Collins et al., 2017)*; and mega industrial projects are those that exceed $1B* (Merrow, 2011).

INTRODUCTION

Pipeline Construction

Many of the pipelines in the United States are nearing the end of their useful life. A significant reinvestment is needed in the upcoming decades to replace or rehabilitate the pipeline infrastructure (ASCE, 2017). Moreover, there is relatively little published work that describes the impact of regulation on pipeline construction project planning, execution, and performance. In 2010, Tonery and Perez reported on the examination of US Gas Pipeline earnings, following the Federal Energy Regulatory Commission (FERC's) proposed changes to pipeline rates under Section 5 of the Natural Gas Act (NGA). They found that regulatory uncertainty is related to *an increase* in the cost of capital, discouraging investment in FERC-regulated pipeline infrastructure, and ultimately resulting in higher prices for gas consumers. Ironically, FERC regulates infrastructure to limit gas prices for consumers (Tonery & Perez, 2010).

Power Utility Construction

There is limited research dedicated to the unique processes that affect power utility construction. Bacon and Beasant-Jones (1998) wrote about power utility construction, stating: “The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical to policies for pricing electricity on the basis of economic costs, because such overruns would lead to underpricing. The financial impact of a cost overrun is the strain on the power utility and on national financing capacity in terms of foreign borrowings and domestic credit.”

Because of the high rate of return demanded on both the debt and the equity of power generation projects, the generation costs may rise rapidly, and if wholesale prices of electricity fall below the required level to repay the investment in the new generation project, the project could turn into a financial failure. Csereklyei et al (2016) found that future financing opportunities and higher oil prices during construction, as well as a positive business climate, make it likelier for a project to be completed faster.

Front End Planning

Front-end planning (FEP), also known as pre-project planning or front-end loading (FEL), is defined as the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project (G. E. Gibson., Kaczmarowski, & Jr., 1993). According to a report from the Construction Industry Institute (CII), FEP is the single most important process in a large industrial project’s life cycle (CII, 2006). FEP begins with a project concept to meet a business need and ends with a decision whether to proceed with detailed design of the proposed project (Gibson, Kaczmarowski, & Jr., 1995). The product of the FEP process is a design-basis package of customized information to support detailed or production engineering of design documents.

Efficacy of FEP

Research shows that effective FEP on industrial projects leads to improved performance in terms of cost, schedule, and operational characteristics (Cho & Gibson, 2001; P. Dumont et al., 1997; Griffith, Gibson, Hamilton, Tortora, & Wilson, 1999; Hamilton & Gibson, 1996; Hanna & Skiffington, 2010; Xia, Xiong, Skitmore, Wu, & Hu, 2015). In particular, Collins et al. (2017) studied forty (40) small industrial projects, representing over 150M USD in investment and found that small industrial projects that are well planned, i.e., well defined prior to detailed design and construction, can save 2% of project budget, while those with poor definition prior to detailed design and construction exceeded the project budget by 14% on average. Similarly, CII (1995) reports that for large industrial projects, well defined projects cost 4% less than budgeted cost on average, while poorly defined projects cost 21% more than budgeted (also on average). El Asmar et al. (2018) document the success FEP on industrial megaprojects, and assess the accuracy and maturity of front end engineering design. Other studies have shown similar results tied to the efficacy of front end planning for both industrial (i.e., power) and infrastructure (i.e., pipeline) projects (Bingham & Gibson, 2016; P. R. Dumont, G. E. Gibson., & Fish, 1997; Andrew Griffith & George E Gibson, 2001).

Measuring Level of Project Definition

Project definition involves the determination of what the owner needs and wants, translation of these needs and wants into design criteria, and generation of a design concept

(Ballard & Zabelle, 2000). The clarity of project definition has a direct impact on project performance. A number of studies point out that poor scope definition can lead to expensive changes, delays, rework, cost overruns, schedule overruns, and project failure, while well defined projects will perform well in terms of cost, schedule, and change orders (Bingham & Gibson, 2016; Cho & Gibson, 2001; W. Collins et al., 2017; P. R. Dumont et al., 1997; El Zomor, Burke, Parrish, & Gibson Jr, 2017).

Multiple resources exist to help project teams measure the level of definition on a project ((CII, 1995, 2015; Wesley Collins, Parrish, & G. E. Gibson., 2017; ElZomor, Burke, Parrish, & G. E. Gibson., 2015; Hackney, 1997). One oft-cited tool to measure project defnition during front end planning is the suite of Project Definiton Rating Index tools, or PDRIs, for industrial (CII, 1995; W. Collins et al., 2017), building (CII, 1999), and infrastructure (Bingham & Gibson, 2016; El Zomor et al., 2017) project types. The primary focus of front end planning tools has been to improve project performance through: (1) providing a structured planning process for use during the front end planning phase of a project, (2) providing a quantitative measure (i.e., score) of the level of scope definition of a project, and (3) correlating the level of scope definition to typical project success factors so that project stakeholders can determine whether to move a project forward into detailed design and construction.

The PDRI tools consist of two main components: a structured list of descriptions detailing specific elements that should be addressed during a project’s front end planning phase, and a weighted score sheet that quantifies the importance of each element relative to all other elements in the tool. A project team determines how well each individual element is defined during an assessment session, which can range from complete definition (i.e., Level 1) to little to no definition (i.e., Level 5). The team records the individual element score, and totals element scores to determine an overall project score. The typical PDRI scoring scheme ensures that a project with all elements assessed at Level 1 totals 70, and a project with all elements assessed as Level 5 totals 1000. Level 2, 3, and 4 scores are linearly interpolated between the Level 1 and Level 5 scores. A lower score (i.e., closer to 70) suggests a greater level of scope definition, while a higher score (i.e., closer to 1000) suggests a lesser amount of scope definition. Any elements deemed not applicable during a project assessment would lower the potential Level 1 and Level 5 scores on a pro-rata basis, depending on the weighting of non applicable elements.

Large projects with PDRI scores less than 200 have better cost, schedule, and change order performance than projects with PDRI scores above 200, based on statistical analysis of actual completed projects (Bingham & Gibson, 2016; CII, 1995, 1999). For smaller projects, the target PDRI score is 300 (W. Collins et al., 2017; El Zomor et al., 2017).

Cost of FEP

Rigorous and effective FEP can cost approximately 3-5% of total project budget, which owners may be hesitant to commit so early on in a project (Merrow, 2011). However, if that investment is not made during the FEP stage, the final cost of the project may increase exponentially due to poor project definition.

Stakeholder Involvement in Front End Planning

CII (2013) found that, “establishing a positive alliance among all key project team members facilitates the potential for an efficient, successful outcome,” particularly if this alliance is achieved early during the planning process. . While all team members must be competent in the project at hand, informed of project decisions, and given the opportunity to attend project planning meetings in order to minimize the impacts on subsequent activities, there are certain key members from the owner's team that should be included in the FEP stage for a successful project. The suggested key members are: (1) the engineering team discipline leads and support services, (2) the project manager/project engineer(s), (3) the project estimator, (4) the owner's engineering project representatives, (5) the owner's business sponsor, (6) key personnel representing the owner's operations, (7) representatives from the owner's support services (e.g., maintenance, construction, safety), (8) the shutdown/turnaround manager if applicable, and (9) contractors, if possible.

Rate of Return Regulation

Regulation of coal, gas, and pipeline projects arose as part of the contract with municipalities and power and pipeline companies, who granted rights of way in exchange for quality standards and price controls on such projects. Rate-of-return, RoR, regulation evolved through a series of landmark court cases in the US to provide procedural fairness in the allocation of rents accruing to franchise monopoly investor-owned utilities (Newbery, 1997). RoR regulation is a form of regulation where a designated regulator sets "fair market prices" for electricity via transmission lines or natural gas via pipelines so that the regulated firm's return on assets attains a target value in each period. Prices are set so that revenues cover not only current operating expenses but also an interest charge on the book value of the firm's operating assets. A frequently voiced claim in the industrial organization literature is that RoR regulation is inherently inefficient. Indeed, Sherman (2020) found that power and pipeline projects had higher estimated costs and higher actual costs in regulated environments than their nonregulated counterparts.

In practice, RoR regulation functions as an additional stage gate for capital projects in regulated environments. Most regulatory agencies require a basis of design, as well as a cost estimate, in order to approve a capital project, thereby authorizing the owner of the project to begin construction. By contrast, a private owner that is not subject to RoR regulation can determine for themselves whether or not to invest in a project, as well as the details of said project. That is, in a nonregulated environment, an owner wanting to pursue a pipeline or power project would have an internal process for gaining project approval, and would not require the extra step of regulatory approval in order to move forward with the project.

Research Hypotheses

Literature documents construction planning processes for capital projects, including for pipeline and power projects. However, literature does not explicitly discuss the impact of regulatory environment on construction planning. The authors explore the impact of regulatory environment on the construction planning process, via three indicators of planning, in this paper. Given that RoR regulation provides an additional stage gate in the construction project lifecycle, the authors hypothesize that projects in regulated environments will be better planned, as they likely need clearer project definition in order to be approved by the regulatory body than a project of similar scope in a nonregulated environment. To that end, this paper addresses the following hypotheses:

H1: Pipeline projects in regulated environments have better project definition, as indicated by FEL score, than pipeline projects in nonregulated environments.

H2: Power projects in regulated environments have better project definition, as indicated by FEL score, than power projects in nonregulated environments.

H3: Pipeline projects in regulated environments will spend more capital on FEP than pipeline projects in nonregulated environments.

H4: Power projects in regulated environments will spend more capital on FEP than power projects in nonregulated environments.

H5: Pipeline projects in regulated environments will engage more key stakeholders than pipeline projects in nonregulated environments.

H6: Power projects in regulated environments will engage more key stakeholders than power projects in nonregulated environments.

Note that for all planning indicators considered, the authors expect that regulated projects will perform better, due to the regulatory body requiring more complete project definition prior to granting project approval.

METHODOLOGY

This section discusses data sources for this study, as well as the data analysis approach used to understand the planning processes for pipeline and power projects in both regulated and nonregulated environments.

Data Source

The dataset for this study was drawn from an existing database of 20,000+ capital projects maintained by Independent Project Analysis (IPA). IPA works with owner organizations that are responsible for developing and executing power and pipeline projects, among others. Their data collection process involves face-to-face interviews with project teams using a structured questionnaire. The questionnaire is designed to gather information related to the project objectives and scope, project management practices, and project performance metrics, among other project information. The data is translated into a structured database, which is used in individual project evaluations and project system benchmarking (IPA 2019). Typically, the interviews are conducted at the time of project authorization, when funds are allocated for the project, and at the end of the project, after mechanical completion and startup (Figure 10). Thus, the first interview occurs during FEP, and the second occurs after FEP.

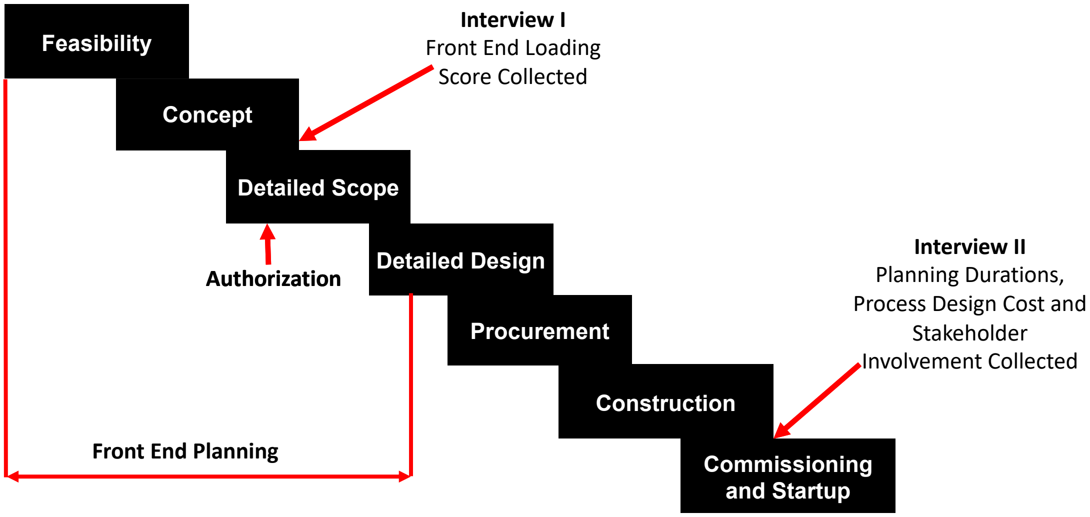

Figure 10: Timeline of Data Collection (Adapted from CII Project Timeline)

Descriptive Statistics of Project Types in Study Dataset

The dataset used for this paper comprises both pipeline and power projects constructed in the US after 2000 to support consistency. The authors categorized the projects in the dataset as "regulated" if the organizations completing the projects were subject to RoR regulation, and non-regulated if not. Table 2 lists the number of regulated and non-regulated projects of various types in the dataset.

Table 2: Descriptions and Descriptive Statistics of Project Types included in Study

Project Type	**Description**	**Frequency: Pipeline Projects (#projects)**		**Frequency: Power Projects (#projects)**	
		n_{reg}	n_{nonreg}	n_{reg}	n_{nonreg}
Greenfield	constructed on a new, undeveloped site or area with an existing site	21	108	13	4
Add-On	constructed within an existing facility where the process did not previously exist	20	72	24	25
Expansion	constructed to increase the capacity of an existing facility of the same type at the same site	12	60	6	13
Co-located	located adjacent to an existing facility, but standalone except for possible utilities	8	38	9	23

Revamp	rebuilds or a refurbishment to an existing facility	60	114	34	58
Other	projects that do not fit in any of the previously described categories.	17	22	3	6
Total		138	414	89	129

The pipeline dataset includes 552 projects that range in length from 1km to 1200 km, diameters ranging from 5.08 to 142.24 centimeters, and water depths ranging from 1 to 2895 meters. These projects comprise both offshore and onshore pipeline. These projects represent data from 51 facility owner organizations and range in completed project size from $337.7 Thousand USD to $2.05 Billion USD.

The Power Dataset is made up of 218 projects that range in capacity from <10MW to >10,000MW. These projects are comprised of multiple feedstocks, such as wind, solar, hydro, coal fired, cogeneration, transmission lines, and electrical distribution. These projects represent data from 57 facility owner organizations and range in completed project size from $69.3 Thousand to $2.05 Billion location-adjusted, 2003 USD.

Data Analysis

For regulated and nonregulated power and pipeline projects, the authors tested the correlation between regulation and: (1) project definition, (2) capital spent on FEP, and (3) stakeholders engaged in FEP. To do so, the authors use the FEL score as a proxy for project definition; Process Design cost is used as a proxy for capital spent on FEP. The authors document stakeholder engagement based on interview responses. These metrics are described in the following subsections; Figure 1 illustrates when each metric is assessed or calculated. Note that for each metric considered, the number of projects included in the analysis varies according to available data. As such, the authors list the number of projects considered in the particular analysis (e.g., *n* nonregulated pipeline projects, *n* regulated pipeline projects, etc.).

FEL Score Performance

The FEL score is a unitless indicator that is determined prior to detailed design (see Figure 1), based on information collected during in person interviews with the project team. The FEL score is similar to the PDRI score discussed earlier in this paper; however, the FEL score is a proprietary metric developed and used by IPA. The FEL score combines several site factors, the team's project execution planning, and the status of design and engineering. This index scores from 3-12, with 4 being best practical (i.e., the target score) and 12 being "screening study," indicating that the project is not yet ready for construction. The FEL score provides a quantitative assessment of the preparedness of a particular project team to successfully execute that project's scope. The FEL score at authorization measures the quality of information used to develop the base cost estimate (Independent Project Analysis, 2019). This is derived from the relationship between the contingency allocated to the project and the completeness of a set of FEL deliverables. Ergo, a lower FEL score would indicate the project has less contingency allocated toward the project and a more complete set of FEL deliverables. Conversely, a higher FEL score would indicate a higher contingency allocated toward the project a less complete set of FEL deliverables. Figure 2 shows the FEL score scale. This is shown in Figure 11.

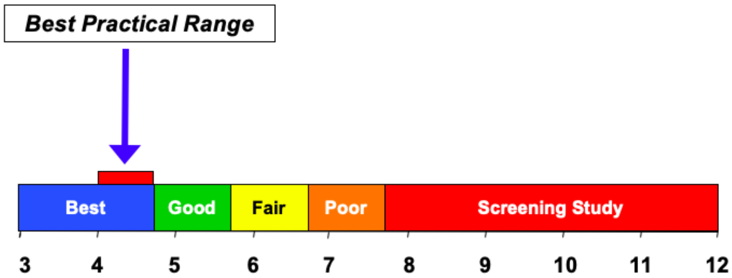

Figure 11: FEL Score Performance – Adapted from IPA FEL Scorecard

Percent Capital Spent on FEP

One key task in FEP is developing process flow diagrams for the project. Accordingly, IPA has a variable that tracks the estimated process design cost, all of which is expended during FEP. This cost is collected during Interview I, along with the estimated total cost (Figure 1). The process design cost is not the full cost of FEP, as it does not include all FEP costs. For example, the costs of developing detailed project staffing, procurement and project control plans are not included. However, the process design cost is a consistent cost among pipeline and power projects, and as such was an appropriate proxy for capital spent in FEP. Using process design cost as a proxy for FEP costs is conservative, i.e., actual FEP costs will always be higher than the process design costs as FEP costs include items not captured in the process design cost. Equation 2 shows the calculation of the percentage of capital spent on FEP – the estimated process design cost is compared to the estimated total project cost, and then converted to a percentage.

$$Percent\ Capital\ Spent\ on\ FEP = \frac{Estimated\ Process\ Design\ Cost}{Estimated\ Total\ Project\ Cost} * 100\%$$

Equation 5: Percent Capital Spent on Front End Planning

Stakeholder Engagement

From the project feasibility stage and throughout the project lifecycle, it is important to have the right people on the project team and in the room contributing to project decision-making to improve project outcomes. As previously discussed, CII (2013) documents a list of project stakeholders required for FEP. These key stakeholders are recorded in IPA's dataset as being represented (recorded as a 1) or not represented (recorded as a 0) during FEP. While there are 14 roles accounted for in the IPA dataset, the only functions captured in this paper are those that are crucial to project success (CII 2013). Table 3 lists these functions.

The authors reviewed the dataset to ensure that if an analyst input information for one stakeholder, they input information for all stakeholders. This ensures that the stakeholder engagement analysis is not falsely counting a "no data" entry as a 0 for that stakeholder's involvement.

Table 3: Mapping of CII's Recommended Stakeholders to Functions Represented in IPA's Database

Functions Represented in IPA's Database
Engineering leads
Project manager
Estimator
Engineering contractor lead
Executive sponsor
Operations representative
Maintenance representative
Construction manager
Construction contractor lead

Statistical Analysis

The authors used various statistical analyses to test the significance of correlation between the planning metrics described and regulatory environment. The authors used

STATA for all statistical tests. First, the authors calculated means and standard deviations for FEL score and percent capital spent on planning for: (1) nonregulated pipeline projects, (2) regulated pipeline projects, (3) nonregulated power projects, and (4) regulated power projects. The authors tested normality of each of the samples (i.e., (1) – (4) listed previously). The data used in this paper had unequal variances; as such, the authors used the Mann-Whitney-Wilcoxon (MWW) statistical test, which is used to compare the means of samples with non-normal distributions (Wilcox, 2009). In all cases, the statistical analysis results in a p-value; all p-values less than or equal to .05 indicate statistical significance with a 95 percent confidence interval.

RESULTS AND DISCUSSION

This research found that RoR regulation had little impact on the planning processes of power and pipeline projects in the 770 projects studied. The following subsections illustrate the impact of regulation on the FEL Score, the percent capital spent on FEP, and the stakeholder involvement from project definition to project completion. The subsections also revisit the research hypotheses.

FEL Score Performance

Figures 12 and 13 illustrate the comparison of FEL Score on nonregulated vs. regulated pipeline and power projects, respectively. The horizontal lines in the plots in Figures 3 and 4 illustrate the mean and vertical lines represent one standard deviation from the mean. The p-value is listed in the upper right corner of each chart. Figure 12 supports testing H1, that the project definition is better, as measured by a lower FEL Score, for pipeline projects in regulated environments than nonregulated environments. Nonregulated pipeline projects have higher FEL scores than regulated pipeline projects. This suggests they are not as well planned as their regulated counterparts. As shown in Figure 12, nonregulated pipeline projects have a mean FEL score of 6.5 while regulated pipeline projects have a mean FEL score of 5.8. These values are statistically significant (p-value = 0.001); hence, the authors accept H1.

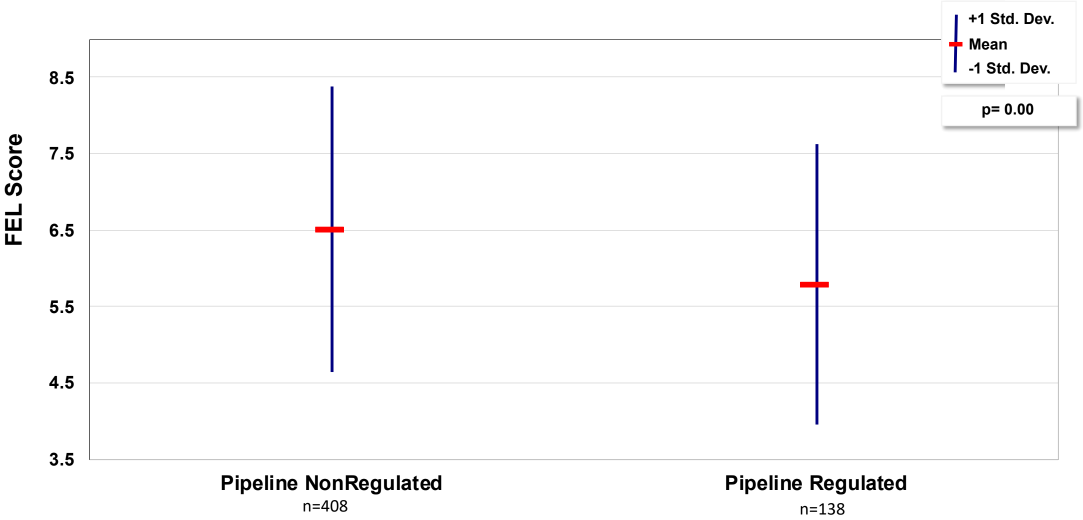

Figure 12: Comparison of FEL Score for Nonregulated and Regulated Pipeline Projects

Figure 13 supports testing H2, that the project definition is better, as measured by a lower FEL Score, for power projects in regulated environments than nonregulated environments. This hypothesis is rejected in favor of the reverse, that project definition is better for power projects in nonregulated environments than regulated environments (p=0.001). As shown in Figure 13, nonregulated power projects have a mean FEL score of 6.05 while regulated power projects have a mean FEL score of 7.47.

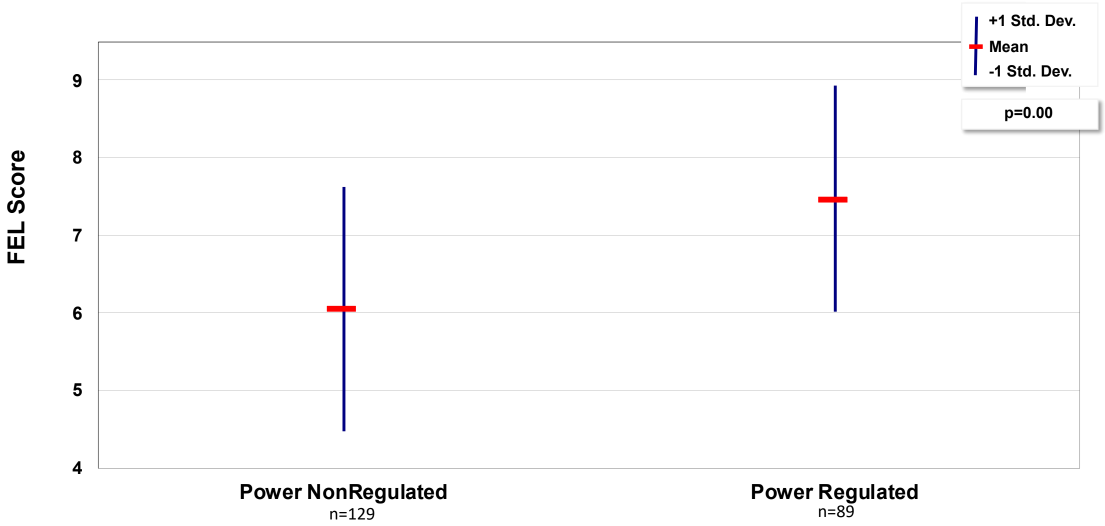

Figure 13: Comparison of FEL Score for Nonregulated and Regulated Power Projects

Overall, pipeline and power projects, whether in a regulated environment or a nonregulated environment, do not score well in FEL (all projects score above the maximum “Good” score of 5.75); this indicates that they are not well defined prior to detailed design. This could be influenced by the amount of project risk that is acceptable in these industries. That is, if projects leave the FEP stage with a relatively large contingency, the project team may be comfortable moving the project forward without as much definition as may be considered prudent. Also, many pipeline and power projects are executed as EPC (engineer-procure-construct) lump sum contracts (Gloria, Siegfriedt, Carstens, & Lundy, 2011) which can be executed with less definition than other contract strategies, i.e., design-bid-build. In particular, EPC contracts allow the Front End Engineering Design to be executed by the contractor, thus allowing design choices to be deferred until they can be made by contractors with knowledge of design as well as construction of pipeline and power projects.

Percent Capital Spent on Front End Planning

Table 4 supports testing H3, that pipeline projects in regulated environments will spend more capital on FEP, measured as the percentage of budget spent on process design, than pipeline projects in nonregulated environments. The authors accept this hypothesis, as regulated pipeline projects spend more on process design than nonregulated pipeline projects. Table 4 also supports testing H4, that power projects in regulated environments will spend more capital on FEP, measured as the percentage of budget spent on process design, than power projects in nonregulated environments. The authors reject this hypothesis, and in fact found, with statistical significance (p=0.001), that power projects in nonregulated environments spend more on FEP than power projects in nonregulated environments.

Table 4: Process Design Costs, as a percentage of Total Project Costs, spent in Front End Planning. Process design costs are a conservative estimate of FEP costs, as described in the Methodology section

			Non-Regulated	Regulated	
Project Type	n_{nonreg}	n_{reg}	Average % budget spent on process design	Average % budget spent on process design	P-value
Pipeline	11	81	1.5	3.0	0.001
Power	123	81	3.5	1.4	0.001

For pipeline projects in nonregulated environments, projects spent, on average, 1.5% of project budget on FEP while their regulated counterparts spent, on average, 3.0% of project budget on FEP. Perhaps this result is to be expected, given that regulated pipeline projects have lower FEL scores, and hence, appear to be better planned, than nonregulated pipeline projects. However, while nonregulated pipeline projects spend less on FEP than regulated projects, previous research illustrates that nonregulated pipeline projects end up costing less (Sherman, 2020). This result may indicate that the process design cost is not a good proxy for the cost of FEP on pipeline projects. Indeed, pipeline projects are less engineering-intensive that power projects; that is, they do not need as much engineering time to achieve a similar level of project definition. For instance, perhaps the nonregulated pipeline projects in the dataset used "standard" process designs, so the process design cost does not accurately measure the cost of FEP.

Power projects in nonregulated environments spent, on average, 3.5% of project budget on FEP while their regulated counterparts spent, on average, 1.4% of project budget on FEP. This result aligns with the fact that nonregulated power projects tend to cost less than regulated power projects of similar scope (Sherman, 2020). Moreover, this result illustrates that nonregulated power projects are making an appropriate investment in FEP, as they likely spend more than the 3.5% of budget reported in Table 4 on FEP.

Stakeholder Involvement

Table 5 illustrates the comparison of the stakeholders engaged on the project team from FEP through project completion for nonregulated and regulated pipeline projects. The engagement of these stakeholders is represented as the average percent time spent on the project. Thus, the 18.4% in the "Exec. Owner" column of the "Non-regulated" row indicates that on average, the executive owner spent 18.4% of total project time engaged and present on the project. Table 6 supports testing H5, that pipeline projects in regulated environments will engage more stakeholders in FEP than pipeline projects in nonregulated environments. Results indicate that stakeholder engagement is greater in nonregulated environments than the regulated counterparts. This is statistically significant for the functions: executive owner, project manager, engineering lead, operations representative, maintenance representative, Estimator, and Contractor Lead Engineer.

Table 5: Functions represented during FEL on Pipeline Projects , as percentage time spent on project

Pipeline	Percent Project Time that Functions represented on team from FEP								
Project Envrnmnt	Exec. Owner	Proj. Mangr	Engr Lead	Oprxns Rep	Maintnce Rep	Constr. Mngr	Estmtr	Engr (Contrctr Lead)	Constr (Contrctr Lead)
Non-regulated (*n* = 318)	18.4%	49.7%	48.9%	25.3%	18.8%	45.9%	27.5%	49.5%	48.4%
Regulated (*n* = 113)	6.7%	27.8%	27.6%	9.2%	10.0%	38.1%	15.6%	28.3%	31.2%
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.5580	0.0200	0.0000	0.0788

For pipeline projects, the only functions that were not statistically significant, but demonstrated a trend of having more engagement in the nonregulated environment were the Construction Manager, and the Contractor Lead Construction representative. Similarly, on regulated pipeline projects, Project Managers were most often represented. Perhaps this difference is explained by the fact that many nonregulated pipeline projects are completed by private owners that have operations and construction staff in house, while regulated projects may have engineering staff in house. A key takeaway from Table 5 is that most all key stakeholders are present in nonregulated pipeline projects for greater percent project time than the regulated pipeline projects.

Table 6 illustrates the comparison of the stakeholders engaged on power project teams from FEP through project completion, and compares engagement for nonregulated and regulated power projects. Similar to Table 6, the percentages listed in Table 7 are the percentage of the total project time that the stakeholder was involved on the project in FEP for the “Nonregulated” and “Regulated” rows, respectively, that include a given stakeholder on the project team from FEP through project completion. Thus, the 25.9% in the "Exec. Owner" column of the "Non-regulated" row indicates that an Executive Owner was present for 25.9% of total project time in the Nonregulated Power Projects. Table 6 supports testing H6 that power projects in regulated environments will engage more stakeholders in FEP than power projects in nonregulated environments. Overall, this was not found to be true. While Table 6 does indicate that power projects in nonregulated and regulated environments engage stakeholders at statistically-significantly different rates, the regulatory environment does not seem to dictate stakeholder engagement as a whole.

Table 6: Functions represented during FEL on Power Projects , as percentage time spent on project

Power	Percent Project Time that Functions represented on team from FEP								
Project Envrnmnt	Exec. Owner	Proj. Mangr	Engr Lead	Oprxns Rep	Maintnce Rep	Constr. Mngr	Estmtr	Engr (Contrctr Lead)	Constr (Contrctr Lead)
Non-regulated (*n* = 318)	25.9%	48.0%	49.4%	34.0%	19.7%	30.4%	19.7%	46.8%	45.3%
Regulated (*n* = 113)	29.6%	61.5%	56.5%	41.0%	41.2%	72.1%	33.2%	92.6%	81.3%
p-value	0.0768	0.1106	0.714	0.3215	0.04	0.000	0.0829	0.0000	0.005

For power projects, only Maintenance Representatives, Construction Managers, Engineering Contractor Leads, and Construction Contractor leads were statistically different between regulated and non-regulated environments. For these functions, they were engaged for more project time in the regulated environment than their nonregulated counterparts. While executive owners, project managers, engineering leads, operations representatives, and estimators were not statistically significantly different, (p>0.05), the trend was present across all stakeholders that the key stakeholders were engaged on more project time in the regulated environment than the nonregulated environment. The authors postulate this may be explained by regulatory guidelines requiring a more stringent protocol when constructing power projects. It is interesting to note that more stakeholder engagement is present in the nonregulated environment in the pipeline projects, while the opposite is true in power projects. This could be explained by the level of complexity in power projects, and the regulatory requirements for power projects dictating a higher level of engineering planning than the pipeline projects in those same environments.

LIMITATIONS

The research described in this paper is limited to the United States pipeline and power projects in the IPA global dataset. This dataset is developed and maintained by IPA global and is subject to human error, as analysts that record and input the data could do so incorrectly. However, this human error is benign unless it always acts in a particular direction (i.e., adds a *bias* to the data). Given that there is no reason to believe that analysts would be biased in one direction or another (i.e., towards regulated or nonregulated projects in this case), the authors are not concerned about bias in the data. Additionally, the stakeholder engagement metrics used in this study do not measure the level of stakeholder involvement (i.e., as a percentage of the stakeholder's time); they merely indicate that the stakeholder was involved at some point between planning and execution.

CONCLUSION

The authors hypothesized that RoR regulation would impact planning indicators for pipeline and power projects. In particular, the authors expected to see: (1) better project definition, evidenced by lower FEL Scores, on regulated projects; (2) more investment in

FEP, evidenced by the percentage of budget allocated to process design, on regulated projects; and (3) more stakeholder engagement on regulated projects.

The authors discovered that nonregulated pipeline projects have higher FEL scores than their regulated counterparts which indicate that regulated projects have better project definition at authorization. This was to be expected as the authors postulated that regulation would incentivize projects to be better planned in order to be approved for funding. However, the opposite is true in the power dataset, where regulated projects also had higher FEL scores. The authors note that neither pipeline nor power projects, regardless of regulatory environment, had "good" project definition at the end of FEP (evidenced by FEL Scores exceeding the 5.6 recommendation).

In terms of budget spent on FEP, the authors found that nonregulated pipeline projects spent less on FEP than regulated pipeline projects; the reverse was true for power projects. The authors once again caution readers that the estimates for budget spent on FEP presented in this paper are conservative, so perhaps these values would change if all FEP costs were to be tracked and reported, rather than simply using the Process Design Cost proxy that we used in this paper.

Finally, with respect to stakeholder engagement, the authors found that there was a mixture of stakeholder involvement in both regulatory environments. In general, most pipeline and power projects do seem to engage the appropriate stakeholders. Pipeline projects had a mixture of stakeholder engagement between the environments. Regulated power projects tend to engage stakeholders for longer durations during the project lifecycle than their nonregulated counterparts.

While FEL scores in both regulatory environments show that pipeline and power projects are not well defined, the other planning indicators tested in this paper show that pipeline and power projects are implementing FEP techniques that align with good project outcomes. For example, projects in both environments are engaging the right stakeholders at the right time. Thus, the planning processes implemented in pipeline and power projects, in both nonregulated and regulated environments, seem to be sound.

ACKNOWLEDGEMENTS

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DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

CHAPTER 4- IDENTIFYING AND CATEGORIZING RISKS INCUMBENT IN US NUCLEAR POWER PLANT CONSTRUCTION

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ABSTRACT

In the US, nuclear power plants offer a means of generating power with less carbon emissions and higher efficiency as compared to traditional fossil plants. Because of this, nuclear power plants offer a solution that meets the requirements of the current regulatory environment. While both hydroelectric and nuclear power are most attractive from an emissions standpoint, these technologies also include greater risk of cost overruns than other types of power plants, e.g., coal fired, combined cycle, or solar. This paper leverages a robust literature search to collect data about nuclear power plant construction projects in the United States, and based on a peer-reviewed risk register, highlights the trends in risk prevalence based on nuclear reactor type, year of construction, and Nuclear Regulatory Commission (NRC) region. This analysis revealed that there was no correlation to NRC region vs. risk. Risks are, for the most part, present in all regions without an obvious correlation between region and risk presence or prevalence. The analysis also demonstrates that among the 4 reactor manufacturers present in the dataset, design risk was the most prevalent risk and that Westinghouse reactors had the greatest occurrence of risk all together. This paper contributes to the power plant construction body of knowledge by: (1) categorizing risks cited in literature from 50 US nuclear power plant construction projects

using an existing peer-reviewed risk register and (2) identifying trends in risks that lead to significant cost and schedule overruns over time.

INTRODUCTION

Need for Nuclear Power

The International Energy Agency (IEA) anticipates the global energy demand to grow by more than 25% requiring more than $2 trillion a year of investment in new energy supply by 2040 (IEA, 2018). With power needs increasing as populations grow and climate extremes become more routine, power companies seek methods to continually increase capacity, improve efficiency, and provide resilience to the power grid, such that they can meet the energy needs of the societies they serve, while minimizing carbon emissions. Alonso et al (2015) found that nuclear power plants are capable of sustainably and reliably supplying the large quantities of clean and economical energy needed to run industrial societies with minimal emission of greenhouse gases. Today, nuclear energy makes up one-third of global low carbon electricity, and countries with the lowest carbon intensities depend heavily on low-carbon sources of baseload power such as nuclear and hydroelectric (Lovering, Yip, & Nordhaus, 2016). Leibowicz et al (2013) found that with current technologies, carbon mitigation that does not rely heavily on nuclear electricity is economically insensible. Bosetti et al (2015) found that the cost of nuclear energy is shown to dominate all other factors (in the study) in affecting future emissions, indicating there is a strong correlation between nuclear power's deployment and the ability to mitigate carbon emissions. Barron and Mcjeon (2015) also found that the cost of nuclear is the single most important driver of the abatement cost of carbon.

Historic Cost Overruns

In a report published by the World Nuclear Association, the "economics of new nuclear plants are heavily influenced by their capital cost, which accounts for at least 60% of their levelized cost of electricity. Interest charges and the construction duration are important variables for determining the overall cost of capital as it pertains to Nuclear Power Plant (NPP)" (World Nuclear Association, 2017). It is proposed by Roberts (2014), if large power projects or certain kinds of large power projects reliably go over budget, then it may be that systematically energy scenarios are mis-predicted and as such, capital budgets are misallocating investment dollars.

While NPP's offer significant opportunities to reduce carbon emissions, provide resilience and capacity to the power grid, these projects tend to be characterized by large investment commitment, vast complexity, and long lasting impact on the economy and society (Brookes & Locatelli, 2015). The unanticipated cost overruns and schedule delays have contributed to the high construction costs of nuclear power; causing a decline in the deployment of these technologies in developed countries, specifically the United States. Bacon and Beasant-Jones (1998) wrote:

> *"The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical to policies for pricing electricity on the basis of economic costs, because such overruns would lead to underpricing. The financial impact of a cost overrun is the strain on the power utility*

> *and on national financing capacity in terms of foreign borrowings and domestic credit." (Bacon & Besant-Jones, 1998)*

NPP construction projects, often classified as a "megaproject", can play a fundamental economic and social role, but are inherently risky to pursue (Locatelli & Mancini, 2010). Megaprojects are usually defined as projects with budgets above $1 billion that involve a high level of innovation and complexity (Flyvbjerg et al. 2003; Locatelli et al. 2014; Merrow 2011; Wee 2007) Megaprojects, such as NPP, tend to be characterized by large investment commitment, vast complexity, and long-lasting impact on the economy and society (Brookes & Locatelli, 2015).

Several analyses of historical nuclear cost trends have indicated escalating construction costs of NPP over time, which raise doubts about whether nuclear can become cost competitive (Cooper, 2014; Hultman, Koomey, & Kammen, 2007). Sovacool et al (2014) found that more than 25% of the worldwide nuclear reactors studied, had overruns above 179% and 1425 $/kWe; overruns afflicted greater than 97% of all nuclear projects examined. Sixty-four projects in this sample had cost overruns exceeding $1 billion, and the single highest overrun had a cost escalation of more than 1200% (Benjamin K Sovacool et al., 2014). Findlay (2010) found that material, labor, and engineering costs for nuclear power plants jumped more than a factor 2.26 between 2000 and 2013, meaning a plant that cost $4 billion to build in 2000 would cost almost $12 billion today (Findlay, 2010). Risks and uncertainties do not impact linear and cyclical activities in the same manner. A small risk may have significant exposure in a cyclical environment as there are many more opportunities for it to take place, which is why a method needs to be developed in order to properly integrate the risks and uncertainties of a project while keeping in mind the nature of the two types of operations. (Shahtaheri et al 2016)

It is commented by Locatelli (2018) that the problem of budget overruns in megaprojects is “systematic with no relevant improvement over time.” Flyvbjerg (2006) states that NPP often underestimate costs and overestimate short term benefits, likely due to insufficient project planning (Flyvbjerg, 2006).

Risks of Nuclear Power Plant Construction

NPP construction projects offer a wide range of risks to consider. These projects have the potential to be exposed to risks driven by public policy and society’s risk perception of the technology. Especially after the partial meltdown of reactors 1, 2, and 3 at the Fukushima NPP in northern Japan, as well as the Three Mile Island (TMI) accident, society’s risk perception became the forefront of conversation. Some nuclear proponents have suggested that irrational public fears of radiation exposure, in combination with the onerous regulation of nuclear designs, construction, and operation, has had a major impact on the rising costs and slowing expansion of nuclear energy (Nordhaus, Lovering, & Shellenberger, 2014). While safety is a concern of the general public, the reactor, which has been selected for use at Southern Co.'s Vogtle site in Georgia and at six other U.S. locations, is designed to shut down automatically and stay within a safe temperature range (Smith, 2009).

According to Project Management Body of Knowledge (PMBOK), “risk is defined as an uncertain event or condition that has a potential effect on at least one project objective” (Project Management Institute, 2017). While this is the broad definition of risk, the authors use a peer reviewed risk register to categorize the risks observed in the newspaper articles analyzed.

While public safety is often the most publicly discussed/protested issue concerning nuclear power plant construction, cost and schedule play a huge role in public perception of nuclear power plants (Baker & Boyd, 1983). This established a realm of need for research into what risks are occurring during nuclear power plant construction, as well as what information is being made publicly available.

Several researchers have identified "regulatory ratcheting" as one of the primary causes of the poor cost and schedule performance of the first generation of U.S. civilian NPPs (Cohen, 1990; Friedrich, Daly, & Dick, 1987; Lillington, 2004; Olyniec, 1986). Regulatory ratcheting is the retroactive extension and application of government regulations that apply to licensed nuclear power construction. Taylor et al. (2012) aimed to discover how public policy and societal risk perception affect the current generation of NPP construction by using a dynamic simulation model of the public policy. This study found that proposed strategies to address public policy and societal issues, may not prevent cost and schedule overruns on the planned next generation of nuclear plants, and that results point to the critical role that societal perceptions of nuclear power risk play in nuclear construction project success (Taylor, Ford, & Reinschmidt, 2012).

While societal risks play a significant role in the construction of NPP, construction cost overruns are multi-causal and not limited to a single factor. There are factors such as a procurement delays and shortages of labor that impact construction schedules (Benjamin K. Sovacool, Daniel Nugent, et al., 2014). The U.S. Energy Information Administration

(EIA) concluded that “increases in the quantities of land, labor, material, and equipment” as well as increases in financing charges all played contributory roles to the significant cost escalation and schedule delays in the previous generation of NPP (EIA, 1986). The quality and quantity of the professional and craft workforce required to construct these new plants is limited ((CBO), 2008).

Sovacool et. al (2014) conducted an analysis of 401 power plant and transmission projects in 57 countries. They found that of the 180 nuclear reactors in the sample, 64 percent of nuclear projects had a time overrun yet close to all of them (97.2 percent) had a cost overrun, which does suggests that the relationship between schedule delays and cost overruns are not monotonic. Sovacool et al. (2014) suggests that costly attempts could have been made to accelerate schedules as to minimize delays. This could have resulted in higher wages and overtime costs, used to attract workers, leading to a decrease in lead times but an increase in expenses.

Maronati (2018) analyzed historical construction cost and schedule information of completed NPP and found that in fact, data shows a cost escalation over the years, that plants with longer construction times were not perceived as more difficult to manage, and were highly affected by regulatory changes, and while utilities did increase construction times and cost estimates as the plants proceeded, they still tended to underestimate the overnight construction costs and times.

Sherman, Parrish et al. (2019) affirm that US NPP construction cost overruns have increased over time indicating project performance has gotten worse over time. It was found that there is a sharp spike in cost overrun percent in 1985, where the greatest cost overrun of completed projects in the United States was observed. The authors take note that Three Mile Island accident happened in 1985 which caused an immediate halt on all nuclear power plant projects, and a consequential review of construction permits, operating permits, as well as the safety of each plant at the time. While there is a sharp spike in percent overruns in 1985, the overall upward trend continued to the end of the dataset. It can be noted that many of these projects were constructed in close time frame to each other, and often times tasks are so expedited that everything is considered on the critical path. There were multiple upgraded and new technology used in the construction of these plants, and as such, lessons learned might not have easily translated to newer projects.

As shown through copious research on the different risks inherent in the NPP process, there are several factors a utility needs to consider when planning for NPP construction. Kim et al. (2017) defined standard risk classifications and structured risk evaluation techniques for power plant construction projects to identify what risks occur within a project. This paper aims at filling the gap in literature by categorizing risks cited in public literature from an existing peer reviewed risk register (Kim et al., 2017) and identifying common themes and trends in risks in past NPP projects that lead to cost and schedule overruns. This methodology is validated through an interrater reliability test, where the categorization of risks manifested in the articles are mutually agreed upon.

BACKGROUND

Risk Types

Independent vs. Interdependent Risks

It is important to note that there are several independent and interdependent risks. Many risks such as “Design Quality” lead to other risks and as such, any subsequent risk resulting from a design quality issue, are considered an interdependent risk, but still included for the purpose of this study is to cite any and all risks publicly demonstrated in newspaper articles. While an independent risk, such as social issues, were prevalent across all nuclear plants, and can be cited in nearly all of the plants in public newspaper. The extent of its’ impact on cost and schedule was not a part of the scope of this paper, only documenting that it occurred. Some of the instances caused the plants to cease construction during the duration of the protest, and several protestors were arrested (Arkansas Nuclear, Washington Post, 1979).

Gap in Research

There is a wealth of previous research dedicated to the risks associated with NPP construction. Several studies (Brookes & Locatelli, 2015; Shin, Shin, & Kim, 2016). have shown that cost overruns and schedule delays during the construction process effect the overall economics of nuclear power as compared to other power plant technologies. Studies (Taylor et al. 2012, Sovacool et al. 2014) also show that there are specific and unique risks associated with the NPP construction process. Previous research has estimated that the risks associated with nuclear power operations vary widely between nuclear industry professionals and academics (NRC, 1975), nuclear power proponents (Cohen, 1990), opponents to nuclear power, and society in general (Rothman & Lichter, 1987). It has been shown that general society estimates nuclear power risks to be significantly higher than estimates from nuclear scientists and engineers (Slovic et al. 1979; Cohen 1990; Duffy 1997). Shin et al. (2016) take a look at the Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) in order to make comparisons between decision-making methods, to assess the potential risks at nuclear power plant construction sites. The FAHP was identified as a suitable method for risk assessment of nuclear power plant construction, compared with risk assessment using the AHP.

The current body of knowledge makes no value judgment regarding the "correctness" of risk perceptions among various stakeholders, nor identify how certain risks are being communicated to the general public by industry professionals, further, how NPP construction risk is influencing public perception of overall NPP risk. The limitations of the current body of knowledge are that the risks being identified do not categorize for unique factors that influence construction such as the year it was constructed, the differences in risks observed by each unique reactor manufacturer, and the unique risks observed by the NRC regions.

Previous research honed in on the risks associated with NPP construction, as well as on the performance of NPP construction projects; however, very little has been done to integrate the two and understand how these risks manifest in different time frames, manufacturers, and NRC regions. The authors aimed to address this gap by exploring the correlation between the risks cited in NPP construction and the NRC Region in which it was constructed. This paper is the next step toward integration of the risks associated with the NPP construction process and construction performance of NPP projects.

OBJECTIVES

Past analysis of historical cost and schedule data of NPP construction (Maronati, 2018; Benjamin K. Sovacool, Alex Gilbert, et al., 2014), show a clear cost escalation over time. The goal of this work is to analyze the historical information on completed NPP to understand which risks were experienced by each plant during construction. In turn, this understanding improves the ability to evaluate the construction risks of future plants. This paper contributes to the power plant construction body of knowledge by: (1) categorizing construction risks cited in literature from 50 US nuclear power plant construction projects using an existing peer-reviewed risk register and (2) identifying trends in risks that lead to significant cost and schedule overruns over time.

METHODOLOGY

This paper uses the (Benjamin K. Sovacool, Alex Gilbert, et al., 2014) dataset as a point of departure for analyzing nuclear power plant projects and the frequency of construction risk occurrence in these projects. The United States nuclear dataset provided in Sovacool et al. (2014) is not an exhaustive list of all of the plants in United States, as it does not include the nuclear power plants built since 2007. The authors included the new units being constructed at two existing plants, Voegel and VC Summer, in this paper. It must be noted that while the risks associated with these new units, which began construction after 2007 (and were therefore not included in the Sovacool et al. (2014) dataset), are categorized in this paper, the schedule and cost information was not available, as the new units were not online (i.e., construction was not complete) at the time of this study.

The authors leveraged the Sovacool et al. (2014) dataset and extracted the 50 nuclear reactor units constructed in the United States. These reactor units are shown geographically in Figure 1. The Sovacool et. al (2014) dataset provided cost and schedule information per unit constructed; the authors used this to calculate cost and schedule performance for each unit.

Kim, Lee et al. (2017) proposes a standardized risk management methodology for comparing distinctive risk characteristics among fossil, gas, and nuclear power plants. The methodology includes standard risk classifications and structured risk evaluation techniques in terms of likelihood, impact, and weightings for different types of power plants. This standard risk classification is used in this study to identify and categorize the risks communicated in public newspaper articles. The risk factors considered in the classification and a brief explanation of each risk factor is described in Appendix 1.

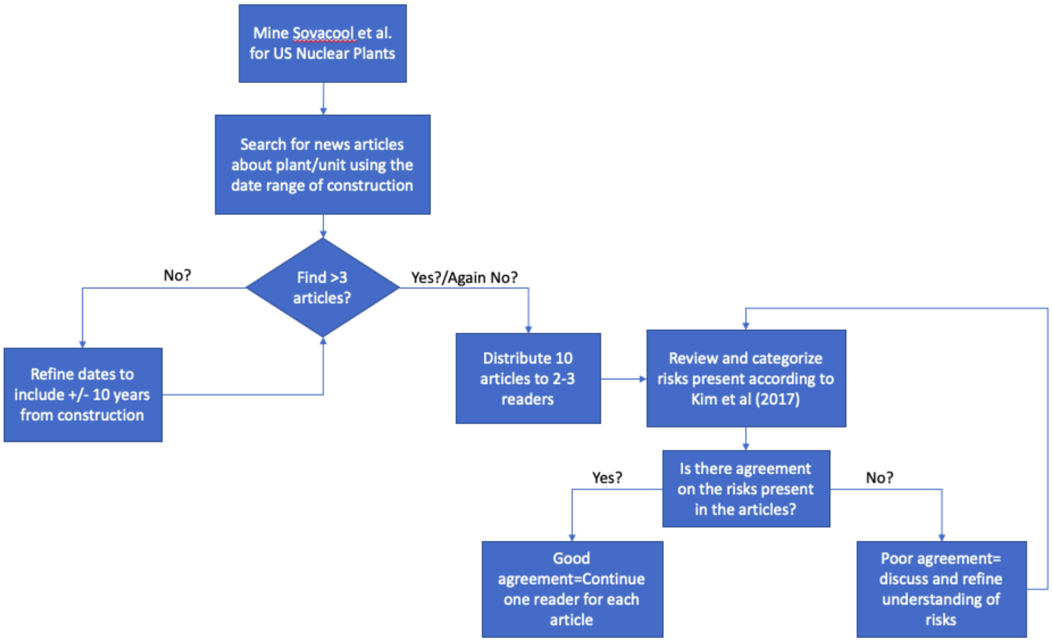

Figure 14: Hierarchy of Data Mining

Figure 14 illustrates the high level approach to mining the (Benjamin K. Sovacool, Alex Gilbert, et al., 2014) dataset to identify risks experienced during construction of the 50 units analyzed in this paper. As shown in Figure 2, initially, the authors filtered the Sovacool dataset for US NPP units. From here, completed NPPs constructed in the US after 2007 were included into the dataset. The authors then, calculate cost and schedule performance for each unit. In order to understand the risks of NPP construction that were communicated to the public via newspaper articles, the authors search ASU One Search and google for articles about the construction process, using construction date range as a filter for the search for each unit. If the search for a UNIT was unsuccessful, authors repeated the search for the PLANT that includes the unit. For each plant, the authors ensure at least three articles were present to review. If YES, at least three articles were present to review, the authors read the articles. If NO, at least 3 articles were not present, the authors expanded the search to include dates that occurred 10 years before and 10 years after construction. The authors had multiple readers read articles and categorize risk according to Kim et al. If readers AGREE (according to IRR), then the risks were categorized as such. If readers DO NOT AGREE (according to IRR), then the readers would read more articles together until agreement is reached. Once agreement was reached, ONE reader read articles for remaining plants and categorize risks

Of the fifty United States Nuclear Power Plants in the dataset, only 46 had publicly available documents to review. It was often the case, however, that plants were not explicitly identified by their unit (i.e. they were identified as “Diablo Canyon Nuclear” rather than “Diablo Canyon Nuclear Unit 2”). Plants were first categorized by what technology they possessed. On the one hand, most plants included in this study comprise multiple units of the same technology that were installed during the same time period (i.e., on the same plant construction schedule), so the plant, rather than the unit, would be discussed in local news articles. On the other hand, news articles do discuss units specifically when plants are comprised of multiple units with *different* technologies. Plants that added units after their original construction and operation often fall into this latter case. In general, note, using these criteria and dataset, the authors discovered at most 15 articles for any given plant or unit. The exceptions to this are Shoreham and Three Mile Island (TMI); the authors found more than 30 articles about each of these plants. For these plants, the authors reviewed articles until no new information was found in three successive articles. For example, for TMI, the searches returned over a hundred articles. The authors read the first 10 and in article 11 did not find new information. The authors then read 12 and 13 and still did not find new risks. Therefore, articles 14-50 were not reviewed. The authors used a similar approach for Shoreham.

However, most documents the authors reviewed did not explicitly identify the separate units. Thus, the authors classify the number of risks occurring in each **plant** rather than per **unit**. In the case that a plant includes multiple units with different technologies, the authors counted risks according to unit rather than according to plant. In all other cases, risk occurrence is assumed to be at the plant-level. The risk classification can be found in Appendix I.

The authors then read the articles obtained from the search and identified specific risks that were identified in those plants during construction using (Kim et al., 2017) risk register. The authors aim, using this categorization was to provide insight into what risks in the plants construction that lead to schedule and cost overruns, thus influencing public perception of nuclear power plants in the United States. the authors searched public documents on the plants’ construction based on the name of the plant or the unit. Specifically, the authors searched for articles published during a plants construction schedule, and reviewed these articles to identify risks occurring during the power plant project. Any retroactive analysis or perception pieces were excluded and only risks that were reported during construction were categorized in this paper. The authors did not review legal documents as these documents do not discuss risks, they present arguments for why a given outcome occurred. Such outcomes often have multiple possible causes, indeed legal documents often present multiple possible causes making the risk categorization inconclusive. Kim et. al (2017) provides a peer reviewed risk classification for power plant projects. The authors use that risk classification to categorize risks occurred in the plants studied.

Inter Rater Reliability (IRR)

To analyze the various newspaper articles, three coders performed a content analysis of the articles (Neuendorf, 2002). Responses for ten articles were coded by the analysts independently and later discussed to achieve consensus. A measure of their first-time inter-rater reliability (Cohen's Kappa) was calculated between each pair of raters. All responses were coded by the analysts independently and later discussed to achieve consensus. Researchers calculated Cohen’s Kappa between each pair of raters for each possible code and then calculate the average of those kappa values to find an IRR.

For the first 10 articles, the three coding analysts achieved first-time inter-rater reliabilities of $\kappa = 0.78$, 0.74, and 0.75 , respectively. Kappas above 0.75 indicate strong agreement, and kappas between 0.40 and 0.75 indicate fair to good agreement (Norusis, 2005). Because strong and good agreement was had between the coders on the first ten articles, the remaining articles were coded independently without for further need for discussion.

RESULTS

Analysis is broken up into three sections; time based risks, manufacturer based risks, and region based risks. Time based risks are influenced by the time period during which the plant was constructed. Manufacturer based risks are influenced by the company that manufactures the nuclear reactor. The Region based risks are influenced by where in the country the reactor was constructed.

Time-based Risks

Figure 15 shows the percent cost overruns of NPP over time. Each point on the graph represents a NPP and their percent cost overrun. As shown in Figure 15, throughout the construction of nuclear power plants, the predictability of the cost of these projects decreased, as there was growing cost overruns plaguing the industry. This data is obtained through Sovacool et al. 2014. The cost values were normalized to US$2012 using historical currency conversions available at Oanda.com and adjustments for inflation from the Statistical Abstracts of the United States.

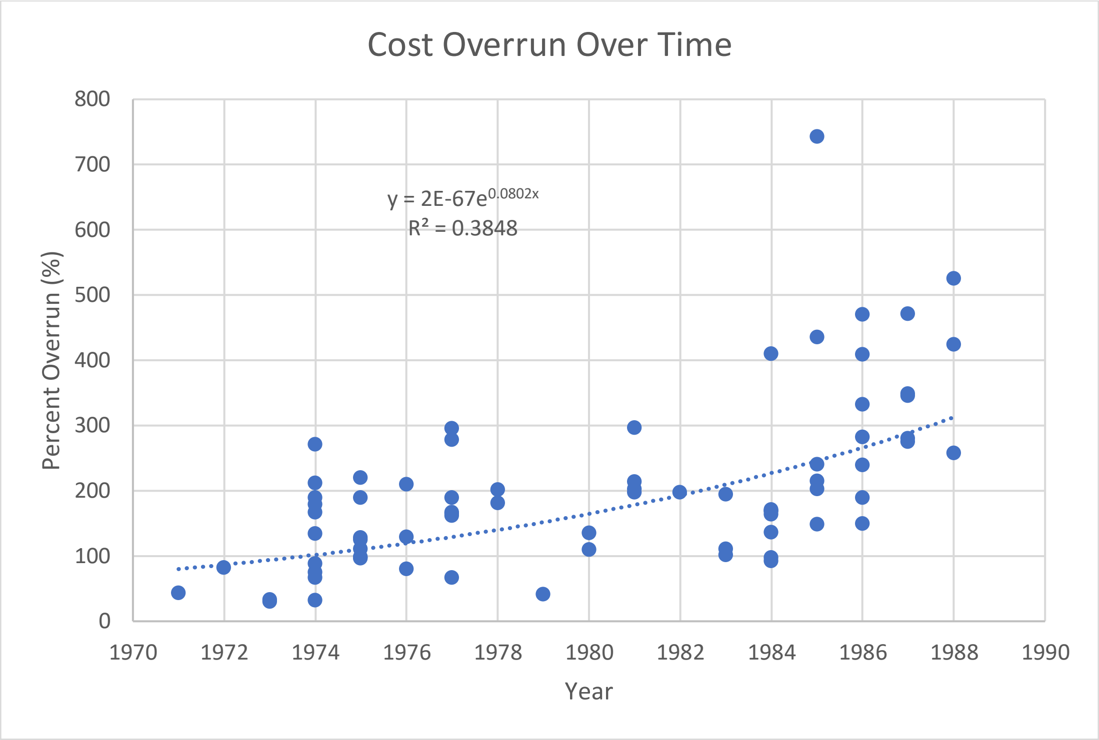

Figure 15: The Cost of Nuclear Power Plants over Time

The authors explored the risks that were inherent through each time period to identify trends in these seemingly apparent issues in predictability. Figure 16 displays the prevalence in different risks throughout time. The risk prevalence was normalized through dividing the number of times that a particular risk occurred within the time period by the total number of plants constructed in that time period. A single risk was only accounted for once per plant (i.e. if a certain risk was reported 3 times in different news articles, it was only accounted as a single occurrence in this analysis).

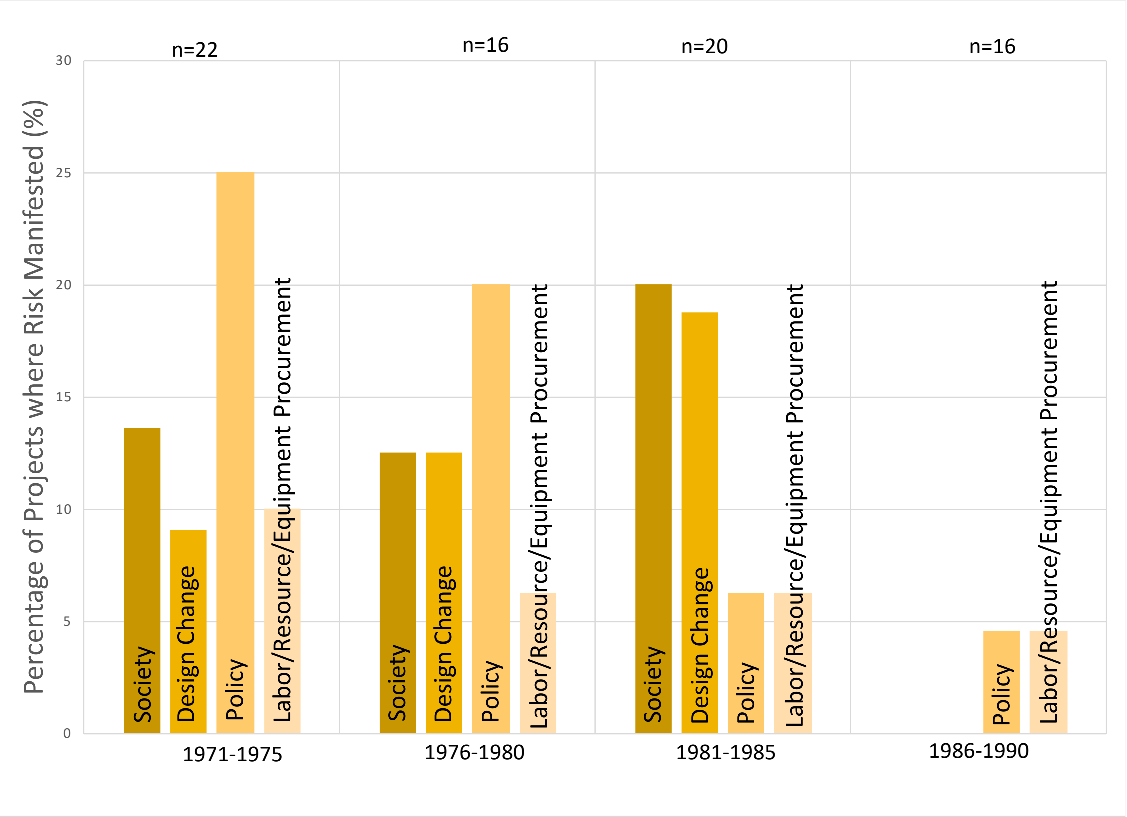

Figure 16: Top Risks vs. Year Constructed

Of the risks cited in (Kim et al., 2017) risk register, Figure 16 shows Policy, Design Changes, and Society risks as being most prominent in all time frames constructed. This indicates that nuclear power plants, regardless of when they are constructed, have struggles with policy changes, design changes, and social perceptions. Because Nuclear Power Plants have such a high upfront cost, when considering finance options, utilities are limited in their ability to successfully obtain funding. Policy risk occurs in all years that NPP were constructed. This suggests that regulatory ratcheting is further confirmed to be a significant risk in NPP construction and a significant risk that is communicated to the public via newspapers. These results point to the critical role that societal perceptions of nuclear power risk play in nuclear construction project success Through policy changes, design changes, and protests incited by societal perceptions, NPP construction schedules were delayed regardless of the year the plant was constructed. Due to the high upfront capital costs of large scale projects, such as NPP projects, a schedule delay directly affects the profitability of such projects. The longer the NPP takes to come online, the more incurred costs the power utility and it's investors experience. When this is communicated to the public via newspaper outlets, it creates a confirmation bias that NPP is unable to provide reliable, affordable, and safe power, as it is advertised to bring. This vicious circle creates a positive feedback loop that has contributed to destroying the public's perception of the benefits of NPP even further.

Plants constructed between the years of 1981 and 1985 had the broadest range of risk occurrence demonstrated amongst the four regions. Interestingly, the Millstone plant accounts for most of these risk occurrences; Millstone was constructed right after TMI and therefore had a public perception battle that impacted the construction of this plant at multiple times. Another interesting risk that all plants constructed regardless of year is labor/resource/equipment procurement risk. Because of the large scale nature of these projects, the specialized labor needs, and the infrequency of their construction, it is to be expected that certain pieces of equipment and certain skilled laborers would be of great need. Without planning in place for these risks, it is inevitable that the project will face setbacks.

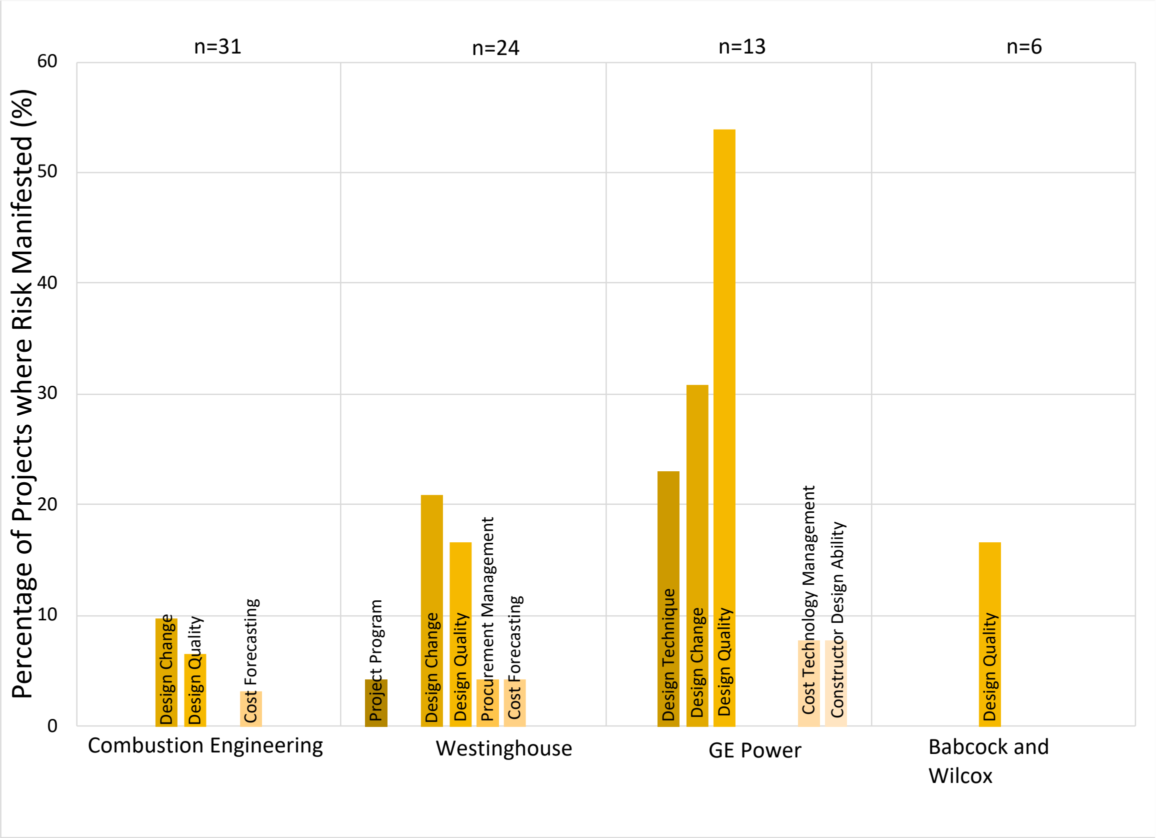

Figure 17: Top Risks vs. Reactor Manufacturer

Design changes are a common occurrence amongst most NPP in the dataset during the construction period. Design changes occur in three of the four reactor types, Combustion Engineering, Westinghouse, and General Electric, but occurs in higher percentages in the General Electric (GE) power reactors. In fact, the most project risks observed overall were found in GE power reactors. It must be noted that this is a study that analyzes the risks that were communicated through newspaper articles to the public. While other manufacturers may have experienced the same risks as GE Power Reactors, the authors further emphasize that the role of public perception greatly influences the success of such projects. Therefore, if design changes are being communicated more often in certain manufacturers, this will create a positive feedback loop that incites the public to think these plants are not well designed, and as such, are less safe and more risky to pursue.

Design quality risks, however, were cited in newspaper articles for all four reactor manufacturers. All identified design quality risks were followed by a design change; however, not all design changes were preceded by a design quality risk.

It is interesting to note the only manufacturer that did not experience a quality assurance risk was Babcock and Wilcox. While it may be due to the small number of Babcock and Willcox plants present in the literature, several plants, spanning the other three technologies, experienced schedule delays due to quality assurance issues.

As shown in Figure 17, Labor, Resource, and Equipment is prevalent only in Regions 1 and 2. Labor scarcity is a significant issue within the con and this could be due to a lack of qualified skilled workers. The North American construction industry began to experience a shortage of skilled labor in the 1980s, which is parallel to when these nuclear power plants were being constructed, which has continued as a repetitive cyclic trend over the last three decades (Karimi, Taylor, Dadi, Goodrum, & Srinivasan, 2018). Additionally, during the time frame at which many of these plants were being constructed, there was a number of resources backlogged due to the amount of construction prevalent during the 17 year time period that these plants were being constructed. While site manager ability risk was not categorized as a region-based risk, is was cited in public literature multiple times as impacting the job site and could explain the presence of Labor/Resource/and Equipment risk.

Region-based Risks

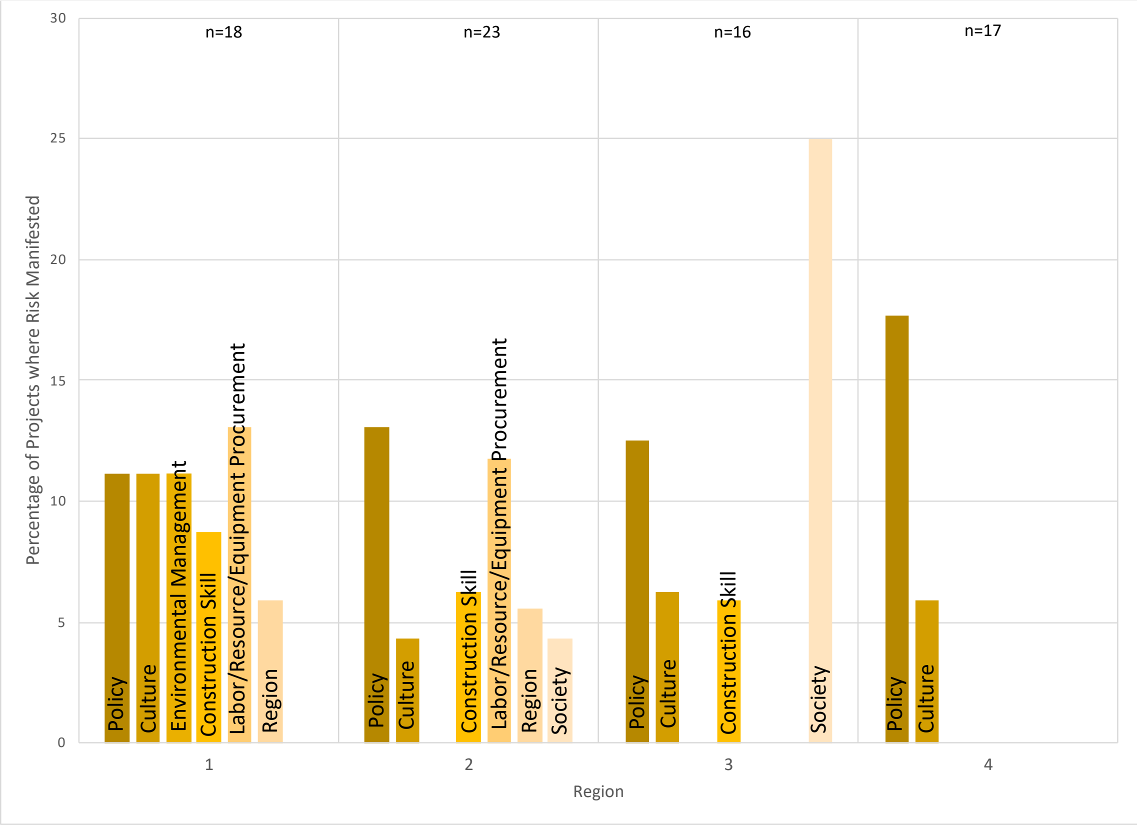

Figure 18: Top Risks vs. NRC Region

Region I encompasses plants constructed in Connecticut, Maryland, Massachusetts, New Hampshire, New Jersey, New York, and Pennsylvania. Region II encompasses plants constructed in Alabama, Florida, Georgia, North Carolina, South Carolina, Tennessee, and Virginia. Region III encompasses plants constructed in Illinois, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. Region IV encompasses plants constructed in Arizona, Arkansas, California, Kansas, Louisiana, Mississippi, Missouri, Nebraska, Texas, and Washington.

As seen in Figure 18, risks are, for the most part, present in all regions without an obvious correlation between region and risk presence or prevalence; however, some interesting trends to note are that region 3 has a larger occurrence of society risk than any of the other regions. Region 3, which holds 16 of the dataset's plants, has two of the top three worst performing plants in the dataset, Fermi 2 and Clinton Nuclear (524.7% cost overrun and 471.5% cost overrun respectively).

DISCUSSION

All plant manufacturers were reported to have experienced the risks in some shape or form. Across National, Industrial, and Project Risks, Design Change, Design Quality, and Policy risks occurred at the greatest rate across all plant manufacturers. This coincides with significant research leaning toward public perception being far different from the industry professional's views of risk of NPP. It is important to note that the impacts and consequences of NPP construction influences the public perception of NPP as a whole. It is important to have a significant planning protocol in place to address the risks commonly cited in newspaper articles. While Front End Loading (FEL) is significant for the success of a NPP construction project, this paper focuses on the risks observed during the construction process, and would be beneficial to consider during FEL as to improve the understanding of the feasibility of the NPP project.

Previous research has estimated that the risks associated with nuclear power operations vary widely between nuclear industry professionals and academics (NRC, 1975), nuclear power proponents (Cohen, 1990), opponents to nuclear power, and society in general (Rothman & Lichter, 1987). It has been shown that general society estimates nuclear power risks to be significantly higher than estimates from nuclear scientists and engineers (Slovic et al. 1979; Cohen 1990; Duffy 1997). The current body of knowledge makes no value judgment regarding the “correctness” of risk perceptions among various stakeholders, nor identify how certain risks are being communicated to the general public by industry professionals or how NPP construction risk is influencing public perception of overall NPP risk. However, this research illuminates part of this gap, through identifying how risks are being communicated to the general public, via newspapers and further understanding the risk prevalence per region and reactor manufacturer. While the TMI accident and the partial meltdown of Fukishima’s reactors (After the partial meltdown of reactors 1, 2, and 3 at the Fukushima NPP in northern Japan (2011), and the Three Mile Island accident (1979) influenced regulatory ratcheting and changes in policy toward the construction of NPP, it must be cited that regulatory ratcheting and policy led to further cost overruns and schedule delays, that created a positive feedback loop that lead to further negative perceptions of what once was the key technology for combatting carbon emissions and providing base load power for the growing society- cost effectively.

Recent Failures in United States Nuclear Power Plant Construction Projects

Following a 30-year period in which few new reactors were built, it is expected that two more new units will come online soon after 2020, these resulting from 16 license applications made since mid-2007 to build 24 new nuclear reactors.

The risks discussed in this paper can provide insight into the failures being seen in the recent US Nuclear Construction projects such as South Carolina Electric and Gas (SCE&G)’s and Santee Cooper’s joint venture, the V.C. Summer project, located in Jenkinsville, South Carolina. This project ultimately cost South Carolina residents 9 billion dollars, with not a single watt of energy ever produced. Some of the construction risks identified in this paper were observed on this project and could have been better planned for, had the research presented in this paper been considered. SCE&G reported "module redesign, production issues, manpower issues, and Quality Assurance and Quality Control issues" leading to an 11 month setback. The company alerted more delays 2 years later, citing manufacturing issues. When the project was finally terminated, documents were released that both SCE&G and Santee Cooper were aware of shortcomings, lack of oversight, and mismanagement which led to the ultimate termination of the project. It is interesting to note that this paper illuminated that design quality risks were cited in newspaper articles for all four reactor manufacturers and if there was a design quality issue cited, a design change subsequently would have happened as well. This held true in the most recent VC Summer project.

LIMITATIONS

The paper was limited to publicly available newspaper articles through the Arizona State University "One Search" database, Google Scholar, and NexusLexus. Oftentimes, only one or two articles were available for review, and thus limited the breadth. The authors did not review legal documents as these documents do not discuss risks, they present arguments for why a given outcome occurred. Such outcomes often have multiple possible causes, indeed legal documents often present multiple possible causes making the risk categorization inconclusive. The authors are limited to the data available in their data sources; while the authors conducted a robust literature search, they did not, for example, interview project personnel for each project, which may have uncovered additional risks.

CONCLUSION

In conclusion, previous research has honed in on the risks associated with NPP construction, as well as on the performance of NPP construction projects; however, very little has been done to integrate the two until now. This paper is a first step toward integration of the risks associated with the NPP construction process and performance of NPP construction, as well as the roll that communication with these public outlets (newspapers) plays in the public at large's perception of NPP construction, by looking at the prevalence of these risks in NPP projects as published in public newspapers. This paper aimed at filling the gap in literature by identifying common themes and trends in risks manifested in past NPP projects that lead to cost and schedule overruns. This methodology was validated through an interrater reliability test, where the categorization of risks manifested in the articles are categorized uniformly.

This analysis revealed that there was no correlation to NRC region vs. risk. Risks are, for the most part, present in all regions without an obvious correlation between region and risk presence or prevalence. The analysis also demonstrates that among the 4 reactor manufacturers present in the dataset, design risk was the most prevalent risk and that Westinghouse reactors had the greatest occurrence of risk all together.

Future Work and Development

In order to further increase the transparency of the risk identification dataset, an extra column for each risk will identify which article these risks were originally described in. This data analysis would be further expanded to include different world regions to examine if the same trend of poor project management, poor public perception, late design changes, and construction mistakes were a common theme.

CHAPTER 5- CONCLUSIONS

In this dissertation, the author aimed to contribute to the construction engineering and management body of knowledge by making explicit the impact of regulatory environment on capital projects. To do so, the author compared the capital project performance of power and pipeline projects in both regulated and nonregulated environments. The author extended that work to assess how regulatory environment impacted metrics associated with front end planning. Lastly, the author critically assessed one highly regulated industry, nuclear power, to document risks inherent in that sector.

Chapter 2 explored the impact of regulatory environment on the cost and schedule performance of power and pipeline projects. The Averch Johnson Effect has long postulated that RoR regulation incentivizes companies to over capitalize on their projects, leading to higher rates that ratepayers must absorb. Ironically, RoR regulation, originally developed to protect consumers from price gouging to fund new projects, seems to have resulted in the opposite. This dissertation discovered that in pipeline and power projects subject to RoR regulation, estimated and actual costs are higher than similar projects in nonregulated environments. Moreover, in regulated environments, rates are set **prior to** project execution to fund the project, and there is no mechanism to pass cost savings on to consumers. By contrast, in nonregulated environments, where rates are set to cover project expenditures following project completion, cost savings *can* be passed on to consumers. The author found that across power and pipeline projects, nonregulated environments resulted in lower cost estimates and lower final costs. Cost growth was not found to plague either industry, suggesting that cost estimates are a good indicator of what the final cost of a project will be.

After completing the work for Chapter 2, the author wanted to understand the root cause(s) for the performance gap between power and pipeline projects in nonregulated environments compared to power and pipeline projects in regulated environments. As such, the author explored how the planning processes may differ for power and pipeline projects in nonregulated environments compared to regulated environments. Using the FEL Score, the relative time spent in planning, and the stakeholders involved in FEP as metrics to assess the planning process, the author hypothesized that power and pipeline projects in regulated environments would perform worse than similar projects in nonregulated environments for each of those metrics. That is, projects in the regulated environment would: 1) have higher FEL scores than projects in nonregulated environments, 2) would spend less time on FEP than projects in nonregulated environments, and 3) not involve the recommended stakeholders in FEP. However, the author found that generally, power and pipeline projects, regardless of regulatory environment, performed about the same in terms of the planning metrics studied. Power and pipeline projects in both regulatory environments were poorly defined at the end of FEP, as indicated by high FEL scores. Conversely, in terms of both time spent in FEP and stakeholders involved, power and pipeline projects in both regulatory environments performed well – the time spent in FEP was over 30% of total project duration on average, and the stakeholders that CII recommends be involved in FEP were involved. Thus, the author concluded that something other than differences in planning would be the root cause of the performance gap between power and pipeline projects in different regulatory environments.

Lastly, Chapter 4 explored one highly-regulated power sector, nuclear power, to see how regulation may change the **risk profile** of a project, as a different risk profile could explain the performance gap between projects in nonregulated and regulated environments. That is, even with strong risk management practices, i.e., the FEP documented in Chapter 3, do power projects in regulated environments contend with additional risks that negatively impact their performance? The author leveraged gray literature and a peer-reviewed risk register (Kim et al. 2017) to document the risk profiles for various nuclear power plants in the US, and categorized these risks according to construction completion date, Nuclear Regulatory Commission (NRC) region, and reactor manufacturer, This analysis revealed that time of construction impacted the risk profile, while NRC region did not. Risks are, for the most part, present in all regions without an obvious correlation between region and risk presence or prevalence. The analysis also demonstrates that among the 4 reactor manufacturers present in the dataset, design risk was the most prevalent risk and that Westinghouse reactors had the greatest occurrence of risk.

Broader Impact

Power utility companies are consistently trying to provide additional capacity and flexibility to deliver power reliably to their customers. This often requires undertaking large and expensive power and pipeline projects which lead to these companies seeking increased rates. Rate of return regulation in theory is in place to protect the customer from a monopoly's (such as a power utility) power, but instead has led to overestimated project costs and higher approved rates for these projects, some of which never go online (i.e., V.C. Summer). Customers are directly impacted when a project is estimated and executed to be more expensive than what is prudent. When customers absorb the costs of a poorly power or pipeline project gone awry, the vulnerable populations and working class of America bear the brunt of the impact. To address this tension between reliably delivering a fluctuating amount of energy and maintaining affordability, the author sought to document the impacts of regulation on power and pipeline projects, such that both power producers and power consumers can advocate for regulatory environments that best support their objectives.

Future Research

The research presented in this dissertation will be the point of departure for my future research as an assistant professor. The author intend to entitle my first project as an Assistant Professor “Power Utilities: Where do our decisions count?” This project will make explicit the planning processes used by power utilities as they plan construction projects. In so doing, the author will be able to understand which decisions are critical and when they occur in the project’s lifecycle. In turn, this will inform a timeline that illustrates when critical decisions must be made to reliably deliver the capital project on time and on budget. Further, as this new timeline develops, the author will understand how to best utilize the stakeholders involved in planning.

More broadly, the author would like my future research to consider how regulations may be updated to reduce the burden they place on power consumers, particularly those from under-represented groups.

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APPENDIX A

NUCLEAR POWER PLANT CONSTRUCTION RISK CLASSIFICATIONS

Risk	Level 1 Risk	Level 3 Risk	Risk Description	Time based	Region based	Manufacturer Based
2	National Risk (RTN)	Policy	Consistency of policy, High level of bureaucracy, Intervene and control of government	x	x	
4		Finance	Financing condition	x	x	
5		Society	Social unrest (war/rebellion/terrorism/hostilities)	x	x	
7		Culture	Communication (language), Public opinion and attitude, Cultural differences, Religion differences	x	x	
8		Region	Geographical distance, International relations with host country	x	x	
10		Governmental System	Immigration control, Arbitration and judicial system, Regulate import and export, Financial system, Construction administrative procedures		x	
11		Law	Complicated law procedures, Insurance, Immaturity/unreliability of legal system, Construction	x	x	

			approval, Change of regulation/low			
15	Industrial Risk (RTI)	Bidding	Bidding volume index, Competitive/negotiated bidding		x	
16		Contract Environments	Strategic contract, Uncertain change of contract conditions		x	
18	Project Risk (RTP)	Environmental Assessment	Environmental evaluation issues, Interventions by environmental agencies		x	
19		Project Program	Project scope, Business objective, Project scope change, Consultant, Advance information of host country			x
22		Design Technique	Complexity of design, Low constructability, Technical incompetency of engineer, Unclear specifications, Design criteria and standard			x
23		Design Change	Design change	x		x
24		Design Approval	Delay of design approval	x	x	

25		Design Quality	Design quality and completeness, Design errors			x
27		Sscheduling Management	Poor project time mgmt., Delay/interruption, Third party delays, Fast track schedule, Influence of precedence construction, Countermeasure of schedule revival	x	x	
29		Procurement Management	Confirmation of material limit, Unavailability of local material, Determine type of procurement			x
34		Cost Forecasting	Uncertainty of cost estimation			x
41		Environment Management	Strict environment regulations	x	x	
53		Technology Management	Technology protection, Profit of technical investment			x
57		Owners Requirement	Requirements reflection, Specific requirements, Unreasonable design change by owner, Performance requirement change, High rework/order change	x	x	

63		Constructor Design Ability	Lack of design ability and experience, Shop drawings			x
64		Construction Skill	Reflection of company’s technique ability, Reflection of local subcontractors’ technical ability, Complexity of construction method and applicability		x	
66		Local Company Management	Unfriendly local subcontractor and friction, Coordination with utility companies, Local subcontractor ability, Information of local subcontractor		x	
68		Labor/Resource/Equipment Procurement	Labor resource, Material resource, Decline of operation rate, Problem of equipment supply	x	x	