Development of the Project Definition Rating Index (PDRI)

for Small Infrastructure Projects

by

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ABSTRACT

Project teams expend substantial effort to develop scope definition during the front end planning phase of large, complex projects, but oftentimes neglect to sufficiently plan for small projects. An industry survey administered by the author showed that small projects make up approximately half of all projects in the infrastructure construction sector (by count), the planning of these projects varies greatly, and that a consistent definition of "small infrastructure project" did not exist. This dissertation summarizes the motivations and efforts of Construction Industry Institute (CII) Research Team 314a to develop a non-proprietary front end planning tool specifically for small infrastructure projects, namely the Project Definition Rating Index (PDRI) for Small Infrastructure Projects. The author was a member of CII Research Team 314a, who was tasked with developing the tool in September 2015. The author, together with the research team, scrutinized and adapted an existing infrastructure-focused FEP tool, the PDRI for Infrastructure Projects, and other resources to develop a set of 40 specific elements relevant to the planning of small infrastructure projects. The author along with the research team supported the facilitation of seven separate industry workshops where 71 industry professionals evaluated the element descriptions and provided element prioritization data that was statistically analyzed and used to develop a corresponding weighted score sheet. The tool was tested on 76 completed and in-progress projects, the analysis of which showed that small infrastructure projects with greater scope definition (based on the tool's scoring scheme) outperformed projects with lesser scope definition regarding cost performance, schedule performance, change performance, financial performance, and customer satisfaction. Moreover, the author found that users of the tool

on in-progress projects agreed that the tool added value to their projects in a timeframe and manner consistent with their needs, and that they would continue using the tool in the future. The author also conducted qualitative and quantitative similarities and differences between PDRI – Infrastructure and PDRI – Small Infrastructure Projects in support of improved planning efforts for both types of projects. Finally, the author piloted a case study that introduced the PDRI into an introductory construction management course to enhance students' learning experience.

DEDICATION

This dissertation is lovingly dedicated to my wife, Engy Maher and my children Youssef and Layla. Their dedication and constant love have sustained me throughout my life. Also, the continuous support and encouragement received by Mother, Dr. Elham, and my father, Dr. Alaa, along with both my sister, Farida and brother, Khaled, were the main force throughout my endeavor.

I strived to make you proud…

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CHAPTER ONE

INTRODUCTION

Planning efforts conducted during the early stages of a construction project, known as pre-project planning or front end planning, have significantly more effect on project success than efforts undertaken after detailed design and construction has begun (Gibson et al., 1993). The Construction Industry Institute (CII), a research consortium based out of the University of Texas at Austin, has made project planning and scope definition a research focus area since the early 1990's. CII has funded the development of several front end planning decision support tools, namely the Project Definition Rating Index (PDRI) tools. Past CII research teams created PDRI tools to provide project teams with a structured approach for developing a good scope definition package, and measuring the level of project scope definition (Gibson et al., 1993). Three such PDRI tools were developed prior to 2013: PDRI-Industrial (CII, 1995), PDRI-Building (Cho and Gibson, 2001), and PDRI-Infrastructure (Bingham and Gibson, 2010). Researchers leveraged project performance data from more than 1,000 projects spanning more than 250 organizations and representing over US $88 Billion in expenditure to develop these tools. Use of the tools supported effective front end planning that in turn supported predictable project cost, schedule, and change performance outcomes (CII, 2010a).

CII desired to develop a front end planning tool for a long-overlooked and ubiquitous project type: small projects. They began this effort in 2013 when they convened CII RT 314 that developed a PDRI for small industrial (Collins et al., 2015). This effort continued in 2015, when CII extended the work of RT 314 to RT 314a that developed a PDRI for small infrastructure projects, described herein. The research outlined in this dissertation describes the development of the PDRI for Small Infrastructure Projects (PDRI – Small Infrastructure). The objective of this dissertation is to outline the tool development methodology, tool testing, and conclusions in relation to the work done by the research team developing the PDRI – Small Infrastructure. The methodologies, testing processes, and conclusions presented are corroborated in this dissertation by statistical analysis and supporting literature.

1.1. Research Team 314a

CII tasked Research Team 314a (RT 314a) with developing an effective, simple, and easy to use scope definition tool (i.e., PDRI tool) specifically for small infrastructure projects in September 2015. The team consisted of fourteen industry professionals from CII member organizations who had experience with infrastructure construction activities, and four academic members. A list of research team members and their organizations is included at the end of this report.

The research team met every 8-10 weeks in various locations across the United States between September 2015 and June 2016, with meetings lasting approximately one and a half days each occurrence. The meetings were hosted by several of the research team members, and facilitated by the academic team members. The purpose of the initial team meeting was to clarify the objectives of the research effort, and outline a research strategy. The research was executed during subsequent meetings, as well as between meetings, through collaboration and individual efforts.

The author was one of the academic members of the research team, and served in many capacities actively participating in and supporting the research effort. The author joined RT 314a after the team drafted the element descriptions and conducted the survey to differentiate between small and large infrastructure projects. The author's primary role was developing the PDRI – Small Infrastructure tool through data collection, analysis, and interpretation, described in detail throughout this dissertation. In addition, the author conducted a rigorous comparison between PDRI – Small Infrastructure Projects and PDRI – Infrastructure Projects and proposed a pilot study to use the PDRI tool in an undergraduate construction management classroom. The author also served as the primary author (or one of the primary authors) for several publications required by CII that summarized the research effort and implementation of the tool. The author further promoted the research through several administrative tasks, including team-member coordination, preparation for team meetings and industry workshops.

1.1.1. Research Objectives

The research team set forth the following objectives:

1. Produce a user-friendly tool for measuring project scope definition of small infrastructure projects with the following characteristics and functions:
    - Based upon the PDRI – Infrastructure, yet tailored specifically to small infrastructure projects
    - Less time-consuming than the PDRI – Infrastructure
    - Is easy to use, yet detailed enough to be effective
    - Helps reduce total project costs
    - Improves schedule performance
    - Serves as a communication and alignment tool
    - Supports decision-making

- Identifies risks
- Reliably predicts project performance
- Is flexible among infrastructure project types

2. Test the tool by comparing the level of project scope definition during the front end planning phase vs. corresponding project performance factors for a sample of completed small infrastructure projects

1.2. Project Domain

Defining "small infrastructure project" was imperative for the research team so that guidance could be provided to PDRI users as to which infrastructure-focused PDRI would be most appropriate for their projects: PDRI – Infrastructure or PDRI – Small Infrastructure. The research team determined, through literature review, discussions with the other research team members, and industry survey responses (n=47), that typical small infrastructure projects meet the following criteria:

1. An infrastructure project such as (or similar to):
    - Security bollards
    - Runway resurfacing and Highway resurfacing
    - Intersection rebuilds
    - Adding railroad track to existing roadbeds
    - Access ramps
    - Pipeline recoating and Pipeline asbestos abatement and re-insulation
    - Fire protection water line relocation
    - Meters and regulator stations

- Transmission line
- Fiber optic line and conduit
- Natural gas pipeline service feeder
- Electrical duct bank insulation

2. A project closely aligning with the following characteristics:
   - Total installed cost less than US $20 Million
   - Engineering effort less than 5000 man-hours
   - Part-time management availability of core team members
   - Construction duration between 6 and 12 months
   - Less than 10 core team members (i.e., project managers, project engineers, owner representatives)
   - Moderate project visibility external to organization
   - Minimal to Moderate existing utility provider interface and coordination
   - The number of jurisdictions involved between 1 and 3

The research team determined that these features are typical of small infrastructure projects, but not a strict definition. This is due to the vast variability in how small projects are defined across the infrastructure sector. It should also be noted that the PDRI is a general-use tool, and was developed to assess a wide range of small infrastructure projects. The project domain includes small infrastructure projects that convey people and freight, fluids, and energy; these projects may be new construction projects, renovation and revamp projects, small projects that are part of a program of many similar projects, and shutdown/turnaround projects. Detail is provided throughout this dissertation that support these assertions, along with the small infrastructure project criteria listed above.

1.3. Organization of the Dissertation

This dissertation is organized into ten chapters, and includes several appendices that provide important additional information including the PDRI – Small Infrastructure tool itself, detailed statistical analysis, and examples of documents utilized for gaining industry involvement during development of the tool. Chapter 1 provides an introduction to the research team, research objectives, project domain, and the research report structure itself. Chapter 2 provides the problem statement of the research, and the hypotheses developed by the research team. Chapter 3 provides the research methodology and framework utilized by the research team in developing the PDRI – Small Infrastructure. Chapter 4 provides a summary of the CII front end planning research thread, previous PDRI research projects and tools, research projects and tools that support the PDRI, and previous research regarding small projects. Chapter 5 details the results of an industry survey regarding the prevalence of small infrastructure projects, the planning practices used for small infrastructure projects, and potential differentiators between small and large infrastructure projects. Chapter 6 details the development process of the PDRI element descriptions and weighted score sheet. Chapter 7 details the testing process completed by the research team to test the efficacy of the tool. Chapter 8 provides a detailed qualitative and quantitative comparison of the PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects. Chapter 9 details the results of introducing PDRI into an undergraduate construction materials, method and equipment classroom. Chapter 10 provides the conclusions of the research, and offers recommendations for future work.

CHAPTER TWO

PROBLEM STATEMENT AND RESEARCH HYPOTHESES

The findings from the literature review (presented in Chapter 4) showed a need for research into the front end planning of small infrastructure projects. There has been little research work to date in this area, especially in studying the effects of front end planning on small project success. The lack of research led the research team to develop a set of hypotheses. This chapter establishes a problem statement, which can be addressed by proving or disproving the research hypotheses.

2.1. Problem Statement

Small projects account for about half of the total number of projects in the infrastructure sector, though the size and scope of small projects vary greatly. Individually, small projects may appear insignificant to an organization's yearly capital expenditure, but cumulatively, small projects can make up a majority of the projects completed. Oftentimes appropriate planning consideration is not given to small projects, consistently leading to cost and schedule overruns. CII developed a suite of PDRI tools (and several complementary tools) that have consistently been shown to improve project cost and schedule performance of large, complex projects through enhanced front end planning. Small project research studies have found that procedures or processes designed for large projects typically are not effective for use on small projects, as they are too cumbersome to be effective. The infrastructure construction sector could greatly benefit from a user-friendly, non-proprietary tool to assist in defining project scope to maximize project success on small projects.

2.2. Research Hypotheses

The PDRI – Small Infrastructure is modeled directly after the previously developed PDRI tools: industrial, building, infrastructure, and small industrial. These PDRI tools all share the first two same basic research hypotheses. The author asserts that (as has been done by each of the preceding PDRI research teams) that the PDRI score indicates the current level of scope definition, and corresponds to project performance. Cost, schedule, and change performance differences between projects with high and low PDRI scores were tested to confirm this assertion. This testing methodology is described in detail in Chapter 7. The specific hypotheses are as follows:

Hypothesis 1*: A finite and specific list of critical issues related to scope definition of small infrastructure projects can be developed.*

A draft tool was developed by the research team and shared with industry experts to test this hypothesis. Their feedback was collected and incorporated into the list of scope definition elements. These elements comprise a finite and specific list of critical issues related to scope definition of small infrastructure projects.

Hypothesis 2*: Projects with low PDRI scores outperform projects with high PDRI scores.*

A draft tool was provided to industry professionals experienced in completing small infrastructure projects to test this hypothesis. Specific project data regarding (1) scope definition (based on the PDRI tool) along with cost and schedule budgets at the beginning of detailed design, and (2) project cost, schedule, and change performance at the completion of the projects, was collected and analyzed. PDRI scores were calculated for each project and compared to the project performance data through statistical analysis.

Hypothesis 3: *The PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects require similar level of project definition, between Complete Definition – Level 1 and definition with Minor Deficiencies - Level 2, during FEP to support predictable project outcomes.*

Hypothesis three addresses the differences and similarities between PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects in terms of their structure, content and weight of the elements, most critical planning elements, and target PDRI score. Chapter 8 identifies qualitative and quantitative similarities and differences between PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects in support of improved planning efforts for both types of projects.

Hypothesis 4: *Undergraduate students in a materials, methods, and equipment course will improve their self-reported skill level in using industry-based tools for construction project management after being introduced to the PDRI in a single class session.*

Hypothesis 5: *Following an in-class activity where undergraduates in a materials, methods, and equipment course articulate how a given PDRI element impacts* *the materials, methods, and equipment, the students will improve their performance in selecting construction methods for a hypothetical project.*

Hypotheses four and five (described in Chapter 9) address the need to increase the deployment of the PDRI beyond the construction profession. Students, particularly undergraduate students, may not be aware of tools such as the PDRI, and therefore, they are often ill-equipped to employ such tools early in their careers. Indeed, literature supports the notion that students require more knowledge of tools used in the profession when they graduate from construction management programs. The author addresses this gap by providing documentation of how a PDRI can be introduced into an introductory construction management course, and discusses how he tested Hypotheses four and five in this case study.

2.3. Summary

This chapter outlined the problem statement and research hypotheses. The research problem is derived from a need to develop a user-friendly, non-proprietary tool to assist in defining project scope and maximizing project success on small infrastructure projects. The research hypotheses assert that the PDRI – Small Infrastructure can effectively improve project performance in the same manner as previously developed PDRI tools. The following chapters detail the research methodology and hypothesis testing procedures used in this study.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter outlines the research methodology employed for producing and testing the PDRI – Small Infrastructure. This methodology was developed and proven in previous PDRI research (Cho and Gibson, 2001, Collins et al., 2015, CII, 1995, Bingham and Gibson, 2010) and chosen due to its reliability in achieving the research objectives and testing the hypotheses. Specific research methods and concepts including content analysis, conceptualization, population sampling, data collection procedures, survey research, questionnaire development, and statistical data analysis procedures are described in this chapter.

Table 3-1 provides a summary of the research methods and data analysis techniques utilized to develop the PDRI – Small Infrastructure. Figure 3-1 provides a logic flow diagram of the research methodology, providing a visual representation of the steps undertaken by the author and the research team to test the research hypotheses described in Chapter 2. The following sections briefly describe the flowchart and the role of the author and research team in each step.

Table 3-1. Research and Data Analysis Methods

PDRI Development Phase	Research Method Employed	Data Analysis Method Employed
Develop PDRI Elements and Score Sheet	Conceptualization Content Analysis Focus Groups	
PDRI Element Prioritization	Focus Groups Purposive Sampling Snowball Sampling Field Research Statistical Analysis	Boxplots Skewness
Test PDRI Research Hypotheses	Survey Research Case Studies Statistical Analysis	Correlation Independent Sample t-test Mann-Whitney U Test Boxplots Regression Analysis
Small Project Definition	Survey Research Purposive Sampling Snowball Sampling Focus Groups Field Research Statistical Analysis	Mann-Whitney U Test

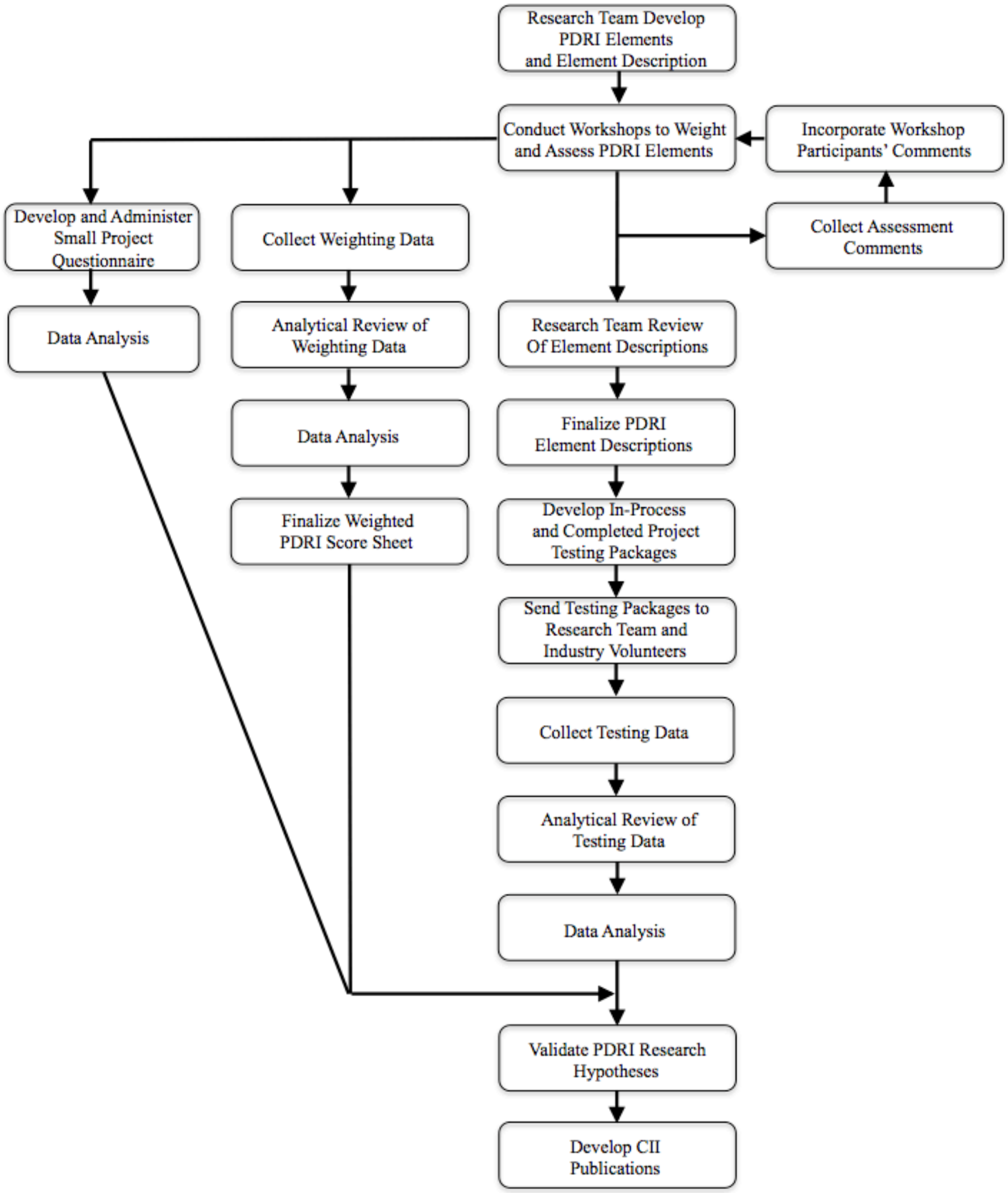


Figure 3-1. Research Methodology Flow Chart

3.1. Data Collection

Data collection was necessary to develop the PDRI elements, PDRI score sheet, prioritization of the PDRI elements, testing of the research hypotheses, and defining small projects in the infrastructure construction sector. The following sections provide an overview of the data collection processes and associated research methods utilized.

3.1.1. Developing the PDRI Elements and Score Sheet

Chapter 4 details the literature review completed by the research team regarding front end planning, previously completed PDRI research projects, and small projects. The literature review is considered a form of content analysis, defined as a study of recorded human communications (Babbie, 2013). Reviewing the documents provided a basis or starting point for the research team to conceptualize the PDRI – Small Infrastructure. Conceptualization is defined as the process whereby imprecise notions or concepts are made more specific and precise (Babbie, 2013). The initial intent was to create a tool with the same “look and feel” of the other PDRIs. The research team developed the PDRI – Small Infrastructure element descriptions and associated score sheet through rigorous discussion and debate after the tool was initially conceptualized, using the PDRI – Infrastructure as a baseline. Individuals that participated in the PDRI weighting focus groups (described in the next section) also reviewed the PDRI element descriptions and provided feedback regarding suggestions for improvement. Detailed explanation of the PDRI development process is provided in Chapter 6.

3.1.2. PDRI Element Prioritization

A basic tenet of front end planning is that not all items to be assessed (i.e., elements) are equally critical to project success. Therefore, each element must be prioritized relative to the total set of elements. Collecting input from all stakeholders involved with small infrastructure projects regarding element prioritization would be impossible. The research team utilized focus groups to gain prioritization data from a subset of the total infrastructure construction stakeholder population, as had been done by the previous PDRI research teams. Focus groups are simply a group of subjects interviewed together, prompting a discussion (Babbie, 2013). Seven such focus groups were convened to weight the PDRI elements. Purposive and snowball sampling techniques were used to empanel the focus groups. Purposive sampling, also referred to as judgmental sampling, is a method in which individuals are selected to be part of the sample based on the researcher's judgment as to which individuals would be the most useful or representative of the entire population (Babbie, 2013). Industry experts with substantial experience in the management and/or design of small infrastructure projects were targeted to participate in the weighting workshops (i.e., focus groups). Snowball sampling, or requesting that targeted individuals suggest other individuals with similar expertise (Babbie, 2013) was used to increase workshop attendance. A detailed description of the workshop procedures is provided in Chapter 6.

3.1.3. Test PDRI Research Hypotheses

Chapter 2 details three hypotheses the research team sought to test. Hypothesis 1 - that a finite list of critical issues relating to scope definition of small infrastructure projects could be developed - was tested through the focus group sessions described in the previous section, and detailed in Chapter 6. Hypothesis 2 - that projects with low PDRI scores outperform projects with high PDRI scores - was tested through surveying industry professionals through the use of a detailed questionnaire. A questionnaire is a document containing questions designed to solicit information appropriate for analysis (Babbie, 2013). RT 314a developed a multi-part questionnaire that solicited information regarding PDRI Score, cost, schedule, change, and operating performance of recently completed small infrastructure projects through a series of open-ended and closed-ended questions. The author used statistical techniques (described later in this chapter) to test the value of the tool through comparison of PDRI scores and project performance.

RT314a also developed a questionnaire for in-progress projects; projects currently in the front end planning phase during the PDRI – Small Infrastructure testing timeframe. Data collected on the in-progress projects were used as case studies, or an in-depth examination of a single instance (Babbie, 2013). RT314a collected data on in-progress projects to discern the various types of small infrastructure projects that the PDRI could be used to assess, typical gap-lists generated, and to determine if value was added to the in-progress projects during the assessments. Chapter 7 details the PDRI testing progress of both completed and in-progress projects.

3.1.4. Small Project Definition

Defining “small project” as it relates to infrastructure projects was necessary to distinguish the PDRI – Small Infrastructure from the PDRI – Infrastructure. The research team developed a questionnaire (analyzed, and interpreted by the author) to gain industry perspective regarding this definition. Open and closed-ended questions and a matrix of 16 separate potential small and large project differentiators were generated based on the small project research previously completed by CII and others, described in Chapter 5. The questionnaire also included a set of closed-ended questions regarding the prevalence of small projects, and typical front end planning practices employed for small projects. Purposive and snowball sampling was used to elicit responses, mainly through targeting CII data liaisons and individuals associated with the research team members. Results from the completed questionnaires were mixed. The questionnaire respondents agreed with few of the metrics identified by the research team as being differentiators between small and large projects. Many of the respondents noted that measures of “project complexity” might be a better way to differentiate between small and large projects.

3.2. Data Analysis

The author used several statistical methods to analyze the data collected from the questionnaires and weighting workshops. Statistical analysis allowed the author to interpret the data, and provided a basis for the author to offer recommendations to the research team and to CII membership at large. The next few sections describe the statistical methods employed by the author, including boxplots, regression analysis, t-tests, and Mann-Whitney U-tests. These methods were chosen due to their successful usage on the previously developed PDRIs. Note that the Mann Whitney U-tests, were only used during statistical data analysis for the PDRI – Small Industrial tool. Microsoft Excel™ and SPSS™ were the two primary software platforms used to aggregate and analyze data.

It should be noted that RT314a made every effort to keep confidential any personal or proprietary information collected from individuals that provided data to support the research effort. Responses were coded during the analysis as to make anonymous all individual, organization, project, or client names or indicators.

3.2.1. The Boxplot

Boxplots are a commonly used method for graphically summarizing the distribution of a data set (Morrison, 2009). The author utilized boxplots to analyze element-weighting data collected during the industry workshops (described in Chapter 6,7), and completed project data collected to test the tool (described in Chapter 7).

Figure 3-2 details the typical values provided by a boxplot. The "box" highlights the interquartile range of the dataset; values between the 25^{th} and 75^{th} percentile (Morrison, 2009). Fifty percent of the dataset falls within this range. The median value is also shown as a horizontal line. If the median does not fall at the center point of the interquartile range, this denotes skewness to the dataset (Morrison, 2009), described further in the next section. The boxplot will also indicate values that fall outside of the interquartile range, namely outlier and extreme values. Outlier and extreme values can skew the statistics of a dataset, specifically causing mean and/or median values to shift away from the central point (Morrison, 2009). The largest and smallest observed-values not considered outliers or extremes are indicated on the boxplot by a "whisker", or lines extending above and below the box.

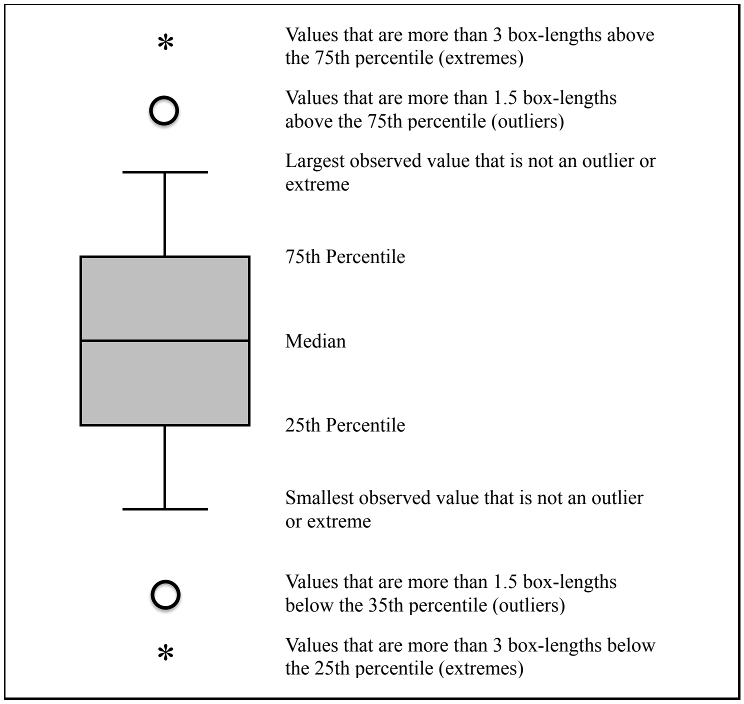


Figure 3-2. Typical Boxplot

A data point is considered an outlier value (X) if:

X < (Q1 – 1.5 IQR) or X > (Q3 + 1.5 IQR)

Where:

Q1 = 25th percentile value and Q3 = 75th percentile value

IQR = Interquartile range = Q1 – Q3

A data point is considered an extreme value (Y) if:

Y < (Q1 – 3 IQR) or Y > (Q3 + 3 IQR)

Where:

Q1 = 25th percentile value and Q3 = 75th percentile value

IQR = Interquartile range = Q1 – Q3

3.2.2. Skewness

Statistical analysis methods, such as independent-sample t-tests, assume that a dataset is normally distributed, or symmetric around some central value such as the mean or median of the dataset (Morrison 2009). If a dataset is highly skewed, mean and median calculations will also be skewed (Morrison, 2009). Outlier and extreme values described in the previous section can lead to skewness. Figure 3-3 highlights positively and negatively skewed distribution.

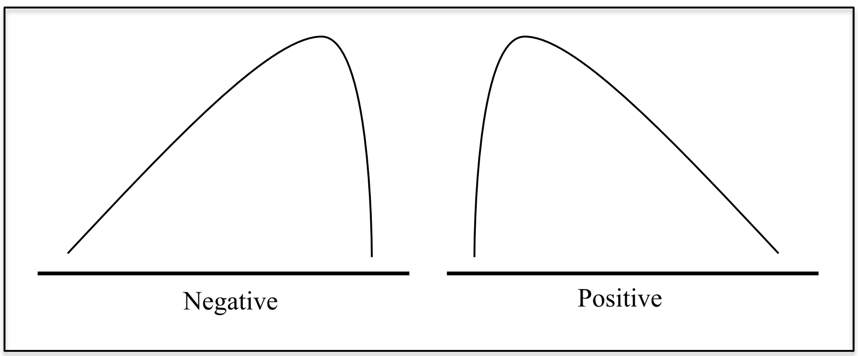


Figure 3-3. Negative and Positive Skewness

3.2.3. Independent Samples t-tests

In theory, two groups may have the same mean, but the data within those groups may be dispersed differently (Morrison, 2009). Groups with a tighter clustering of data points around the mean value will have a higher statistical significance than those groups where the data points are more dispersed (Morrison, 2009). Independent sample t-tests are used to determine if the means of two groups are statistically different from one another (Morrison, 2009). The author utilized independent sample t-tests to compare projects at various PDRI score levels vs. project cost, schedule and performance values (described in Chapter 7).

The t-statistic is calculated as:

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where:

n_1 and n_2 = sample sizes

$\bar{x}_1$ and $\bar{x}_2$ = sample means

s_1 and s_2 = sample standard deviations

The null hypothesis, or H_O, is that the mean values of the two groups being tested against each other are equal, or nearly equal (Morrison, 2009). The alternate hypothesis, or H_1, is that the mean values of the two groups being tested against each other are not equal, or nearly equal (Morrison, 2009). The t-value derived from the t-statistic equation is tested against a critical t-value, to test of the null hypothesis is to be accepted or rejected (Morrison, 2009). The critical t-value is dependent on the degrees of freedom of the samples (Morrison, 2009). Values derived from the t-tests also have an associated p-value, or probability, which is used to determine if the difference between mean values of the groups are statistically significant (Morrison, 2009). A confidence interval for the test is stated; the typical confidence interval being 95 percent, which corresponds to an alpha level (or rejection level) of 5 percent (Morrison, 2009). If the associated p-value from the t-test is greater than .05 (i.e., 5 percent), then there is a greater than 5 percent chance that the mean values of the two groups being compared are equal, or nearly equal, and the null hypothesis is accepted. If the associated p-value from the t-test is less than or equal to .05

(i.e., 5 percent), then there is a less than 5 percent chance that the mean values of the two groups being compared are equal, or nearly equal, and the null hypothesis is rejected.

An assumption of the t-test is that the two groups being compared have equal variance (Morrison, 2009). The Levene's test for Equality of Variance is used to determine if two groups being compared have equal variance, if the sample size is small (i.e., total sample size is less than 100 and if either group in the sample is less than 30). Levene's test is also an hypothesis test, where the null hypothesis, or H_O, is that the variances of the two groups being tested against each other are not equal, or nearly equal (Morrison, 2009). The alternate hypothesis, or H_1, is that the variances of the two groups being tested against each other are equal, or nearly equal (Morrison, 2009). Levene's test also uses a p-value to determine statistical significance. If the associated p-value from the test is greater than .05 (i.e., 5 percent), then there is a greater than 5 percent chance that the variances of the two groups being compared are equal, or nearly equal, and the null hypothesis is accepted. If the associated p-value from the t-test is less than or equal to .05 (i.e., 5 percent), then there is a les than 5 percent chance that the variances of the two groups being compared are not equal, or nearly equal, and the null hypothesis is rejected.

Statistical tools such as SPSS™ can be utilized to perform t-tests. Figure 3-4 provides a sample SPSS™ Levene's T-test output. As shown, the variances between the two groups have equal variance (i.e., the p-value is .874, which is greater than .05), and the two groups have a statistically significant difference (i.e., the p-value is .010, which is less than .05). However, if Levene's Mean test is statistically significant ($p < .05$), then variances are significantly different and the assumption of equal variances is not met. In that case, the Equal variances not assumed line would be used – for which SPSS adjusts the test statistic (t), degreeds of freedom (df), and significance (p) as appropriate. Both the top and bottom rows of the Levene's T-test output provide the same information; however, they use different tests to calculate the test statistic, which results in slightly different calculations.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Performance	Equal variances assumed	.025	.874	2.744	31	.010	6.09821	2.22233	1.56575	10.63068
	Equal variances not assumed			2.704	22.039	.013	6.09821	2.25491	1.42230	10.77413

Figure 3-4. Sample t-test Output from SPSS™

3.2.4. Mann-Whitney U Test

Mann-Whitney U Tests are used when comparing mean values of two groups where data within the groups are based on a ranked order-scale (Wilcox, 2009). An example of a ranked-order scale is a Likert scale. The Mann-Whitney U Test is similar to t-tests, but is used for comparing means where equal variance cannot be assumed, referred to as being nonparametric (Wilcox, 2009). The author utilized Mann-Whitney U Tests to compare financial performance and customer satisfaction scores of completed projects used to test the PDRI (described in Chapter 7).

The Mann-Whitney U statistic is calculated as:

$$U = N_1 N_2 + \frac{N_1(N_1 + 1)}{2} - R_1$$

Where:

N_1 and N_2 = Sample sizes

R_1 = Sum total of ranks for Sample 1

The sampling distribution of U has a mean, μ_U, calculated as:

$$\mu_U = \frac{N_1 N_2}{2}$$

The sampling distribution has a variance calculated as:

$$\sigma_U^2 = \frac{N_1 N_2 (N_1 + N_2 + 1)}{12}$$

The distribution of U is assumed to be a normal, or Z distribution. The Z value to compare against the critical Z value of 1.96 is calculated as:

$$U = \frac{U - \mu_U}{\sigma_U}$$

Statistical tools such as SPSS™ can be utilized to perform Mann-Whitney U tests. Figure 3-7 provides a sample SPSS™ output. The test statistics table is used to determine if the there is a statistical difference between the two groups through the calculation of a probability, or p-value. A confidence level for the statistical significance is stated; the typical confidence level being 95 percent, which corresponds to an alpha level (or rejection level) of 5 percent (Wilcox, 2009). If the p-value of the test is greater than .05 (i.e., 5 percent), then there is not a statistical difference between rank-order of the two groups (Wilcox, 2009). If the p-value of the test is less than .05 (i.e., 5 percent), then there is a statistical difference between rank-order of the two groups (Wilcox, 2009). As shown, the test shown in Figure 3-5 does not show a statistically significant difference between the two groups (i.e., the p-value is .191, or greater than .05).

Mann-Whitney Test

Ranks

		N	Mean Rank	Sum of Ranks
Test Groups	1.00	19	17.63	335.00
	2.00	12	13.42	161.00
	Total	31		

Test Statistics[a]

	Group 1
Mann-Whitney U	83.000
Wilcoxon W	161.000
Z	-1.308
Asymp. Sig. (2-tailed)	.191

Figure 3-5. Sample Mann-Whitney U Test Output from SPSS™

3.2.5. Correlation

Correlation, commonly denoted as r, measures the strength of the linear relationship between a set of two quantitative variables (Sorola and Moore, 2010). The author calculated correlation as part of the regression analysis performed to compare PDRI scores and project performance of completed projects (described in Chapter 7).

Aggregated data in the form of dependent (Y) and independent (X) variables are first graphed in the form of a scatterplot as shown in Figure 3-6. Independent variables, or response variables, are graphed based on their position along the Y-axis, and dependent variables, or explanatory variables, are graphed based on their position along the X-axis (Sorola and Moore, 2010). Statistical tools such as Microsoft Excel™ and SPSS™ can be utilized to create scatterplots.

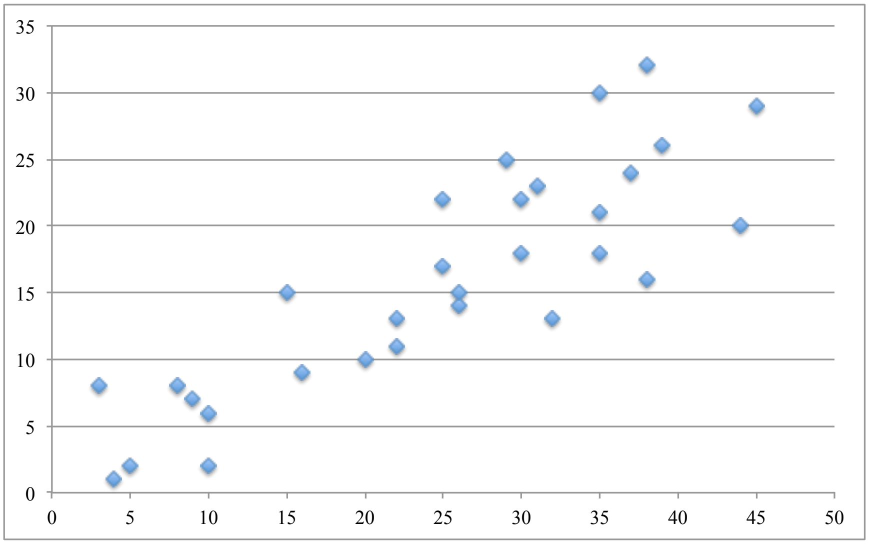


Figure 3-6. Sample Scatterplot from Microsoft Excel

The independent variable is assumed to predict behavior of the dependent variable (Sorola and Moore, 2010). The strength of the relationship is determined by how closely the points follow a clear form or direction. Calculating r provides this determination.

r is calculated as:

$$r = \frac{1}{n-1} \sum \left(\frac{x_i - \bar{x}}{s_x}\right)\left(\frac{y_i - \bar{y}}{s_y}\right)$$

Where:

n = total sample size

$\bar{x}$ = sample mean value of x

$\bar{y}$ = sample mean of y,

s_x = sample standard deviation of x

s_y = sample standard deviation of y

A positive r-value indicates a positive association between the variables, and a negative r value indicates a negative association. r-values will always be numbers between -1 and 1, where a value close to 0 indicates a weak correlation between the variables and a value closer to -1 or 1 indicates a strong correlation (Sorola and Moore, 2010). Outlier and extreme values in the data set can skew these values.

3.2.6. Regression Analysis

A simple linear regression model attempts to model the relationship between one independent (Y) and one dependent (X) variable, with the basic assumption that the relationship between the variables behaves in a linear fashion (Waissi, 2015). The author performed regression analysis to compare PDRI scores and project performance of completed projects (described in Chapter 7).

Linear regression, also known as least squares estimation, uses formulas for finding the y-intercept and slope of a line such that the sum of squares distances of the data points from the line itself are kept to a minimum (Waissi, 2015).

The equation used to generate a regression line for linear bivariate regression is:

$$Y = b_1X + b_0$$

Where:

b_1 = slope or regression coefficient, calculated as $b_1 = r\,\frac{s_y}{s_x}$

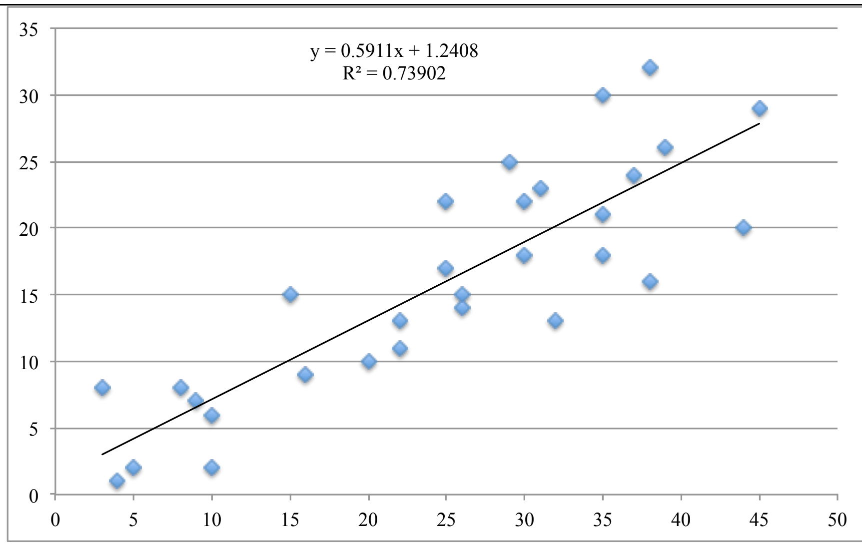
b_0 = Y Intercept, calculated as $b_0 = \bar{y} - b_1\bar{x}$

The strength of the regression model (i.e., fit) is calculated as r^2, where:

$$r^2 = \frac{Sum\ of\ Squares\ (Total)}{Sum\ of\ Squares\ (Regression)}$$

The r^2 value, denotes how well the regression equation explains the dependency between the X and Y variables. The r^2 value will always be positive, and between 0 and 1. The r^2 value denotes what percentage of the variation in the dependent variable (Y) is explained by the dependent variable (X) (Waissi, 2015).

Statistical tools such as Microsoft Excel™ and SPSS™ can be utilized to perform regression modeling. Figure 3-7 shows the trendline, regression equation and r^2 value of the scatterplot provided in Figure 3-7. As shown, the dependent variable (X) explains approximately 74 percent of the variation in the independent variable (Y).



Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.860[a]	.739	.730	4.42072

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1549.503	1	1549.503	79.288	.000[b]
	Residual	547.197	28	19.543		
	Total	2096.700	29			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.241	1.833		.677	.504
	X	.591	.066	.860	8.904	.000

Figure 3-7. Sample Regression Model

Figure 3-5 also includes the SPSS™ regression modeling output, which includes the model summary, the analysis of variance (i.e., ANOVA) table, and the coefficients table. The ANOVA table is used to determine of the regression model is statistically significant through the calculation of a probability, or p-value (denoted as "Sig." in SPSS™). A confidence level for the statistical significance is stated; the typical confidence level being 95 percent, which corresponds to an alpha level (or rejection level) of 5 percent . If the p-value of the regression model is greater than .05 (i.e., 5 percent), then a significant portion of the total variability in the data is primarily due to randomness, or error in the model (Waissi, 2015). If the p-value of the regression model is less than .05 (i.e., 5 percent), then a significant portion of the total variability in the data can be attributed to the relationship between the variables (Waissi, 2015). As shown, the model given in Figure 3-7 is statistically significant (i.e., the p-value is .000, or less than .05).

The coefficients table is used to determine if the model parameters (i.e., the y-intercept and slope) are significantly different than zero. A confidence level for the statistical significance is stated; the typical confidence level being 95 percent, which corresponds to an alpha level (or rejection level) of 5 percent (Waissi, 2015). If the p-value of the model parameter is greater than .05 (i.e., 5 percent), then the parameter is not statistically different than zero (Waissi, 2015). If the p-value of the model parameter is less than .05 (i.e., 5 percent), then the parameter is statistically different than zero (Waissi, 2015). As shown, the constant (i.e., y-intercept) in the model given in Figure 4-6 is not statistically significant (i.e., the p-value is .504, or greater than .05), but the slope (i.e., X) is statistically significant (i.e., the p-value is .000, or less than .05).

3.3. Limitations of the Data Analyses

Several limitations exist with this data analysis, as with any data analysis. Optimally, the projects utilized to weight the PDRI, and the projects used to test the PDRI would come from a random sample. In this case, the data collected came from individuals who volunteered to participate in the research study. The RT314a stressed to focus group members that both “good” and “bad” projects were desired. However, the final selection of projects used during the workshop sessions came from the focus group members themselves, and they seem to have disproportionally “bad” projects. As such, generalizing the results of this study to the entire population is not possible.

The second limitation to this study stems from data collected during the testing process. Collecting “after the fact” data required respondents to refer back to the point in time just prior to the start of detailed design on the chosen projects. This point may have been weeks, months, or even years prior to the volunteer completing the testing questionnaire. This method may have led to inaccurate information due to memory lapse of the project participants during that time period. Having knowledge of the actual project outcomes may also have biased the respondent’s answers to be more or less favorable. However, given the short schedule of the research investigation, tracking projects from planning through completion was not possible.

3.4. Summary

This chapter outlined the research methodology employed for producing and testing the PDRI – Small Infrastructure. Seven separate focus groups were empaneled to gain industry perspective on the PDRI tool itself, as well as prioritization of the elements. Questionnaires were developed to test the tool on both completed and in-progress projects. A questionnaire was also developed to gain industry perspective on small infrastructure projects. Various statistical methods were used to analyze the data received.

CHAPTER FOUR

LITERATURE REVIEW

The RT314a performed a literature review to establish a theoretical baseline concerning previous research investigations into front end planning and small projects. The articles and studies detailed in this chapter served as the starting point for the research team to develop the PDRI – Small Infrastructure tool. This chapter introduces and discusses relevant organizations, terms, research, and existing tools central to the development of the tool.

4.1. Construction Industry Institute Research

This section details the literature review findings stemming from the Construction Industry Institute, including the project definition rating index (PDRI) tools, and front end planning tools associated with the PDRI.

4.1.1. The Construction Industry Institute (CII)

The Construction Industry Institute (CII) is a unique knowledge creation organization and consortium of owner, engineering-contractor, and supplier firms that join together to enhance the business effectiveness and sustainability of the capital facility life cycle through research. The purpose of CII is to measurably improve the delivery of capital facilities. This purpose is achieved through the funding of collaborative research where academics and industry professionals unite to identify and address significant opportunities for construction industry improvement. CII's mission is stated as (CII Website 2015):

CII creates global, competitive, and market advantages for its members through its research-based, member-driven creation of knowledge and CII Best Practices. The institute's ability to disseminate this knowledge and assess its implementation gives members a decisive industry edge. Employees of CII member organizations cooperatively engage with leading academics to generate CII knowledge; this unprecedented partnering of industry and academia creates the perfect forum for identifying the most significant opportunities for industry improvement. These industry participants and academics also benefit from the professional development and career advancement the collaborative effort provides.

Front end planning has been considered by CII to be a Best Practice for over 15 years, which has led to a considerable amount of research into this area. The development of the PDRI – Small Infrastructure was sponsored by CII as a research investigation in 2015. Several key terms and definitions produced by previous CII research teams are provided in the next few sections.

4.1.2. Early CII Research into Project Planning

Research into the relationship between pre-project planning impacts and facility construction outcomes had not been conducted prior to 1991 (CII, 1994a). CII established the Pre-Project Planning Task Force in 1991 to outline the functions involved in the pre-project planning of capital facilities. The task force defined pre-project planning as "the process of developing sufficient strategic information for owners to address risk and decide to commit resources to maximize the chance for a successful project" (Gibson et al., 1993). Pre-project planning is considered an important subset of the overall project planning endeavor; it begins after the business leadership of an organization deems a project concept desirable, and continues until the beginning of detailed design and construction of a project (Gibson et al. 1995). Decisions made during the early stages of the project life cycle have a much greater influence on a project's outcome than those made in later stages (CII, 1994a), illustrated in Figure 4-1.

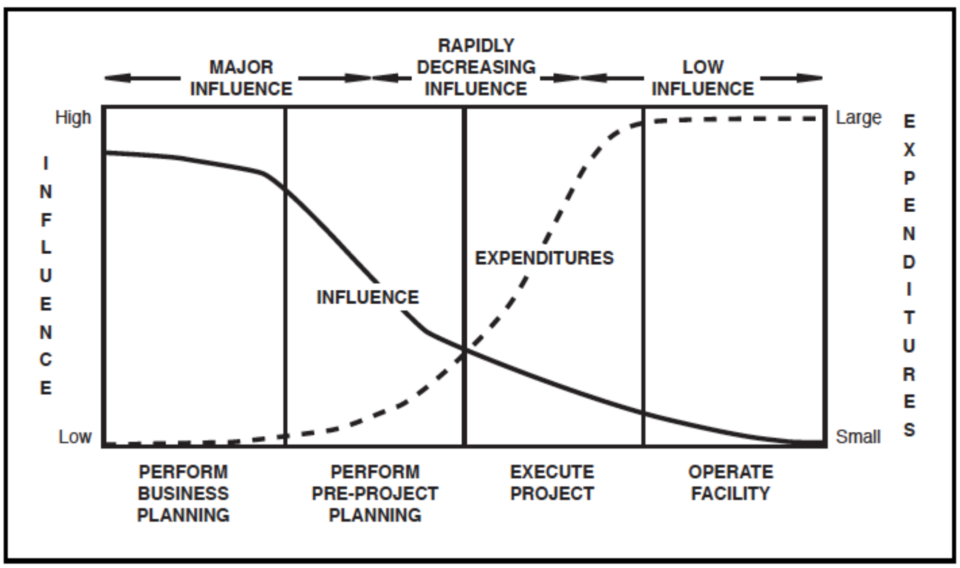


Figure 4-1. Influence and Expenditures Curve for the Project Life Cycle (CII 1994)

The Pre-Project Planning Task Force developed a generic model expressing the typical pre-project planning process (Gibson et al., 1993, CII, 1995), a quantitative study comparing pre-project planning effort vs. project success factors (Hamilton and Gibson, 1996, Gibson and Hamilton, 1994), and culminated with a pre-project planning handbook that detailed specific steps typical in planning capital projects (CII, 1995). The Task

Force found that well performed pre-project planning could reduce the total project design and construction costs by as much as 20 percent, reduce the total project design and construction schedule by as much as 39 percent, improve project predictability in terms of cost, schedule, and operating performance, and increase the chance of a project meeting stated environmental and social goals (CII, 1994a, Gibson and Hamilton, 1994, Hamilton and Gibson, 1996).

4.1.3. Project Scope Definition Tools

CII initiated the development of three pre-project planning tools for quantifying, rating, and assessing project planning efforts based on the conclusions found by the Pre-Project Planning Task Force, namely the Project Definition Rating Index (i.e., PDRI) tools, between the years of 1994 and 2013. Separate research teams developed tools to specifically address large and small industrial projects, building projects, and infrastructure projects. The purpose of the tools is three-fold: (1) to provide a structured planning process for use during the front end planning phase of a project, (2) to provide a quantitative measure (i.e., a score) of the level of scope definition of a project, and (3) to correlate 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.

4.1.3.1. PDRI-Industrial

CII formed the Front End Planning Research Team in 1994 to "produce effective, simple, easy-to-use pre-project planning tools that extend the work of the Pre-Project Planning Research Team so that owner and contractor companies can better achieve business, operational, and project objectives" (CII, 1995). The 16 individuals (from both industry and academia) that made up the research team were initially split into two separate sub-teams: one team tasked with developing a tool for measuring project scope development of industrial construction projects, and the other tasked with developing a guideline for measuring alignment within project teams. (The outcomes of the alignment research are provided in section 4.1.4.1).

The Front End Planning Research Team determined that, at a minimum, any tools developed for measuring project scope definition should provide (CII, 1995):

- A checklist that a project team can use for determining the necessary steps to follow in defining the project scope
- A listing of standardized scope definition terminology throughout the construction industry
- An industry standard for rating the completeness of the project scope definition to facilitate risk assessment and prediction of escalation, potential for disputes, etc.
- A means to monitor progress at various stages during the pre-project planning effort
- A tool that aids in communication between owners and design contractors by highlighting poorly defined areas in a scope definition package
- A means for project team participants to reconcile differences using a common basis for project evaluation
- A training tool for companies and individuals throughout the industry

- A benchmarking tool for companies to use in evaluating completion of scope definition versus the performance of past projects, both within their company and externally, in order to predict the probability of success on future projects.

The research team developed the Project Definition Rating Index-Industrial Projects (PDRI-Industrial) to address these challenges. The research team considered industrial projects to include the following types of facilities (CII, 1995):

- Oil/gas production facilities
- Chemical plants
- Paper mills
- Power plants
- Food processing plants
- Textile mills
- Pharmaceutical plants
- Steel/aluminum mills
- Manufacturing facilities
- Refineries

The PDRI – Industrial tool includes two main components: a structured list of descriptions detailing specific elements that should be addressed during the front end planning phase of industrial projects, and a weighted score sheet that corresponds to the element descriptions. The purpose of the weighted score sheet is to quantitatively gauge the scope definition of a project. The research team identified 70 elements critical to the planning of industrial construction projects. The research team divided the elements into three separate sections (Basis of Project Decision, Front End Definition, Execution

Approach), and further divided the elements into 15 categories. This arrangement places similar elements together for ease of discussion during pre-project planning assessments. Each element also has a detailed narrative that provides description of the element, and certain additional items to consider when assessing a project. Figure 4-2 provides an example of element A.1 Reliability Philosophy from the PDRI – Industrial. The structure of each element in the PDRI is typical of Figure 4-2.

A.1 Reliability Philosophy

A list of general design principles to be considered to achieve dependable operating performance from the unit/facility or upgrades instituted for this project. Evaluation criteria should include:

- Justification of spare equipment
- Control, alarm, security and safety systems redundancy, and access control
- Extent of providing surge and intermediate storage capacity to permit independent shutdown of portions of the plant
- Mechanical/structural integrity of components (metallurgy, seals, types of couplings, bearing selection)
- Identify critical equipment and measures to be taken to prevent loss due to sabotage or natural disaster
- Other

Additional items to consider for Renovation & Revamp projects

- Potential impacts to existing operations

Figure 4-2. Sample Element Description from PDRI – Industrial

The research team hypothesized that all elements within the PDRI were not equally important regarding their potential impact to overall project success. The team convened two workshops where 54 project managers and estimators experienced with a variety of industrial construction projects provided input concerning the relative importance (i.e., weight) of each element included in the PDRI. The team developed the PDRI score sheet based on the element prioritization data provided by the workshop participants, deriving a scoring scheme for the score sheet such that a lower score indicates a project with a greater level of scope definition, while a higher score indicates a lesser amount of scope definition. Each element in the PDRI was given five potential levels of definition, ranging from complete definition (i.e., Level 1) to little to no definition (i.e., Level 5). The workshop participants provided weights for each element at each score level.

The typical PDRI scoring scheme is such that a project with all elements assessed as Level 1 totals 70, and a project with all elements assessed as Level 5 totals 1000. Level 2, 3, and 4 scores range between the Level 1 and Level 5 scores. Any elements deemed not applicable during a project assessment would lower the potential total project score on a pro-rata basis, depending on the weighting of non-applicable elements. Figure 4-3 provides a section and category breakdown of the finalized PDRI – Industrial Projects score sheet, based on definition Level 5 weights of the elements in each section and category. Figure 4-3 also provides the top ten highest weighted elements in the PDRI – Industrial Projects, based on the definition Level 5 weights. These ten elements were deemed to be the most critical to project success of all of the 70 elements included in the tool, hence the most critical to address during front end planning of an industrial project.

Section		Weight
I.	Basis of Project Decision	499
II.	Basis of Design	423
III.	Execution Approach	78
		1000

Category		Weight
A.	Manufacturing Objectives Criteria	45
B.	Business Objectives	213
C.	Basic Data Research & Development	94
D.	Project Scope	120
E.	Value Engineering	27
F.	Site Information	104
G.	Process/Mechanical	196
H.	Equipment Scope	33
I.	Civil, Structural & Architectural	19
J.	Infrastructure	25
K.	Instrument & Electrical	46
L.	Procurement Strategy	16
M.	Deliverables	9
N.	Project Control	17
P.	Project Execution Plan	36
		1000

Element		Weight
B.1	Products	56
B.5	Capacities	55
C.1	Technology	54
C.2	Processes	40
G.1	Process Flow Sheets	36
F.1	Site Location	32
G.3	Piping & Inst. Diagrams (P&ID's)	31
D.3	Site Characteristics (Avail. Vs. Req)	29
B.2	Market Strategy	26
D.1	Project Objectives Statement	25
		384/1000

Figure 4-3. PDRI – Industrial Projects Section and Category Weights, and Top 10 Highest Weighted Elements

The team confirmed the element weightings through testing of the PDRI-Industrial on 40 completed projects, totaling over $3.3 billion in expenditure (CII, 1995). The research team determined through analyzing the 40 completed projects that projects with PDRI scores lower than 200 statistically outperformed projects with PDRI scores above 200 regarding cost, schedule, and change order performance. Figure 4-4 provides a summary of the PDRI-Industrial testing results at the 200-point PDRI score cutoff.

	PDRI Score		
Performance	**< 200**	**> 200**	**Δ**
Cost	5% below budget	14% above budget	19%
Schedule	1% behind schedule	12% behind schedule	11%
Change Orders	2% of total cost	8% of total cost	6%
	(n=20)	(n=20)	

Figure 4-4. PDRI–Industrial Projects Cost, Schedule, and Change Order Performance based on 200-Point Cutoff

4.1.3.2. PDRI-Building

The Front End Planning Research Team concluded that separate PDRI tools should be developed for industrial, building, and infrastructure Projects. The success of the PDRI-Industrial tool led CII to form Research Team 155 in 1998 for the purpose of developing a PDRI tool specifically for building projects. The PDRI-Building was developed for building projects, excluding residential houses, performed in both the public and private sector, and was most applicable to multi-story or single story commercial, institutional, or light industrial facilities such as (Cho and Gibson, 1999):

- Offices
- Banks
- Medical facilities
- Institutional buildings
- Dormitories
- Hotels/motels
- Warehouses
- Churches
- Recreational/athletic facilities
- Industrial control buildings
- Schools
- Research and laboratory facilities
- Nursing homes
- Stores/shopping centers
- Apartments
- Parking structures
- Light assembly/manufacturing
- Airport terminals
- Public assembly/performance halls

Research Team 155 utilized the same development and testing procedure established by the Front End Planning Research Team (CII, 1995) when developing the PDRI-Building. The team identified 64 elements critical to the planning of building construction projects. The elements were broken into three separate sections (Basis of Project Decision, Basis of Design, Execution Approach), and further broken down into 11 categories. Each element had a detailed narrative providing description of the element, and certain additional items to consider when assessing a project. The element descriptions were structured similar to the PDRI-Industrial element descriptions, shown in Figure 4-2.

The team convened seven workshops in various locations across the United States where 69 project managers, architects and engineers experienced with a variety of building construction projects provided input concerning the relative importance (i.e., weight) of each element included in the PDRI. The team used the element prioritization data provided by the workshop participants to develop the weighted PDRI score sheet. The team used the same scoring scheme as the PDRI-Industrial, where scores range from 70-1000, and a lower score indicates a greater level of scope definition.

Figure 4-5 provides a section and category breakdown of the finalized PDRI score sheet, based on definition Level 5 weights of the elements in each section and category. The sections and categories are listed from highest total weight to lowest total weight. Figure 4-5 also provides the top ten highest weighted elements in the PDRI-Building, based on the definition Level 5 weights. These ten elements were deemed to be the most critical to project success of all of the 64 elements included in the tool, hence the most critical to completely address during front end planning of a building project.

Section		Weight
I.	Basis of Project Decision	413
II.	Basis of Design	428
III.	Execution Approach	159
		1000

Category		Weight
A.	Business Strategy	214
B.	Owner Philosophies	68
C.	Project Requirements	131
D.	Site Information	108
E.	Building Programming	162
F.	Building/Project Design Parameters	122
G.	Equipment	36
H.	Procurement Strategy	25
I.	Deliverables	11
J.	Project Control	63
K.	Project Execution Plan	60
		1000

Element		Weight
A.1	Building Use	44
A.5	Facility Requirements	31
A.7	Site Selection Considerations	28
A.2	Business Justification	27
C.6	Project Cost Estimate	27
A.3	Business Plan	26
C.2	Project Design Criteria	24
C.3	Evaluation of Existing Facilities	24
A.6	Future Expans./Alt. Considerations	22
F.2	Architectural Design	22
		275/1000

Figure 4-5. PDRI-Building Section and Category Weights, and Top 10 Highest Weighted Elements

The team confirmed the element weightings through testing of the PDRI tool on 33 completed building projects, totaling nearly $900 million in expenditure. The team determined through analyzing the 33 completed projects that projects with PDRI scores lower than 200 statistically outperformed projects with PDRI scores above 200 regarding cost, schedule, and change order performance, the same as the PDRI-Industrial. Figure 4-6 provides a summary of the PDRI-Building testing results at the 200-point PDRI score cutoff.

	PDRI Score		
Performance	**< 200**	**> 200**	**Δ**
Cost	1% above budget	6% above budget	5%
Schedule	2% behind schedule	12% behind schedule	10%
Change Orders	7% of budget	10% of budget	3%
	(n=16)	(n=17)	

Figure 4-6. PDRI-Building Cost, Schedule, and Change Order Performance based on 200-Point Cutoff

4.1.3.3. PDRI-Infrastructure

CII formed Research Team 268 in 2008 to develop a PDRI tool specifically for Infrastructure projects. The research team defined an infrastructure project as (Bingham and Gibson, 2010):

An infrastructure project is defined as a project that provides transportation, transmission, distribution, collection or other capabilities supporting commerce or interaction of goods, service, or people. Infrastructure projects generally impact multiple jurisdictions, stakeholder groups and/or a wide area. They are characterized as projects with a primary purpose that is integral to the effective operation of a system. These collective capabilities provide a service and are made up of nodes and vectors into a grid system (e.g., pipelines (vectors) connected with a water treatment plant (node)).

Research Team 268 utilized the same development and testing procedure established by the Front End Planning Research Team (CII, 1995) and Research Team 155 (Cho and Gibson, 1999) when developing the PDRI – Infrastructure. The team identified 68 elements critical to the planning of infrastructure construction projects. The elements were broken into three separate sections (Basis of Project Decision, Basis of Design, Execution Approach), and further broken down into 13 categories. Each element had a detailed narrative providing a description of the element, and certain additional items to consider when assessing a project. The element descriptions were structured similar to the PDRI – Industrial and PDRI – Building element descriptions, shown in Figure 4-2.

The team convened six workshops in various locations across the United States and Great Britain where 64 industry professionals representing multiple owner and contractor organizations experienced with a variety of infrastructure construction projects provided input concerning the relative importance (i.e., weight) of each element included in the PDRI. The team used the element prioritization data provided by the workshop participants to develop the weighted PDRI score sheet. The team used the same scoring scheme as the PDRI – Industrial and PDRI – Building, where scores range from 70-1000, and a lower score indicates a greater level of scope definition.

Figure 4-7 provides a section and category breakdown of the finalized PDRI score sheet, based on definition Level 5 weights of the elements in each section and category. The sections and categories are listed from highest total weight to lowest total weight. Figure 4-7 also provides the top eight highest weighted elements in the PDRI-Infrastructure, based on the definition Level 5 weights. These eight elements were deemed to be the most critical to project success of all of the 68 elements included in the tool, hence the most critical to completely address during front end planning of an infrastructure project.

Section		Weight
I.	Basis of Project Decision	437
II.	Basis of Design	293
III.	Execution Approach	270
		1000

Category		Weight
A.	Project Strategy	112
B.	Owner/Operator Philosophies	67
C.	Project Funding and Timing	70
D.	Project Requirements	143
E.	Value Analysis	45
F.	Site Information	119
G.	Location and Geometry	47
H.	Associated Structures and Equipment	47
I.	Project Design Parameters	80
J.	Land Acquisition Strategy	60
K.	Procurement Strategy	47
L.	Project Control	80
M.	Project Execution Plan	83
		1000

Element		Weight
A.1	Need and Purpose Documentation	44
A.2	Investment Studies & Alternate Assess.	28
C.3	Contingencies	27
L.2	Design and Construction Cost Estimates	25
B.1	Design Philosophy	22
C.2	Preliminary Project Schedule	22
D.3	Evaluation of Compliance Requirements	22
D.4	Existing Environmental Conditions	22
		234/1000

Figure 4-7. PDRI-Infrastructure Section and Category Weights, and Top 8 Highest Weighted Elements

The team confirmed the element weightings through testing of the PDRI tool on 22 completed infrastructure projects, totaling over $6 billion in expenditure. The team determined through an analysis of the 22 completed projects that projects with PDRI scores lower than 200 statistically outperformed projects with PDRI scores above 200 regarding cost, schedule, and change order performance, the same as the PDRI-Industrial and PDRI-Building. Figure 4-8 provides a summary of the PDRI-Infrastructure testing results at the 200-point PDRI score cutoff.

	PDRI Score		
Performance	**< 200**	**> 200**	**Δ**
Cost	2% under budget	23% above budget	25%
Schedule	5% behind schedule	29% behind schedule	24%
Change Orders	3% of total cost	10% of total cost	7%
	(n=13)	(n=9)	

Figure 4-8. PDRI-Infrastructure Cost, Schedule, and Change Order Performance based on 200-Point Cutoff

4.1.3.4. PDRI – Small Industrial

CII formed Research Team 314 in 2013 to develop a PDRI tool specifically for Small Industrial projects. Research Team 314 utilized the same development and testing procedure established by the Front End Planning Research Team (CII, 1995), Research Team 155 (Cho and Gibson, 1999) and Research Team 113,when developing the PDRI – Small Industrial. The team identified 41 elements critical to the planning of small industrial construction projects. The elements were broken into three separate sections (Basis of Project Decision, Basis of Design, Execution Approach), and further broken down into 8 categories. Each element had a detailed narrative providing a description of the element, and certain additional items to consider when assessing a project. The element descriptions were structured similar to the PDRI-Industrial, PDRI-Infrastructure and PDRI-Building element descriptions, shown in Figure 4-2.

The team convened five workshops in various locations across the United States where 65 industry professionals representing multiple owner and contractor organizations experienced with a variety of infrastructure construction projects provided input concerning the relative importance (i.e., weight) of each element included in the PDRI. The team used the element prioritization data provided by the workshop participants to develop the weighted PDRI score sheet. The team used the same scoring scheme as the PDRI – Industrial, PDRI – Infrastructure and PDRI – Building, where scores range from 70-1000, and a lower score indicates a greater level of scope definition.

Figure 4-9 provides a section and category breakdown of the finalized PDRI score sheet, based on definition Level 5 weights of the elements in each section and category. The sections and categories are listed from highest total weight to lowest total weight. Figure 4-9 also provides the top eight highest weighted elements in the PDRI – Small Industrial, based on the definition Level 5 weights. These eight elements were deemed to be the most critical to project success of all of the 41 elements included in the tool, hence the most critical to completely address during front end planning of a small industrial project.

Section		Weight
I.	Basis of Project Decision	288
II.	Basis of Design	425
III.	Execution Approach	287
		1000

Category		Weight
A.	Project Alignment	153
B.	Project Performance Requirements	135
C.	Design Guidance	133
D.	Process/Product Design Basis	145
E.	Electrical and Instrumental Systems	71
F.	General Facility Requirements	76
G.	Execution Requirements	129
H.	Engineering/Construction Plan and Approach	158
		1000

Element		Weight
A.1	Project Objectives Statement	47
A.2	Project Strategy and Scope of Work	45
H.2	Project Cost Estimate	39
D.3	Piping and Instrumentation Diagrams (P&ID's)	36
A.4	Location	36
G.5	Shutdown/Turnaround Requirements	32
B.2	Capacities	31
C.3	Project Site Assessment	29
		295/1000

Figure 4-9. PDRI- Small Industrial Section and Category Weights, and Top 8 Highest Weighted Elements

The team confirmed the element weightings through testing of the PDRI tool on 42 completed infrastructure projects, totaling over $151 Million in expenditure. The team determined through an analysis of the 42 completed projects, that projects with PDRI scores lower than 300 statistically outperformed projects with PDRI scores above 300 regarding cost, schedule, and change order performance. Figure 4-10 provides a summary of the PDRI – Small Industrial testing results at the 300-point PDRI score cutoff.

Performance	PDRI Score < 300	PDRI Score > 300	Δ
Cost	2% under budget	14% above budget	16%
Schedule	7% behind schedule	22% behind schedule	15%
Change Orders	13% of total cost	16% of total cost	3%
	(n=24)	(n=16)	

Figure 4-10. PDRI – Small Industrial Cost, Schedule, and Change Order Performance based on 300-Point Cutoff

4.1.4. Other CII Front End Planning Research Supporting the Process

CII has funded several research projects to further investigate aspects of front end planning that should be addressed along with project scope definition. These aspects include project team alignment, renovation and revamp projects, integrated project risk assessment, information flow to support front end planning, and optimizing construction input during front end planning.

4.1.4.1. Project Team Alignment

An objective of the CII Front End Planning Research Team was to investigate alignment during the pre-project planning phase. The team defined alignment as "The condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives"

(Griffith and Gibson, 2001). The project objectives are formed in the early stages of project development, must meet the business requirements and overall corporate strategy of the project stakeholders, and have a critical impact on project success (CII, 1997). Alignment in the project environment was found to exist in three dimensions, shown in Figure 4-11. Without commitment to the project objectives by all project stakeholders within the three dimensions, there is no alignment (CII, 1997).

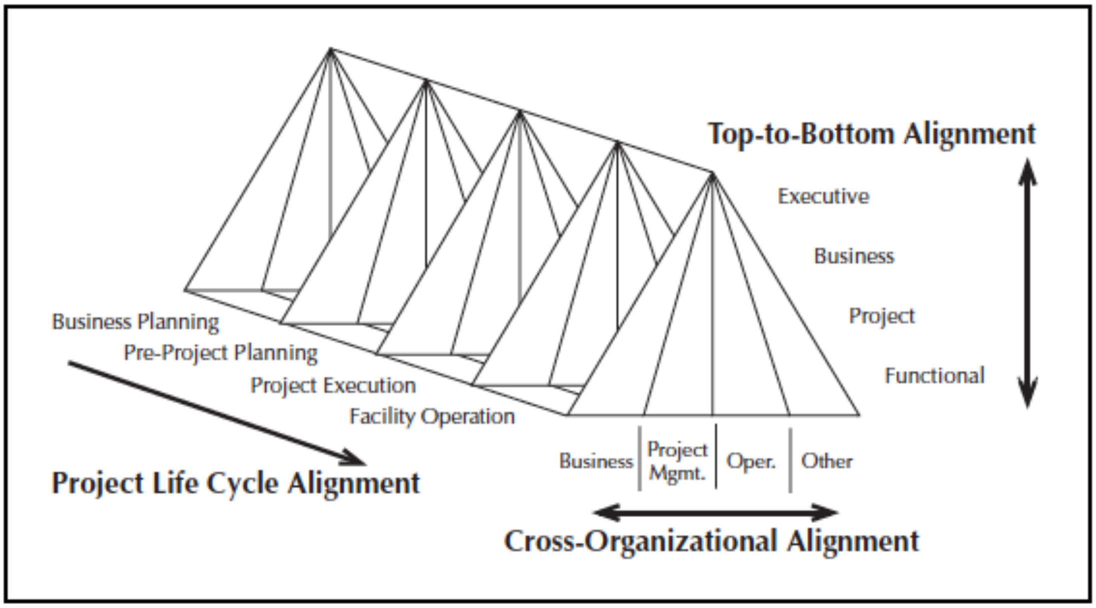


Figure 4-11. Three Dimensions of Alignment in the Project Environment (Taken from CII 1997)

The team developed a list of critical issues found to have the greatest effect on team alignment and project success through a series of three workshops and 54 structured interviews with industry professionals (Griffith and Headley, 1995). The team also developed a tool called the Alignment Thermometer used to assess how well a project team is aligned during front end planning. The ten most critical alignment issues are (CII, 2010a):

1. Stakeholders are appropriately represented on the project team
2. Project leadership is defined, effective, and accountable
3. The priority between cost, schedule, and required project features is clear
4. Communication within the team and with stakeholders is open and effective
5. Team meetings are timely and productive
6. The team culture fosters truth, honesty, and shared values
7. The pre-project planning process includes sufficient funding, schedule, and scope to meet objectives
8. The reward and recognition system promotes meeting project objectives
9. Teamwork and team building programs are effective
10. Planning tools (e.g., checklists, simulations, and work flow diagrams) are effectively used

4.1.4.2. Renovation and Revamp Projects

CII Research Team 242 studied renovation and revamp (R&R) projects for the purpose of offering support to the case for performing adequate front end planning on R&R projects. The team defined a R&R project as “one that is focused on and existing facility and includes the act, process, or work of replacing, restoring, repairing, or improving this facility with capital or non-capital funds. It may include additional structures and systems to achieve a more functional, serviceable, or desirable condition, including improvement in: profitability; reliability; efficiency; safety; security; environmental performance; and/or compliance with regulatory requirements” (CII, 2010a). The team completed a review of R&R projects through a survey of individuals employed by CII member organizations, and a case study of completed projects by these organizations. The team stated that some R&R projects may be small, while other may be hundreds of millions of dollars in cost, and that 30 percent of projects completed by CII member organizations were considered R&R projects at that time (CII, 2010a). The team found that the planning of R&R projects differs from greenfield projects in that such projects are fraught with the risk of unknown existing site conditions, and are oftentimes undertaken while a facility is still in operation (CII, 2010a). The absence of a proper planning approach can result in disputes, delays, and cost increases (CII, 2010a). The research team identified several unique characteristics to planning for R&R projects including:

- Safety and security issues of work force interfacing with existing conditions
- Unforeseen site conditions more prevalent
- Scope definition, estimating the amount of work more difficult
- Scheduling intensity, higher in many cases
- Shutdown issues occur on many projects
- Greater need to interface with operations/tenants, maintenance, and construction personnel
- Additional schedule constraints occur due to operational interfaces
- Different funding sources, including both local capital and non-capital funds

The team's study of R&R projects led to them updating certain elements within the PDRI – Industrial, PDRI – Infrastructure and the PDRI – Building with specific items to consider when planning a project that included an R&R component, or was completely an R&R project.

The team also developed a separate tool specifically for shutdown/turnaround/outage (STO) projects, called the Shutdown/Turnaround Alignment Review (STAR) tool, as STO projects were found to make up a significant portion of R&R projects completed by CII member organizations (CII, 2014a). Shutdown/turnaround/outage is defined as "A project or portion of a project that is executed during a planned disruption in normal use or operation where return to service is a business priority." STO projects were described as "a single point in time where multiple projects converge to a point of "time-constrained" integration and rapid schedule execution" (CII, 2010a). The STAR tool was developed to complement the PDRI, providing measurement of key planning attributes unique to STO's. The STAR tool tests the alignment or preparedness of these multiple projects to be completed during the STO so that associated risks can be identified and acted upon (CII, 2010a).

4.1.4.3. Integrated Project Risk Assessment

CII Project Team 181 developed a risk assessment tool in 2003 for the purpose of assessing risk on any project, but specifically complex projects in unfamiliar venues or locations. Initially named the International Project Risk Assessment tool, or IPRA tool, the title was updated in 2013 to Integrated Project Risk Assessment due to the wide applicability of the tool to domestic projects along with international projects.

The team found several definitions for risk as it relates to construction, such as "the potential for loss or injury", "the exposure to the chance occurrences of events that adversely or favorably affect project objectives as a consequence of uncertainty", and "the presence of potential or actual threats or opportunities that influence project objectives during project planning, construction, and commissioning; and these objectives are in the form of cost, schedule and quality" (CII, 2013). Coordinating risk management between disparate project stakeholders is not typically done in a formalized manner on most construction projects. Risk comes from different viewpoints depending on the project stakeholder: engineers/contractors/designers see technical risks, owners and developers see economic and financial risk, safety and health professionals see hazard impact/mitigation risk (CII, 2013). Several benefits to project success exist when project stakeholders collaboratively identify and manage risk, including:

- Allows for early identification or hazards and opportunities
- Communicates risks between project participants
- Identifies and manages uncertainty
- Identifies and considers worst case scenarios
- Established ownership of risks and risk mitigation actions
- Enhance risk-based decision-making

The IPRA tool is a structured risk identification and assessment process, designed for use as part of an overall risk assessment strategy. The IPRA was developed with participation from 113 industry professionals, including 26 structured interviews to help develop the element descriptions, four workshops in North America, and was tested on 15 completed projects, and seven in-process projects. The IPRA consists of four sections (commercial, location, facilities, production/operations), 14 categories, and 82 elements, and is applicable to industrial, building, and infrastructure projects. Each element/risk item is ranked depending on two factors: the likelihood of occurrence of the risk, and the potential impact to the project if the risk were to materialize. Figure 4-12 provides the IPRA Risk Assessment Matrix used to visually summarize project risks. The IPRA tool is to be used three times during project planning: validation of the project feasibility, project definition, and decision to proceed. The tool provides a structure for project teams to develop mitigation strategies once risks are defined, and to continually assess identified risks throughout the planning and construction process.

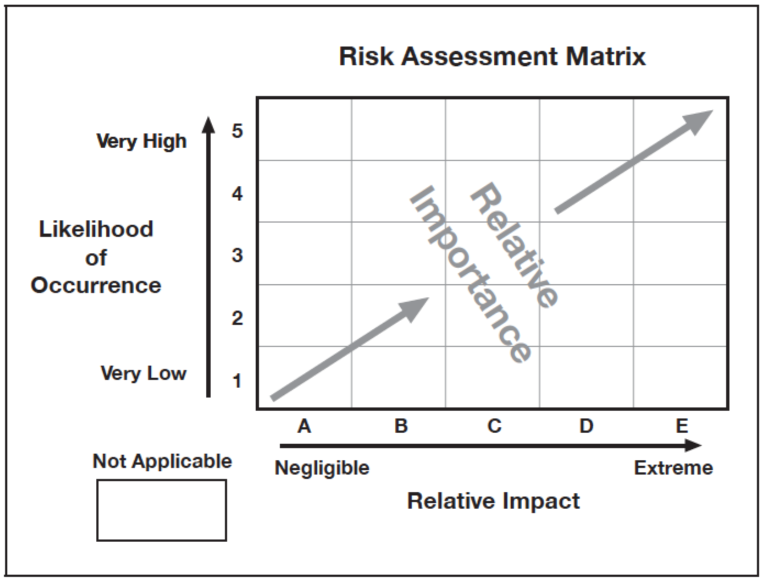


Figure 4-12. IPRA Element Risk Assessment Matrix (taken from CII 2013)

4.1.4.4. Information Flow to Support Front End Planning (2007)

CII Research Team 221 studied information flow to support the front end planning process of engineer-procure-construct (EPC) projects. The objectives of the research were to identify the information flow activities in front end planning and their interrelationships, identify the information requirements for front end planning activities, and provide recommendations for improving information flow to support front end planning. The team found that “The quality of information and the manner in which information flows, with respect to its comprehensiveness, correctness, and completeness, can either enhance or hinder the successful execution of work" (George, 2007). Front end planning is both information intensive and information dependent, and successful front end planning is dependent on the utilization of information that is generated and/or managed both internally and externally to project organizations ((George, 2007). It is important to identify when and what information is required within the planning process and how the generation or exchange of information can be improved within each individual phase of project delivery. The lack of availability or inadequacy of necessary information during front end planning will diminish the likelihood of successful project performance (George, 2007).

The team developed logic flow diagrams for 33 information flow activities showing the interrelationships between information flow tasks on typical EPC projects. The research team found that successful projects executed the information flow activities successfully and efficiently, devoted more time and resources to the execution of information flow activities, and the activities had all of the necessary information available when needed (George, 2007).

4.1.4.5. Optimizing Construction Input in Front End Planning (2009)

CII Research Team 241 studied how construction input during front end planning could improve project performance. The purpose of the research was to develop a CII best practice related to maximizing the value for construction input during front end planning to bring significant improvements in construction and commissioning phases of projects to improve project performance (Gokhale et al., 2009). The team found three principal barriers impeding on the involvement of construction input during front end planning:

1. Silos between design, construction and ownership, causing stakeholders to optimize their own interests rather than the overall project
2. Traditional contract models that institutionalize non-collaborative approaches
3. The lack of a decision tool to allow project managers to prioritize activities requiring construction input during front end planning

The team developed the Construction Input Assessment Tool (CIAT) through literature review, case studies, and industry questionnaires. The purpose of the tool is assist project decision makers in identifying and prioritizing key construction items and activities that require construction input during front end planning (Gokhale et al., 2009). The team used the PDRI-Industrial and PDRI-Building tools as a baseline, but utilized only those elements that required construction input during front end planning. Usage of the CIAT tool consists of four steps:

1. Assess the level of construction input necessary (on a scale of zero percent to 100 percent) for a project based on the element description within the tool, and determine if there is sufficient in-house expertise to successfully address the construction related issues.
2. A high-level assessment of the project concerning necessary construction input, comparing the current level of construction input versus the target level of construction input thought to be needed (from step one)

3. A detailed-level assessment of the project concerning necessary construction input, comparing the current level of construction input versus the target level of construction input thought to be needed (from step one)
4. Final result of the assessment, comparing the target level of construction input (taken from step one) and comparing that to the high level and detailed level assessments (from steps two and three) to highlight which elements have sufficient construction input, and which elements need additional construction input.

4.1.5. Efficacy of the PDRI tools

CII twice sought to determine the efficacy of their front end planning research. The next section describes these two studies, and highlights several continuous improvement areas where the front end planning tools have been updated to meet the ever-changing field of construction.

4.1.5.1. Front End Planning: Break the Rules, Pay the Price (2006)

CII Research Team 213 investigated the importance and value of the front end planning process, the resources required to perform the front end planning process effectively, and to outline key "rules" to the front end planning process (CII, 2006). The team utilized the CII Benchmarking and Metrics programs to collect project data regarding:

- The cost of front end planning
- Project performance (i.e., cost, schedule, change orders) based on assessing projects with the PDRI-Industrial and PDRI-Building tools

- Typical percentage of design completion at the end of scope definition
- Comparison of the Pre-Project Planning performance index vs. cost, schedule, and change performance
- Comparison of alignment during front end planning vs. cost, schedule, and change performance.

The research team found that (CII, 2006):

- Four percent of total installed cost was spent on front end planning for all projects. This percentage was slightly higher for small projects
- Projects scoring below 200 (with the PDRI – Industrial and PDRI – Building) performed better than those scoring above 200 regarding cost, schedule, and change performance
- Projects with 20 percent of design completed at the end of frond end planning performed better than projects with a lesser amount of design completed at the end of front end planning
- Projects with Pre-Project Planning Index scores above the median mark (i.e., 7.9 out of 10) performed better than projects scoring below the median mark regarding cost, schedule, and change performance. Higher Pre-Project Planning Index scores (i.e., closer to 10) equate to more intensive front end planning. (Note: the Pre-Project Planning Index was developed by the CII Benchmarking and Metrics group to determine the relative level of front end planning at project authorization to expend funds for design and construction.)
- Projects with Alignment Index scores above the median mark (i.e., 7.8 out of 10) performed better than projects scoring below the median mark regarding cost and

schedule performance. Higher Alignment Index scores (i.e., closer to 10) equate to more aligned projects

The team completed several other tasks, including replacing the term pre-project planning with front end planning, believing that the planning process includes efforts performed during the project, not just before as pre-project planning implied, and to better relate to industry specific terminology. The team also updated the PDRI – Industrial and PDRI – Building tools, and also developed an html based tool/process map to replace the pre-project planning handbook that had been developed by the Pre-Project Planning Task Force in 1991. The team concluded with developing a set of critical success factors, or "rules", for front end planning (CII, 2006):

- Develop and consistently follow a defined front end planning process
- Ensure adequate scope definition prior to moving forward with design and construction; use front end planning tools
- Define existing conditions thoroughly
- Select the proper contracting strategy early
- Align the project team, including key stakeholders
- Build the project team, including owner stakeholders and consultants
- Include involvement from both owners and contractors
- Staff critical project scoping and design areas with capable and experienced personnel
- Identify and understand risks of new project types
- Address labor force skill and availability early in planning because this issue can effect project success

- Provide leadership at all levels for the front end planning process, including executive and project, owner, and contractor

4.1.5.2. Adding Value through Front End Planning (2012)

The second objective of CII Research Team 268 (beyond developing the PDRI – Infrastructure tool) was to study how organizations have utilized the CII front end planning tools since the time of the 2006 study. The team was also tasked with updating the front end planning toolkit, and developing an overarching front end planning publication titled " Adding Value Through Front End Planning" that pulled together the 20 years of front end planning research completed by CII.

The team found that front end planning products sold by CII had been downloaded 39,585 times between the years of 1985 to 2011 (Bosfield and Gibson Jr., 2012). The team also surveyed the 116 CII member organizations to determine specifically what tools were CII members currently using. Fifty-nine responses were received to their survey, and the team completed 15 in-depth follow-up interviews. The team found that (Bosfield and Gibson Jr., 2012):

- Seventy-eight percent of respondents used at least one CII front end planning tool, mainly the PDRI-Industrial
- The overall usage of front end planning tools was higher for owners than contractors.
- Forty-two percent of respondents stated that the PDRI was included in their organization's budgetary approval process

- Ninety percent of respondents felt that the PDRI tools had a positive impact in their planning process effectiveness
- The PDRI tools were mainly used on medium to large projects, but sometimes for small projects.
- The most prevalent reason cited by respondents for not using CII front end planning tools included not being familiar with the tools, or using different tools. One respondent stated (regarding the difficulty of tool usage): “We do small projects, $1 million to $50 million and the PDRIs are too complex. When we get time we’re going to simplify the PDRI Industrial for our use.”

4.2. Small Project Research

Past work by CII, published in 1991 and 2003, described the difficulty of defining the term “small project.” RT 314, convened in 2013, focused their investigation defining small industrial projects and developing a PDRI tool for such projects. Research Team 314a felt it imperative to review previous research studies into small projects to ensure the PDRI – Small Infrastructure tool addressed and conformed with any significant research findings in the area. The next sub-sections describe handbooks, manuals, and research studies that provided the research team background into the various definitions of “small project,” as well as small project characteristics, suggestions for effective management, and success factors for small projects.

4.2.1. Managing the Engineering and Construction of Small Projects (1985)

The *Managing the Engineering and Construction of Small Projects* handbook was developed for the purpose of providing a practical management method for project engineers tasked with managing small industrial projects, but not experienced with project management. Small projects can include maintenance, upgrading, revamps, turnarounds and outages, research, engineering, plant improvements, light construction, or environmental work, and can be capital or non-capital expensed projects. Westney (1985) defines small projects as having one or more of the following characteristics:

- Cost levels from $5,000 to $50,000,000
- Cost levels less than 5 percent of annual budget for projects
- Numerous other similar projects take place concurrently
- Labor and equipment resources shared with other projects
- The company doing the project is, itself, small

Westney (1985) states that small projects can be just as important as large projects, and sometimes even more important. The value of successfully competing a small project can be far greater than the project itself, an example being a turnaround project being completed on an essential manufacturing process. The plant's profitability can be significantly reduced if the project takes too long, causing valuable production to be lost. Westney (1985) also states that the total cost of small projects is not small at all; the aggregate cost of all small projects in a facility may be substantial.

Westney (1985) asserts that one of the most difficult aspects of managing small projects is dealing with multiple projects at once, which is typically not an issue with large projects. The projects will also all be at various stages (i.e., design and procurement, under construction, start-up) of completion, causing project engineers to constantly change their priorities. Other typical issues with small projects include (Westney, 1985):

- Many small projects occur in an active production environment
- Organizations are not designed for projects (i.e., project being managed by production engineers not project managers). Management lacks formal procedures, methods, and data to properly plan, estimate, and manage projects
- Standard approaches used for large projects don't work for small projects.
- Many small projects are revamps within active production facilities, which imposes many constraints such as restricted access to project sites, hot work permits, construction personnel working around production personnel, (where production takes priority over construction), unpredictable nature of plant operations causes frequent changes to scheduled work site access, and access to knowledgeable plant personnel.
- Projects in manufacturing plants often experience significant increases to the scope of work due to specific scope items not being apparent until work has progressed to a certain point.

4.2.2. Manual for Small Special Project Management (1991)

The CII Small Projects Action Team was tasked with developing a comprehensive manual for managing small projects that was based on adapting generally accepted management techniques developed for large projects to small projects. The action team focused on small projects in four categories: engineering only, construction only, Engineer-Procure-Construct (EPC), and revamp (a term encompassing rebuild, retrofit, shutdown, add-on, and upgrade, but not maintenance).

The team found many problems and characteristics typical of small projects, including (CII 1991):

- The word "small" – dictionary definition is little, puny, meager, insignificant, unimportant. Using the word small may cause such projects to be seen as unimportant, hence undeserving of traditional management attention.
- Inexperienced Management – least experienced project managers used for small projects. The best management personnel are saved for large projects
- Combined Operating/Construction Responsibilities – operations or maintenance personnel tasked with managing small projects, even though they are seldom adequately prepared to do so
- Multiple Project Responsibilities – Project managers have simultaneous responsibility for multiple projects, taxing the manager's ability to give each project its due attention
- Multiple Individual Responsibilities – individuals assigned to small projects are responsible for multiple functions. There is less attention paid to comprehensive look-ahead planning as the "squeaky wheel gets the grease."
- Safety and Quality Easily Compromised – Adequate attention not given to safety and quality due to lack of time and dedicated functional staff
- Short Duration – The typical short project duration provides insufficient time for detailed planning and in-process correction of problems. Personnel are still climbing the learning curve when the project is completed.

- Poor Career Attractiveness – Individuals tend to seek the stability of large projects as opposed to small projects, which are seen as having low visibility, questionable job security, involving frequent movement, and being non-career enhancing.
- Lost Expertise – Many experienced engineers and constructors that have traditionally served as mentors to younger personnel have left the workforce due to economic conditions, creating a lost generation of valuable experience
- High Loss Potential – Economic risks vs. project value (and profit) are much higher proportionately on small projects than large projects
- Poor Scope Definition – Poor scope definition effects both small and large projects, but can be devastating to small projects due to limited response time available for scope changes
- Poor Basis for Control – Limited availability of project managers and limited time leads to lack of established baselines for project control
- Inapplicability of Company Standard Control Systems – Robust control systems design for large projects may be overwhelming to small projects if not simplified and adapted
- Contractor Competence – Contractors accustomed to large projects tend to avoid small projects. If they do undertake them, they tend to overkill them. Some small contractors are excellent, while others lack the necessary skills and resources.
- Lack of Computer Literacy – Small contractors sometimes lack experience with or appreciation of the potential for computerization or automation of project management functions

- Regulatory Requirements Applicability – Safety, health, environmental, and government regulations apply with equal force to large and small projects
- Subcontracting vs. Direct Hire – Subcontractors may be necessary to obtain desired skills, but the project schedule may be extended due to the time needed to select an appropriate subcontractor, and addressing any scope changes. The use of direct-hires involves problems with timely recruitment of properly skilled personnel.
- Remote Location – Problems of remoteness: logistics, personnel availability, communication, are more challenging for small projects than large projects due to the limited number of project management staff

The team developed a detailed manual for addressing the typical problems and characteristics related to managing small projects, with nine focus areas including organizational structure and guidelines, planning, in-process management, revamp projects, contracts and contract administration, project controls, total quality management, safety and health, and environmental protection. Each focus area in the manual includes a description of the issue, and ways that organizations can plan, structure, and manage small projects to address the issue. The team also chose to refer to "small" projects as "special" projects in an attempt to remove the negative stigma associated with the project type.

One of team's the most significant findings was that due to the wide variations in relative size, complexity, schedule duration and cost of projects executed by an even less homogeneous cross section of owners, architects, engineers and constructors, it was impossible to clearly define "small project." The team asserted, "If the project is felt to be small relative to the culture and available resources within an executing entity, then it is indeed a small project. ” The team suggested that one possible method for differentiating between small and large projects might be to list the typical characteristics of large projects, and if a project lacks several of these characteristics, then it would be considered small. The characteristics commonly associated with large projects were identified as (CII, 1991):

- Has full-time staff
- Staff large enough to have functional specialists
- Company standard procedures are applicable (i.e., small project may need their own)
- Standard company control systems and reporting procedures are used (i.e., small projects may need their own)
- Duration is long enough to permit personnel to progress comfortably up the learning curve and to have time to adjust to in-process problems and mistakes
- Receives considerable management attention
- Takes a significant percentage of company resources or capabilities

The team ultimately concluded that the boundary between large and small projects could not be strictly defined, after much debate amongst the team members. The team chose to instead provide (in an appendix to the manual) a listing of possible small project parameters, including:

- Length of project: 1-15 months engineering only, 1-14 months for construction only, 2-30 months for EPC

- Personnel hours: 200-65,000 work hours for engineering only, 2,500 – 500,000 for construction only, 1,500 – 750,000 for EPC
- Cost: less than 5 percent of an organizations annual construction budget, cost under $50,000,000, $2,000 - $3,500,000 for engineering, $100,000 - $25,000,000 for construction only, $100,000 - $100,000,000 for EPC
- Management Approach: part-time management
- Controls Involved: simpler controls than large projects due to compressed time and multiple responsibilities of the management team
- Other: one or a few design disciplines, very few crafts, project execution completely within the control of an operating plant manager, ratio of engineering to construction higher than normal, ratio of manual to non-manual personnel costs in the construction phase higher than normal

4.2.3. Developing an Effective Approach to the Procurement and Management of Small Building Works within Large Client Organizations (1995)

Griffith and Headley (1995) summarized a major research study into the procurement and management of small building “works” (i.e., projects) within large owner-organizations in the United Kingdom. Griffith and Headley (1995) found that little previous research had been undertaken regarding small projects, and that the level of commitment needed to undertake small projects successfully is underestimated in many organizations. Griffith and Headley (1995) asserted that small projects require thorough and dedicated procurement, organization, and management if they are to be efficient and cost effective and that the specific tools, techniques, and procedures required must be appropriate to the nature and scale of projects.

Data from interviews and case studies highlighted two common problems the exist in small project procurement and management: the failure to recognize the fundamental characteristics of small projects and how these influence procurement and management approach, and from the misconceptions regarding the significance, composition, and value of small project loading within organizations Griffith and Headley (1995). The study also found that small projects are not managed as efficiently and effectively as they might be, and that no recognized procedure or practice existed for the management of small projects. Ineffective management of small projects was found to be due to project managers becoming organizationally consumed in reacting to events, the need to authorize each and every job and inevitably lack sufficient time to manage the organizational small projects workload and each individual job in the sense that modern management techniques are applied to other processes in different industries.

Griffith and Headley (1995) defined small projects as featuring certain characteristics that make them discernable from other types of building projects, including:

- Limited cost
- Low complexity
- Short duration
- Limited inputs (materials and labor)
- Harbor practical and financial uncertainty due to lack of scope definition
- Utilize limited formal documentation

- Diverse in basic characteristics (size, value, complexity)
- Occur in active environments

Griffith and Headley asserted that these categorizations are oftentimes arbitrary, typically done with a level of cost as the differentiator. They contended that using a level of cost or type of work alone to different between project classes is insufficient and that projects should be looked at holistically through an appreciation of their particular characteristics within the core business and operation of the client organization. Griffith and Headley (1998) also asserted that small works fall along a spectrum that takes in to consideration their characteristics and classes, as shown in Figure 4-13.

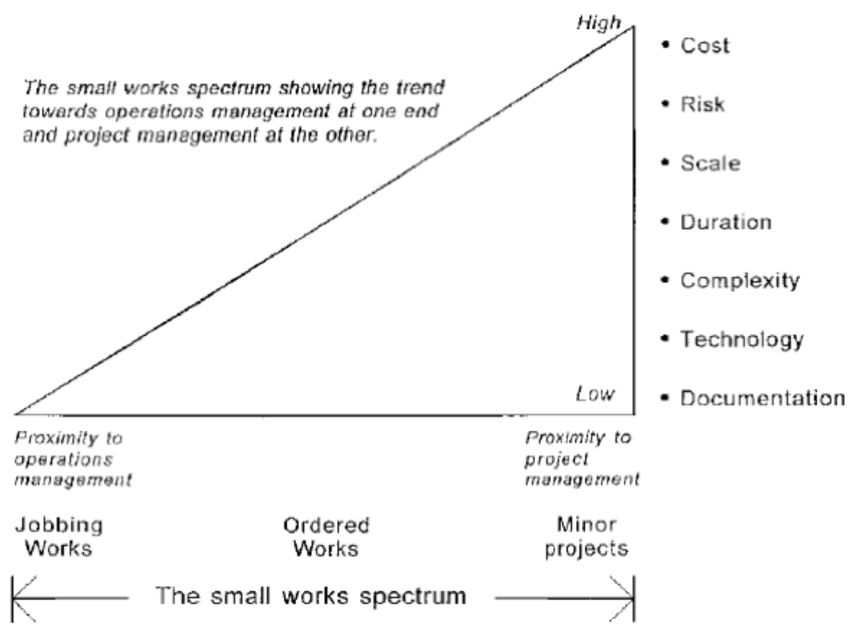


Figure 4-13. Small Works Spectrum

4.2.4. Small Projects Toolkit (2001)

The CII Executing Small Capital Projects research team (RT 161) developed the Small Projects Toolkit in 2001 to assist project managers in improving small project programs and small project execution. The team asserted that small project execution is important due to 40-50 percent of capital budgets being spent on small projects for the purpose of increasing production capacities, improving product quality, improving efficiencies, and maintaining functionality of a plant for continued operation and production (CII, 2001). The team defined small projects at projects having a total installed cost range between $100,000 and $2,000,000 (CII, 2001).

The toolkit outlines small project best practices in the areas of front end planning, design, procurement, construction, start-up and commissioning, people, small projects organizations, processes, small projects controls, contracting, safety, health and environment, and technology and information systems. Regarding front end planning, the research team found that the planning of small projects must be completed in an environment with a compressed timeframe, few dedicated project resources, and a variable funding process. Having an owner representative/leader with profound knowledge of a facility and plant personnel to facilitate scope definition and plant input and approval, a clear, succinct, detailed identification of project scope prior to funding to avoid continued design improvements to the end, and funding processes that are clear, dependable, and make sense are the front end planning issues that can have the strongest impact on small project success. The team suggested several best practices for small project design and management, including (CII, 2001):

- Standardization of equipment and designs

- Larger project contingencies
- Project checklists
- Small project program team, providing consistency and continual improvement from quarter to quarter
- Separate funding for front end planning of small projects
- Dependable project funding
- Modified PDRI, even though the tools were not specifically design for small projects where many of the elements may be not applicable

4.2.5. Budget and Schedule Success for Small Capital-Facility Projects (2002)

Gao et al. (2002) provides the results of a literature review and industry survey (completed by 36 respondents) to determine what constitutes success on small projects, specifically if there was a difference between success factors for large and small projects. Small projects used in the survey were "theoretically limited" to those projects not less than $100,000, and no more than $2,000,000. Gao et al. (2002) found that the most frequently noted project success factors (from both the literature and survey) were cost, schedule, technical performance, client satisfaction, and that these factors did not differ between small and large projects. Gao et al. (2002) highlighted several attributes of small projects and small project execution within project organizations, including:

- The significance of front end planning for small projects should not be underestimated. Scope changes, schedule slippage, delayed work, communication issues, and shifting priorities were the most frequently noted by survey respondents regarding problems encountered on small projects. Enhanced project scope definition can best address these issues. The front end planning process in many organizations was not well defined.

- When large project processes are imposed on small project programs, they may likely contribute to bureaucratic inefficiency in the small project delivery system. Those attempting to use large project procedures on small projects had less project success.
- Small projects consisted of 16% of total capital project budgets for survey respondents, but were 80% of the work volume (based on the number of projects)
- Firms with capital budgets below $20 million, or had a ratio of small to large projects at or above 20 percent, were classified as having a small project focus. Firms with a small project focus had more projects complete five percent below budget, and completed on or before the target date
- Contractors with binding agreements to provide maintenance work in addition to small capital project work were able to maintain a consistent workforce, the primary advantage being better budget performance. However, maintenance work must be concurrently scheduled with small projects, possibly producing more delays for project sites where maintenance and capital projects are performed at the same time.
- The projects that used a core management group for small capital facility projects showed a benefit in schedule performance due to improved communication processes and reduced potential for conflicts.

4.2.6. Is a Small Project Really Different? (2005)

Liang et al. (2005) sought to outline the differences between the project performance of small and large projects. Small projects were defined as projects having:

- Total installed cost between $100,000 and $5,000,000
- Duration of 14 months or less
- Site work hours up to 100,000
- Project does not require full-time project management resources or significant percentage of company resources
- Any level of complexity and nature including maintenance and expense projects

Project data was collected from CII member organizations through the development and administration of a multi-part electronic questionnaire, and selected projects taken from the CII Benchmarking and Metrics database. The portion of the questionnaire described in Liang et al. (2005) dealt only with project performance differences between small and large projects. Small projects were found (through statistical analysis) to have more variable cost, schedule, and change order performance (from the owner and contractors perspectives) than large projects based on an analysis of 356 projects.

4.2.7 PDRI – Small Industrial Projects (2015)

Research Team 314 developed a PDRI for small industrial projects, as described previously (see Section 4.1.3.4). They defined a small industrial project to align with the following characteristics:

  - Total installed cost less than US $10 Million

- Construction duration between 3 and 6 months
- Project funding approval at a regional or corporate level
- Moderate project visibility to owner management
- 7 to 9 core team members (i.e., project managers, project engineers, owner representatives)
- Part-time management availability of core team members
- None to minimal external permitting required
- None to local/state permits required
- 3 to 4 separate trade contractors

4.3. Literature Review Findings

The primary focus of the CII front end planning tools to date has been to improve project performance on large, complex projects, excepting RT 314, which developed the PDRI – Small Industrial Projects. This point is highlighted in Table 4-1, showing the average cost of projects utilized for the testing phase of the PDRI for Industrial, Building, and Infrastructure. Several of the small project research studies noted that procedures or processes designed for large projects scenarios are typically not effective for use on small projects, as they are too cumbersome to be effective. Several studies also noted the importance of front end planning for small projects; that it should not be underestimated, and that in many organizations the process is not well defined. All of these factors confirmed for Research Teams 314 and 314a the need to develop front end planning tools specifically for smaller projects.

Table 4-1. Average Cost of Projects Used in PDRI Testing

	Number of Projects Collected	Total Expenditure (Approximate)	Average Project Cost
PDRI for Industrial Projects	40	$3,300,000,000	$82,500,000
PDRI for Building Projects	33	$889,500,000	$26,954,545
PDRI for Infrastructure Projects	22	$6,080,000,000	$276,363,636
PDRI for Small Industrial Projects	65	$151,770,118	$3,794,253

The review of small project-related literature highlighted for the research team that a consistent definition of "small project" did not exist, as shown in Table 4-2. This lack of definition suggested that the research team would need to develop a definition of small project for the purpose of guiding industrial PDRI users to the appropriate tool. The small project literature did highlight several common attributes to be considered for successfully completing small projects that should be incorporated into a front end planning tool for small projects, such as having project management with the appropriate level of expertise (i.e., experienced managers, not new-hires in training), realizing that many small projects are R&R and/or completed as part of a larger program of projects, and completed in active environments, and that the aggregate importance of small projects should not be underestimated; the criticality of small projects oftentimes outweigh their cost.

Table 4-2. Small Project Definitions from Literature

References	Cost	Duration	Other
Westney (1985)	\$5,000 to \$50 million	N/A	Numerous other projects taking place concurrently, labor and equipment resources shared with other projects
CII (1991)	\$2,000-\$3.5 million for engineering only, \$100,000-\$25 million for construction only, \$100,000-\$100 million for EPC	1-15 months small engineering-only projects, 1-14 months for construction only, 2-30 months for EPC	Personnel hours - 200-65,000 for engineering only, 2,500-500,000 for construction only, 1,500-750,000 for EPC, part-time management, simpler project controls
Griffith and Headley (1995)	Limited cost	1-3 months	Low complexity, limited inputs, limited formal documentation, occur in active environments
Liang et al. (2005)	Total installed cost between \$100,000 and \$5 million	14 months or less	Site work hours up to 100,000, part-time project management, any level of complexity
(Collins et al., 2015)	Less than \$10 million	3-6 months of construction duration	7 to 9 core team members, part time availability of staff

4.4. Summary

The literature review provided the theoretical baseline concerning previous research investigations into front end planning and small projects that was utilized by Research Team 314 and 314a to develop the PDRI – Small Industrial Projects and PDRI-Small Infrastructure Projects, along with their companion Selection Guides. The literature review highlighted that the front end planning research focus by CII over the past 25 years has consistently provided construction project stakeholders with tools to improve project performance. This has been accomplished through the development of PDRI tools for industrial, building, and infrastructure projects, as well as complementary tools for R&R projects, shutdown/turnaround/outage projects, project team alignment, integrated project risk assessment, information flow into front end planning, and construction input during front end planning. The literature also showed that the preceding PDRI tools were developed for large projects, and that tools developed for large projects are typically not effective for use on small projects.

CHAPTER FIVE

SMALL PROJECT PREVALENCE, PLANNING PRACTICES, AND DIFFERENTIATORS IN THE INFRASTRUCTURE CONSTRUCTION SECTOR

The RT314a concluded that a sufficient and consistent definition of what differentiates a small project from a large project did not exist, based on a thorough literature review as discussed in Chapter 4. The RT314a determined that additional information should be sought from industry to clarify the current metrics used to differentiate between small and large infrastructure projects, as well as the prevalence of small projects, and typical front end planning practices employed for small projects. RT 314a developed a survey using previous small project research to poll industry members familiar with infrastructure projects. The next few sections describe the survey methodology, structure, response, and results.

5.1. Survey Development Methodology and Structure

RT 314a developed a multi-part survey of 26 open-ended and closed-ended questions to collect information on small project prevalence, planning practices, and metrics used in industry to differentiate between small and large infrastructure projects. The survey instrument was developed and administered with the CII *Select Survey* system, a proprietary online survey tool owned by CII.

The survey included two questions regarding the prevalence of small infrastructure projects. The first question asked, “On a cost basis, what percentage of your organization’s yearly capital construction budget would be considered small projects?” The second question asked, “On a count basis, what percentage of your organization’s yearly capital construction budget would be considered small projects?”

Each question included six possible response ranges, including < 10 percent, 11-30 percent, 31-50 percent, 51-70 percent, 71-90 percent, and > 90 percent, and the respondents were asked to choose one response range for each question. The survey did not include a definition for "small project". Survey respondents were to answer the questions based on their organization's definition.

The survey included four questions regarding front end planning practices for small infrastructure projects. The first question asked, "What is your organization's front end planning process for projects that meet your definition of a small project?" Six possible front end planning processes were posed, including: (1) front end planning happens only at the program/portfolio level, (2) dedicated task force for all small projects, (3) internally developed scope definition tools, (4) structured stage gate, (5) ad hoc, and (6) none. Respondents were asked to select all that applied to their organization.

Three questions asked specifically about the respondents familiarity with the PDRI tools, and if these tools were used during the front end planning of small projects. The first question asked, "How often has your organization used the Project Definition Rating Index (PDRI) tool in the past?" Four separate options were given, including on a few selected projects, on most projects, on all projects, and never, and the survey instructed respondents to choose one of the four. The second question asked, "Does your organization use the Project Definition Rating Index (PDRI) for projects that meet your definition of a small project?" The third question asked, "Has your organization developed a modified PDRI or other tool for projects that meet your definition of a small project?" Respondents were asked to choose "yes" or "no" to the second and third questions. If the respondent chose yes to the third question, they were prompted to describe the modified PDRI or other tool used in their organization.

The research team took 16 separate metrics from the literature review and their own experience that they felt could differentiate small infrastructure projects from large. The research team gave each metric a set of associated “break points” for small and large projects, some of which were numerical (i.e., above or below US $20 Million of total installed cost), while others were scaled (i.e., none to local/state permits versus local/state to national permits). The break points were based on the literature review, as well as the experience of the research team members. Table 5-1 shows the 16 metrics and associated break points. RT 314a developed separate, multi-part questions for each of the 16 metrics asking if (1) the metrics were used (within the respondent’s organization) as a differentiator between small and large infrastructure projects, and (2) if the metric was used as a differentiator, was the associated break point correct. Each part of the questions could be answered “yes” or “no”. If the respondent answered yes to the first portion of the question regarding the metric itself, but no to the second portion of the questing regarding the break points, they were prompted to provide the break point that was used in their organization. Each of the questions provided the respondents with the option to provide any additional comments that they may have regarding the metric or break points posed.

Table 5-1. Project Size Differentiators Posed in Survey

Complexity Factor	Small Projects	Large Projects
Total Installed Cost*	<$20 Million	>$20.1 Million
Engineering Effort*	< 5000 Hours	> 5000 Hours
Construction Duration**	6-12 Months	>18 Months
Number of Core Team Members**	<10 individuals	>10 individuals
Availability of Core Team Members**	Part-time availability	Combination of part-time and full-time to completely full-time
Project Visibility External to Organization (Public)	Moderate	Significant
Extent of Permitting	None to moderate permitting	Significant permitting
Number Jurisdictions Involved	1-3 jurisdiction	> 5 jurisdictions
Existing Utility Provider Interface & Coordination	Minimal to Moderate	Significant
Sources of Funding	Singular	Multiple
Types of Permits	None to local/state permits	Local/state to national permits
Number of Trade Contractors	3-4 separate trade contractors	7-8 separate trade contractors
Extent of Public Outreach Effort	Minimal to Moderate	Significant
Management of Public Outreach Effort	Project Team	Corporate Executives
Right Of Way (ROW) procurement effort	Minimal to Moderate	Significant
Right Of Way (ROW) parcels required	1-2 parcels	>5 parcels

* More than 50% of respondents reported this factor as a differentiator between small and large projects

** More than 48% of respondents reported this factor as a differentiator between small and large projects

Table 5-1 provides suggestions about how to determine the appropriate PDRI tool for use on an infrastructure project, but should not be used as a strict guideline. Note the complexity factors appear according to order of importance reported by survey respondents; that is, total installed cost is the most important factor for differentiating small projects from large, while the number of Right of Way (ROW) parcels required is the least important differentiator. While Table 5-1 provides guidance as to factors to consider, the values that serve as delineators between small and large projects will vary from one organization to another. For instance, in some organizations, projects with total installed costs of $20 million may be considered very small, while in other organizations, projects of this caliber would be considered very large. In choosing a suitable tool for a specific project, users are urged to consider such factors and let common sense prevail. If project team members feel that a certain project should be considered small based on their experiences in their organization, it probably is. The same can be said about large projects.

Users of PDRI – Small Infrastructure should keep in mind that RT 314a developed the tool only for assessing small projects. The tool is not intended as a short cut to use in lieu of assessing a project with PDRI – Infrastructure Projects. Some organizations may wish to base the selection criteria on the characteristics of their typical projects; however, RT 314a's research validated the PDRI – Small Infrastructure Projects for projects meeting the criteria presented in Table 5-1.

Two open-ended questions were posed at the end of the survey, asking "If you could improve the PDRI to make it more applicable to projects that meet your definition of small project, what would you include or exclude?" and "Please add any additional comments you have about improving planning for small projects as compared to large projects." The survey also provided for the respondent an option to provide their name and organizational affiliation.

5.2. Survey Respondent Solicitation

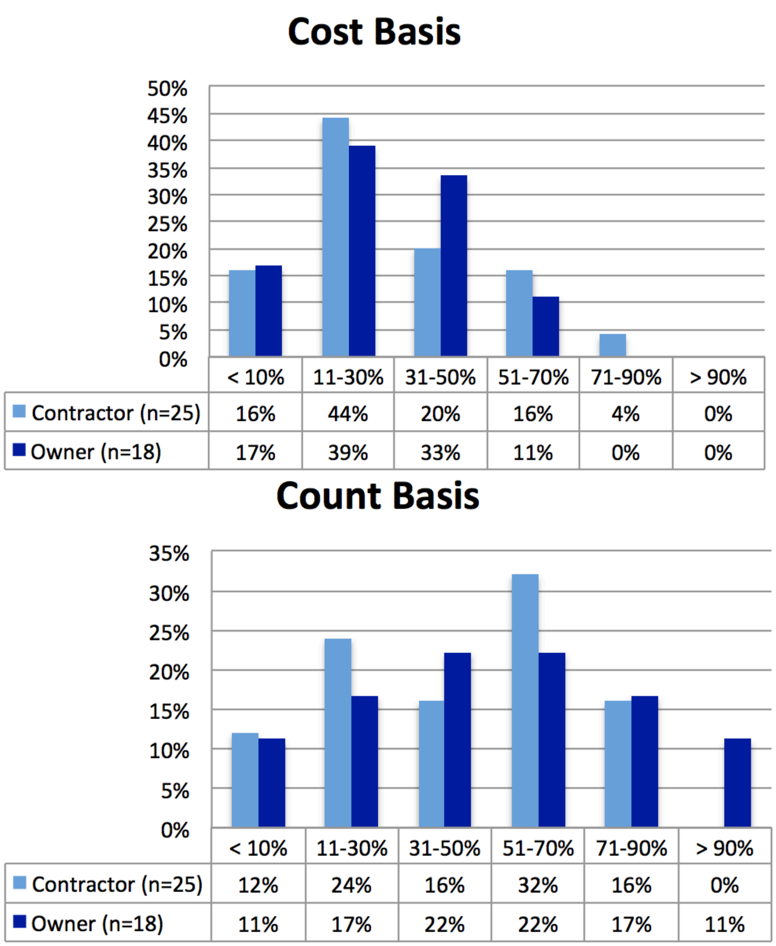
The research team determined that surveying individuals from CII member organizations could provide substantial insight into the prevalence of and planning practices for small infrastructure projects, as CII member organizations cover a vast cross-section of the infrastructure sector. CII provided the research team with contact information for approximately 190 practitioners from their member database that had agreed to provide data for ongoing research projects, namely the "CII Data Liaisons." RT 314a sent an email to each of the CII data liaisons with a brief description of the study and a solicitation to complete the survey through a provided website link. The industry members of Research Team 314a were also asked to complete the survey. Each individual was asked to pass along the solicitation to any other practitioner that they felt might be interested in providing data regarding the prevalence and planning practices of small infrastructure projects. Moreover, the Research Team 314a sent the survey to their own professional network to increase the breadth of perspectives included in the survey. In total, the survey was sent to 211 people.

5.3. Survey Responses and Analysis

The survey was open for approximately two-month period between November 2015 and January 2016. In total, 47 responses (out of the 211 individuals contacted) to the survey were received, approximately a 23 percent response rate. Individuals from 47 separate organizations completed the survey, a listing of which is included in Appendix A. The breakdown of the organizational types between survey respondents is 28

Contractors (60%) and 19 owners (40%). The respondents from owner organizations were less than those from contractor organizations.

Figure 5-1 provides a summary of the responses regarding the prevalence of small projects within the survey respondent's organizations during the fiscal year prior to survey being completed. Both the Owner and Contractor respondents estimated that less than 50 percent of projects completed during the preceding fiscal year met their definition of small project on a cost basis, while the majority of both Owners and Contractors felt that more than 50 percent of projects were small on a count basis.



Cost Basis

	< 10%	11-30%	31-50%	51-70%	71-90%	> 90%
Contractor (n=25)	16%	44%	20%	16%	4%	0%
Owner (n=18)	17%	39%	33%	11%	0%	0%

Count Basis

	< 10%	11-30%	31-50%	51-70%	71-90%	> 90%
Contractor (n=25)	12%	24%	16%	32%	16%	0%
Owner (n=18)	11%	17%	22%	22%	17%	11%

Figure 5-1. Prevalence of Small Projects within Survey Respondent Organizations

5.3.2. Front End Planning Processes for Small Projects

Figure 5-2 provides a summary of the responses regarding the typical front end planning processes used for small projects. Responses ranged across all eight possible processes, with “internally developed scope definition tool” and “Ad hoc” being the most prevalent, and receiving the highest number of responses. A few respondents also selected “Other” (not shown in Figure 5-2). The only respondent that selected “Other” and provided a comment offered “currently being revised” as their comment5.

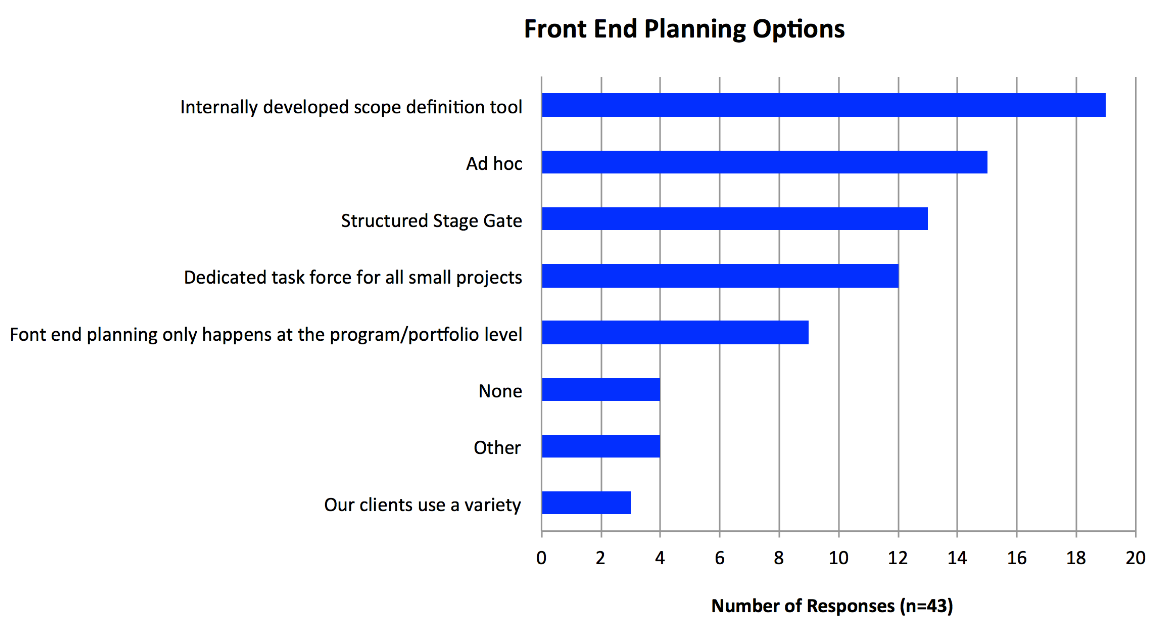


Figure 5-2. Front End Planning Processes for Small Projects within Survey Respondent Organizations

Figures 5-3, 5-4 and 5-5 provide a summary of the responses regarding PDRI familiarity and usage on small projects. A majority of respondents stated that they had used the PDRI on only a few selected projects, as shown in Figure 5-3, and the PDRI tools had mostly not been used (or modified for use) for small projects, as shown in Figure 5-5.

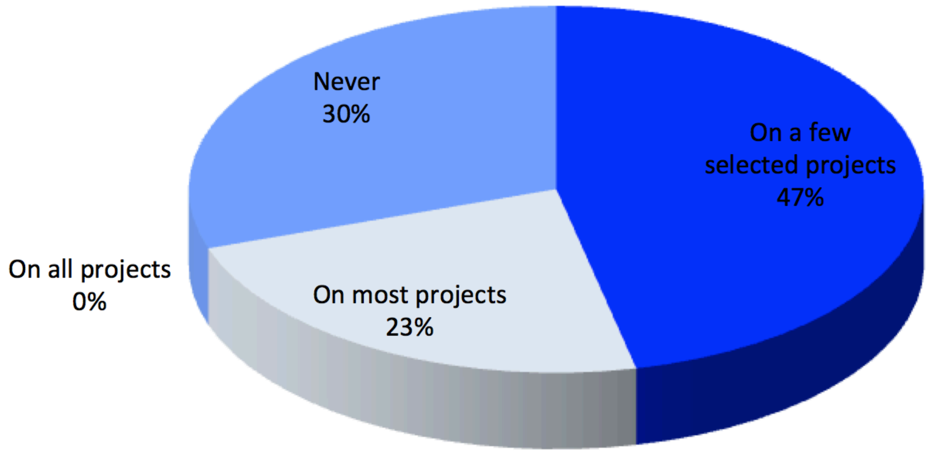


Figure 5-3. Overall Usage of the PDRI Within Survey Respondent Organizations

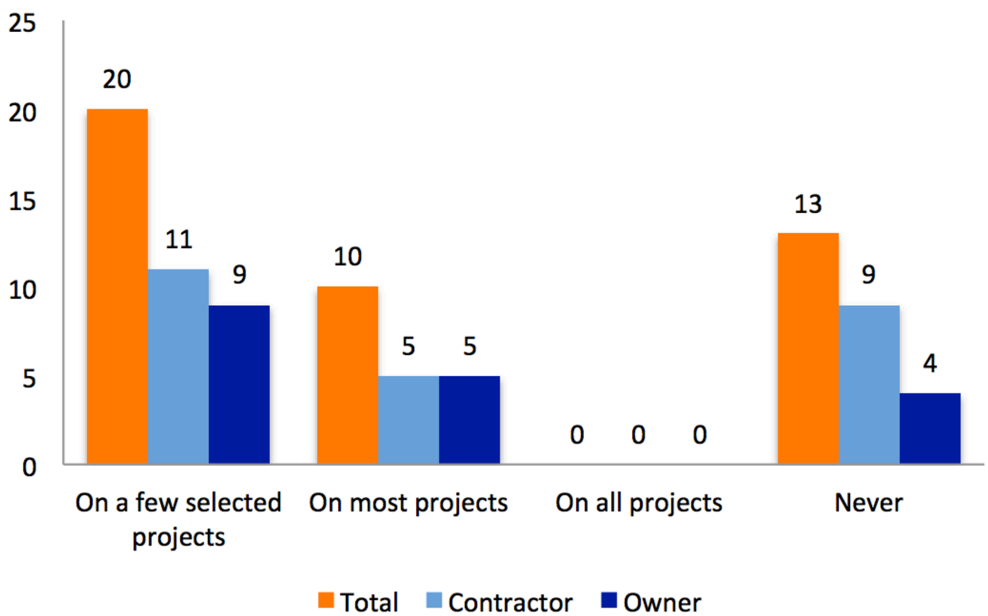


Figure 5-4. Comparison of the Usage of the PDRI Within Survey Respondents of both Owner and Contractor Organizations

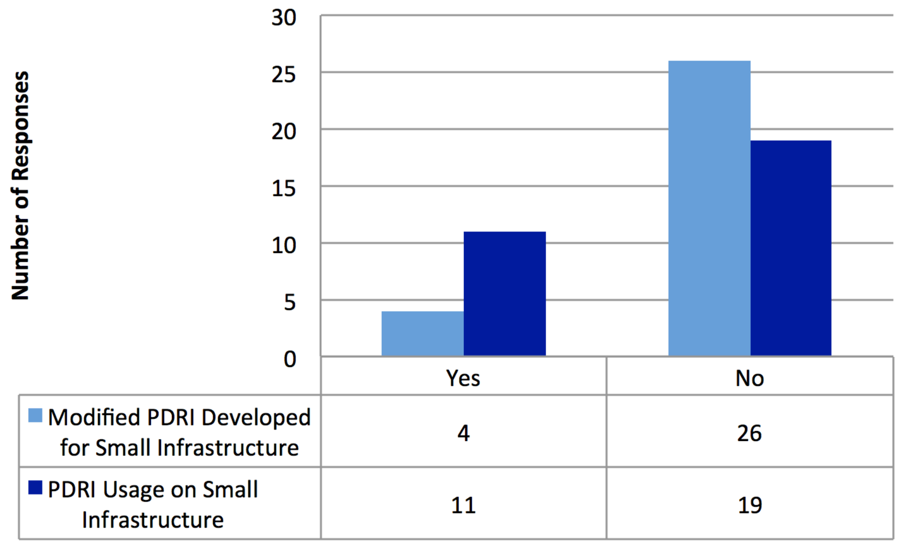


Figure 5-5. Usage and Modification of the PDRI for Small Projects within Survey Respondent Organizations

5.3.3. Small Project vs. Large Project Differentiators

Figure 5-6 summarizes the survey responses regarding adequacy of the sixteen separate metrics posed as possible differentiators between small and large projects, listed in the rank-order of their associated yes and no responses. Respondents only clearly agreed (i.e., responded "yes") that three of the metrics posed were used in their organizations to differentiate between small and large projects: total installed cost, engineering effort, and Sources of Funding. Three of the metrics had total agree/disagree (i.e., yes and no) responses that were very close and could be considered possible differentiators: Construction Duration, Availability of Core Team Members and Number of Core Team Members. Respondents clearly disagreed (i.e., responded "no") with ten of the metrics, including: Project Visibility External to Organization (Public), Extent of Permitting, Types of Permits, Number of Trade Contractors, Management of Public

Outreach Effort, Extent of Public Outreach Effort, Number Jurisdictions Involved, ROW parcels required, ROW procurement effort, Existing Utility Provider Interface & Coordination.

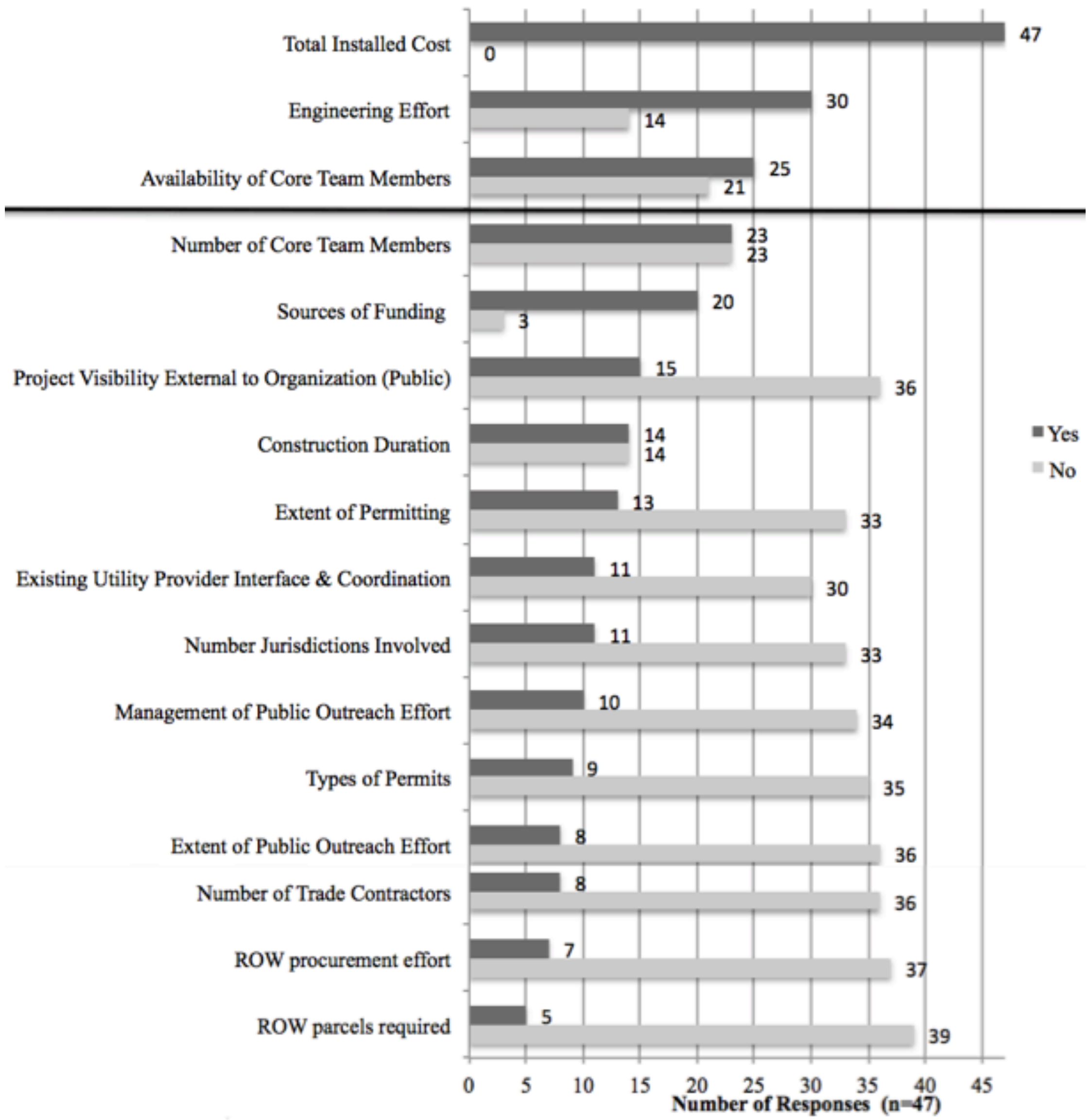


Figure 5-6. Survey Responses Regarding Project Size Differentiation Metrics

5.3.4. Discussion of Survey Results and Comments from Respondents

The responses shown in Figure 5-2 matched the assumptions of the research team prior to the survey, as well as the results found in Gao et al. (2002), that the number of small projects completed in many organizations is substantial, but do not make up a large percentage of the total capital expenditure. The amount of expenditure is still considerable though, with a majority of the respondents estimating that 11-30 percent or 31-50 percent of their capital expenditure is spent on small projects while approximately half of their total number of projects are small projects.

Total installed cost was the metric most agreed upon by the survey respondents, as shown in Figure 5-6. This finding aligns with previous research, as well as the opinions of the research team, that cost alone is the most common differentiator in most organizations as to what is considered a small vs. a large project. Approximately fifty percent of the participants agree that less than $20 million is the break point regarding what is considered a "small project," but responses suggest that the break point can range from $10 million to $40 million. These responses show that with such a large discrepancy across the industry, defining a specific dollar amount as the sole differentiator would not be valid. Responses regarding engineering effort follow a similar logic to total installed cost. Most respondents agreed that this metric differentiates small projects from small, and many support the break point suggested (5,000 hours). Interestingly, equal numbers of respondents agreed and disagreed that construction duration differentiates small projects from large. The majority of the respondents that felt construction duration differentiated small and large projects also agreed with the breakpoint of 12 months;

however four respondents suggested a different breakpoint ranging from 6, 9, 12 and 18 months..

Comments regarding the metrics that had varied agree/disagree responses, provided insight that project complexity should be considered when planning for a small project. Of the remaining metrics, approximately 60% of respondents felt that the following metrics would not differentiate a small project from a large one: Project Visibility External to Organization (Public), Extent of Permitting, Types of Permits, Number of Trade Contractors, Management of Public Outreach Effort, Extent of Public Outreach Effort, Engineering Effort, Number Jurisdictions Involved, ROW parcels required, ROW procurement effort, Existing Utility Provider Interface & Coordination

5.4. Summary

Research Team 314a surveyed 47 individuals from CII member organizations to discern the current metrics utilized to differentiate between small and large industrial projects, as well as the prevalence of small projects, and typical front end planning practices employed for small projects. The survey results showed that small projects make up approximately half of the projects completed in the infrastructure sector, planning of these projects varies greatly across the industry, and based on industry perceptions, the metrics posed were largely considered inappropriate for use in differentiating between small and large projects. Survey respondent commentary also suggested that a PDRI tool specifically for small projects should be less granular than the PDRI tools used for large projects, and such a tool should require less time to assess a project's scope definition.

Table 5-2 provides the definition for "small industrial project" gleaned from the survey responses. The author in conjunction with Research Team 314a utilized the definition provided in Table 5-2 to help weighting workshop volunteers select appropriate projects for use, described further in the next chapter.

Table 5-2. Small Infrastructure Project Definition From Survey Responses

PROPOSED METRICS	INDICATORS
Total Installed Cost	Less than $20 Million
Engineering Effort	Less than 5000 Hours
Construction Duration	6-12 Months
Number of Core Team Members	Less then 10 individuals
Availability of Core Team Members	Part-time availability
Project Visibility External to Organization (Public)	Moderate
Extent of Permitting	None to moderate permitting
Number Jurisdictions Involved	1-3 jurisdiction
Existing Utility Provider Interface & Coordination	Minimal to Moderate
Sources of Funding	Singular
Types of Permits	None to local/state permits
Number of Trade Contractors	3-4 separate trade contractors
Extent of Public Outreach Effort	Minimal to Moderate
Management of Public Outreach Effort	Project Team
Right Of Way (ROW) procurement effort	Minimal to Moderate
Right Of Way (ROW) parcels required	1-2 parcels

Research Team 314a determined that all of the metrics considered in the survey might be more suitably thought of as *indicators* of the level of project complexity, as opposed to *differentiators* between small and large projects, based on the comments provided by the survey respondents.

CHAPTER SIX

PDRI DEVELOPMENT PROCESS

This chapter details the steps involved in developing the PDRI – Small Infrastructure. Specifically, the chapter outlines the results of data obtained during weighting workshops, and how input obtained from these workshops was used to develop the final PDRI element descriptions and weights. This chapter includes a description of workshop facilitation, participant demographics, and data screening techniques, along with findings from the analyses of the finalized PDRI, and instructions on "how to use" the PDRI – Small Infrastructure.

6.1. Background of the PDRI – Small Infrastructure Projects

The thorough analysis of planning tasks recommended for infrastructure projects completed by CII Research Team 268 led to the development of the PDRI – Infrastructure. The tool has successfully been used to assess the level of scope definition on many infrastructure construction projects across the globe since its initial publication. Research Team 314a felt it prudent to use this document as the baseline for developing the PDRI – Small Infrastructure element descriptions.

The team was initially broken down into three sub-teams, each separately focusing on one of the three PDRI sections (Basis of Decision, Basis of Design, Execution Approach). The sub-teams reviewed and scrutinized the element descriptions in each section for applicability to small projects over the course of five months and several separate team meetings. The sub-teams utilized brainstorming sessions during team meetings, web-based conference calls, and individual reviews to complete this evaluation. Non-pertinent elements and "items to-be considered" bullets were removed, re-written, or combined with other elements. New elements were developed as necessary. The entire research team thoroughly reviewed all of the elements during four separate team meetings, and decided upon the final set of element descriptions after rigorous discussion and debate. The team broke the 40 element descriptions into three sections and eight categories to keep the same "look and feel" structure as the previously developed PDRIs.

Industry volunteers familiar with small infrastructure projects were asked to provide feedback regarding the element descriptions during the weighting workshops (described in further detail in the following sections). The workshop facilitators noted all items brought up during workshop discussions. Each participant could also record additional thoughts on "Suggestions for Improvement" sheets. Appendix E includes a sample copy of this form. The author along with RT 314a reviewed all comments collected during the workshops, and revised the element descriptions as appropriate after the comments were thoroughly vetted by the entire research team. No elements were added or deleted after the workshop sessions had begun. Figure 6-1 shows the finalized list of element descriptions. Appendix B includes the complete list of elements and their descriptions.

I. BASIS OF PROJECT DECISION

A.	**Project Alignment**	**B.**	**Project Requirements**
A.1	Need & Purpose Statement	B.1	Functional Classification & Use
A.2	Key Project Participants	B.2	Physical Site
A.3	Public Involvement	B.3	Dismantling & Demolition Requirements
A.4	Project Philosophies		
A.5	Project Funding		
A.6	Preliminary Project Schedule		

II. BASIS OF DESIGN

C.	**Design Guidance**	**D.**	**Project Design Parameters**
C.1	Lead/Discipline Scope of Work	D.1	Capacity
C.2	Project Codes and Standards	D.2	Design for Safety & Hazards
C.3	Topographical Surveys & Mapping	D.3	Civil and Structural
C.4	Project Site Assessment	D.4	Mechanical and Equipment
C.5	Environmental & Regulatory Consideration	D.5	Electrical and Controls
C.6	Value analysis	D.6	Operations and Maintenance
C.7	Construction Input		
E.	**Location And Geometry**	**F.**	**Associated Structures & Equipment**
E.1	Schematic Layouts	F.1	Support Structures
E.2	Alignment and Cross-Section	F.2	Hydraulic Structures
E.3	Control of Access	F.3	Miscellaneous Elements
		F.4	Equipment List

III. EXECUTION APPROACH

G.	**Execution Requirements**	**H.**	**Engineering/Construction Plan And Agreements**
G.1	Land Acquisition Strategy	H.1	Design/Construction Plan & Approach
G.2	Utility Adjustment Strategy	H.2	Project Cost Estimate and Cost Control
G.3	Procurement Strategy	H.3	Project Schedule and Schedule Control
G.4	Owner Approval Requirements	H.4	Project Quality Assurance & Control
G.5	Intercompany and Interagency Coordination	H.5	Safety, Work Zone & Transportation Plan
		H.6	Project Commissioning/Closeout

Figure 6-1. PDRI SECTIONS, Categories, and Elements

A basic tenet of front end planning is that not all items to be assessed are equally critical to project success. Certain elements are higher in the hierarchical order than others with respect to their relative importance. An analysis was necessary to “weight” the elements accordingly. The next section describes in detail the weighting workshop sessions held to gather feedback from industry professionals familiar with small infrastructure projects regarding the sufficiency and prioritization of the elements developed by the research team

6.2. PDRI Weighting Workshops

The author in conjunction with RT 314a collected element weighting data through focus group sessions, referred to as “weighting workshops.” This method was successfully utilized by each of the previous PDRI research teams, the details of which can be found in Gibson Jr and Whittington (2009). Workshops were held in multiple locations in an effort to gain a variety of industry perspectives related to typical small infrastructure projects. Industry members of the research team hosted the workshops, and recruited industry professionals to participate. Table 6-1 provides the workshop locations, dates, and number of participants.

Table 6-1. Weighting Workshops

Location	Date	Number of Participants
Houston	February 10th, 2016	20
Tempe	February 23rd, 2016	5
Mobile	March 1st, 2016	6
New York	March 10th, 2016	10
Detroit	April 6th, 2016	15
London, UK	April 14th, 2016	8
Tempe 2	April 21st, 2016	7

The seventy-one workshop participants represented multiple owner and contractor organizations, industries, and geographic sectors. A list of participating organizations can be found in Appendix A. The industry participants were professionals such as project managers, project engineers, program managers, engineering managers, and construction managers. Figure 6-2 provides some demographical background information about the participants and the projects they used for reference during the workshops.

- 71 Weighted PDRI forms completed
- 71 participants
- 1,261 Collective years of experience
  - 17 years (on average) estimating/project management experience
  - 60% of experience (on average) related to small projects
  - 51% of experience (on average) related to infrastructure construction projects
- 43 Organizations represented
- $529 Million in project cost represented

Figure 6-2. Weighting Workshop Summary

6.3. Workshop Process

Research Team 314a facilitated each of the workshop sessions hosted by several industry members from RT 314a. All industry members were tasked with recruiting practitioners familiar with small infrastructure projects to participate in the workshop sessions. Research Team 314a sent information packets electronically to all confirmed workshop participants prior to each session; these included background information about the research study and the purpose of the workshop itself. Similar information packets were sent out prior to all of the workshop sessions. Potential workshop participants were asked to review all of the “pre-read’ information prior to the workshop sessions, which included familiarizing themselves with specific front end planning and project performance details of a sample small infrastructure project recently completed by their organization that met the small project "definition" developed by the research team. The sample project would be used as reference throughout the workshop session.

Workshop participants were also provided with a packet at the beginning of each session that included: an agenda for the session, instructions for evaluating the PDRI, PDRI – Small Infrastructure element descriptions, blank weighting factor evaluation sheets, participant background information sheet, suggestions for improvement sheet, copies of the workshop session presentation slides, and an unweighted score sheet. Appendix D includes a copy of a typical workshop session packet. The packet contents were color-coded to assist in describing and collecting each research instrument.

Each session began with a Microsoft PowerPoint™ presentation (included in Appendix D) that briefly described the objectives of the workshop, background of the research project, background of the PDRI, and instructions for evaluating the PDRI – Small Infrastructure documents. Each of the forty PDRI element descriptions were then reviewed, one by one, once the background presentation was complete. Figure 6-3 provides an example element description for element A.5 Project Funding.

A.5 Project Funding

Funding of projects can come from various sources and must be identified, budgeted and documented for the project. Preliminary cost estimates are required to determine how much funding a project needs, and in turn, whether or not the project is worth pursuing. Items to consider should include:

- ☐ Congruity with local infrastructure projects and programs
- ☐ Comparison of funding options (public vs. private, expense vs. capital)
- ☐ Cash flow, spend plan, funding participants, cost drivers and contingencies
- ☐ Initial estimates (e.g., engineering, construction, right-of-way, and operating costs)
- ☐ Input into any required funding approval documents
- ☐ Other (user defined)

Figure 6-3. Example Element Description, A.5 Project Funding

Workshop participants were asked to consider all pertinent factors that could effect project success related to each element, including changes in project schedule, cost, or scope changes. Participants were then asked to assign two weights to each element based on their sample project: the first weight was to be based on if the items described in the element were completely defined and accounted for just prior to beginning detailed design, and the second weight was to be based on if the items described in the element were not defined or accounted for at all just prior to detailed design. The weights correspond to Level 1 and Level 5 scope definition, respectively. Workshop facilitators encouraged participants to think of the weights as a contingency for each element, i.e., what contingency would you assign to this element if it were completely defined, or incomplete or poorly defined, at a point just prior to detailed design. Preceding PDRI research teams concluded that participants involved in the weighting workshops tended to provide linear interpolation of their contingency responses for definition levels 2, 3, and

4. The research team chose not to collect contingency amounts for these definition levels from the workshop participants, due to these values being fairly simple to calculate. The interpolation calculation method used by the author is described in detail later in this chapter.

Participants recorded the two weights as contingency amounts on blank weighting factor evaluation sheets. Contingency was defined as the element's individual impact on total installed cost, stated as a percentage of the overall estimate at the point just prior to the commencement of detailed project design. Contingency amounts were to be given as integers. Figure 6-4 provides an example of how a workshop participant would record the contingency amounts.

SECTION I - BASIS OF PROJECT DECISION								
CATEGORY Element		**Definition Level**						
		N/A	**1**	**2**	**3**	**4**	**5**	**Comments**
A. PROJECT ALIGNMENT								
A.1	Need & Purpose Statement		5%				10%	
A.2	Key Project Participants		10%				50%	
A.3	Public Involvement		20%				60%	
A.4	Project Philosophies	X						
A.5	Project Funding		5%				40%	
A.6	Preliminary Project Schedule		10%				50%	

Definition Levels
0 = Not Applicable 1 = Complete Definition 2 = Minor Deficiencies 3 = Some Deficiencies
4 = Major Deficiencies 5 = Incomplete or Poor Definition

Figure 6-4. Sample of Workshop Weighting Category A

The workshop facilitators conveyed that if an element were completely defined just prior to detailed design, it would logically have a lower contingency than if the element was not defined at all. The facilitators further explained that any amount of contingency could be given, as long as a relative consistency of element importance (as compared to the balance of elements in the tool) was kept for all responses. Participants were provided time at the end of each session to review their weights and ensure consistency of their responses.

It was noted that some elements (and possibly entire categories) might not be applicable to the projects being referenced by the participants. Non-applicable elements were described as elements that truly would not need to be considered during front end planning. Participants were instructed to indicate an element was not-applicable (i.e., N/A) by making a check in the N/A column, and not to list contingency amounts for either Level 1 or Level 5 definition (see Figure 6-4). Non-applicable elements were to be recorded separately from elements that would not need any contingency (i.e., zero percent contingency for Level 1 definition) if the element were completely defined prior to detailed design. Assessing the elements in this fashion mitigated the possibility of receiving incorrect data that could possibly skew the overall responses during the data analysis.

The facilitators addressed any questions posed by the workshop participants as the elements were individually reviewed. Adequate time was provided for participants to assess each element, but not enough time to "over think" the elements, keeping a consistent flow throughout the session. Participants were asked to record additional thoughts/comments about specific elements or the PDRI in general in either the comments section of the blank weighting factor evaluation sheets, or the suggestions for improvement sheet. Research Team 314a reviewed all commentary received, and incorporated it into the PDRI element descriptions and score sheet where applicable. The comments were reviewed by the entire research team during subsequent team meetings.

Following the review of the element descriptions, the facilitator asked each participant to fill out an unweighted score sheet for their project, where they assessed the level of definition for each element at the end of front end planning. This data, along with the project performance data the participants provided, was used to test the effectiveness of the PDRI – Small Infrastructure in predicting project performance. Chapter 7 discusses PDRI testing.

In summary, the weighting workshops for PDRI – Small Infrastructure largely followed the methodology used by Research Team 113, PDRI – Industrial, Research Team 155, PDRI – Building, and Research Team 268, PDRI – Infrastructure. The key difference was that the team collected PDRI testing data at the workshop, rather than following the workshop. Industry practitioners were asked to weight each element based on relative importance to typical small infrastructure projects. The workshops were very successful in both collecting weighting data and receiving insight from experience industry professionals on the value and use of the tool. The workshops also allowed the researchers to expediently collect data to test the tool, namely project performance data and a PDRI assessment of the project using the unweighted score sheet. Workshop data was used to develop a weighted score sheet for the PDRI, as described in the next section, and to test the PDRI – Small Infrastructure, as described in Chapter 7.

6.4. Developing the PDRI Element Weights

The author reviewed the weighting factor evaluation sheets for completeness after each workshop. Responses from six workshop participants were not used in the data analysis: one due to unresponsive answers (the participant did not follow instructions), another provided an out of scope project (industrial project), three due to lack of sufficient industry experience (i.e., less than 5 years). Finally, the author along with RT 314a removed one response from one organization, as that organization would otherwise have accounted for more that 10% of the data collected, which the author felt could skew the sample. The research team deemed data from the remaining responses satisfactory for analysis, and that data was normalized for statistical comparison.

6.4.1. Normalizing Process

The workshop facilitators did not provide a contingency range to the workshop participants. The only stipulation posed was that the contingency amounts provided should indicate the relative importance of each element as compared to the balance of elements in the tool. For example, if an element were given a Level 5 contingency amount of 20 percent, this element would be twice as critical to project success as an element that received a Level 5 contingency amount of 10 percent. This same consistency could be used by a separate workshop participant, but with different contingency amounts. For example, instead of using 20 percent and 10 percent, another participant may use 50 percent and 25 percent. In relative terms, both of these participants weighted the elements equally, with one element being twice as important to project success as the other. An issue arises when attempting to compare the responses from these two workshop participants, as the numerical values appear to be drastically different, when in fact both participants assign equal relative importance to the two elements at hand. Normalizing, or adjusting values to match a standard scale, is necessary to compare responses such as these.

The normalizing process consisted of four steps: (1) compiling all workshop participant data, (2) calculating non-applicable element weights, (3) calculating normalizing multipliers, and (4) calculating adjusted element weights. Figure 6-2 gives an excerpt of the data used for the normalization process for participant TX-160210-O-4 (Texas workshop on February 10, 2016, owner participant number 4). This figure is used throughout the explanation of the four normalization steps. The same methodology was used for all workshop participants. The research team chose to use the same scale as the previously developed PDRIs (e.g., sum of all Level 1 definitions equals 70, the sum of all Level 5 definitions equals 1000) for the normalization process.

Table 6-2. Excerpt of Data used for Normalizing Level 1 and Level 5 Weights for TX-160210-O-4

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
	Contingency Weight		Non-Applicable Elements		Normalizing Multiplier		Normalized Weight	
Element	Level 1	Level 5	Added Weight for 1's	Added Weight for 5's	Level 1 Multiplier	Level 5 Multiplier	Level 1	Level 5
A.1	10	40	-	-	1.18	3.63	18.2	145.3
A.2	1	10	-	-	1.18	3.63	1.8	36.3
A.3	N/A	N/A	1.6	20.6	1.00	1.00	1.6	20.6
A.4	2	30	-	-	1.18	3.63	3.6	109.0
A.5	N/A	N/A	1.7	28.5	1.00	1.00	1.7	28.5
A.6	1	10	-	-	1.18	3.63	1.8	36.3
B.1	N/A	N/A	1.2	23.6	1.00	1.00	1.2	23.6
B.2	1	5	-	-	1.18	3.63	1.8	18.2
-	-	-	-	-	-	-	-	-
G.1	N/A	N/A	1.9	33.6	1.00	1.00	1.9	33.6
G.2	1	3	-	-	1.18	3.63	1.8	10.9
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
H.6	2	6	-	-	1.18	3.63	3.6	21.8
Totals	35	246	6.4	106.3	-	-	70.00	1000.00

Step 1 – Compiling all workshop participant data

- In total, Research Team 314a collected data on 71 completed projects. Immediately, the author had to remove two projects from this sample – one was not an infrastructure project and one participant did not provide any project performance data. Weighting data from the remaining 69 workshop participants were compiled into one Microsoft Excel™ spreadsheet. Each participant was given an alphanumeric code based on the workshop in which they participated in, and the type of organization they represented. For example, TX-160210-O-4 stands for the Texas workshop, date of workshop, "O" denotes the participant represents an Owner organization, and participant number 4. The alphanumeric code was created to keep personal workshop participant and proprietary project information guarded.
- The data was categorized by element and definition level weights provided by the participants
- The Level 1 and Level 5 weights were totaled. As shown in columns 1 and 2, the total Level 1 and Level 5 elements weights given by workshop participant TX-160210-O-4 were 35 and 246 respectively.

Step 2 – Calculating Non Applicable Element Weights

- Non applicable elements notwithstanding, the basic process for normalizing a participant's Level 1 responses would be to divide 70 by the total Level 1 element weights, or 35 in this case. As shown in columns 1 and 2, four elements, A.3, A.5, B.1 and G.1, were not applicable to the project assessed by TX-160210-O-4. As previously stated, non-applicable elements should lower the potential Level 1 and

Level 5 scores on a pro-rata basis depending on the element weighting. To take this into account, weights were added to the non-applicable elements based on the average weight of that element from all workshop participants that considered the element applicable (shown in columns 3 and 4).

- The total Level 1 and Level 5 non-applicable elements weights attributed to workshop participant TX-160210-O-4 were 6.4 and 106.3, respectively.

Step 3 - Calculating Normalizing Multipliers

- Equation 1 shows the calculation for the Level 1 normalizing multiplier, used to normalize the Level 1 responses to a total score of 70.

$$Normalizing\ Multiplier = \frac{70 - Total\ Level\ 1\ Non - Applicable\ Weights}{Total\ Level\ 1\ Element\ Weights}$$

- Equation 2 shows the calculation for the Level 5 normalizing multiplier, used to normalize the Level 5 responses to a total score of 1000.

$$Normalizing\ Multiplier = \frac{1000 - Total\ Level\ 5\ Non - Applicable\ Weights}{Total\ Level\ 5\ Element\ Weights}$$

- The Level 1 and Level 5 normalizing multipliers calculated for workshop participant TX-160210-O-4 were 1.1818 and 3.63, respectively.

Step 4 – Calculating adjusted element weights

- Each individual element weight was multiplied by the normalizing factors to determine the participant's adjusted Level 1 and Level 5 weights, shown in columns 7 and 8. The result of totaling the adjusted weights for each element (including those considered non-applicable) at definition Level 1 and Level 5 equal 70 and 1000, respectively.

In summary, the normalization process for PDRI-Small Infrastructure followed the methodology used by Research Team 113, PDRI – Industrial, Research Team 155, PDRI – Building, Research Team 268, PDRI – Infrastructure, and Research Team 314, PDRI – Small Industrial. Workshop participant weighting scores were normalized to a standard scale for comparison purposes. The next section describes the screening of the adjusted element weights.

6.4.2. Screening the Data Using Boxplots

The author sought to include only those data sets that were as close to a normal distribution as possible to determine appropriate mean element weights that would be used to create the weighted score sheet. The author utilized SPSS™ and Microsoft Excel™ to calculate the descriptive statistics (e.g., mean, median, standard deviation, variance, skewness) after the adjusted element weights were developed. Analysis of descriptive statistic data revealed that several of the elements were either moderately or highly skewed, indicating that responses from several of the participants were skewing the overall data set.

The author generated boxplots in SPSS™ detailing the interquartile range, median, outliers (shown as circles in Figure 6-5), and extreme values (shown as stars in Figure 6-5) for each element, at both Level 1 and Level 5 weights to visually identify participant weights that were skewing the mean element weights. Figure 6-5 shows the boxplots for six element weights at definition Level 5 in Category A.

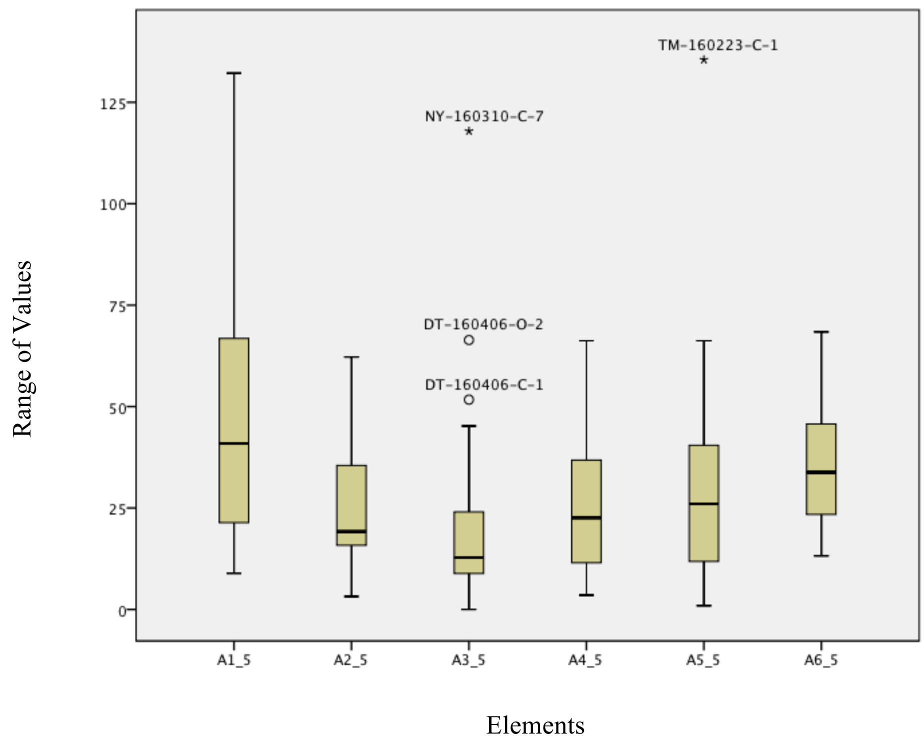


Figure 6-5. Boxplots of Category A, Definition Level 5 Weights

The author utilized Microsoft Excel™ to derive the interquartile range, median, outlier, and extreme value thresholds associated with each element. The author highlighted individual workshop participant element weights considered outliers or extreme, and calculated the total number of outliers and extremes per participant. The author also calculated "Contribution scores" (i.e., the amount a participant was skewing the data) for each workshop participant based on the number of outlier and extreme values. The contribution scores were calculated as:

$$Contribution\ Score = 3\ x\ (Number\ of\ Extremes) + \ 1\ x\ (Number\ of\ Outliers)$$

Table 6-3 shows each workshop participant's contribution score. Figure 6-6 provides the contribution scores (by score category) in a bar chart format. Viewing the weighting data in this fashion highlighted the contribution score ranges skewing the mean element weights the most, and ranges of scores that were relatively higher than the total workshop participant set.

Table 6-3. Workshop Participant Contribution Scores (Ranked Highest to Lowest)

Workshop Participant	Contribution Score	Workshop Participant	Contribution Score	Workshop Participant	Contribution Score
TX-160210-O-3	0	TX-160210-O-9	2	TM-160223-C-3	6
TX-160210-O-19	0	TX-160210-O-15	2	AL-160301-C-5	6
TM-160223-C-2	0	TX-160210-C-16	2	DT-160406-C-5	6
NY-160310-C-7	0	NY-160310-C-6	2	DT-160406-C-15	6
DT-160406-O-4	0	DT-160406-C-10	2	TM-160223-O-5	7
DT-160406-C-11	0	LD-160414-C-4	2	DT-160406-O-12	7
DT-160406-O-14	0	LD-160414-C-8	2	LD-160414-O-6	7
LD-160414-O-2	0	PX-160420-O-3	2	TX-160210-C-8	8
PX-160420-O-7	0	PX-160420-O-6	2	TX-160210-C-10	8
TX-160210-O-2	1	AL-160301-O-1	3	DT-160406-O-2	8
TX-160210-O-5	1	AL-160301-C-3	3	DT-160406-C-7	8
TX-160210-O-6	1	AL-160301-C-6	3	LD-160414-O-7	8
TX-160210-C-11	1	DT-160406-O-6	3	PX-160420-O-4	8
TX-160210-C-13	1	PX-160420-O-5	3	TM-160223-C-1	9
TM-160223-O-4	1	TX-160210-O-17	4	PX-160420-O-2	9
AL-160301-C-4	1	NY-160310-O-2	4	NY-160310-O-1	10
DT-160406-C-1	1	NY-160310-O-4	4	DT-160406-C-9	10
DT-160406-C-3	1	NY-160310-C-8	4	NY-160310-C-5	12
DT-160406-C-8	1	LD-160414-O-3	4	TX-160210-O-18	13
DT-160406-O-13	1	TX-160210-O-1	5	AL-160301-C-2	13
LD-160414-O-5	1	TX-160210-O-4	5	LD-160414-C-1	14
				NY-160310-C-3	16
				NY-160310-C-9	16

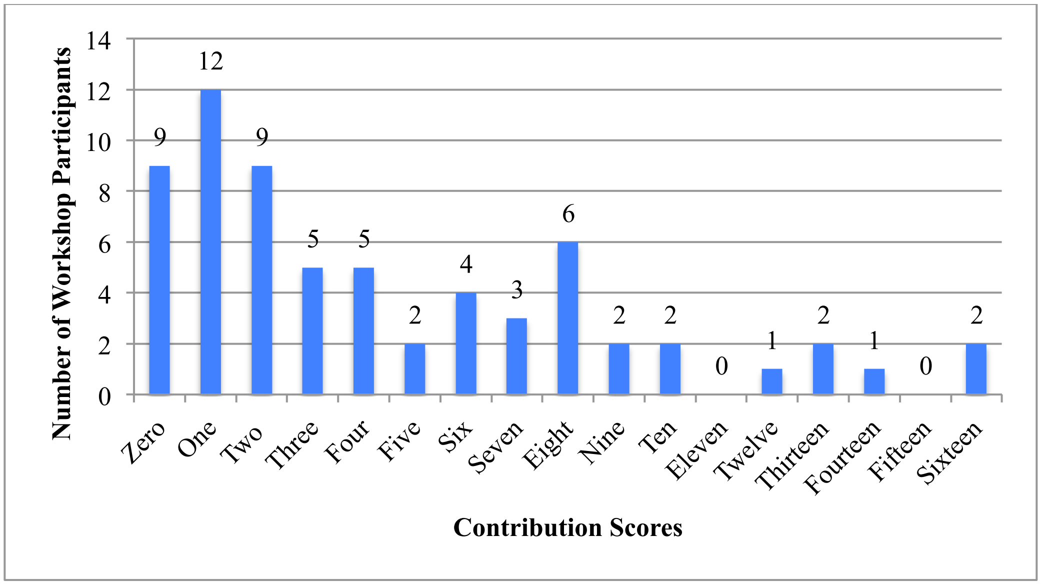


Figure 6-6. Workshop Participant Contribution Scores (By Score Category) (n=65)

Previous PDRI research teams had contemplated five options for removing data that was skewing the mean element weights. The first option was to decide if the outliers and extremes were still valid data points and use all data sets and points to determine the element weights. The second option was to throw out entire data sets, or workshop participants, who had contribution scores deemed “too high” or “too low” or “too far away from mean” by the research team. The third option was to keep all data sets but remove only the data points that were outliers or extremes on any given element. The fourth option was a combination of options two and three, to remove entire data sets for the workshop participants whose contribution score was determined to be “too high” by the research team, similar to option two, but also remove any remaining outliers and extremes on individual elements, similar to option three. The fifth and final option was to remove only those data points that were calculated as extremes and leave the data points calculated as outliers.

Option two, to remove entire data sets of those workshop participants whose contribution scores were determined to be “too high”, was used. This was the option chosen by all of the previous PDRI research teams, and Research Team 314a deemed it prudent for this research effort. The team determined that workshop participants with a contribution score greater than ten should be removed from the data set. This was a logical conclusion based on the groupings of scores shown in Table 6-3 and Figure 6-6. Data sets from six workshop participants (TX-160210-O-18, AL-160301-C-2, NY-160310-C-3, NY-160310-C-5, NY-160310-C-9, LD-160414-C-1) were removed from the total data set.

The author utilized the same procedure for normalizing weights and calculating adjusted element weights on the remaining workshop participant element weights. The author also used the same procedure to create boxplots, and calculate interquartile range, median, outlier, and extreme value thresholds, and contribution scores. Appendix C includes the set of boxplots from this analysis. The author found that several workshop participants had contribution scores that could be considered “too high” (i.e., higher than ten) after completing the second round of analysis. The author realized that after removing these data sets from the total data set, the mean element scores were only slightly adjusted, and that this slight adjustment would make little difference when developing the final PDRI score sheet. No further workshop participant responses were removed from the analysis based on this determination.

The next section describes the procedures used for finalizing the PDRI – Small Infrastructure score sheet, including interpolation of scores for Levels 2, 3, and 4, and rounding of element weights.

6.4.3 Finalizing the PDRI Score Sheet

The individual Level 1 and Level 5 element scores were developed through the data analysis described in the previous section, as the typical 70-1000 PDRI scoring range was used during the normalization process. The next step was to determine the Level 2, 3, and 4 element weights. Calculating these scores was done by linear interpolation between the Level 1 and Level 5 scores already established. The weights were calculated as follows:

Level 2 Weight = ((Level 5 Weight – Level 1 Weight) / 4) + Level 1 Weight

Level 3 Weight = ((Level 5 Weight – Level 1 Weight) / 4) + Level 2 Weight

Level 4 Weight = ((Level 5 Weight – Level 1 Weight) / 4) + Level 3 Weight

The calculations used to determine the adjusted element weights for Levels 1 and 5, and interpolated weights for Level 2, 3, and 4 produced non-integer numbers. Rounding of each number was necessary to complete the PDRI score sheet, as only integers are used as weights on the PDRI score sheets. A standard rounding procedure was used, where numbers with decimals equal to or greater than .50 were rounded up, and numbers with decimals less than .50 were rounded down. This held true for a majority of the weights, but a few of the element weights that were just below .50 were rounded up instead of down so that the Level 1 and Level 5 scores could exactly equal 70 and 1000, respectively. Adjusting numbers in this fashion was deemed acceptable by the research team, as the PDRI is not necessarily a precision tool; slight adjustments to scores make little difference to project success. Table 6-4 provides the results of the interpolation calculations (including rounding).

Table 6-4. Results of Interpolation for Level 2, 3, and 4 Element Weights

	Definition Level						Definition Level				
	1	2	3	4	5		1	2	3	4	5
A.1	2	16	29	42	55	F.1	1	7	12	16	22
A.2	1	6	11	16	21	F.2	2	6	10	14	18
A.3	1	6	11	15	20	F.3	1	5	9	12	16
A.4	1	9	16	23	30	F.4	2	7	13	18	23
A.5	2	9	16	23	29	**F Totals**	**6**	**25**	**44**	**60**	**79**
A.6	3	11	19	26	34	**Sec II Totals**	**33**	**144**	**254**	**360**	**470**
A Totals	**10**	**57**	**102**	**145**	**189**	G.1	2	10	18	27	35
B.1	1	7	12	18	23	G.2	2	8	14	19	25
B.2	3	12	21	30	39	G.3	2	7	13	18	24
B.3	2	8	13	19	24	G.4	1	5	9	13	17
B Totals	**6**	**27**	**46**	**67**	**86**	G.5	1	6	11	16	21
Sec I Totals	**16**	**84**	**148**	**212**	**275**	**G Totals**	**8**	**36**	**65**	**93**	**122**
C.1	2	9	17	24	31	H.1	2	7	13	18	23
C.2	2	8	14	20	26	H.2	3	9	15	22	28
C.3	2	9	15	22	28	H.3	2	9	15	22	28
C.4	2	10	17	25	32	H.4	2	7	11	16	21
C.5	2	9	16	23	31	H.5	2	6	10	14	18
C.6	1	4	8	11	14	H.6	2	5	8	12	15
C.7	2	8	14	19	25	**H Totals**	**13**	**43**	**72**	**104**	**133**
C Totals	**13**	**57**	**101**	**144**	**187**	**Sec III Totals**	**21**	**79**	**137**	**197**	**255**
D.1	2	8	14	21	27						
D.2	2	7	12	17	22						
D.3	2	7	12	17	22	**PDRI Totals**	**70**	**307**	**539**	**769**	**1000**
D.4	2	7	12	17	22						
D.5	1	7	12	17	23						
D.6	1	5	9	12	16						
D Totals	**10**	**41**	**71**	**101**	**132**						
E.1	1	8	15	22	29						
E.2	2	8	14	20	26						
E.3	1	5	9	13	17						
E Totals	**4**	**21**	**38**	**55**	**72**						

The author completed a final check of the element weights for definition Levels 1-5 and a weighted score sheet created after the data interpolation. Appendix B provides the weighted score sheet. The score sheet has a definition level 0 added for elements not applicable to projects being assessed with the tool.

6.5. Analyzing the Weighted PDRI

The weighted element score sheet can be used to highlight sections, categories, and elements of greatest importance to project success. Reviewing only the highest weighted elements could be a method to quickly assess a project if a project team had limited time. Project teams should focus on the sections, categories and elements that have the highest contribution to the PDRI score. Section II, Basis of Design, has the highest total score. Elements in this section have the highest probability to effect project success if the scope of a project were such that all categories would be pertinent. Figure 6-7 shows the PDRI sections and their corresponding Level 5 weights.

Section	Weights
SECTION I - BASIS OF PROJECT DECISION	275
SECTION II - BASIS OF DESIGN	470
SECTION III - EXECUTION APPROACH	255
Total	1000

Figure 6-7. PDRI Sections and Total Level 5 Weights

Figure 6-8 provides a breakout of each of the three sections based on their categories. Category A, Project Alignment, carries the highest weight of all of the categories, followed by Category C, Design Guidance, and Category H, Engineering/Construction Plan And Agreements. If a project team wanted to focus on specific elements that would have the highest impact on project success, concentrating on elements with the highest weights would be prudent.

Category	Weights
Section I	
A. Project Alignment	189
B. Project Requirements	86
Section II	
C. Design Guidance	187
D. Project Design Parameter	132
E. Location and Geometry	72
F. Associated Structures & Equipment	79
Section III	
G. Execution Requirements	122
H. Engineering/Construction Plan and Agreements	133

Figure 6-8. PDRI Categories and Total Level 5 Weights

Figure 6-9 provides a listing of the top eight PDRI elements based on Definition Level 5 weight. The workshop participants judged these elements as being the most critical to project success for people and freight, fluids, and energy small infrastructure projects. The top eight elements make up nearly 30 percent of the total weight of all elements. Four of the eight elements are included in Section I, three elements are included in Section II, and one element is included in Section III.

Rank	Element	Element Description	Definition Level 5 Weights	Section
1	A.1	Need & Purpose Statement (Highest)	55	I
2	B.2	Physical Site	39	I
3	G.1	Land Acquisition Strategy	35	III
4	A.6	Preliminary Project Schedule	34	I
5	C.4	Project Site Assessment	32	II
6	C.1	Lead/Discipline Scope of Work	31	II
	C.5	Environmental & Regulatory Considerations	31	II
8	A.4	Project Philosophies	30	I
		Total	287	

Figure 6-9. Top Eight PDRI Elements by Weight (Definition Level 5)

6.5.1. Element Weights for Project Types

The author along with Research Team 314a were curious about how different small infrastructure project subsets were represented within the PDRI, in addition to understanding the blended results of the small infrastructure project types (represented by the workshop participants). The question was "how would the element weights change if a select group of participants or project types were evaluated separately?" The author analyzed the data in the following two ways to address this question:

- Element weight ranking by owners vs. engineers/contractors
- Element weight ranking on People & Freight, Energy, and Fluids projects

The next section describes the results of this analysis.

6.5.2. Comparison of Owners and Engineers/Contractors

Thirty-eight workshop participants were owners and 33 were engineers/contractors, of the 71 total workshop participants used for developing the weighted PDRI score sheet. The author categorized and analyzed the element weights reported by these workshop participants separately to discern if there was a significant difference between the two data sets. Figure 6-10 details the top ten elements based on Definition Level 5 ranks of the two groups. Although there were differences between the two data sets, in general, the element weight rankings were fairly similar. The analysis also highlighted areas where owners and engineers/contractors would typically differ in ranking the importance of different project aspects.

Owners

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	48
2	G.1	Land Acquisition Strategy	38
3	B.2	Physical Site	35
4	C.4	Project Site Assessment	33
5	H.2	Project Cost Estimate and Cost Control	32
	E.1	Schematic Layouts	32
	C.1	Lead/Discipline Scope of Work	32
8	A.6	Preliminary Project Schedule	31
	A.4	Project Philosophies	31
10	C.3	Topographical Surveys & Mapping	30
		Total	342

Engineers/Contractors

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	64
2	B.2	Physical Site	44
3	C.5	Environmental & Regulatory Considerations	42
4	A.6	Preliminary Project Schedule	39
5	A.5	Project Funding	37
6	C.4	Project Site Assessment	31
	C.1	Lead/Discipline Scope of Work	31
8	G.1	Land Acquisition Strategy	30
9	H.3	Project Schedule and Schedule Control	29
	D.1	Capacity	29
		Total	376

Figure 6-10. Comparison of Top Ten Definition Level 5 Ranks from Owners and Engineers/Contractors

Elements A.1, Need & Purpose Statement, and B.2 Physical Site ranked in the top three highest weighted elements for both owners and contractors/engineers. This shows a consensus of how important it is to understand what the objectives of the project are, how the objectives will be accomplished, and what financial considerations will be necessary to complete the objectives of typical small infrastructure projects. The other four elements included in the top ten for Owners and Contractors/Engineers were A.6 Preliminary Project Schedule, C.4 Project Site Assessment, C.1 Lead/Discipline Scope of Work and G.1 Land Acquisition Strategy.

Owners highly ranked elements such as A.1, Need & Purpose Statement, G.1 Land Acquisition Strategy and B.2 Physical Site. These elements stress the importance of understanding operational characteristics of the project, as opposed to construction characteristics. An operational focus would be expected of an owner more than a contractor/engineer, as they will “live with” the final outcomes of the project long after construction is completed.

Engineers/contractors highly ranked elements such as C.5 Environmental & Regulatory Considerations, A.6 Preliminary Project Schedule, A.5 Project Funding, C.4 Project Site Assessment and H.3 Project Schedule and Schedule Control. These elements emphasize a typical area of project scope on many infrastructure construction projects, the environmental assessment, as well as the project schedule and site, in addition to the funding of a project. It is incumbent for engineers/contractors to address these project aspects during front end planning if small infrastructure projects are to be successful for those actually designing and building them.

The difference in rankings is not enough to warrant the creation of separate PDRIs for owners and engineers/contractors, but does suggest areas where these different groups may want to focus their efforts during front end planning to mitigate the potential of future risks related to project unknowns. In the end, RT 314a felt that it was important to keep the PDRI blended with both owner and engineer/contractor perspectives to better represent a true risk level during assessment.

6.5.3. Comparison of People & Freight, Fluids and Energy Projects

This tool and these descriptions have been developed to address a variety of types of small infrastructure projects that are "horizontal" in nature and connect nodes (e.g., buildings and industrial facilities) in different systems. Three basic varieties of projects are addressed in this tool: 1) projects that convey people and freight, such as runway resurfacing and intersection rebuilds, 2) projects that convey fluids, such as reconditioning pipelines and pipeline relocations, and 3) projects that convey energy, such as transmission lines or electrical ductbank insulation.

Workshop participants were asked to provide typical small infrastructure projects recently completed in their organization, aligned to People & Freight, Fluids, or Energy project types. Twenty-four projects were people & freight related, twenty-nine were fluids related and 17 projects were energy related, of the 71 total projects used by the workshop participants for the final PDRI element weighting. The element weights reported on these projects (regardless of owner or engineer/contractor participant) were categorized separately and analyzed to discern if there was a significant difference between the three data sets. Figure 6-11 details the top ten elements based on Definition Level 5 ranks of the three project types (People & Freight, Fluids, and Energy). The analysis shows some differences between the three data sets, but in general, the element weight rankings were fairly similar. This is analogous to the owner and engineer/contractor comparison described in the previous section.

People & Freight

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	46
2	B.2	Physical Site	42
3	A.5	Project Funding	40
4	C.4	Project Site Assessment	35
5	C.5	Environmental & Regulatory Considerations	34
	E.1	Schematic Layouts	34
7	A.4	Project Philosophies	32
	G.1	Land Acquisition Strategy	32
9	A.6	Preliminary Project Schedule	31
10	G.2	Utility Adjustment Strategy	30
		Total	356

Fluids

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	71
2	B.2	Physical Site	41
3	D.1	Capacity	34
4	A.6	Preliminary Project Schedule	36
5	C.5	Environmental & Regulatory Considerations	33
6	C.1	Lead/Discipline Scope of Work	32
7	A.4	Project Philosophies	31
	G.1	Land Acquisition Strategy	31
9	C.3	Topographical Surveys & Mapping	29
10	E.1	Schematic Layouts	28
		Total	366

Energy

Rank	Element	Element Description	Definition Level 5 Weight
1	G.1	Land Acquisition Strategy	56
2	A.6	Preliminary Project Schedule	40
3	A.1	Need & Purpose Statement	39
4	C.4	Project Site Assessment	37
5	C.1	Lead/Discipline Scope of Work	36
6	B.2	Physical Site	35
	H.3	Project Schedule and Schedule Control	35
8	A.3	Public Involvement	33
9	H.2	Project Cost Estimate and Cost Control	32
	C.5	Environmental & Regulatory Considerations	32
		Total	375

Figure 6-11. Comparison of Top Ten Definition Level 5 Ranks from People & Freight, Fluids and Energy Projects

Five elements are ranked in the top ten highest weighted elements for People & Freight, Fluids, and Energy Projects: A.1 Need & Purpose Statement, B.2 Physical Site, C.5 Environmental & Regulatory Considerations, G.1 Land Acquisition Strategy, and A.6 Preliminary Project Schedule. This consistency confirms that the PDRI – Small Infrastructure is suitable for assessing People & Freight, Fluids, and Energy Projects. Research Team 314a felt it prudent to keep a blended PDRI to reflect the issues of People & Freight, Fluids, and Energy small infrastructure project types.

6.6 Summary

This chapter outlined the process that the author in conjunction with Research Team 314a followed to develop the PDRI – Small Infrastructure. Data was primarily collected through several workshops held across the United States and the United Kingdom. The workshop facilitation was described and the process of weighting elements was given. This chapter also discusses interesting comparisons of element weights based on workshop participant affiliation (i.e., Owner versus Engineer/Contractor) and project types.

CHAPTER SEVEN

PDRI TESTING

This chapter summarizes the testing process for the PDRI – Small Infrastructure. The purpose of the testing process was to determine the efficacy of the PDRI – Small Infrastructure tool to predict project success. Research Team 314a utilized two methods to test the efficacy of the tool: statistically comparing PDRI scores vs. cost, schedule, change, financial performance, and customer satisfaction, on a sample of recently completed small infrastructure projects, and soliciting industry volunteers to assess projects currently in the front end planning phase (i.e., in-progress projects) with the tool. This chapter describes the testing questionnaires, supporting statistical analysis data, and conclusions derived from the statistical analysis.

7.1. Completed Projects

Research Team 314a collected completed project data in order to test the hypothesis that scores derived by assessing a project with the PDRI – Small Infrastructure tool correlate to levels of project performance. A higher PDRI score indicates incomplete scope definition during front end planning, leading to poor project performance. A lower PDRI score indicates sufficient scope definition, leading to improved project performance.

Research Team 314a sought People & Freight, Fluids, and Energy infrastructure projects that met the “small project” definition provided in Chapter 5. Workshop participants provided the data for PDRI testing. The team asked that volunteers provide project data on both "successful" and "unsuccessful" projects so that a thorough analysis of typical small infrastructure projects could be completed.

7.1.1. Testing Data

Research Team 314a developed a multi-part questionnaire of open and closed-ended questions to collect information on recently completed successful and unsuccessful small infrastructure projects. Appendix E includes a copy of the questionnaire (Project Background). The Project Background sheet solicited information about:

- Project name, location, facility type
- If the project was new construction, renovation/revamp, or both
- If the project would be considered people & freight, fluids or energy related
- Project driver (maintenance/replacement, production process improvement, technology upgrade, governmental regulation, etc.)
- Project Design information, both planned and actual
- Project schedule information, both planned and actual
- Project cost information, both planned and actual
- Project change information
- Operating performance information (i.e., if the project met operating expectations)
- Financial information (i.e., level of approval, financial measurement used to authorize the project, if the project met financial expectations)
- Customer satisfaction with the project

As previously mentioned, workshop participants were asked to evaluate a small infrastructure project their organization had recently completed, assessing the level of definition for each of the elements provided in the PDRI – Small Infrastructure tool and presented at the workshop. The participants were also asked to provide detailed project background and performance information. The participants determined the level of scope definition the project team responsible for planning the project had achieved just prior to the start of detailed design and construction based on the PDRI scoring scheme, and recorded the levels on the un-weighted PDRI score sheet (see Appendix E).

7.1.2. Sample Characteristics

Research Team 314a distributed the Project Background sheet electronically to each industry member of Research Team 314a, as well as to each of the workshop participants. RT 314a sent the sheet out in advance of the workshop to allow participants to collect the data over time and in their office, where accessing the required project performance data would be easiest. In total, the Research Team 314a collected data on 71 completed projects. Immediately, the author had to remove two projects from this sample – one was not an infrastructure project and one participant did not provide any project performance data. The remaining 69 projects represent $529 million in project expenditure. The sample projects were constructed in two separate countries, and included renovation an revamp projects, new construction projects, and projects that included both. The sample projects included 24 people & freight, 29 fluids, and 17 energy projects. The author calculated the PDRI scores for each of the completed projects based on the levels of definition noted in each participant's unweighted score sheet. The PDRI scores ranged from 97 to 595, with an average score of 317. Table 7-1 provides a breakdown of the completed project sample. It should be noted that eight of the 69 projects used in testing were above the $20 million cost threshold noted in the small project definition developed by the research team. The author in conjunction with RT 314a chose to keep these projects in the testing sample as they represented projects considered “small” by the organizations that submitted them, yet removed the seven projects (identified in Table 7-1) that are less than $100,000 and greater than $50 million when calculating the PDRI target score.

Table 7-1. Completed Small Infrastructure Projects used during Testing of the PDRI – Small Infrastructure Projects tool

Project Number	Project Code	Organization Type O: Owner C: Contractor	P: People &Freight E: Energy F: Fluids*	N: New R: Renovation/Revamp B: Both	Total Installed Cost	Normalized PDRI Score
1	P.1	O	F	N	$21,600,000	422
2	P.2	O	F	B	$2,160,000	324
3	P.3	O	F	B	$20,950,000	326
4	P.4	O	F	N	$11,000,000	468
5	P.5	O	P	R	$10,500,000	461
6	P.6	O	F	B	$8,900,000	323
7	P.7	O	F	R	*$545,000,000	NA
8	P.8	C	F	N	$4,100,000	537
9	P.9	O	F	N	Not Provided	593
10	P.10	C	E	B	$16,752,000	218
11	P.11	C	F	R	Not Provided	325
12	P.12	C	F	N	Not Provided	422
13	P.13	C	E	B	Not Provided	595
14	P.14	O	F	N	*$147,000,000	NA
15	P.15	O	F	B	*$25,000,000	NA
16	P.16	C	F	R	$12,000,000	363
17	P.17	O	F	B	*$70,000,000	NA
18	P.18	O	F	N	$2,100,000	342
19	P.19	O	E	B	$43,800,000	353
20	P.20	C	P	R	$5,000,000	552
21	P.21	C	F	B	$2,100,000	447
22	P.22	C	P	N	$15,665,000	480
23	P.23	O	F	N	$2,500,000	243
24	P.24	O	P	R	Not Provided	266
25	P.25	O	F	R	$775,000	277
26	P.26	C	E	B	Not Provided	432
27	P.27	C	F	B	$43,000,000	142
28	P.28	C	P	B	$600,000	374
29	P.29	C	P	R	$1,397,686	104
30	P.30	C	F	N	$7,790,000	233
31	P.31	O	F	N	$7,500,000	144

Table 7-1 (Continued). Completed Small Infrastructure Projects used during Testing of the PDRI – Small Infrastructure Projects tool

32	P.32	O	E	R	$993,000	300
33	P.33	C	NA	N	$12,500,000	246
34	P.34	O	E	R	$3,690,000	568
35	P.35	C	E	B	$22,000,000	235
36	P.36	C	P	N	$13,322,000	319
37	P.37	C	P	N	$13,322,000	319
38	P.38	C	F & P	N	*$54,200,000	NA
39	P.39	C	F	R	Not Provided	438
40	P.40	C	F	B	$8,200,000	355
41	P.41	O	E	N	Not Provided	153
42	P.42	C	E	R	Not Provided	286
43	P.43	O	F	N	$2,499,916	189
44	P.44	C	E	N	$30,500,000	224
45	P.45	O	E	B	$1,530,000	277
46	P.46	C	F	B	$8,000,000	586
47	P.47	C	P	R	$5,300,000	320
48	P.48	C	E	Not Provided	$16,000,000	221
49	P.49	C	E & P	N	$8,455,000	275
50	P.50	C	E	R	$1,500,000	272
51	P.51	O	E	B	$3,780,000	282
52	P.52	O	E & P	N	$8,840,000	309
53	P.53	O	E	B	$340,000	97
54	P.54	C	F	B	$9,400,000	162
55	P.55	C	P	B	$34,606,000	216
56	P.56	O	F	R	$29,900,000	408
57	P.57	O	P	N	$564,000	355
58	P.58	C	P	B	$2,475,000	220
59	P.59	O	P	B	*$35,119	NA
60	P.60	O	P	B	$916,500	206
61	P.61	O	P	R	$1,170,300	241
62	P.62	C	Not Provided	Not Provided	Not Provided	383
63	P.63	O	F	N	*3150,000,000	NA
64	P.64	O	P	B	$1,270,000	465
65	P.65	O	P	R	$7,000,000	129
66	P.66	O	P	N	$1,900,000	534
67	P.67	O	P	N	$15,665,000	265
68	P.68	O	P	N	$9,400,000	195
69	P.69	O	P	R	$13,700,000	202
				Total Project Expenditure	**$528,928,402**	
				Average Project Expenditure	**$10,171,700**	

* A Project that is not included when Testing the PDRI (TIC is less than $100K and/or greater than $50M or insufficient data).

7.1.3. Project Performance Analysis

Research Team 314a sought to determine what a "good" PDRI score would be, where "good" meant a score threshold (i.e., level of scope definition) that a project team should achieve prior to moving a small infrastructure project forward into detailed design. Three separate project performance factors (i.e., schedule, cost, change) were calculated and compared to each project's corresponding PDRI score at seven separate scoring thresholds with increments of 50 (i.e., 200, 250, 300, 350, 400, 450, 500) to discern if and how project performance changed as PDRI scores increased. The author also conducted the analysis with increments of 25 (i.e., 200, 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500). However, the author, in conjunction with the research team, agreed to ignore these increments to align with previous PDRI tools' cutoff scored which were analyzed with increments of 50. The author calculated schedule, cost, and change performance of the projects in the sample using the following formulas:

$$Schedule\ Performance = \frac{Actual\ Project\ Duration - Planned\ Project\ Duration}{Planned\ Project\ Duration}$$

Where:

$$Actual\ Project\ Duration = Actual\ Date\ of\ Mechanical\ Completion - Actual\ Project\ Start\ Date$$

$$Planned\ Project\ Duration = Planned\ Date\ of\ Mechanical\ Completion - Planned\ Project\ Start\ Date$$

$$Cost\ Performance = \frac{Actual\ Project\ Cost - Budgeted\ Project\ Cost}{Budgeted\ Project\ Cost}$$

$$Change\ Performance = \frac{Positive\ Change\ Orders + |Negative\ Change\ Orders|}{Actual\ Project\ Cost}$$

The positive change order costs added to the absolute value of negative change order costs was calculated to determine the total change order costs on the projects. Calculating the total change order costs in this manor allowed the author to discern the total cost “turbulence” (i.e., additions and subtractions) of the projects.

The results of the analysis are shown in Table 7-2. The values shown in Table 7-2 are averages of the project performance factors for the projects included in each sub-group (i.e., the projects with scores above and below each threshold). As shown, projects that scored above and below the 300-point PDRI score threshold maintained the second highest difference in cost performance of any of the thresholds tested and at the same time recorded differences in both the Schedule and Change Performance. A 2 percent difference in schedule performance was shown between projects scoring above and below 300, and a 21 percent cost performance difference was shown. Change performance for the 200, 350 and 500 categories showed equal differences (i.e., three percent to zero percent) for projects scoring above and below the PDRI score thresholds.

Table 7-2. PDRI Scores vs. Project Performance Factors

	Normalized PDRI Score														
	< 200	> 200	< 250	> 250	< 300	> 300	< 350	> 350	< 400	> 400	< 450	> 450	< 500	> 500	All Projects
Schedule Performance	-5.7%	7%	-3%	10.7%	4%	5.5%	1%	12.9%	2%	13%	6.0%	0.8%	5%	3%	4.9%
N = 43	8	35	18	25	23	20	28	15	31	12	34	9	38	5	43
Cost Performance	2%	15%	5%	18%	3%	24%	3%	34%	7%	29%	10%	24%	11%	28%	12%
N = 51	9	42	22	29	29	22	35	16	39	12	42	9	46	5	51
Change Performance	7%	10%	6%	11%	7%	12%	9%	9%	11%	5%	10%	7%	9%	10%	9%
N = 53	9	44	22	31	29	24	36	17	41	12	44	9	48	5	53

The author utilized independent samples t-tests, boxplots, and regression analysis to determine if a statistical difference existed between project scoring above and below the 300-point PDRI score threshold. The next few sections describe this analysis. Note that the author use different sample sizes for the different performance metrics based on data received; stated another way, not all projects provided the complete set of performance data required for analysis.

7.1.3.1. Project Performance vs. PDRI Scores using Independent Samples t-tests

7.1.3.1.1 Schedule Performance

The author summed schedule performance factors for projects scoring above and below the 300-point PDRI score cutoff. The author then calculated a mean value of the schedule performance factors. Figure 7-1 shows the comparison of the mean schedule performance factors for projects with PDRI scores above and below 300.

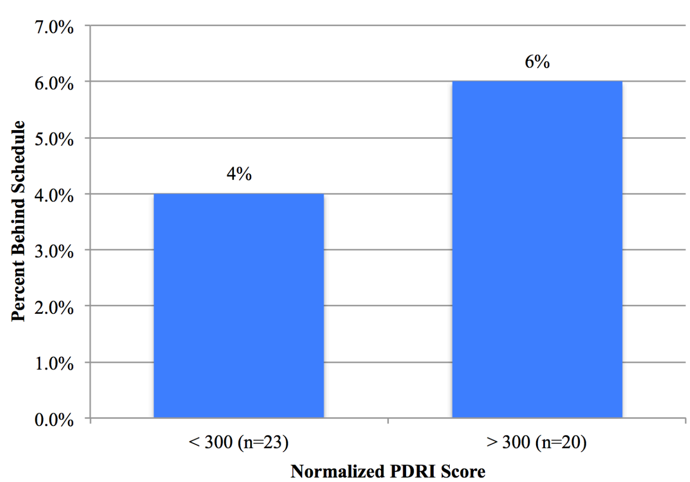


Figure 7-1. Average Schedule Performance by PDRI Score Grouping

The author found the mean schedule performance difference was two percent between projects with PDRI scores above and below the 300 point cutoff, where projects scoring below 300 averaged a 4 percent schedule duration increase as compared to the planned schedule duration, and projects scoring above 300 averaged a 6 percent schedule duration increase as compared to the planned schedule duration. An independent samples t-test was performed to determine if a statistical difference existed between the schedule performances of the two groups. Figure 7-2 provides the schedule performance independent samples t-test results from SPSS™. As shown, the variances were assumed to be equal based on the results of the Levene's test (p value = 0.086), but there was not a statistical difference at a 95% confidence interval between the two groups based on the p-value of 0.942.

Group Statistics

	PDRI_Score_Schedule	N	Mean	Std. Deviation	Std. Error Mean
Schedule_Performance	>= 300.00	20	.0545	.52551	.11751
	< 300.00	23	.0446	.35376	.07376

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Schedule_Performance	Equal variances assumed	3.099	.086	.073	41	.942	.00993	.13506	-.26283	.28268
	Equal variances not assumed			.072	32.558	.943	.00993	.13874	-.27249	.29234

Figure 7-2. Independent Samples t-test Results for Schedule Performance at the 300 Point PDRI Score Cutoff

7.1.3.1.2 Cost Performance

The author summed cost performance factors for projects scoring above and below the 300-point PDRI score cutoff, and calculated a mean value of the cost performance factors in each sub sample. Figure 7-3 shows the comparison of the mean cost performance factors for projects with PDRI scores below and above 300, respectively.

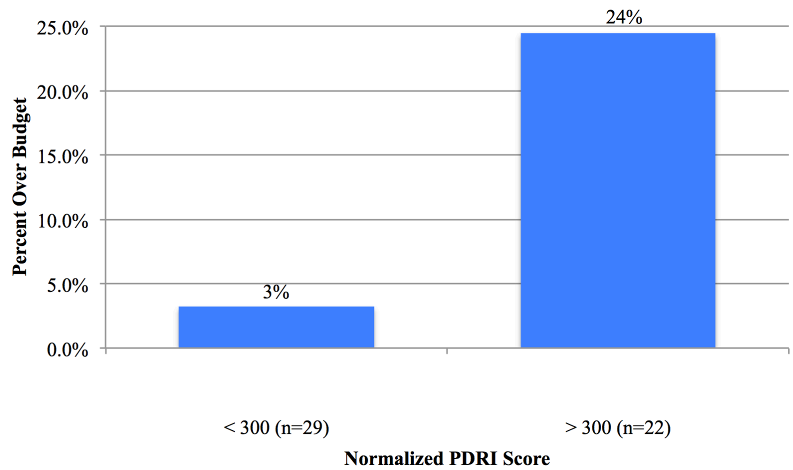


Figure 7-3. Average Cost Performance by PDRI Score Grouping

The author found the mean cost performance difference was 21% between projects with PDRI scores above and below the 300 point cutoff. Projects scoring below 300 averaged a 3 percent cost increase as compared to the planned project cost, and projects scoring above 300 averaged a 24 percent cost increase as compared the planned project cost. An independent samples t-test was performed to determine if a statistical difference existed between the cost performances of the two groups. Figure 7-4 provides the cost performance independent samples t-test results from SPSS™. As shown, the variances were assumed not to be equal based on the results of the Levene's test (p value = .000). SPSS automatically calculates the p-value when the variances are not equal; it is evident in the second row of the analysis output (equal variance not assumed) and consequently increasing the p-value above the critical significance level of 0.05. Therefore, there was a statistical difference at a 95% confidence interval between the two groups based on the p-value of .048.

Group Statistics

	PDRI_Score_Cost	N	Mean	Std. Deviation	Std. Error Mean
Cost_Performance	>= 300.00	23	.2265	.40311	.08405
	< 300.00	28	.0392	.17859	.03375

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Cost_Performance	Equal variances assumed	23.807	.000	2.211	49	.032	.18725	.08467	.01710	.35741
	Equal variances not assumed			2.067	29.051	.048	.18725	.09058	.00202	.37249

Figure 7-4. Independent Samples t-test Results for Cost Performance at the 300 Point PDRI Score Cutoff

7.1.3.1.3 Change Performance

The author summed change performance factors for projects scoring above and below the 300 point PDRI score cutoff, and a mean value of the change performance factors was calculated. Figure 7-5 shows the comparison of the mean change performance factors for projects with PDRI scores above and below 300.

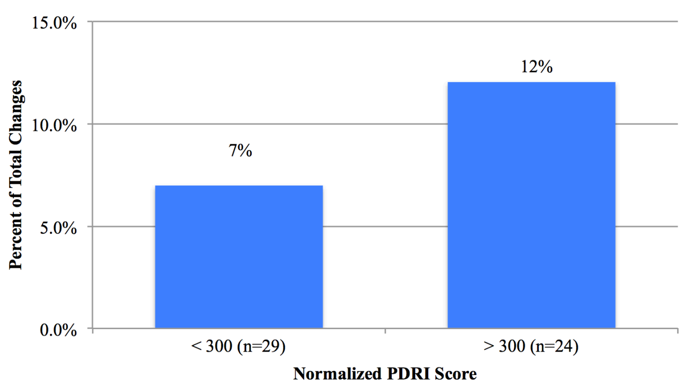


Figure 7-5. Average Change Performance by PDRI Score Grouping

The author found that the mean performance difference was 5% between projects with PDRI scores above and below the 300 point cutoff, where projects scoring below

300 averaged total change orders of approximately percent of the final project cost, and projects scoring above 300 averaged total change orders of approximately 12 percent of the final project cost. An independent samples t-test was performed to determine if a statistical difference existed between the change performances of the two groups. Figure 7-6 provides the cost performance independent samples t-test results from SPSS™. As shown, the variances were not assumed to be equal based on the results of the Levene's test (p value = .003), and there was not a statistical difference at a 95% confidence interval between the two groups based on the p-value of .324.

Group Statistics

	PDRI_Score_CO	N	Mean	Std. Deviation	Std. Error Mean
CO_Performance	>= 300.00	25	.1182	.21475	.04295
	< 300.00	28	.0702	.11405	.02155

Independent Samples Test

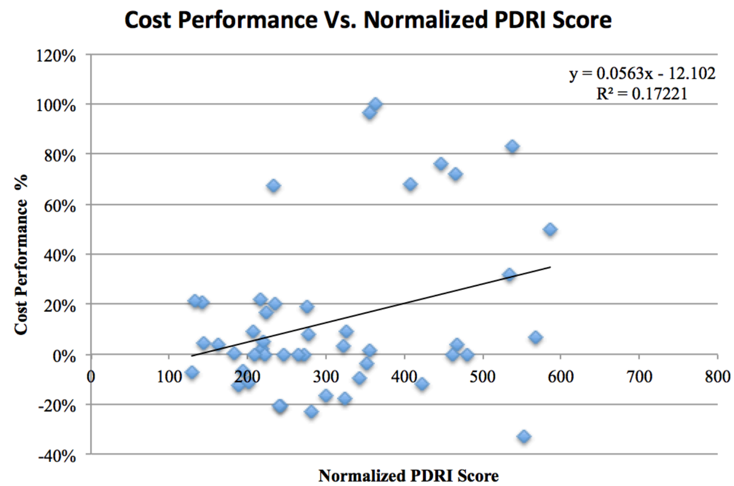
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CO_Performance	Equal variances assumed	9.866	.003	1.033	51	.307	.04804	.04652	-.04536	.14144
	Equal variances not assumed			1.000	35.603	.324	.04804	.04805	-.04945	.14554

Figure 7-6. Independent Samples t-test Results for Change Performance at the 300 Point PDRI Score Cutoff

7.1.3.2. Project Performance vs. PDRI Scores using Regression Analysis

The author completed a regression analysis to compare the cost performance factors of the sample projects against their normalized PDRI scores to discern if a linear relationship existed between the variables. Cost performance was considered the dependent variable, and the associated PDRI score was considered the independent variable. Regression analysis was also used to test the hypothesis that a lower PDRI score indicates sufficient scope definition, which leads to improved project performance. Improved project performance could also be considered less variable project performance. The distribution of performance factors for projects with lower PDRI scores should be tighter. As PDRI scores rise, so would the variability in project performance, leading to a wider distribution of project performance factors.

Figure 7-7 provides the summary of the regression analysis and Analysis of Variance (ANOVA) for cost performance. The r-value of .317 indicates that there is a positive correlation between PDRI score and cost performance. The r^2 value of 0.10 indicates that approximately 10 percent of the variability in the cost performance is explained by the PDRI score, meaning that over 90 percent of the variability is not explained by the PDRI score. The p-value of .024 corresponding to the f-test in the ANOVA table indicates that the regression is significant at a 95% confidence level (p-values less than .05 denote statistical difference for a 95% confidence interval). Given that the survey results (see Table 5-1) indicated that cost was the most common differentiator between small and large infrastructure projects, Research Team 314a wanted to ensure that projects scoring below the PDRI target score would contribute to predictable cost performance, i.e., the change in cost performance should be statistically significant at a 95% confidence interval for the target score (300 in this case). RT 314a checked for statistical significance at a 90% confidence interval for the cost, schedule and change performance, yet the results reflected statistical significance for only the cost and change performance. Research Team 314a decided to keep the 95% confidence interval, and notes that the change performance (p value = .055) was very close to statistically significant at the 95% confidence interval.



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.317[a]	.100	.082	.29931

ANOVA[a]

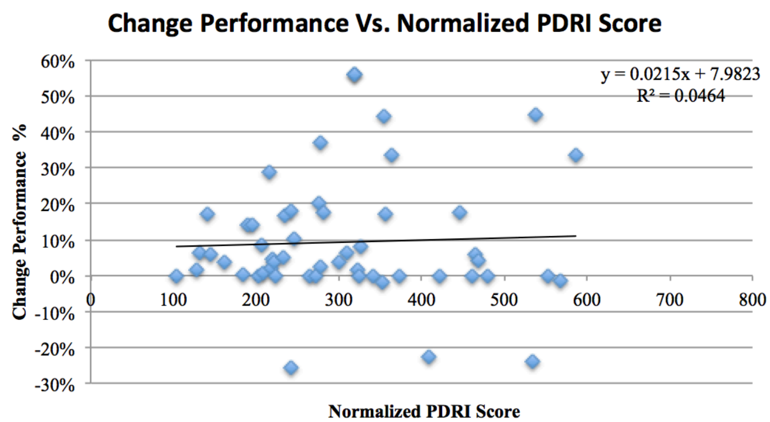
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.489	1	.489	5.461	.024[b]
	Residual	4.390	49	.090		
	Total	4.879	50			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-.120	.113		-1.069	.290	-.346	.106
	PDRI_Score_Cost	.001	.000	.317	2.337	.024	.000	.001

Figure 7-7. Cost Performance Regression Analysis Summary

Figure 7-8 provides the summary of the regression analysis and Analysis of Variance (ANOVA) for change performance. The r^2 value of 0.07 indicates that approximately 7 percent of the variability in the change performance is explained by the PDRI score, meaning that nearly 93 percent of the variability is not explained by the PDRI score. The p-value of .055 corresponding to the f-test in the ANOVA table indicates that the regression is not significant at a 95% confidence level.



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.265[a]	.070	.052	.17194

ANOVA[a]

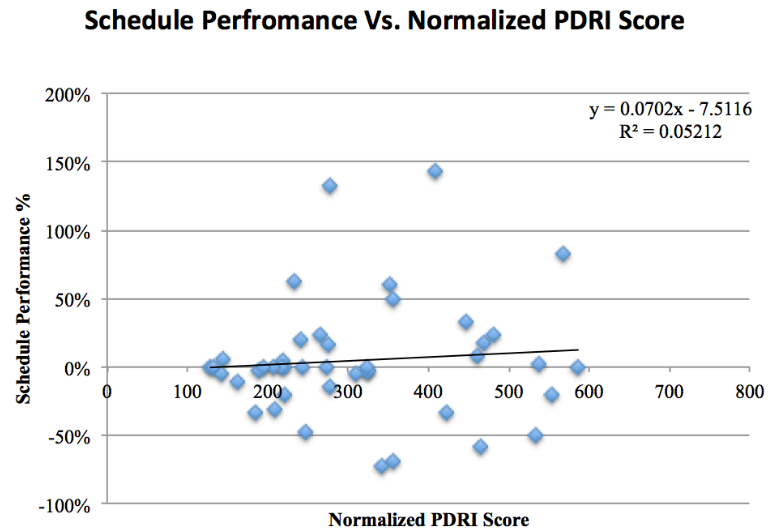
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.114	1	.114	3.858	.055[b]
	Residual	1.508	51	.030		
	Total	1.622	52			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.036	.064		.566	.574	-.092	.164
	PDRI_Score_CO	.000	.000	.265	1.964	.055	.000	.001

Figure 7-8. Change Performance Regression Analysis Summary

Figure 7-9 provides the summary of the regression analysis and Analysis of Variance (ANOVA) for Schedule performance. The r^2 value of 0.007 indicates that approximately 1 percent of the variability in the change performance is explained by the PDRI score, meaning that nearly 99 percent of the variability is not explained by the PDRI score. The p-value of .592 corresponding to the f-test in the ANOVA table indicates that the regression is not significant at a 95% confidence level.



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.084[a]	.007	-.017	.44020

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.056	1	.056	.292	.592[b]
	Residual	7.945	41	.194		
	Total	8.001	42			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	-.039	.176		-.220	.827	-.395	.318
	PDRI_Score_Schedule	.000	.001	.084	.540	.592	-.001	.001

Figure 7-9. Schedule Performance Regression Analysis Summary

7.1.4. Change Performance (Alternative Method)

The author tested an alternative method for change performance due to the minimal difference shown in the base analysis method. Change order costs and actual project costs (at completion of the projects) taken from the testing questionnaires were used to derive alternative change performance factors for each submitted completed projects. The alternative method change performance was calculated as:

$$Change\ Performance = \frac{Positive\ Change\ Orders + \ Negative\ Change\ Orders}{Actual\ Project\ Cost}$$

The positive change order costs added to the negative change order costs was calculated to determine the actual change order costs on the projects. The method was chosen as total project changes are typically summed in this fashion when calculating the final total installed cost of a project, where:

$$Final\ Total\ Installed\ Cost$$
$$= Original\ total\ installed\ cost + actual\ change\ order\ costs$$

The author summed the alternative change performance factors for projects scoring above and below the 300 point PDRI score cutoff, and a mean value of the alternative change performance factors was calculated. Figure 7-10 demonstrates the completed projects scoring below 300 averaged total change orders of 11 percent of the final project cost, and projects scoring above 300 averaged total change orders of 21 percent of the final project cost, a 10 percent mean change performance difference.

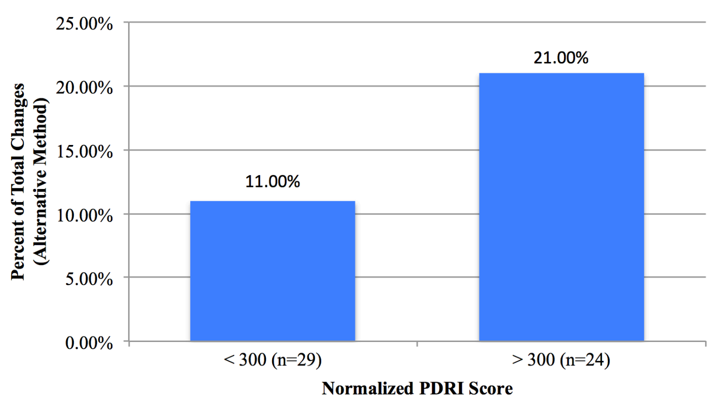


Figure 7-10. Average Change Performance by PDRI Score Grouping

Figure 7-11 provides the alternative change performance independent samples t-test results from SPSS™, which was performed to determine if a statistical difference existed between the change performances of the two groups. As shown, the variances were assumed not to be equal based on the results of the Levene's test (p value = .020), but there was not a statistical difference at a 95% confidence interval between the two groups based on the p-value of .058 (p-values less than .05 denote statistical difference for a 95% confidence interval).

Group Statistics

	PDRI_Score_CO	N	Mean	Std. Deviation	Std. Error Mean
CO_Performance_Alternative_Method	>= 300.00	25	.2020	.20469	.04094
	< 300.00	28	.1078	.13595	.02569

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CO_Performance_Alternative_Method	Equal variances assumed	5.739	.020	1.994	51	.052	.09422	.04726	-.00066	.18911
	Equal variances not assumed			1.949	40.977	.058	.09422	.04833	-.00339	.19184

Figure 7-11. Independent Samples t-test Results for Alternative Change Performance at the 300 Point PDRI Score Cutoff

7.1.5. Analysis of Project Financial Performance and Customer Satisfaction

The author sought to determine if lower PDRI scores (i.e., better scope definition) indicate better financial performance and customer satisfaction for the completed projects. Most workshop participants that submitted completed project data noted in their questionnaires the project's financial performance and customer satisfaction, each on a scale of one to five. For financial performance, a score of one equated to the project falling far short of expectations at authorization, and a score of five equated to the project far exceeding expectations at authorization. For customer satisfaction, a score of one equated to the overall success of the project being very unsuccessful, and a score of five equated to the overall success of the project being very successful.

The financial performance and customer satisfaction ratings were summed for projects scoring above and below the 300 point PDRI score cutoff, and mean values of each were calculated. Figure 7-13 shows the comparison of the mean financial performance and customer satisfaction ratings for projects with PDRI scores above and below 300.

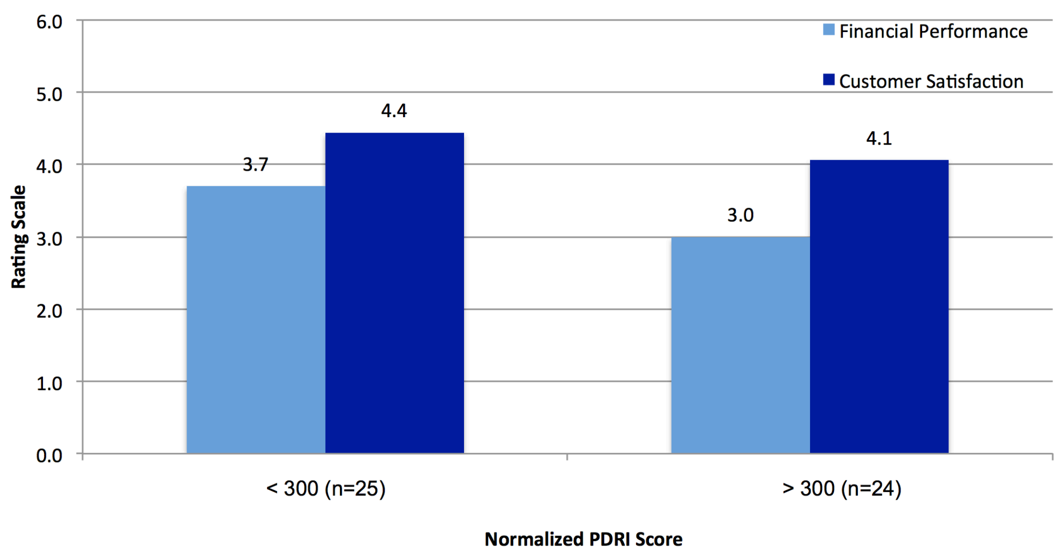


Figure 7-12. Average Financial Performance and Customer Satisfaction Rating by PDRI Score Grouping

Completed projects with PDRI scores below 300 had better mean financial performance and customer satisfaction ratings than projects with PDRI scores above 300, as shown in Figure 7-12. The author performed a Mann-Whitney U Test to determine if a statistical difference existed between the financial performance and customer satisfaction of the two groups. Figure 7-13 provides the Mann-Whitney U Test results from SPSS™. As shown, the financial performance rank-order differences were statistically different at a 95% confidence level between the two groups based on a calculated p-value of .033, but customer rank-order differences were not statistically different at a 95 percent confidence level between the groups based on a calculated p-value of .134 (p-values less than .05 denote statistical difference for a 95% confidence interval).

Mann-Whitney Test

Ranks

	Rating	N	Mean Rank	Sum of Ranks
Financial_Performance	1.00	25	29.08	727.00
	2.00	24	20.75	498.00
	Total	49		
Customer_Satisfaction	1.00	25	27.78	694.50
	2.00	24	22.10	530.50
	Total	49		

Test Statistics[a]

	Financial_Performance	Customer_Satisfaction
Mann-Whitney U	198.000	230.500
Wilcoxon W	498.000	530.500
Z	-2.135	-1.497
Asymp. Sig. (2-tailed)	.033	.134

Figure 7-13. Mann-Whitney U Test Results for Financial Performance and Customer Satisfaction at the 300 Point PDRI Score Cutoff

7.1.6. Summary of Completed Project Performance Evaluation

The results of the completed-project analysis showed that projects with PDRI scores lower than 300 outperform projects with PDRI scores above 300 regarding cost performance, schedule performance, change performance, financial performance, and customer satisfaction. Figure 7-14 summarizes the mean cost, schedule, and change performance factors for project with PDRI scores above and below 300.

PDRI Score			
Performance	**< 300**	**> 300**	**Δ**
Cost (N=51)	3% above budget (N=29)	24% above budget (N=22)	21%
Schedule (N=43)	4% behind schedule (N=23)	6% behind schedule (N=20)	2%
Change Orders* (N=53)	7% of budget (N=29)	12% of budget (N=24)	5%

Figure 7-14. Summary of Cost, Schedule, and Change Performance at the 300 Point PDRI Score Cutoff

The independent samples t-test and regression analysis tests for cost performance were both statistically significant at a 95 percent confidence level. No statistically significant difference was found for schedule performance and change performance, with change performance calculated with two separate methods. The opinion of the research team was that statistical significance was not found for schedule and change performance for two reasons. First, changes to project scope after front end planning is complete (both addition and deletion) can drastically affect even well-planned projects, as the original scope of small projects is limited and more sensitive to change. Second, concurrency of design and construction, which may be a reality of small infrastructure projects, may play a role in schedule and change performance. Change orders will typically be necessary to complete projects to meet the owner's needs if the design intent is incomplete during front end planning.

Note that regression analysis was performed as part of the hypothesis testing; specifically, regression analysis tested the hypothesis that projects with lower PDRI scores indicate projects with better cost, schedule, and change performance. Regression analysis is a statistical method used to determine the dependency between two variables, and to understand the magnitude of their association (Wilcox, 2009), as noted in Chapter 3. The greater the association, the closer the coefficient of determination, or r^2 value, will be to 1. Regression analysis may not be an accurate assessment method for this research, as it would be impossible to ever achieve an r^2 value at or close to 1 with the hypothesis that lower PDRI scores indicate projects with greater levels of scope definition, and higher PDRI scores indicate projects with lesser levels of scope definition. This is evidenced in Figure 7-7 showing the regression analysis of cost performance. The regression is statistically significant, but the r^2 value is .100, meaning that on 10 percent of the variability in the cost performance of the sample of completed projects is explained by the PDRI score.

Lesser scope definition would arguably equate to more variable cost, schedule, and change performance on projects, meaning that the distribution of performance factors would be wider as PDRI scores grow larger. With wider distributions of project performance, less of the variability can be explained through regression. The red dashed lines in Figure 7-15 highlight this point, showing the width of the 95% confidence intervals based on the regression equation calculated for cost performance. It would be expected that the distribution of cost performance factors would generally match these intervals if additional projects with PDRI scores greater than 400 were collected, analyzed, and plotted.

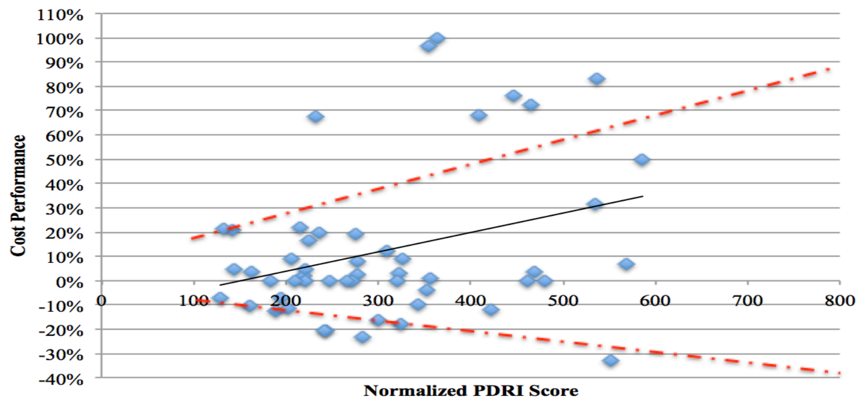


Figure 7-15. Regression Line and Confidence Intervals for Cost Performance

This point is further emphasized with the boxplots provided in Figure 7-16, showing the distribution of cost performance factors for sample projects with PDRI scores above and below 300. As shown, the distribution of cost performance values for sample projects with PDRI scores greater than 300 have a greater spread than the sample projects with PDRI scores lower than 300. In general, the cost performance factors for projects scoring above 300 are also higher than the projects scoring below 300, indicative of additional costs being necessary to complete projects with less scope definition.

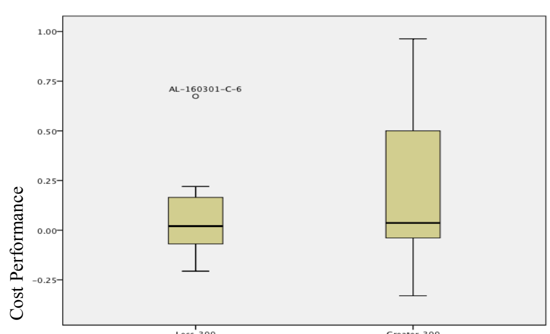


Figure 7-16. Boxplot of Cost Performance at 300-point PDRI Score Breakpoint

Breakpoint 300

7.2. In-Progress Projects

The author along with RT 314a created a separate multi-part questionnaire to observe the effectiveness of the PDRI tool to develop a scope definition package on projects currently in the front end planning phase, and distributed it electronically to workshop participants that expressed an interest in using the tool as well as members of RT 314a. In total, the tool was used to assess scope definition of seven separate small infrastructure projects by seven organizations. Table 7-3 lists the projects, which comprise budgeted total project expenditure of approximately US $35.5 million. The projects covered an all of infrastructure project types, with one people & freight, one fluids and four energy projects, with budgeted costs ranging from $300,000 to nearly US $13 million.

Table 7-3. In-Progress Projects Used During Testing of the PDRI-Small Infrastructure

Project Number	N: New R: Renovation/Revamp B: Both	P: People & Freight E: Energy F: Fluids	Total Installed Cost (Estimated)	PDRI Score
P.1	R	E	$2,100,000	86
P.2	N	E	$13,300,000	113
P.3	B	F	$2,762,000	482
P.4	B	P	$4,000,000	306
P.5	N	E	$302,000	84
P.6	R	E	$13,000,000	276
P.7	R	Not Provided	Not Provided	231
	Total Project Expenditure		**$35,464,000**	
	Average Project Expenditure		**$5,910,667**	

The author analyzed each of the completed questionnaires, and found that the average time to complete a project assessment was 1.5 hours, with an average of 6 individuals in each assessment. The author also found that the overall feedback from users was positive. Users noted that the tool performed well in identifying critical risk issues during the front end planning process, and spurred important conversations about elements not yet considered by the project teams. Two participants indicated that assessing a project with the tool added value to the front end planning process assessment while one didn't, however all participants agreed that they would use the tool again to assess a future project.

7.3. Summary

The research team collected data on 76 projects, 69 completed projects and seven in-progress projects, with an overall expenditure of over $564 million to test the efficacy of the PDRI – Small Infrastructure tool. The data showed a difference regarding schedule, cost, change, financial performance, and customer satisfaction on projects with PDRI scores below 300 compared to projects with PDRI scores above 300. The author and research team determined that a project scoring below 300 would be appropriate to move forward into detailed design based on three factors:

- The 300-point cutoff had substantial percentage difference (between projects scoring above and below the mark) across all the project performances (schedule, cost, and change), based on the performance factors of the sample projects used during the testing process.
- The 300-point cutoff had the greatest statistical difference (between projects scoring above and below the mark) in cost performance of any of the score levels tested, based on the performance factors of the sample projects used during the testing process.
- The 300-point cutoff liaised with the PDRI – Small Industrial Projects score.

It should be noted that this score differs from the PDRI – Infrastructure, PDRI – Buildings, and PDRI – Industrial tools which all suggest a 200 point PDRI score cutoff as being appropriate to move a project forward into detailed design.

Users of the tool on in-progress projects stated that the tool facilitated the identification of critical risk issues during the front end planning process, and spurred important conversations about elements not yet considered by the project teams. Moreover, in-progress projects agreed to use the tool again in the future, and that assessment times were much shorter (averaging 1.5 hours) than typical assessment times when using the PDRI – Infrastructure, which typically take 2 to 5 hours to complete.

Several limitations exist with this data analysis, as with any data analysis. A majority of the data collected and used for this analysis came from individuals who were asked to refer back to a point in time just prior to the start of detailed design on their chosen projects, which may have been weeks, months, or even years prior to the testing questionnaire being completed. This method may have led to slightly inaccurate information due to memory lapse of the project participants during that time period. Having knowledge of the actual project outcomes may also have biased the respondent's answers to be more favorable. Also, the sample of completed projects used in this analysis is relatively small as compared to the total population of small infrastructure projects completed each year across the globe, which easily numbers in the thousands.

CHAPTER EIGHT

COMPARISON OF THE PDRI - INFRASTRUCTURE VS. THE PDRI - SMALL INFRASTRUCTURE

This Chapter addresses hypotheses three, which is that both PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects require similar level of project definition, between Complete Definition – Level 1 and definition with Minor Deficiencies - Level 2, during FEP to support predictable project outcomes.

8.1. Abstract

Despite the need to reform and maintain the deteriorating infrastructure in the United States, as well as create new infrastructure to meet the needs of future generations, the construction industry often struggles to deliver infrastructure projects that meet their budgeted cost and planned schedule. Infrastructure projects play a critical role in the built environment, as they connect building and industrial projects to energy, water, and other utilities, as well as to each other. These types of projects may present unique planning challenges, as they may involve right-of-way acquisitions or adjustments, include more underground construction than building or industrial projects, and may require more interfacing with the public than other types of construction projects. One successful tool that assists in planning such projects is an evidence-based tool, the Project Definition Rating Index (PDRI), which supports the front-end-planning (FEP) for projects. PDRI – Infrastructure Projects and PDRI – Small Infrastructure projects effectively facilitate FEP efforts for infrastructure projects. Both tools provide a structured checklist of element descriptions and an accompanying score sheet that supports alignment among project stakeholders through providing an assessment of a project's level of scope definition.

During the FEP phase of a project, which is prior to detailed design and construction, testing of these infrastructure tools suggests that a more defined project during FEP leads to more predictable cost, schedule, and change performance; that is, infrastructure projects with lower PDRI scores usually maintain more robust cost and schedule performance than those with higher PDRI scores.

This chapter provides a definition of a small infrastructure project as well as a detailed comparison of PDRI – Infrastructure and PDRI – Small Infrastructure projects. Specifically, the author distinguish between the two PDRIs in terms of their structure, content and weight of the elements, most critical planning elements, and target PDRI score. This chapter contributes to the FEP body of knowledge by: (1) characterizing a small infrastructure project based on 16 factors of complexity, five of which were corroborated via a survey of practitioners, and (2) identifying qualitative and quantitative similarities and differences between PDRI – Infrastructure and PDRI – Small Infrastructure Projects in support of improved planning efforts for both types of projects. The author along with RT 314a identified the Total Installed Cost (TIC) to be the main differentiator between small and large infrastructure projects, with small infrastructure projects having a TIC cap of $20M while larger projects exceed $20M. The author's analyses show that both small and large infrastructure project types require similar levels of project definition, namely between Complete Definition (Level 1) and definition with Minor Deficiencies (Level 2) during FEP to support predictable performance outcomes.

8.2. Introduction

An infrastructure project is defined as a capital project that provides transportation, transmission, distribution, collection, or other capabilities that support commerce or interaction of goods, service or people (Bingham and Gibson, 2016, CII, 2010a); typically, an infrastructure project is "horizontal" in nature and acts as a vector that connects building and industrial "nodes" within the built environment. Infrastructure projects may convey people and freight, such as highways, railroads, and tunnels; they may convey fluids, such as pipelines, open channels, and pumping stations; or they may convey energy, such as transmission lines, electrical towers and substations (CII, 2010a). The American Society of Civil Engineers rates the U.S. infrastructure once every four years; in 2017 ASCE reported a score of "D+" for infrastructure, confirming that the U.S. infrastructure systems are declining due to negligence, overuse, insignificant investment and poor construction (Canning, 1998, ASCE, 2017). Studies by ASCE further indicate that the U.S. requires approximately $3.6 trillion to construct and revamp the infrastructure to achieve an acceptable level. In response to this need, the U.S. has allocated and spent funds to improve the infrastructure systems, but there is still more to do. Perhaps more importantly, infrastructure projects are often plagued by cost and schedule overruns that reduce the effectiveness of allocated funds to meet infrastructure need (Agarwal et al., 2016).

Numerous construction management best practices focus on delivering success once a project begins construction (e.g., (Becerik-Gerber et al., 2012, Becker et al., 2014, Caldas et al., 2014, Rajendran et al., 2012, Song et al., 2009, Thomas et al., 1989, Griffith and Gibson, 2001). Research shows that arguably the best way to deliver predictable project outcomes, though, is not only to focus on best practices during construction, but also spend time on the front end planning (FEP) of projects prior to authorizing their funding and subsequent construction (CII, 1999, CII, 2008, CII, 2010a, Gibson et al., 1993, Gibson and Hamilton, 1994, Hamilton and Gibson, 1996). FEP begins after the business leadership of an organization deems a project concept desirable, and continues until the beginning of detailed design and construction of a project (Gibson and Hamilton, 1994). Decisions made during this phase of the project life cycle have a much greater influence on a project's outcome than those made in later stages (Gibson et al., 1993, CII, 1994a). FEP is a fundamental process of developing sufficient strategic definitions and information with which the project's stakeholders can address and assess risks in order to maximize the possibilities of a successful project (Hamilton and Gibson, 1996).

The Construction Industry Institute (CII) developed several PDRI tools to assist project teams throughout FEP by providing a structure for assessing the project's level of definition during FEP. The first PDRI tool was developed for industrial projects and its success led to development of similar tools that focused on building and infrastructure projects (CII, 1995, CII, 1999, CII, 2010a). Research shows that PDRIs support successful project delivery; in fact, well performed FEP can reduce the total project design and construction costs by as much as 20%, reduce the total project design and construction schedule by as much as 39%, improve project predictability in terms of cost, schedule, and operating performance, and increase the chance of a project meeting stated environmental and social goals (Cho and Gibson, 2001, Bingham and Gibson, 2016, Gibson and Hamilton, 1994, CII, 1994a, Hamilton and Gibson, 1996).

As most previous research efforts were not focused on small projects directly, there is a research gap in the area of FEP for small infrastructure projects. Meanwhile, the cumulative effect of poorly planned small infrastructure projects can have a major impact on an organization's bottom line; consequently, Research Team 314a (RT 314a) developed the PDRI – Small Infrastructure Projects specifically to address this project type (Burke et al., 2016, ElZomor et al., 2016a). This chapter defines small infrastructure projects and summarizes the differences between small and large infrastructure projects. The chapter contributes new insights into the infrastructure body of knowledge through comparison of the small and large infrastructure PDRI tools. The author discusses the qualitative and quantitative similarities and differences between PDRI – Small Infrastructure and PDRI – Infrastructure Projects.

8.3. Other PDRI Research and Background

Much of the infrastructure project planning literature focuses on large and complex infrastructure projects (Haimes and Jiang, 2001, Karlaftis and Peeta, 2009, Nasir et al., 2015). Nasir et al. (2015) utilized a FEP tool to predict the productivity and schedule performance for large infrastructure projects. Aktan et al. (2016) recommended a common international ontology for infrastructure and acknowledged that infrastructure has been classified into sectors, but did not define the differences between these infrastructure project sectors. Bocchini et al. (2013) established a framework of risk assessment for large infrastructure projects while Ke et al. (2010) discussed the risk allocation in public-private partnership of infrastructure projects.

Some planning literature does focus on small projects, but it does not provide insight to small infrastructure projects specifically. Liang et al. (2005) attempted to differentiate between small and large projects in general without representing a specific project type, and provided guidance for owners to identify small projects and their criticality. Gao et al. (2002) revealed that the number of small capital facility projects completed in many organizations is substantial, thus these smaller projects deserve the same level of planning as their larger counterparts; however, their research also did not differentiate between building, industrial and infrastructure project types (CII, 2002). These findings are consistent with those of past CII investigations, which showed that these types of small projects are handled differently than large projects and pose unique risks (Collins et al., 2016). However, even past CII work did not specifically address infrastructure projects. Yet, in most infrastructure owner organizations, approximately half of the number of projects completed in a fiscal year are considered small (Burke et al., 2016), and thus this project type deserves study (ElZomor et al., 2016a).

CII convened RT 314a in May 2015 to develop a PDRI for small infrastructure projects, *PDRI – Small Infrastructure Projects*. This team comprised 20 participants, including the author and 13 practitioners whose professional responsibilities include planning, managing, and executing small infrastructure projects spanning the people and freight, fluids, and energy project types. This section provides an introduction to their work, which serves as the background to the analysis presented in the chapter.

Liang et al. (2005) provide a detailed discussion of PDRI – Small Infrastructure development. This discussion is outside the scope of this chapter, however, the author present salient details of the PDRI structure and development required to understand the balance of this chapter. The PDRI is an index that assesses the level of project definition during the FEP phase of a project. A PDRI comprises a structured checklist of elements and descriptions that support scope definition on various project types and a corresponding set of "weights" for those elements, one for each level of scope definition. Research Teams develop element weights based on practitioner input and a normalization process, as described in CII (1995, 1999, 2015). The weight of a given element measures its importance relative to other elements. For example, if an element has a Level 5 weighting of 10, and another has a Level 5 weighting of 20, then the latter is twice as important as the former. PDRI scores range from 70 (well-defined project scope) to 1,000 (poorly defined scope), with a lower score indicating a better definition of project scope.

8.4. Comparison Methodology

To define a small infrastructure project, RT 314a surveyed organizations involved in infrastructure projects, asking respondents if characteristics of "small" projects found in literature were indeed used in practice to differentiate small projects from large. The survey sought to gain a better understanding of the following questions: (1) How do organizations define a "small infrastructure project?; (2) What is the prevalence of small projects in the infrastructure sector?; and (3) How do organizations plan for such projects? The team developed the survey in an electronic format and distributed it to 210 infrastructure project practitioners. Forty-seven of these survey recipients responded (a 23 percent response rate). The author investigated these responses to: distinguish between large and small infrastructure projects in terms of project characteristics, determine the importance of FEP efforts for small infrastructure projects, and identify different processes of project delivery for small infrastructure projects.

To identify qualitative and quantitative similarities and differences between PDRI – Infrastructure and PDRI – Small Infrastructure projects, the author compared the tools in four ways:

(1) **Quantitatively comparing the Section Weights and Element Descriptions**:

The author analysed the structural differences within PDRI – Small Infrastructure and PDRI – Infrastructure via an assessment of the content of the element descriptions and a comparison of element weights within the two infrastructure PDRIs.

(2) **Comparing Owner and Contractor Perspectives in the PDRI – Infrastructure and PDRI – Small Infrastructure Tools**: The author identified the highest weight elements, as ranked by practitioners from both Owner and Contractor organizations, in both the PDRI – Infrastructure and PDRI – Small Infrastructure tools.

(3) **Comparing Infrastructure Project Types:** The author compared the top planning elements across infrastructure project types (People and Freight, Energy and Fluid projects) in both the PDRI – Infrastructure and PDRI – Small Infrastructure tools.

(4) **Comparing Target Scores from the PDRI – Infrastructure and PDRI – Small Infrastructure Projects Tools:** The author compares the target score of PDRI – Infrastructure and PDRI – Small Infrastructure to understand the differences in the level of definition required to achieve predictable project outcomes on large and small infrastructure projects.

8.5. Results and Discussion

In this section, the author explores the outcomes of the surveys to: (1) define the different project phases of both small and large infrastructure projects, and (2) validate the definition of small infrastructure projects through defining the complexity associated with small and large infrastructure projects. Subsequently, the author discusses the qualitative and quantitative similarities and differences between PDRI – Small Infrastructure and PDRI – Infrastructure Projects based on the four comparisons discussed in the methodology.

8.5.1. Defining Small Infrastructure Projects

8.5.1.1. Distinguishing Between "Large" And "Small" Infrastructure Projects

RT 314a developed a list of 16 project characteristics that case study research, literature review and experience suggested differentiate large infrastructure projects from their smaller counterparts. Table 8-1 lists these characteristics, including project cost, number of team members from different disciplines, and length of construction schedules, among others. The author and research team created a survey that asked practitioners to either agree or disagree with each characteristic and the differentiating value for that characteristic (Burke et al., 2016). The majority of survey respondents agreed with five of the characteristics and their associated thresholds: total installed cost (where small projects cost less than US $20 Million), engineering effort (where small projects require 5,000 hours or less), construction duration (where small project duration ranges from six to twelve months), availability of core team members (where small projects include part-time management), and number of core team members (where small projects maintain less than 10 core team members i.e., project managers, project engineers, and owner representatives). Other characteristics for differentiating small projects from large, developed by the author and research team but not corroborated by the survey respondents, include source of funding, project visibility to owner management, extent of external permitting required, number of local/state permits required, and number of separate trade contractors. Table 8.1 presents project characteristics in order of importance, as reported by survey respondents; that is, total installed cost is the most important characteristic for differentiating large infrastructure projects from small, while the number of Right Of Way parcels required is the least important.

Table 8-1. Characteristics of Small and Large Infrastructure Projects

Project Characteristic	Small Projects	Large Projects
Total Installed Cost*	<$20 Million	>$20.1 Million
Engineering Effort*	< 5000 Hours	> 5000 Hours
Construction Duration**	6-12 Months	>18 Months
Number of Core Team Members**	<10 individuals	>10 individuals
Availability of Core Team Members**	Part-time availability	Combination of part-time and full-time to completely full-time
Project Visibility External to Organization (Public)	Moderate	Significant
Extent of Permitting	None to moderate permitting	Significant permitting
Number Jurisdictions Involved	1-3 jurisdiction	> 5 jurisdictions
Existing Utility Provider Interface & Coordination	Minimal to Moderate	Significant
Sources of Funding	Singular	Multiple
Types of Permits	None to local/state permits	Local/state to national permits
Number of Trade Contractors	3-4 separate trade contractors	7-8 separate trade contractors
Extent of Public Outreach Effort	Minimal to Moderate	Significant
Management of Public Outreach Effort	Project Team	Corporate Executives
Right Of Way (ROW) procurement effort	Minimal to Moderate	Significant
Number Of Right Of Way (ROW) parcels required	1-2 parcels	>5 parcels

* More than 50% of respondents reported this factor as a differentiator between small and large projects

** More than 48% of respondents reported this factor as a differentiator between small and large projects

Several respondents explained that the characteristics would not necessarily be used to differentiate between small and large projects, but would be useful in their organizations for determining project complexity. Small infrastructure projects should not be differentiated from large projects solely on the basis of project cost levels within an organization or across the industry at large. Survey responses indicated that project complexity is the true differentiator between 'small' and 'large' infrastructure projects. CII's Research Team 305 defined project complexity as the degree of interrelatedness between project attributes and interfaces, and their consequential impact on predictability and functionality (CII, 2014b). They concluded that with selected management strategies in place to control diverse project attributes and interfaces, the probability that projects can be successful and predictable is increased. Infrastructure projects range from projects with little to no complexity (i.e., simple maintenance projects such as re-surfacing or pipe replacement) to highly complex projects (i.e., a subway project or major river crossing). The rigor of planning efforts expended on a project should align with the project's complexity.

8.5.1.2. Front End Planning (FEP) Efforts For Small Infrastructure Projects

The respondents were asked to consider seven typical FEP procedures and select those used in their organizations to plan for small infrastructure projects. There was also an option to select "other" and describe a procedure used by their organization but not listed. Figure 8-1 shows the categories of all survey responses; overall, these responses indicate that the organizations commonly depended on more than one method, and most frequently include "structured stage gate", "ad hoc" and "internally developed scope definition tools". From these results, the author recognized that the planning processes for small infrastructure projects vary across the infrastructure sector, and even within organizations.

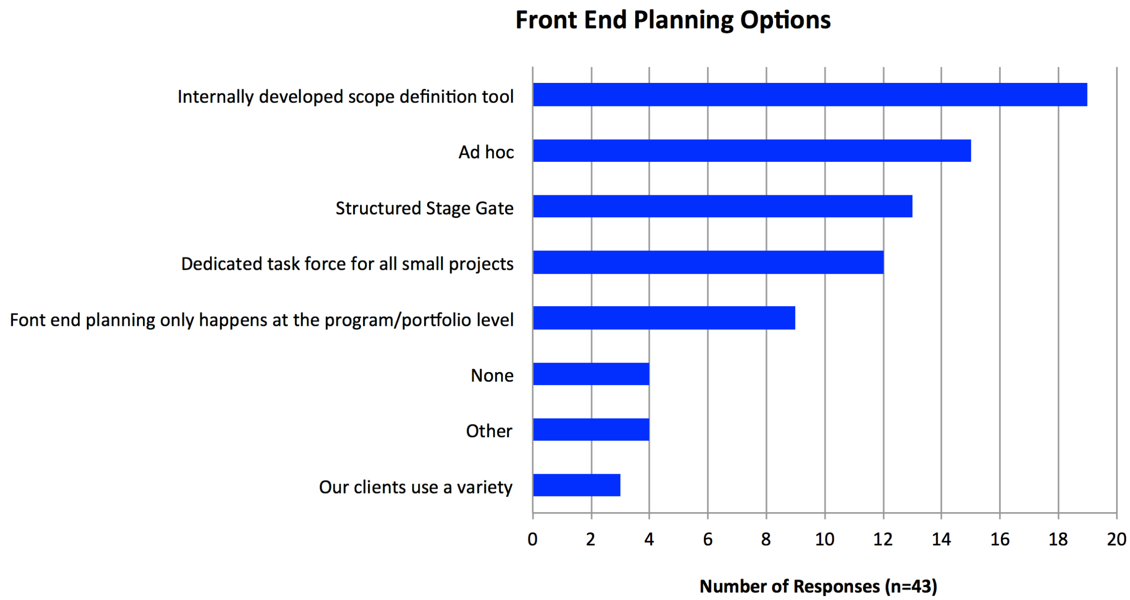


Figure 8-1. Survey Responses Regarding Typical FEP Processes Used in Practice (Note four respondents did not answer this question)

Figure 8-2 presents responses to questions concerning the cost and count of small infrastructure projects completed in the survey respondents' organizations during the prior fiscal year. Sixty percent of survey respondents identify as working for contractor organizations and 40% identify as working for owner organizations. As shown, both the Owner and Contractor respondents estimated that 11-30 percent of projects completed during the preceding fiscal year met their organization's definition of small project on a cost basis. Owners report 31-70 percent of the total number of projects completed in the previous fiscal year met their organization's definition of a small project. By contrast, contractors report that 51-70 percent of the total number of projects completed by their organization in the previous fiscal year met their organization's definition of "small." These responses illustrate that small projects make up about half of the number of projects completed, but account for less than half of the capital expenditure in the infrastructure sector each year.

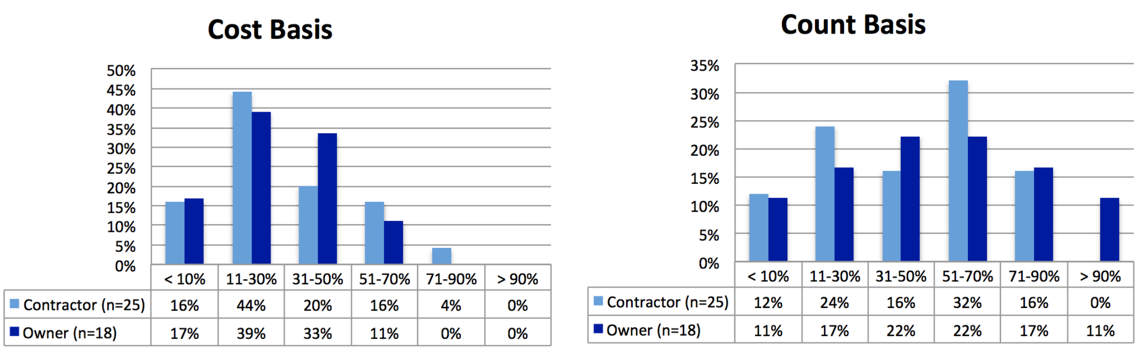


Figure 8-2. Prevalence of Small Projects in Survey Respondents' Organizations

8.5.1.3. Front End Planning (FEP) Process of project Delivery for Infrastructure Projects

Figures 8-3 and 8-4 illustrate two possible sequences for the FEP phase of projects. The PDRI was originally envisioned as a decision-support tool for determining whether or not to fund detailed design and construction. Research supports the notion that employing the tool more than once prior to detailed design and construction can have benefits for project performance (CII, 1995, CII, 1999, CII, 2010a, CII, 2015). RT 314a found that for small infrastructure projects, certain phases of FEP may overlap, which made determining two or more application points for the PDRI – Small Infrastructure Projects tool challenging.

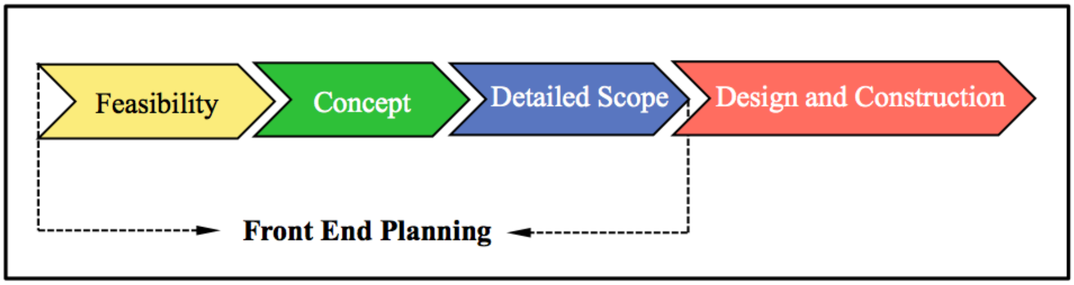


Figure 8-3. The "Traditional" FEP Diagram, which describes most large infrastructure projects' FEP (color)

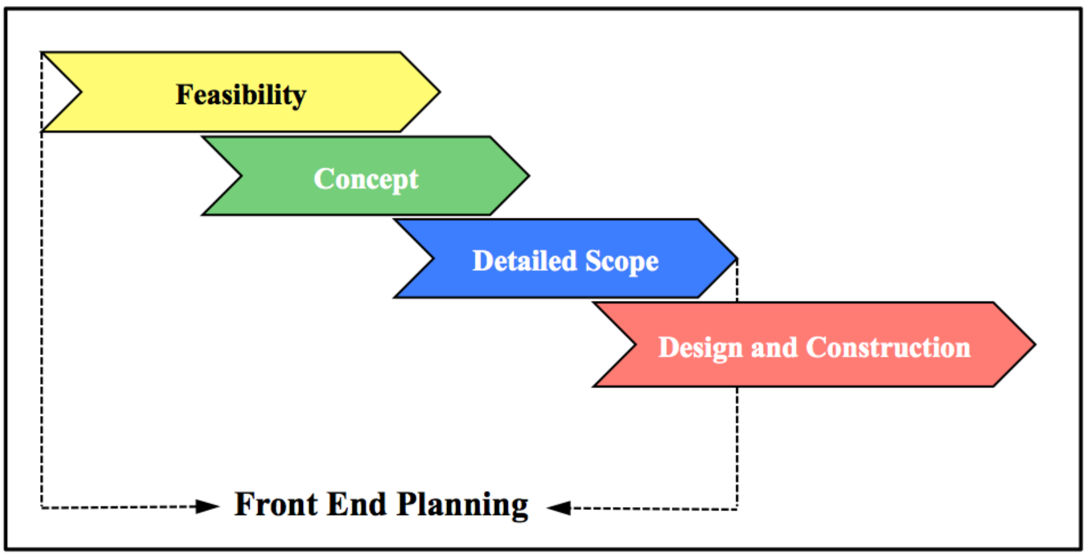


Figure 8-4. Concurrent FEP, which describes FEP on some Small Infrastructure Projects

8.5.2. Quantitative evaluation of the Element Descriptions and Section Weights in both Infrastructure PDRI Tools

Table 8-2 shows a structural comparison of PDRI – Infrastructure and PDRI – Small Infrastructure. The only quantitative similarity between them is the number of sections; both PDRIs include the same three sections, Basis of Project Decision (Section I), Basis of Design (Section II), and Execution Approach (Section III). PDRI – Small

Infrastructure includes approximately fifty percent fewer categories and elements than its counterpart PDRI – Infrastructure; however, the number of pages of element descriptions was decreased by only about 25%. Given that the PDRI – Small Infrastructure element descriptions incorporate the critical content from PDRI – Infrastructure, it follows that despite decreasing the number of elements, the total number of pages does not decrease by the same factor. The greatest reduction in the number of elements within PDRI – Small Infrastructure is in Section I, with 60% fewer elements, followed by Section II, with 50% fewer elements than in PDRI – Infrastructure, largely due to combining several elements of PDRI – Infrastructure into a single element in PDRI – Small Infrastructure (Table 8-2). Section II of PDRI – Small Infrastructure, Basis of Design, includes fifty percent of the total number of elements in that tool (20 elements in this case); therefore Section II of the PDRI – Small Infrastructure is the most critical.

Table 8-2. Structural Comparison of PDRI – Small Infrastructure and PDRI - Infrastructure

Comparison	**PDRI – Small Infrastructure**	**PDRI – Infrastructure**	Δ
Overall			
Number of Sections	3	3	0
Number of Categories	8	16	-8
Number of Elements	40	68	-28
Number of Pages of Element Descriptions	28	39	-11
Elements per Section			
Section I - Basis of Project Decision	9	23	-14
Section II - Basis of Design	20	23	-3
Section III - Execution Approach	11	22	-11
Weight per Section			
Section I - Basis of Project Decision	275 (27.5%)	437 (43.7%)	-162
Section II - Basis of Design	470 (47%)	293 (29.3%)	177
Section III - Execution Approach	255 (25.5%)	270 (27.0%)	15
Total	1000 (100%)	1000 (100%)	

The relative weight of Section I compared to Section II (Basis of Project Decision and Basis of Design, respectively) varies between PDRI – Small Infrastructure and PDRI – Infrastructure. The most important (i.e., highest weighted) section in PDRI – Small Infrastructure is Section II, Basis of Design, with 470 points while for PDRI – Infrastructure, the highest weighted section is Section I, Basis of Project Decision with 437 points. This aligns with the notion that large infrastructure projects often require a robust decision making effort to define the project scope and location while less complex or "small" infrastructure projects may already have these items defined prior to FEP. For example, in a "large" highway project the project team must determine the exact location and routing of the highway. For a "smaller" highway project (e.g., re-paving) the location need not be determined as part of the FEP efforts, as this may be considered a maintenance activity that requires a prompt action in a pre-determined location. For PDRI – Small Infrastructure projects, Section II (Basis of Design) is more critical especially for those with concurrent FEP (Figure 8-4), as design begins "earlier".

While the relative weights of the Sections may suggest that different priorities exist for small and large infrastructure projects, a closer examination of the categories that comprise the Sections tells a different story. For instance, in both PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects, determining the project need and purpose (part of Category A in both tools) is critical. In fact, Category A is the second-highest weighted category in PDRI – Infrastructure (Figure 8-5) and the highest weighted category in PDRI – Small Infrastructure. (Figure 8-6). Figure 8-5 outlines the logic flow for PDRI – Infrastructure and Figure 6 outlines the same for PDRI – Small Infrastructure. In general, while the Section weights vary between the tools, similar categories surface as most important, mainly those related to understanding the purpose of the project and the stakeholders involved (Category A in both tools), as well as the design constraints (Category E in PDRI – Infrastructure and Category C in PDRI – Small Infrastructure) and parameters (Category I in PDRI – Infrastructure and Category D in PDRI – Small Infrastructure). Thus, the author conclude that much of the shift in weight from Section I of PDRI – Infrastructure to Section II in PDRI – Small Infrastructure is due to the reduction in number of elements to consider in Section I, and the relatively larger portion of elements to consider in Section II, for PDRI – Small Infrastructure Projects.

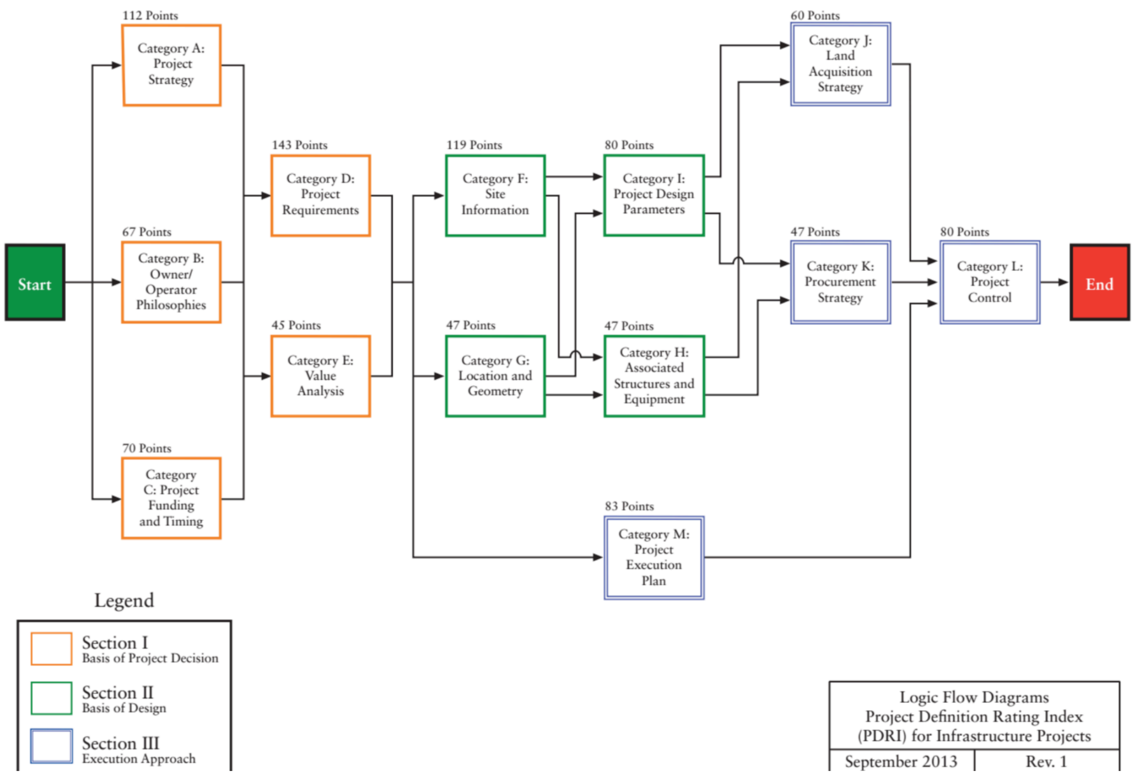


Figure 8-5: PDRI – Infrastructure Projects Logic Flow Diagram (Color)

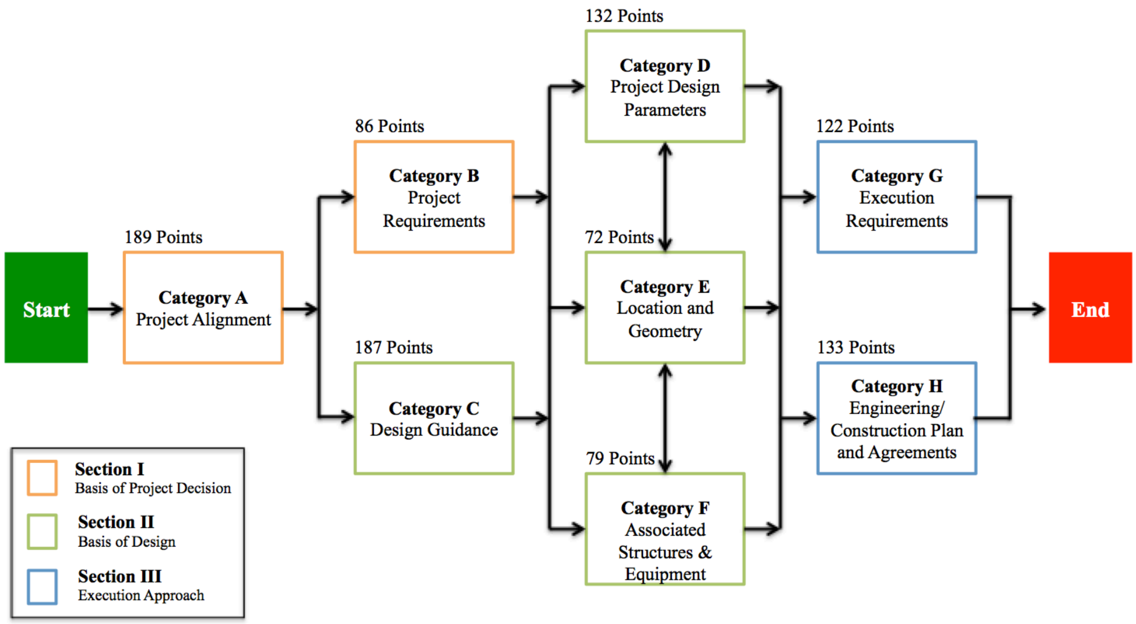


Figure 8-6: PDRI – Small Infrastructure Projects Logic Flow Diagram (Color)

8.5.2.1. Assessing The Content of the Element Descriptions for both Infrastructure PDRI Tools

The author in conjunction with RT 314a analysed the element descriptions of both PDRIs to determine how the elements from the PDRI – Infrastructure compare to those in PDRI – Small Infrastructure. Table 8-3 illustrates examples of elements that are identical between PDRI – Infrastructure and PDRI – Small Infrastructure. It also shows elements from PDRI – Infrastructure that were combined to create a single element in PDRI – Small Infrastructure. Note the majority of elements in PDRI – Small Infrastructure are shared from PDRI – Infrastructure, albeit with some edits. Those common elements, critical to both large and small infrastructure projects, align in title and description to ensure that PDRI users consider and define these key scope elements regardless of the project's size and complexity. The combined elements group several related PDRI –

Infrastructure element descriptions into a single PDRI – Small Infrastructure element. For example, PDRI – Infrastructure includes several elements discussing project philosophies: Design Philosophy, Operating Philosophy, and Maintenance Philosophy while PDRI – Small Infrastructure joins those elements into element A3, Project Philosophies. This, and similar changes enables small project teams to complete their PDRI assessment of their project in less time, but still cover those scope elements relevant to small projects. Project teams that implemented the PDRI – Small Infrastructure during their FEP efforts report that it took about 90 minutes to complete the PDRI – Small Infrastructure assessment and the tool added value to the FEP process and the project as a whole (ElZomor et al., 2016a).

Table 8-3. Comparison of Section I (Basis of Project Decision) Elements in PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects

PDRI for Infrastructure Projects		PDRI for Small Infrastructure Projects	
SECTION I - BASIS OF PROJECT DECISION		**SECTION I - BASIS OF PROJECT DECISION**	
A	PROJECT STRATEGY	A	PROJECT ALIGNMENT
A1	Need & Purpose Documentation	A1	Need & Purpose Statement
A2	Investment Studies & Alternative Assessments		
D1	Project Objectives Statement		
A3	Key Team Member Coordination	A2	Key Team Member & Public Coordination
A4	Public Involvement		
B1	Design Philosophy	A3	Project Philosophies
B2	Operating Philosophy		
B3	Maintenance Philosophy		
C1	Funding & Programming	A4	Project Funding, Programming, Schedule & Contingencies
C2	Preliminary Project Schedule		
C3	Contingencies		
D	PROJECT REQUIREMENTS	B	PROJECT REQUIREMENTS
D2	Functional Classification & Use	B1	Functional Classification & Use
D3	Evaluation of Compliance Requirements	B2	Evaluation of Compliance Requirements
D4	Existing Environmental Conditions	B3	Existing Environmental Conditions
D5	Site Characteristics Available vs. Required	B4	Site Characteristics Available vs. Required
B4	Future Expansion & Alteration Considerations		
D6	Dismantling & Demolition Requirements	B5	Dismantling & Demolition Requirements
D7	Determination of Utility Impacts	B6	Determination of Utility Impacts

8.5.3. Comparing the Owner and Contractor Perspectives for both Infrastructure PDRI Tools

Figure 8-7 compares the Top 10 Most Important Elements identified by owners to those identified by contractors in the PDRI – Infrastructure Projects. Note both owners' and contractors' top ten most important elements include Need and Purpose Documentation, Design & Construction Cost Estimates, Investment Studies & Alternatives Assessment, Contingencies, Preliminary Project Schedule, Evaluation of Compliance Requirements, and Capacity (CII, 2010a). It comes as no surprise that both owners and contractors of large infrastructure projects would mutually rank these elements in their top ten highest elements; these elements stress the importance of understanding the design, cost and schedule of the construction project to be able to commit adequate resources to a large infrastructure project. Owners' Top 10 most important elements also include Geotechnical Characteristics, Design Philosophy, and Key Team Member Coordination. This seems reasonable, as these elements may represent scope items that can be costly if overlooked, and would be more likely to cost an owner money than a contractor money. On the other hand, contractors' Top 10 most important elements also include Funding and Programming, Existing Environmental Conditions, and Functional Classification & Use, likely because these items are within the contractor's purview. The ranking of these elements show that contractors feel these elements need to be well defined in order to mitigate future risks and project unknowns, and thus increase the likelihood of delivering a large infrastructure project on schedule and on budget.

In PDRI – Small Infrastructure Projects, both owners and contractors ranked Need & Purpose Statement, Land Acquisition Strategy, Physical Site, Project site Assessment, Preliminary Project Schedule, and Lead/Discipline Scope of Work in their top 10 most important elements (Figure 8-7). These six common elements emphasize the importance of understanding the preliminary requirements that need to be committed to the project, by both owners and contractors. Owners' Top 10 most important elements also include Project Cost Estimate and Cost Control, Schematic Layouts, Project Philosophies and Topographical Surveys & Mapping. These four elements demonstrate the owners' focus on ensuring they get the project they want for the price they can afford. Contractors' Top 10 most important elements also include Environmental & Regulatory Considerations, Project Funding, Project Schedule and Schedule Control, and Capacity. These elements illustrate the contractors' focus on addressing these project aspects during front end planning to anticipate cost, schedule and change orders that may result from the small infrastructure project, and ensure that the project can be delivered on time and within the allocated budget.

A

Small Infrastructure Projects – Owners

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	48
2	G.1	Land Acquisition Strategy	38
3	B.2	Physical Site	35
4	C.4	Project Site Assessment	33
5	H.2	Project Cost Estimate and Cost Control	32
	E.1	Schematic Layouts	32
	C.1	Lead/Discipline Scope of Work	32
8	A.6	Preliminary Project Schedule	31
	A.4	Project Philosophies	31
10	C.3	Topographical Surveys & Mapping	30

Large Infrastructure Projects – Owners

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	58
2	L.2	Design & Construction Cost Estimates	33
3	A.2	Investment Studies & Alternatives Assessment	31
4	C.3	Contingencies	30
5	C.2	Preliminary Project Schedule	27
	F.1	Geotechnical Characteristics	27
7	B.1	Design Philosophy	26
8	A.3	Key Team Member Coordination	25
9	D.3	Evaluation of Compliance Requirements	24
	I.1	Capacity Study	24

B

Small Infrastructure Projects – Engineers/Contractors

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	64
2	B.2	Physical Site	44
3	C.5	Environmental & Regulatory Considerations	42
4	A.6	Preliminary Project Schedule	39
5	A.5	Project Funding	37
6	C.4	Project Site Assessment	31
	C.1	Lead/Discipline Scope of Work	31
8	G.1	Land Acquisition Strategy	30
9	H.3	Project Schedule and Schedule Control	29
	D.1	Capacity	29

Large Infrastructure Projects – Engineers/Contractors

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	39
2	A.2	Investment Studies & Alternatives Assessment	30
3	C.3	Contingencies	27
4	C.1	Funding & Programing	26
	D.4	Existing Environmental Conditions	26
6	C.2	Preliminary Project Schedule	24
	I.1	Capacity Study	24
8	D.2	Funding Classification & Use	23
	L.2	Design & Construction Cost Estimates	23
	D.3	Evaluation of Compliance Requirements	23

Small Infrastructure Projects | **Large Infrastructure Projects** (CII, 2010)

Figure 8-7. Most Important Elements from Owner and Contractor Perspectives in the PDRI – Small Infrastructure Projects (left column) and PDRI – Infrastructure Projects (right column)

In both PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects, both owners and contractors ranked the Need & Purpose Statement/Documentation element as the most important. This establishes a consensus of how vital it is to identify the objective(s) of the project early on, how the objective(s) will be accomplished, and the financial considerations required to complete the infrastructure project, regardless of size. In addition, for PDRI – Small Infrastructure, both owners and contractors include the Physical Sites element in their top three most important elements, demonstrating the significance of defining the physical site and its correlation to the success of a small infrastructure project. Further, for PDRI – Infrastructure, both owners and contractors included the Investment Studies & Alteration Assessment and Contingencies elements within their top four most important elements, illustrating the importance of the feasibility analysis and assessment to the success of a large infrastructure project. Figure 8-7, section A demonstrates that owners of both small and large infrastructure projects rank the following PDRI elements in their Top 10: Project Philosophies, Design Philosophy, Topographical Surveys & Mapping, and Geotechnical Characteristics. This seems reasonable, as these elements are generally the responsibility of owners. These elements inform the overall design, ensure the desired levels of service and lay out guidelines to maintain adequate and safe operations, respectively. Similarly, section B of figure 8-7 shows that contractors that work on both small and large infrastructure projects include Environmental & Regulatory Considerations, Existing Environmental Conditions, Project Funding, and Funding & Programming in their Top 10 most important elements. These elements focus on payment and environmental requirements, and more directly impact the contractor's day-to-day activities than the owners selected elements, so here to, the selection of elements seems reasonable.

Although the authors note some difference in the most important elements from the owner versus contractor perspective, in general the owners and contractors provided similar weights for the highest ranked elements for both the small and large infrastructure PDRIs. Thus, it is appropriate to have a single PDRI tool that both owners and contractors can implement during FEP for their infrastructure projects. This analysis also suggests areas where these different groups may want to focus their efforts during FEP to mitigate their unique unforeseen risks related to an infrastructure project.

8.5.4. Comparison of Element Weights by Project Type

Figure 8-8 compares the top 10 most important elements, highest-weighted, based on infrastructure project type (People & Freight, Fluids, and Energy).

In PDRI –Infrastructure, four common elements appear in the ten highest-weighted elements for People & Freight, Fluids and Energy Projects. Figure 8 shows these elements, namely Need & Purpose Documentation, Investment Studies & Alternatives Assessment, Design & Construction Cost Estimates, and Preliminary Project Schedule. This consistency confirms that the PDRI – Infrastructure is suitable for assessing People & Freight, Fluids and Energy Projects. Likewise, the first three highest weighted elements within each of the three project types were similar. The analysis also illustrates weighting differences among elements of PDRI –Infrastructure dependent on project type. Only People & Freight projects highly rate Funding & Programming, Existing Environmental Conditions, and Environmental Documentation; meanwhile, only Fluids projects highly rate Geotechnical Characteristics, and Functional Classification & Use. Lastly, only Energy projects highly rate Key Team Member Coordination, Determination of Utility Impacts, and Future Expansion & Alteration Consideration. These differences seem reasonable, as they speak to the nature of construction (e.g., given the relative prevalence of underground work in fluids projects, geotechnical considerations seem more critical) as well as the stakeholders involved (e.g., energy projects often involve utilities, so it follows that these projects may focus more on utility impacts than other project types).

In PDRI – Small Infrastructure, five common elements rank in the ten highest-weighted elements for People & Freight, Fluids, and Energy Projects. Figure 8 lists these five elements, 1) Need & Purpose Statement, 2) Physical Site, 3) Environmental & Regulatory Considerations, 4) Land Acquisition Strategy, and 5) Preliminary Project Schedule. The consistency of the three highest-weighted elements within each of the project types confirms that the PDRI – Small Infrastructure is suitable for assessing all project types. The analysis also confirms differences in weights for PDRI – Small Infrastructure elements dependent on project type. These differences largely relate to the nature of these different project types. For instance, People & Freight projects highly rate Project Funding, and Utility Adjustment Strategy elements; this seems reasonable as the success of these projects depend on consistent funding and the ability to move utilities to make room for the project. Fluids projects highly rate Capacity and Topographical Surveys & Mapping; this too seems reasonable as these projects may be controlled by the topography of the site and the capacity of existing pipes. Energy projects highly rate Lead/Discipline Scope of Work, Project Schedule and Schedule Control, Public Involvement, and Project Cost Estimate and Cost Control. Perhaps more than other types, Energy projects may be subject to "not in my backyard" mentality, explaining the importance of public involvement on this project type. It also seems that energy projects require more clarity about cost, schedule, and discipline-specific scope of work, which may be attributable to the cost growth, unforeseen conditions, and complex work breakdown structures common for projects of this type, or the fact that they are generally "for profit" undertakings. Although the comparison displays some differences between the three data sets, the element weights are fairly similar, as in the owner and contractor comparison.

The common critical elements in both small and large People & Freight projects (section A of Figure 8-8) include Project Funding and Funding & Programming. This indicates that the success of People & Freight projects may be more dependent on funding than other types of infrastructure projects. This seems reasonable given the public funding associated with many People & Freight projects. Topographic Surveys & Mapping and Geotechnical Characteristics are elements that only Fluid projects deem critical (section B of Figure 8-8), regardless of size. This seems reasonable given the importance of topography and geotechnical conditions to construct structures that will efficiently move fluids. Energy projects seem to show the most variance based on size (section C of Figure 8-8). Perhaps this is due to the nature of projects in the author's sample of projects, or perhaps this is because large energy projects tend to involve more stakeholders than other project types (on average), while small projects may be subject to "scope creep" so it is critical to clearly lay out cost and schedule control during FEP. Both the People & Freight and Fluid Projects maintain very similar elements, suggesting that both PDRI – Small Infrastructure and PDRI – Infrastructure are suitable for assessing project scope definition for those infrastructure project types. Even for Energy projects, both tools seem appropriate, given that they allow PDRI users to focus on the unique scope elements that can be critical for projects of different sizes.

A

Small Infrastructure Projects — People & Freight

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	46
2	B.2	Physical Site	42
3	A.5	Project Funding	40
4	C.4	Project Site Assessment	35
5	C.5	Environmental & Regulatory Considerations	34
	E.1	Schematic Layouts	34
7	A.4	Project Philosophies	32
	G.1	Land Acquisition Strategy	32
9	A.6	Preliminary Project Schedule	31
10	G.2	Utility Adjustment Strategy	30

Large Infrastructure Projects (CII, 2010) — People & Freight

Rank	Element	Element Description	Definition Level 5 Weight
1	C.1	Funding & Programming	34
2	A.1	Need & Purpose Statement	33
3	A.2	Investment Studies & Alternatives Assessment	30
4	C.3	Contingencies	29
5	L.2	Design & Construction Cost Estimates	29
6	D.4	Existing Environmental Conditions	28
	C.2	Preliminary Project Schedule	25
8	D.3	Evaluation of Compliance Requirements	23
9	A.4	Public Involvement	22
	F.5	Environmental Documentation	22

B

Small Infrastructure Projects — Fluids

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	71
2	B.2	Physical Site	41
3	D.1	Capacity	34
4	A.6	Preliminary Project Schedule	36
5	C.5	Environmental & Regulatory Considerations	33
6	C.1	Lead/Discipline Scope of Work	32
7	A.4	Project Philosophies	31
	G.1	Land Acquisition Strategy	31
9	C.3	Topographical Surveys & Mapping	29
10	E.1	Schematic Layouts	28

Large Infrastructure Projects (CII, 2010) — Fluids

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	53
2	A.2	Investment Studies & Alternatives Assessment	33
3	F.1	Geotechnical Characteristics	30
4	L.2	Design & Construction Cost Estimates	28
5	I.1	Capacity Study	26
6	B.1	Design Philosophy	25
	D.3	Evaluation of Compliance Requirements	25
8	C.2	Preliminary Project Schedule	23
9	A.4	Public Involvement	21
	D.2	Functional Classification & Use	21

C

Small Infrastructure Projects — Energy

Rank	Element	Element Description	Definition Level 5 Weight
1	G.1	Land Acquisition Strategy	56
2	A.6	Preliminary Project Schedule	40
3	A.1	Need & Purpose Statement	39
4	C.4	Project Site Assessment	37
5	C.1	Lead/Discipline Scope of Work	36
6	B.2	Physical Site	35
	H.3	Project Schedule and Schedule Control	35
8	A.3	Public Involvement	33
9	H.2	Project Cost Estimate and Cost Control	32
	C.5	Environmental & Regulatory Considerations	32

Large Infrastructure Projects (CII, 2010) — Energy

Rank	Element	Element Description	Definition Level 5 Weight
1	A.1	Need & Purpose Statement	65
2	C.3	Contingencies	40
3	C.2	Preliminary Project Schedule	29
4	B.1	Design Philosophy	28
5	A.2	Investment Studies & Alternatives Assessment	27
	A.3	Key Team Member Coordination	27
7	I.1	Capacity Study	26
8	L.2	Design & Construction Cost Estimates	24
	D.7	Determination of Utility Impacts	24
10	B.4	Future Expansion & alteration Consideration	23

Small Infrastructure Projects | **Large Infrastructure Projects** (CII, 2010)

Figure 8-8. Most Important Elements for Various Infrastructure Project Types in the PDRI – Small Infrastructure Projects (left column) and PDRI – Infrastructure Projects (right column)

8.5.5. Comparison of Target Scores

The author determined the target score for each of the infrastructure PDRIs via statistical analyses (see (CII, 2010a, ElZomor et al., 2016a). Statistical tests confirm that lower PDRI scores, in both PDRI – Infrastructure and PDRI – Small Infrastructure, correlate to improved project performance, with improved cost performance being statistically significant in both cases. For "large" infrastructure projects, the author analyzed 22 completed projects with an approximate expenditure of $6.1 billion. This analysis revealed that PDRI scores lower than 200 outperformed projects with PDRI scores above 200, in terms of a project's cost, schedule, and change order performance, with cost being statistically significant (CII, 2010a). Similarly, an analysis of 69 completed small infrastructure projects with an approximate expenditure of $529 million proved that projects with PDRI scores lower than 300 outperformed projects with PDRI scores above 300 in terms of schedule, cost and change order performance, with cost being statistically significant (ElZomor et al., 2016a). Figure 8-9 demonstrates the two target scores of PDRI – Small Infrastructure and PDRI – Infrastructure in relation to the level of definition. This comparison illustrates that smaller infrastructure projects need less definition during front end planning to achieve an equivalent predictability as their larger counterparts in terms of cost, schedule and change performance. Almost all elements in a small infrastructure project can have definition level 2 and achieve predictable cost and schedule performance. By contrast, larger infrastructure projects require that nearly half of the elements have definition level 1 in order to achieve predictable cost and schedule performance.

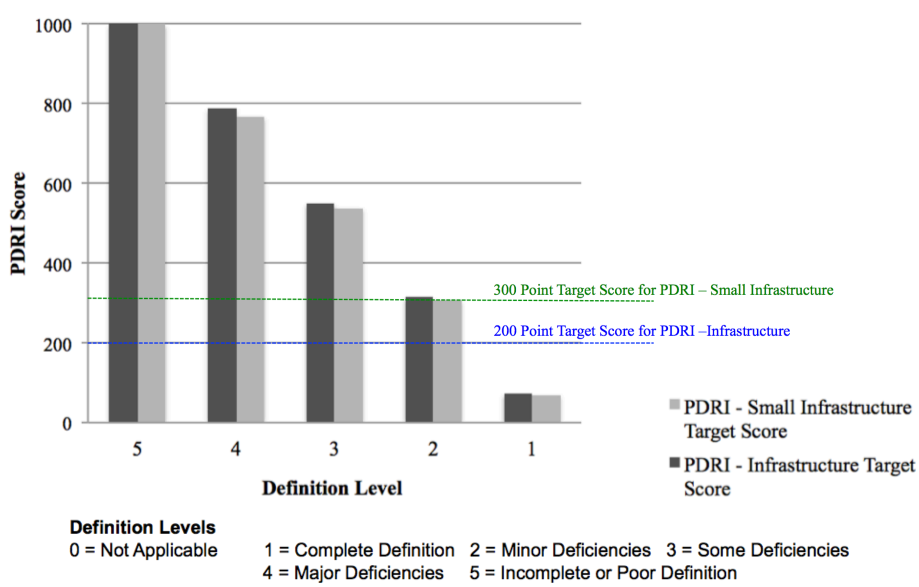


Figure 8-9. Comparison of PDRI – Infrastructure and PDRI – Small Infrastructure in terms of target score

While the predictability of success is the same for large and small infrastructure projects with PDRI scores below the target score, the target scores differ between large and small infrastructure projects. On the one hand, a large infrastructure project requires a “Completely Defined” level of definition or definition with Minor Deficiencies to achieve its planned schedule, budgeted cost and reduce the magnitude of changes. That is, for a large infrastructure project to achieve a score of 200, the majority of element descriptions must be between definition Level 1 and 2 otherwise the score will exceed the 200-point target score, which indicates the project performance is at risk. On the other hand, small infrastructure projects could tolerate less definition and maintain the same level of project performance as its larger counterpart. For example, small infrastructure projects with a schedule of 12 months or less may not have the time for scope evolution as it does in a larger projects, so less definition early on would not negatively impact project performance. Even if small projects require a change, the changes are often simpler to make, as the project is limited in scope and may require fewer team members to approve than a large project would. Concurrent project phasing may also explain why a small infrastructure project requires less definition, as the project may be able to adapt in real time to changes in scope.

8.6. Conclusion

Infrastructure projects represent a significant portion of the U.S. economy, as well as the bulk of work for transportation agencies and utilities nationwide. Successfully planning and executing these projects is vital to maintaining access to critical goods and services throughout the nation. PDRI – Infrastructure and PDRI – Small Infrastructure tools assist in the front end planning efforts for large and small infrastructure projects, respectively. This chapter presented the definition of small infrastructure projects, and compared such projects to large infrastructure projects. The definition and comparison yielded contributions to the FEP body of knowledge; first defining a small infrastructure project based on literature review and a survey of infrastructure project practitioners, and secondly, confirming that both small and large infrastructure projects require similar level of project definition, between Complete Definition – Level 1 and definition with Minor Deficiencies - Level 2 during FEP to support predictable project outcomes. The latter contribution is counterintuitive to the planning efforts assigned to the different project sizes. The chapter also illustrates the similarity in priorities for owners and contractors on both small and large projects, as indicated by similar weighting of PDRI elements in both the PDRI – Infrastructure and PDRI – Small Infrastructure Projects tools. Likewise, critical elements for various project types remain consistent in the PDRI tools for both small and large projects. These findings confirm that a single PDRI tool for each project size provides value across stakeholders and project types.

8.6. Acknowledgements

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CHAPTER NINE

INTEGRATING THE PDRI IN AN UNDERGRADUATE CONSTRUCTION CLASSROOM: A PILOT STUDY ABOUT LEARNING CONSTRUCTION MATERIALS, METHODS AND EQUIPMENT

This Chapter will be submitted for publication in the peer-reviewed journal of ASCE, Journal of Professional Issues in Engineering Education and Practice. Most of the text appears exactly as in the manuscript with the exception of text and figure formatting. This chapter addresses hypotheses four and five.

9.1. Abstract

Increasingly, construction practitioners expect, and in some cases require, that their new hires have knowledge of, and competence in, tools used in the construction industry. Some advanced courses may focus on "tools" used in construction practice for instance a course in Building Information Modeling (BIM). However, most introductory construction courses do not teach students about project management tools used in industry, e.g., scheduling software, front end planning (FEP), or site logistics planning, instead concentrating on the theory underlying such tools. This paper presents a case study where authors introduced a project management tool, the Project Definition Rating Index (PDRI), into an introductory construction management course (Construction Materials, Methods, and Equipment). Results of this in-class activity suggest that introducing the PDRI improves students' understanding of construction methods and how methods impact a construction project. This paper presents successes and challenges from this case study and provides suggestions for future use of the PDRI in construction materials and methods courses.

9.2. Introduction

The engineering education process include ineffective educational paradigms, tiring introductory courses and repetitive learning methods, must undergo dramatic changes in order to meet future schooling challenges (Felder, 2012, Sheppard et al., 2008). Rather than embracing creative problem solving and employing professional tools within lower-division curriculum, engineering courses are taught in a straightforward way based on fragmented concepts (Sallfors et al., 2000, Forcael et al., 2014). This timeworn pedagogy does not encourage complex problem solving, nor prepare undergraduates for their future careers. Higher education in the 20th century is viewed as a pillar that forms the primary backbone of our economy (Oakes et al., 2015, Sullivan and Rosin, 2008). As such, many graduating students, especially in the field of construction, find themselves interviewing for positions that not only require technical and professional skills, but more importantly proficiency with the software tools used within the industry (Hersh and Merrow, 2015). To this end, a robust construction engineering and management education should be implemented to prepare lower division students in exceeding the demands of the market.

The construction industry utilizes the PDRI to improve the predictability of project performance and define the scope of a project during front end planning (CII, 1994). This paper presents results from a case study where the authors introduced the PDRI in a Building Construction Materials, Methods, and Equipment course at Arizona State University. Specifically, this paper describes the in-class activity and outputs along with lessons learned, recommendations for future courses, and limitations. Results of the ASU case study indicate that students feel that learning about the PDRI improves their understanding of project scope and risk, as indicated through responses to two questions included in a pre- and post-course survey. Results further suggest that undergraduate construction management students improved their understanding of materials, methods, and equipment based on the in-class activity, as evidenced by their deliverable from said activity. Indeed, student performance in the “methods” area of the final report rubric in the semester that the PDRI was introduced is improved compared to previous semesters.

The paper closes with a discussion of how other instructors and educators can integrate the PDRI, or another project management tool, into an introductory construction management course. The paper contributes to the construction management education body of knowledge through providing a proof of concept that integrating an industry tool into undergraduate construction materials, methods, and equipment course enhances students’ learning and skills in said course.

9.3. Literature Review

Front end planning (FEP) has a significant impact on project success since it supports project stakeholders in setting up the project’s concept, defining the scope and mitigating risks. Because of the aforementioned justifications, it is fundamental to introduce construction students to additional professional tools that are used in the industry especially FEP tools, which are overlooked by the construction curricula.

9.3.1. Front end planning (FEP) and Project Definition Rating Index (PDRI) tools.

Planning efforts conducted during the early stages of a construction project, known as pre-project planning or front end planning, have significantly more effect on project success than efforts undertaken after detailed design and construction has begun

(Gibson et al., 1993). Gibson and Hamilton (1994) showed that effective front end planning improves project performance in terms of both cost and schedule, since it reinforces the positive impact of early scope definition on project success. The Construction Industry Institute (CII) has created a suite of tools to quantitatively measure the level of scope definition on projects prior to detailed design as part of their front-end, or pre-project, planning research efforts. CII's Project Definition Rating Index (PDRI) allows a project team to assess, quantify, and rate the level of scope definition and readiness for project execution, prior to detailed design and construction (CII, 1997, CII, 2001, CII, 2006). Moreover, it is a means by which project enablers can be identified early and acted upon. Its ability to provide these early measures and indicators makes the PDRI a remarkably powerful tool for proactive project management.

FEP planning is considered an important subset of the overall project planning endeavor; it begins after the business leadership of an organization deems a project concept desirable, and continues until the beginning of detailed design and construction of a project (Hamilton and Gibson, 1996). Research into the relationship between pre-project planning impacts and facility construction outcomes had not been conducted prior to 1991 (CII, 1994b). CII established the Pre-Project Planning Task Force in 1991 to outline the functions involved in the pre-project planning of capital facilities. The task force defined pre-project planning as "the process of developing sufficient strategic information for owners to address risk and decide to commit resources to maximize the chance for a successful project" (Gibson et al., 1993). CII initiated the development of five pre-project planning tools for quantifying, rating, and assessing project planning efforts based on the conclusions found by the Pre-Project Planning Task Force, namely the Project Definition Rating Index (i.e., PDRI) tools, between the years of 1994 and 2017. These five PDRI tools are PDRI-Industrial (Gibson and Dumont, 1996), PDRI-Building (Cho and Gibson, 2001), PDRI-Infrastructure (Bingham and Gibson, 2010), PDRI – Small Infrastructure (Collins et al., 2015) and PDRI – Small Infrastructure . The purpose of the tools is three-fold: (1) to provide a structured planning process for use during the front end planning phase of a project, (2) to provide a quantitative measure (i.e., a score) of the level of scope definition of a project, and (3) to correlate 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 to meet these objectives: a structured list of descriptions detailing specific elements that should be addressed during the front end planning phase, and a weighted score sheet that corresponds to the element descriptions. The element description is divided into three separate sections (Basis of Project Decision, Front End Definition, Execution Approach), and further divided into multiple categories. This arrangement places similar elements together for ease of discussion during pre-project planning assessments. Each element also has a detailed narrative that provides description of the element, and certain additional items to consider when assessing a project. Fig. 9.1 provides an example of an element description H.1 Design/Construction Plan and Approach from the PDRI Small Infrastructure Projects (CII, 2017).The format for describing each element shown in Fig. 9.1 is typical of all other PDRI tools as well. CII's research outcomes included the development of a generic model expressing the typical pre-project planning process (Hamilton and Gibson, 1996, Gibson et al., 1993), a quantitative study comparing pre-project planning effort vs.

project success factors (Gibson and Hamilton, 1994), and culminated with a pre-project planning handbook that detailed specific steps typical in planning capital projects (CII, 1994b). The quantitative study found that well-performed pre-project planning could reduce the total project design and construction costs by as much as 20 percent, and reduce the total project design and construction schedule by as much as 39 percent (Hamilton and Gibson, 1996, Gibson et al., 1993).

H1. Design/Construction Plan and Approach

Document the methodology for project engineering and construction, including the following items:

- ❑ Project work breakdown structure
- ❑ Contracting plans (e.g., logistics, labor and resource availability, partnering and strategic alliances, work week schedule and restrictions)
- ❑ Project staffing plans (e.g., definition of roles, responsibilities, experience, licenses and registrations, other special skills and credentials, critical personnel)
- ❑ Project risk mitigation plan and contingency forecast/ allowance
- ❑ Integration of other plans into construction execution (e.g., right-of-way management, environmental monitoring and controls, stormwater pollution prevention, utility adjustment, safety and health program, public space plan)
- ❑ Other (user defined)

If this is an instance of a repetitive program

- ❑ Compatibility of this project with program's engineering and construction plan and approach

Figure 9-1. Sample element description form the PDRI-Small Infrastructure

9.3.2. Professional Tools in Construction Courses – (Literature demonstrates that PDRI was never used in classroom)

Upper-level construction education integrates multiple professional tools in their curriculum to enhance the learning environment (Clevenger et al., 2010). Abudayyeh et al. (2000) demonstrated that lower-level classes in construction education rather focuses more on theories and understanding the fundamentals with limited innovative pedagogies, in addition to reduced exposure to how the construction process does actually operate. However, some lower-level construction courses do include industry practitioners in classes through construction site visits and guest lectures. Becerik-Gerber et al. (2011) identified some upper-level construction courses that integrate “tools” used in construction practice, e.g., a course in Building Information Modeling (BIM), virtual reality or front end planning. Unfortunately, lower-level construction students lack the opportunity to learn from these tools in their early academic careers as students are rarely exposed to the actual construction project management tools used in field. However in light of the changes of teaching method in construction education, the authors have tested and implemented several advanced techniques into a construction materials and methods lower-level course (ElZomor et al., 2016b, Ghosh et al., 2015, Antaya and Parrish, 2014). The educational means are shifting from the traditional theory-based curriculum to PBL, VI, problem solving with open-ended solutions and hands-on projects. Research has shown that these innovative pedagogies helped students better understand and visualize construction projects.

Although the PDRI tool has demonstrated tangible design, scope and schedule benefits to different projects, it remains a tool that is only used in the professional field and not integrated into a construction syllabus. This represents a gap in the literature, students' understanding and skill competency of professional tools. This study addresses this gap, providing documentation of how a PDRI can be introduced into an introductory construction management course, and discussing the results of such an introduction. This study investigated two hypotheses (representing hypotheses 4 and 5 in the overall scheme of this dissertation):

Hypothesis 1: *Undergraduate students in a materials, methods, and equipment course will improve their self-reported skill level in using industry-based tools for construction project management after being introduced to the PDRI in a single class session.*

Hypothesis 2: *Following an in-class activity where undergraduates in a materials, methods, and equipment course articulate how a given PDRI element impacts the materials, methods, and equipment, the students will improve their performance in selecting construction methods for a hypothetical project.*

9.4. Research Method

The PDRI tool was introduced in the classroom through a one-class activity. The authors introduced two categories from Section III, Execution Approach, of the PDRI – Small Infrastructure Projects, totaling ten PDRI elements. All PDRI tools include the main three sections (I. Basis of Project Decision, II. Basis of Design and III. Execution Approach), yet each PDRI tool does discuss different categories and elements. For this workshop the authors selected section III, Execution Approach, of the element description that closely represents section III in all developed PDRI tools. The execution approach section includes two categories G. Execution Requirements and H. Engineering/Construction Plan And Agreements and each section includes five and six elements respectively. The PDRI tool aligns with project types building, industrial and infrastructure. Since the small PDRIs inherently consist of less scope than large projects, the authors opted to use one of the small PDRI project tools to accommodate for a 75-minute in-class activity; CII developed two small PDRI tools, PDRI – Small Industrial (Collins et al., 2015) and PDRI – Small Infrastructure. The authors believe that all vertical construction projects have a horizontal small infrastructure element that ties the project to the existing infrastructure system. Therefore, it was effective to utilize PDRI – small Infrastructure tool in the classroom to further develop the student's awareness about actual complexities of construction projects. Also this case study serves in informing students about the effective means adopted by professionals to define the scope of projects and identify potential risks. In turn, the authors anticipated this implementation would lead to students improving their self-reported technical skill level in addition to developing their competency to articulate and solve interdisciplinary project challenges. The assessment of this implementation was based on testing the two hypotheses. Hypothesis one is tested through an indirect measurement of evaluating the students' self-reported skill level. Hypothesis two included an indirect assessment that corroborates the courses' technical objective skills through an in-class workshop activity in addition to a direct assessment of comparing students' performance in describing construction methods.

9.4.1. The course and project selected

Construction Methods, Materials and Equipment (CON 252) is a lower-division construction management course taught each semester at Arizona State University. CON 252 focuses on vertical construction with a ground-up approach: it begins with content on earthwork and building foundations, and progresses towards building materials, building construction methods, and finally installed building equipment. This course seeks to summarize the materials used in building construction and the methods employed to place them on a construction site. This helps students to identify and understand the most common building construction materials and methods for various building types, thus, it focuses on lower levels of Bloom's taxonomy (Anderson et al., 2001, Krathwohl, 2010). Specifically, Table 9-1 show CON 252 eight course learning objectives.

Table 9-1. Course Learning Objectives for CON 252

- Explain the vernacular of building design and construction including terminology, units of measure, standard designations, sizes, graduations testing methods, reference standards, and regulatory codes.
- Summarizing the basic processes of designing and constructing a building
- Explaining the most common systems of excavation and building foundation systems
- Explaining the most common types of building structural systems
- Describing systems used to keep structures free from water infiltration and remember the systems used to do this, including roofing, caulking, etc.
- Summarizing mechanical, electrical, plumbing, and vertical transportation systems
- Explaining the advantages of different construction methods and material
- Utilize teamwork and team-building skills to integrate information from various team members and present construction method and material options and explain the advantages of each in written, oral, and graphica communication

During Spring 2015 and 2017 the focus of the CON 252 final project was heat mitigation. Since increasing temperatures in the Phoenix valley (the area surrounding ASU's campus) are an issue that all CON 252 students can relate to, the final project for CON 252 asked teams of students to develop prototype buildings for multi-family, retail, office, and "other" building types. The project specifically required students to address how their prototype building would mitigate heat exposure, and explain how all construction endeavors, including materials, methods, and equipment used would strategically combat the issue of heat vulnerability in the Phoenix metropolitan area. Each general contractor team (represented by a team of 4 or 5 students) prepared a Construction Proposal that describes their team, their approach to their specific building type, and their construction methods for that building type.

9.4.2. Students' Self-reported Skill level

The indirect assessment was conducted through a pre- and post-course survey to analyze the students' self-reported technical skill level in relation to understanding and utilizing professional construction tools. Surveys were deployed two times during the Spring 2017 semester to assess the students' self-reported skill levels in technical course objectives. The authors worked with Arizona State University's University Office of Evaluation and Educational Effectiveness (UOEEE) to create evaluation instruments and statistical analysis that assess the student's technical skills (Chester et al., 2017). These surveys were deployed twice, at the start and the end of the Spring 2017 semester. The questions were consistent on each of the two surveys, and the students voluntarily completed both surveys in class. Students developed personal identification codes for the pre-course surveys, and they utilized the same codes for the post- course surveys. Using these codes, researchers were able to match pre-course and post-course responses to gain better insight into changes in students' self-reported skills. Moreover, the authors decided to include a direct measurement to evaluate the student's skill level. This was conducted through comparing the rubric grades of the construction methods section in the student's final projects in the semester that the PDRI was introduced to previous semesters without the PDRI.

9.4.3. Corroborating the courses' technical objective skills

The students were required to fill in worksheets that correlate between the PDRI element description and their knowledge of construction materials, methods and equipment. Students were divided into eight groups for the in-class activity, according to their final project groups. This activity documented how the students enhanced their understanding of project scope, identifying of project risk "delays" and defining the various impacts of materials, methods and equipment on the project, which were not part of the CON 252 course learning objectives. This activity mirrors a PDRI weighting workshop (e.g., (CII, 2010b, CII, 1995, CII, 1999, CII, 2015, CII, 2017)) where firstly, the students are introduced to the PDRI as a tool and concept, then they are required to read the element description and collectively discuss each element's impact on the material, method and equipment selections for their final project, if any. Figure 9-2 show the template that was provided to the students to report their updated selections and provide their comments. The element description prompts discussion between students about how each element impacts the project, specifically in terms of material, method, and equipment choices. The goal of the in-class activity was to have students improve their understanding of construction materials, methods, and equipment through evaluating PDRI element descriptions and articulating their impacts on materials, methods and Equipment.

SECTION III - EXECUTION APPROACH	MATERIAL, METHODS AND EQUIPMENT Consideration
G. EXECUTION REQUIREMENTS	
G2. Utility Adjustment Strategy	
G3. Procurement Strategy	
G4. Owner Approval Requirements	
G5. Intercompany and Interagency Coordination	

Figure 9-2. Template for CON 252 students to report their updated material, method and equipment selections based on the PDRI element description

To corroborate the findings of the in-class activity, the authors compare student performance on the final construction proposals. Specifically, the authors compare the rubric grades for the construction methods documented in the student's final projects. They compare performance in the semester that the PDRI was introduced (Spring 2017) to students' performance on the same metric in the semester where PDRI was not included (Spring 2015).

9.5. Results and Discussion

9.5.1. Survey Questions to evaluate the student's skill level

The pre- and post surveys included two questions that ask students to self report their current skill level for each of the following skill areas (a) "Utilizing tools adopted by professionals to understand project scope and risk" and (b) "Identifying required activities to complete a project based on the elements of the Project Definition Rating

Index (PDRI)" labeled as "SkillScopeRisk" and "SkilldentPDRI" respectively in figure 3. The survey utilized a five-point scale: 1 = "no knowledge", 2 = "beginner" (some experience or basic knowledge), 3 = "proficient" (can utilize at a satisfactory level), 4 = "advanced" (can utilize better than most), and 5 = "expert" (can utilize with a superior level of skill and teach to others).

In Spring 2017, the majority of CON 252 students, 38 out of 40, were undergraduates. The student body for this course includes freshmen (34%), sophomores (29%), juniors (26%) and seniors (8%) and Master students (2%). CON 252 is a required course for construction management majors and approximately 80% of the students enrolled are construction management majors. Other student majors include construction engineering, architecture, and Business Administration, among others.

Figure 9.3 confirms that CON 252 students improved their PDRI skills over the course of the semester. Whereas at the beginning of the course about 6% of the students rated themselves as having "no knowledge" and 41% reported "beginners" in Utilizing tools adopted by professionals to understand project scope and risk, by the end of the course none of the students reported "no knowledge" and only 19% reported they were "beginners". Thus, students shifted from "no knowledge" to higher skill levels. In fact, the percentage of students reporting "Advanced" tripled by the end of the course. Similarly, 24% of students reported "no knowledge" in Identifying required activities to complete a project based on the elements of the Project Definition Rating Index (PDRI) in the pre-course survey, and by the post-course survey, only 4% reported "no knowledge". Fifty-five percent of students reported "no knowledge" and "beginner" before the course, while after the course, this shifted, with 71% of students reporting they were “Proficient” or “advanced”.

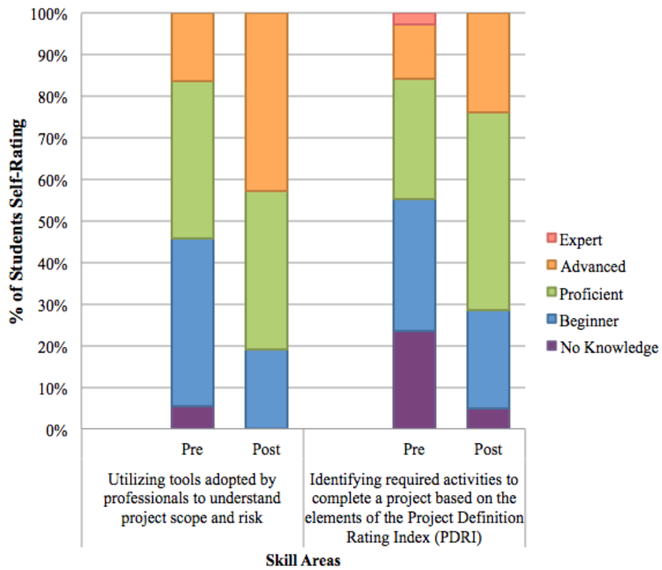

Figure 9-3. Students’ self-reported gains in skill level from the pre-course to the post-course survey

Figure 9-4 demonstrates that the post-course medians for skills related to the in-class PDRI activity were between “proficient” and “advanced”. This represents an increase, as the pre-course medians were between “beginner” and “proficient”. The students’ gains in the self-reported skill levels are noticeable post the introduction of the PDRI. The authors link the increase in median skill level to the in-class PDRI exercise since the course eight objectives didn’t focus on either scope or risk elements, that the PDRI introduced. The PDRI not only did enhance the student’s self-reported skill levels but also familiarized the students with professional FEP tools. The authors surmised that students’ skills in identifying risks associated with project scope (SkillScopeRisk in Figure 9-4) may have increased due to both the in-class PDRI exercise and participating in the CON 252 course. This result supports hypothesis 1 that lower division construction students in a materials and methods course improved their own self-reported skill level in using industry-based tools for construction project management after being introduced to the PDRI in one class session. To this end, the integration of professional tools into lower division construction method classes help student develop their skills beyond the set course learning objects especially that these tool inspire depth to their understanding of the course.

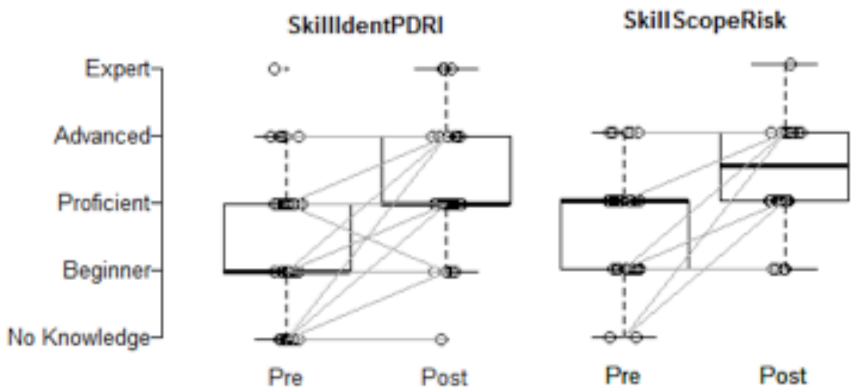

Figure 9-4. Comparison of Students' Skill Level over the course of the Spring 2017 semester

9.5.2. Comparison of Student Performance in describing construction methods

As a direct assessment of the change in students' ability to articulate and describe construction methods, the authors compared student grades for the construction methods portion of the final project. Specifically, the authors compare the "construction methods" line of the final project rubrics from Spring 2017, to Spring 2015 (a semester when the PDRI was not implemented). Figure 9-5 illustrates the rubric used for this assessment (Appendix G includes the complete set of Rubric and the in class workshop sheet). Figure 9-6 shows that the grades of CON 252 students increased from 55% of students scoring an “A” in Spring 2015 to 75% of students scoring an “A” when the PDRI was implemented (Spring 2017). Also, none of the Spring 2017 students scored less than a “B” while during Spring 2015, approximately ten percent of students scored a “C”. This assessment verifies hypothesis two, as the student performance improves when the PDRI tools is implemented.

Rubric

Attribute	Developing (C-level)	Developed (B-level)	Excellent (A-level)
Content			
Did you explain the **methods** used to construct each of the three concepts you present?	Methods are absent or are only included for the proposed concept	Methods are described well for the proposed concept and mentioned for alternatives	All three concepts include a comprehensive discussion of the construction methods

Figure 9-5. The rubric used for the student performance assessment

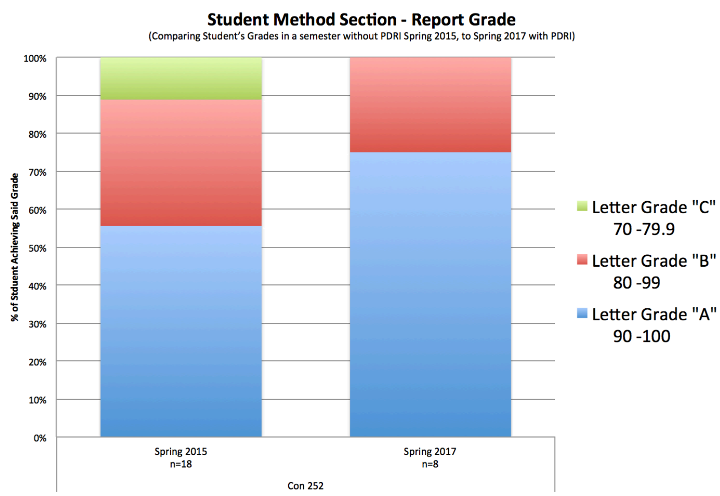

Figure 9-6. . Comparison of Students’ Method Grades in a semester without PDRI, Spring 2013, to Spring 2016

The authors attribute the improvement in grades of the method section to the in-class PDRI activity. The PDRI presents and discusses several construction execution approaches that the CON 252 students may not otherwise have knowledge of, given the scope of the CON 252 learning objectives (Table 9-1). For example, the PDRI explicitly requires students to consider a Work Zone Safety and Transportation plan (element H5), which is not typically covered in the CON 252 curriculum. However, following the inclusion of the PDRI activity in the Spring 2017 semester, the instructor noted that multiple student reports describe the transportation plan associated with their proposed project. Similarly, more students discussed their procurement plans in detail, likely based on their exposure to this topic in the PDRI exercise. Utilizing the PDRI in class broadened students' understanding of project scope and seemed to also enhance their understanding of the construction methods that may be used for each of the areas of project scope outlined in the course learning objectives (e.g., foundations, structural system).

9.5.3. In-class workshop activity

To articulate how a given PDRI element impacts undergraduates in a materials and methods course, students were asked to participate in a 75-minute in-class activity. The activity introduced students to a section of the PDRI, Section III – Execution Approach, and then students worked in their final project groups to analyze how, if at all, these elements would impact their material, method and equipment decisions for their final projects. The authors then coded the students' comments for each element to relate the comment to a CON 252 course-learning objective.

Section III consists of two categories (G – Execution Requirements and H – Engineering / Construction Plan and Agreements) with five elements in category G and six in H. CII (2017) provided details for these two categories along with their element description. Table 9-2, demonstrate the students comments on four of the five Execution Requirements elements, which are G2. Utility Adjustment Strategy, G3. Procurement Strategy, G4. Owner Approval Requirements and G5. Intercompany and Interagency

Coordination. Several teams have identified various elements of the PDRI that impacted the selection of material, method and equipment for their final project. Five groups mentioned the importance of Owner approval as a factor that impacts the alternatives of material, method and equipment. Four groups mentioned the impact of Long-lead items on the planning and procurement of material and equipment, which also impacts the method of construction activities. Similarly, category H. Engineering/Construction Plan And Agreements includes six elements that focus on ensuring successful design, engineering, construction and closeout; these elements are, H1. Design/Construction Plan & Approach, H2. Project Cost Estimate and Cost Control, H3. Project Schedule and Schedule Control, H4. Project Quality Assurance & Control (QA/QC), H5. Safety, Work Zone & Transportation Plan and H5. Project Commissioning/Closeout. Table 9-3, show that several teams valued that the element description impacted their selection of material, method and equipment. For example, seven groups mentioned that cost estimate and control influences the methods, materials and equipment used on a project, while six groups encouraged the projects' stakeholders involvement in schedule as it impacts the method, material and equipment. Also, five groups stated that the construction methodology needs to be planned and documented, as it will impact the material and equipment selections. Finally, four groups mentioned the importance of Quality Assurance & Quality Control as it controls the materials, method and equipment used in the project, equally students highlighted the criticality of the work zone control plan implemented as it reflects safety which impacts materials, methods and equipment choices as well.

Table 9-2. Student comments on Execution Requirements PDRI elements

			# of Teams	MATERIAL, METHODS AND EQUIPMENT CONSIDERATION
SECTION III – EXECUTION APPROACH (PDRI – Small Infrastructure Project)	G. EXECUTION REQUIREMENTS	G2. Utility Adjustment Strategy	4	Consider Procurement of material and equipment especially the long-lead items.
			2	Address the need for temporary facilities during construction i.e. generators
			3	Planning for material, method and equipment of HVAC systems, plumbing, drainage, electrical and utilities that require different installation methods
			3	Consider permitting and regulations imposed by county/city specifically to the use of materials, approved working hours, regulation of storage, requirements and possibilities of using public streets.
		G3. Procurement Strategy	2	Developing a detailed schedule of activities will facilitate identifying and delivering specific long-lead materials
			4	Planning and procurement of materials and equipment is important as it impacts how methods of construction activities will be handled.
			1	Bidding process and cost estimation impacts the materials and equipment choices
			1	It is the General Contractor's (GC) responsibility to track the procurement matrix for equipment and materials, also GC should encourage early material submittals from subcontractors to avoid delays
			1	Without quality assurance the materials might not meet the required standards thus delays the project
		G4. Owner Approval Requirements	5	Consider approval of schedule from owner, which impacts the method of construction, as well as the invoices process. Also, Owner needs to approve all materials and equipment
			3	Project team is to schedule weekly meetings to discuss material, method and equipment. Projects may as well consider advanced professional tools for construction as BIM. The Owner impacts the method of construction since he/she approve all software required by project team
		G5. Intercompany and Interagency Coordination	2	Project team should identify entities that impose restrictions on materials used to avoid any unforeseen delays.
			2	The equipment used on site and the methods need to conform with the project's code and regulation
			1	Make sure all public and private funding is accounted for and addressed before construction, as this is another source of jeopardizing the cash flow of the project
			2	Coordination with officials could affect the methods and equipment used based on the plans and location of site. Lack of coordination with entities around the project can cause major delays

Table 9-3. Student comments on Engineering / Construction Plan and Agreements PDRI elements

Section	Category	Element	# of Teams	MATERIAL, METHODS AND EQUIPMENT CONSIDERATION
SECTION III – EXECUTION APPROACH (PDRI – Small Infrastructure Project)	H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS	H1. Design/ Construction Plan & Approach	5	All construction approaches need to be planned and documented as these will impact the selection of materials, methods and equipment
			3	Resource availability and staffing have direct impact on the methodology of construction
			3	Material, method and equipment will impact the Risk identification and mitigation plans
		H2. Project Cost Estimate and Cost Control	7	Determining effective methods, materials and equipment are needed to ensure profitability of projects.
			2	Consider the environmental permits as it imposes strict guidelines on the construction method and materials
			2	Costs are generated from materials, method and equipment. Consider taxes and incentives when planning for methods, materials and equipment
		H3. Project Schedule and Schedule Control	6	All project stakeholders input impact the schedule and thus the method, material and equipment of construction. Any disruptions can affect the construction methods and delay the project
			2	The Schedule can be affected by unforeseen conditions that can impact the material delivery
			2	Schedule control procedure can impact the method and equipment of construction. The schedule may set up an early Internal completion date, to account for delays
		H4. Project Quality Assurance & Control	4	QA/QC can impact the materials method and equipment used in the project.
			1	RFI submittal procedures can impact materials and methods
			1	Performance testing will be taken account for during materials and methods choices to avoid delays
			4	QA/QC reflects safety measures to the workers and encourages material approval.
		H5. Safety, Work Zone & Transportation Plan	2	Transportation requirements can affect the schedule and thus the methods and equipment
			4	Work zone control plan is implemented to reflect safety and it impacts materials, methods and equipment choices
			2	Logistics of material storage and handling impacts materials, equipment and methods of construction
		H6. Project Commissioning /Closeout	3	The method and sequence of handing over the site is important as this may delays the completion date
			4	The project can be delayed if the project team did not identify the method of relocating and removing the equipment and materials off site

Students' comments in table 9-2 and 9-3 demonstrated how the element description impacted their selection of materials, methods, and equipment used for their final projects. This aligns with hypothesis 2 that undergraduates in a materials and methods course will articulate how a given PDRI element impacts the materials, methods, and equipment sections on a project following a 75-minute introduction to a set of PDRI elements. The authors expected depth in students' final presentation due to the introduction of the PDRI, since the PDRI introduced other learning objectives that were not part of the eight course learning objectives. Although most of the students' comments were not part of the course objectives, their comments can be associated with the courses' learning objectives. The introduction of the PDRI developed the students' understanding of construction projects especially that this tool provides a rounded perspective of how projects are scoped and managed. The PDRI also encourages students to consider various elements, requirements and stakeholders of the construction process, which usually are overlooked in a lower-division construction management course. For example, students' explored construction safety, procurement strategies, approvals and coordination with officials in an introductory construction course in Spring 2017, and this is the first time the authors explicitly saw students understand these elements of the construction process. The students leveraged the introduction of PDRI to develop clearer descriptions of construction methods and equipment in their final projects. Based on the student comments, the authors also recognize that introducing the PDRI in an undergraduate construction class developed students' understanding of construction risk. When the student responses were coded, many discussed "potential delays," and "potential cost overruns," and "safety concerns," among others, that in fact describe construction project risk. While only a handful of students used the word "risk" in their comments on the worksheet (tables 9-2 and 9-3), most students articulated risk in an implied sense. The authors felt that students did a better job of selecting materials, methods and equipment for their final construction proposals as a result of the PDRI activity, as discussed in the following section.

9.6. Limitations and Future Research

While the authors endeavoured to develop a transferable, 75-min activity that introduced the PDRI in an undergraduate construction management session their study includes limitations. Limitations comprise the framework development as well as the assessment methods implemented. Specific limitations include:

- **Using PDRI – Small Infrastructure Projects:** This activity was implemented into a construction class that focuses on buildings. The authors decided to use the PDRI - Small infrastructure projects instead the PDRI – Building projects since the latter PDRI requires more time to be introduced in a classroom. The results demonstrate that lower-division construction students enhanced their skills when introduced to the PDRI tool. Perhaps if CII developed a PDRI tool that discusses only small building projects, then all students that take a class on building construction materials and method, i.e. most CM undergraduates, would be able to use such a tool to improve their understanding of projects.
- **Introducing only one section of the PDRI element description:** Despite the fact that the authors intended to conduct this activity during a one class session, this reflects a limitation since it is challenging to go through a full set of element description, three sections, in a 75-min class. Therefore, future research could

investigate increasing the duration of the activity to three lectures where the first is an introduction, the second explains the element description of a complete PDRI tool and the third requires students'' to participate in the in-class workshop.

- **Student Self-Reported Skill Level:** It seemed surprising that so many students indicated that they had PDRI knowledge in the pre-course survey, as this did not match the authors' observations in class when the PDRI was introduced. Students may over estimate their own actual skill levels, so results reported in this paper, may not be replicable if the framework is implemented at another institution.
- **Assessment of Student Self-Reported Skill Level:** This research did not include a direct assessment of students' skill level related to ability to articulate and define project scope and risk. However, the authors leveraged final report grades of the "method" section as a metric to assess of the effectiveness of students' understanding of materials, methods, and equipment based on the in-class activity.
- **Assessment of student performance**: While the same instructor in both the Spring 2015 and Spring 2017 semesters determined the "method" assessment metric, student populations did change. Thus, their demographics may have also been different, e.g., the Spring 2017 students may have been pre-disposed to higher scores based on their incoming GPA, or other factors.
- **A Pilot Study:** This implementation is a proof of concept and a first-time case study that was examined during the spring 2017 semester. However, since the initial results of the case study are promising, the instructor is planning to incorporate it again in her CON 252 class at Arizona State University.

- **Include the activity early during the semester**: The authors deemed to include this activity during the second to last week of classes, however the activity might suitably be introduced in the second third of the semester, so that the PDRI can inform the project and students can build on its content rather than only using it as a tool that updates their projects.

9.6. Conclusion

This research's aim was to expose construction students to the real world of building construction applications, through piloting an in-class workshop that integrates a FEP tool into the classroom. The authors anticipated that implementing the PDRI, FEP tool, into lower division construction courses could aid in bridging the gap between theoretical learning and the actual application of professional practices. The introduction of the PDRI equips students with an additional tool that properly equips them for their professional careers. The study utilized direct and indirect analyses that confirm the effectiveness of the 75-minute in-classroom activity. Results of this case study suggest that introducing the PDRI support students' understanding of construction methods, also the PDRI improves their ability to articulate how methods can impact a construction project, which was reflected in their course performance.

CHAPTER TEN

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the conclusions of the PDRI - Small Infrastructure research, and the recommendations of the research based on the research results.

10.1. Research Objectives

The research team initially set forth the following objectives:

1. Produce a user-friendly tool for measuring project scope definition of small infrastructure projects with the following characteristics and functions:
    - Based upon the PDRI – Infrastructure, yet tailored specifically to small infrastructure projects
    - Less time-consuming than the PDRI – Infrastructure
    - Is easy to use, yet detailed enough to be effective
    - Helps reduce total project costs
    - Improves schedule performance
    - Serves as a communication and alignment tool
    - Supports decision-making
    - Identifies risks
    - Reliably predicts project performance
    - Is flexible among infrastructure project types
2. Test the tool by comparing the level of project scope definition during the front end planning phase vs. corresponding project performance factors for a sample of completed small infrastructure projects

The research results presented in this dissertation have met all of the stated research objectives. An extensive literature review highlighted the value of implementing the front end planning tools developed by CII, the lack of a non-proprietary tool specifically for small infrastructure projects, and the inherent differences between small and large projects. The members of Research Team 314a utilized the existing literature to develop a simple, easy to use tool specifically for small infrastructure projects, a project type found to make up approximately half of completed projects (by count) each year in the infrastructure sector. Seventy-one industry professionals participated in seven separate weighting workshops providing valuable feedback on the tool's element descriptions, in addition to providing input for element prioritization, and data project data that was used to develop an infrastructure PDRI selection guide. The tool was tested on 69 completed projects with an overall expenditure of over US $529 million, which showed a difference regarding schedule, cost, change, and financial performance, and customer satisfaction on projects with PDRI scores below 300. These results demonstrate the ability of the tool's scoring scheme to highlight the risk factors most important to address during the front end planning of small infrastructure projects, and the negative impacts to project performance if they are not properly addressed. The tool is also currently being used in industry, with every indication that its implementation within organizations will provide just as much value as the preceding PDRIs have. Feedback from industry professionals that test the tool on seven separate in-progress projects (with overall project budgets totaling more that $35 million) suggested that the tool provides an effective platform for aligning team members to project goals, and individuals that the PDRI added value to their projects.

A survey of CII member organizations showed that planning practices for small infrastructure projects vary greatly across the industry, and even within organizations. The PDRI – Small Infrastructure was designed to provide a structured approach to the industry for the purpose of improving project performance. The PDRI – Small Infrastructure was also developed so that it is flexible enough to be used on a wide assortment of small infrastructure project types, but detailed enough to add value to the front end planning process. The number of elements within the tool is significantly lower than the PDRI – Infrastructure, but this was not done simply for the purpose of lowering the assessment time. The purpose of front end planning is to sufficiently define scope items necessary to complete a project, and the rigor of that process should match the rigor of the project itself. The detail within the PDRI – Small Infrastructure element descriptions is sufficient for assessing the scope definition of infrastructure projects with a lesser amount of project scope, hence less project complexity.

10.1.1. Research Hypotheses

The specific hypotheses were as follows:

Hypothesis 1*: A finite and specific list of critical issues related to scope definition of small infrastructure projects can be developed.*

The PDRI – Infrastructure tool was used as a baseline to develop the PDRI – Small Infrastructure. Element descriptions within the PDRI – Infrastructure were reviewed, scrutinized, adapted, and revised by the research team, leading to the development of 40 elements specifically for assessing small infrastructure projects.

Seventy-one industry professionals reviewed and prioritized the elements, with 69 of them providing sufficient feedback to develop a final set of element descriptions and corresponding score sheets, as described in Chapter 5. The tool was also tested on seven in-progress projects, of which the users noted the effectiveness of the tool to sufficiently address key issues in the front end planning of small infrastructure projects.

Hypothesis 2*: Projects with low PDRI scores outperform projects with high PDRI scores.*

The results of the completed-project analysis showed that projects with PDRI scores lower than 300 outperform projects with PDRI scores above 300 regarding cost performance, schedule performance, change performance, financial performance, and customer satisfaction, as described in Chapter 7. Independent samples t-tests (p-value of .048) indicated that the cost performance is statistically significant and the regression analysis (p-value of .024) for cost performance was also statistically significant at a 95 percent confidence level. On the other hand, no statistically significant difference was found for schedule performance and change performance when conducing the t-test and the regression analysis.

Hypothesis 3: *The PDRI – Infrastructure Projects and PDRI – Small Infrastructure Projects require similar level of project definition, between Complete Definition – Level 1 and definition with Minor Deficiencies - Level 2, during FEP to support predictable project outcomes.*

The results confirm that both small and large infrastructure projects require similar level of project definition during FEP to support predictable project outcomes. This contribution is counterintuitive to the planning efforts assigned to the different project sizes. The comparison also illustrates the similarity in priorities for owners and contractors on both small and large projects, as indicated by similar weighting of PDRI elements in both the PDRI – Infrastructure and PDRI – Small Infrastructure Projects tools. Likewise, critical elements for various project types (i.e., energy, fluids, people and freight) remain consistent in the PDRI tools for both small and large projects. These findings confirm that a single PDRI tool for each project size provides value across stakeholders and project types.

Hypothesis 4: *Undergraduate students in a materials, methods, and equipment course will improve their self-reported skill level in using industry-based tools for construction project management after being introduced to the PDRI in a single class session.*

Hypothesis 5: *Following an in-class activity where undergraduates in a materials, methods, and equipment course articulate how a given PDRI element impacts the materials, methods, and equipment, the students will improve their performance in selecting construction methods for a hypothetical project.*

Results of this pilot in-class activity verify that introducing the PDRI supports students' improvement in self-reported skill levels and improve their ability to develop appropriate construction methods for a hypothetical project as described in Chapter 9.

10.2. Advice to Users

The PDRI – Small Infrastructure is intended for use as a scope assessment, project alignment, and risk assessment tool. The tool was designed so that it can be used only once during front end planning, or successively if time allows. If the tool is used only once, the earlier in the front end planning process the better. Project teams are urged not to solely focus on the scores derived through using the tool. Even projects that score below the 300-point threshold suggested in this document might still have significant issues that should be addressed prior to moving a project forward into detailed design and construction. Disregarding these risk issues might significantly affect project performance.

The PDRI – Small Infrastructure was designed for use on smaller, less complex, infrastructure projects, NOT as a shortcut to the PDRI – Infrastructure tool. Users are urged to closely consider the attributes of their project through use the Infrastructure PDRI Selection Guide (Appendix H) or other internally developed guidelines, and choose the PDRI tool that best suits their project. The PDRI – Small Infrastructure (or any PDRI) should also not be used to forecast project performance. The results provided in this report are based on a small sample size of completed and in-progress projects, but these projects may not be representative of the entire population of infrastructure projects.

10.3. Research Contributions to Knowledge

The research completed by the author (in conjunction with the research team) has provided contributions to four bodies of knowledge: (1) the current front end planning body of knowledge, (2) the small projects body of knowledge, (3) the infrastructure body of knowledge, and (4) the construction education body of knowledge. The most substantial contribution to the front end planning and small projects bodies of knowledge was the development of a novel, non-proprietary tool specifically for the front end planning of small infrastructure projects. The development of the tool has not only expanded the long-standing CII Best Practice of frond end planning, but also greatly contributed to the limited small projects research base. Moreover, the testing results provide quantitative proof that a greater level of scope definition during the front end planning of small infrastructure projects drastically affects cost and schedule performance. This research contributes to the infrastructure body of knowledge in two ways: (1) it characterizes a small infrastructure project based on 16 factors of complexity, five of which were corroborated via a survey of practitioners, and (2) it identifies qualitative and quantitative similarities and differences between PDRI – Infrastructure and PDRI – Small Infrastructure Projects in support of improved planning efforts for both types of projects. The research contributes to the construction education body of knowledge by providing a proof of concept of a methodology for instructors to introduce the PDRI, or another project management tool, into an introductory construction management course.

10.4. Research Limitations

The research described in this dissertation was limited to the infrastructure construction sector. The PDRI – Small Infrastructure would not be appropriate for use on projects in the building or industrial construction sectors, but the methods that have been outlined could be used to develop a tool for small building projects. The data collected for testing of the PDRI – Small Infrastructure was also a relatively small sample of all small infrastructure projects completed across the industry. The testing results provided in the dissertation may not be accurate for all small infrastructure projects, or all infrastructure-focused organizations. Moreover, the data was primarily collected from industry professionals and organizations based out of North America and the United Kingdom. The author (and research team) made every effort to collect data from a diverse group of individuals and organizations, but again, the results provided in the dissertation may not be accurate for all small infrastructure projects, or all infrastructure-focused organizations.

Chapters 8 and 9 also discuss specific limitations related to the comparison of PDRI tools for infrastructure projects and the introduction of the PDRI – Small Infrastructure Projects into a construction management classroom, respectively.

10.5. Recommendations for Future Research

The author, in conjunction with the research team, recommends four areas of future research regarding small projects. Development of an HTML-based front end planning toolkit specifically for small projects could provide great value to industry. The current CII front end planning toolkit was designed for use on large, complex projects, and used the pre-project planning handbook developed by the Pre-Project Planning Task Force as a baseline. The structured, phase-gated front end planning process is embedded in the toolkit, with links to the PDRI – Industrial, PDRI – Building, and PDRI – Infrastructure, as well as the other complementary front end planning tools developed by CII. This structure is too cumbersome for use on small projects, similar to the preceding PDRI tools themselves. A new toolkit could be developed using the Manual for Small Special Project Management (CII 1991) and Small Projects Toolkit (CII 2002) (described in Chapter 4) as a baseline. These documents include substantial information regarding the planning and execution of small projects, which could be reviewed and updated to develop a toolkit pertinent to the current construction environment.

CII Executing Small Capital Projects Research Team (CII 2002) suggested that a small project program team best manages small projects, where the project managers within this team are solely responsible for the small projects completed within an organization. Future researchers could perform case studies to determine if there is a statistically significant difference (regarding project performance) between organizations that utilize small project program teams vs. those that assign small projects to project managers that are also responsible for large projects.

Future researchers could also perform case studies to discern how use of the PDRI – Small Infrastructure specifically affects project change, specifically cost and schedule changes. Chapter 7 detailed the procedures used by RT 314a to test the efficacy of the PDRI – Small Infrastructure, but the project performance differences that were found came from a sample of completed projects. The PDRI – Small Infrastructure has been used on seven in-progress projects, but the final cost, schedule and change performances of these projects are not known at the time of this publication. Future researchers could compare the performance of these seven projects that utilized the PDRI – Small Infrastructure to in-progress projects of similar complexity and scope that do not employ the PDRI – Small Infrastructure. Researchers would thus need to expand their inquiry within or outside of organizations who have already provided in-progress data to test the efficacy of the tool. Understanding the efficacy of the PDRI – Small Infrastructure to improve project performance may provide further incentive for organizations to use the tool.

Lastly, the author suggests that a final PDRI tool be developed for small building projects. Empirical evidence would suggest that small projects are just as prevalent in the building sector and wrought with similar project performance issues as the industrial and infrastructure sectors. Further extending the CII front end planning focus towards small building projects could greatly benefit the buildings and educational sectors, as the PDRI – Small Infrastructure and PDRI – Small Industrial have done for the infrastructure and industrial sectors, respectively. Perhaps if CII developed a PDRI – Small building Project tool, then all undergraduate students taking a building construction materials and method course, i.e. most Construction Management (CM) undergraduates, will be able to use a concise building-related PDRI tool to improve their understanding of building construction projects. The author introduced PDRI –Small Infrastructure Projects into a Construction Management classroom during Spring 2017 at Arizona State University. The results of this pilot study demonstrate that lower-division construction students enhanced their skills as well as their performance when introduced to the PDRI tool.

REFERENCES

ABUDAYYEH, O., RUSSELL, J., JOHNSTON, D. & ROWINGS, J. 2000. Construction engineering and management undergraduate education. *Journal of construction engineering and management,* 126**,** 169-175.

AGARWAL, R., CHANDRASEKARAN, S. & SRIDHAR, M. 2016. Imagining Construction's Digital Future. Available: http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future [Accessed 10 March 2017].

AKTAN, A., MOON, F., BARTOLI, I. & SJOBLOM, K. 2016. Identification of Infrastructure Systems. *Journal of Infrastructure Systems,* 23**,** 11 pp.

ANDERSON, L. W., KRATHWOHL, D. R. & BLOOM, B. S. 2001. *A Taxonomy for Learning, Teaching, and Assessing: a Revision of Bloom's Taxonomy of Educational Objectives,* New York, NY, Longman.

ANTAYA, M. C. L. & PARRISH, K. 2014. Assessing comprehension with student-developed construction games. *age,* 24**,** 1.

ASCE. 2017. *2017 Infrastructure Report Card* [Online]. Reston, VA: American Society of Civil Engineers. Available: http://www.infrastructurereportcard.org/ [Accessed 10 March 2017].

BABBIE, E. R. 2013. *The basics of social research*, Cengage Learning.

BECERIK-GERBER, A. A., BURCIN, KU, K. & JAZIZADEH, F. 2012. BIM-enabled virtual and collaborative construction engineering and management. *Journal of Professional Issues in Engineering Education and Practice,* 138**,** 234-245.

BECERIK-GERBER, B., GERBER, D. J. & KU, K. 2011. The pace of technological innovation in architecture, engineering, and construction education: integrating recent trends into the curricula. *Journal of Information Technology in Construction (ITcon),* 16**,** 411-432.

BECKER, T. C., JASELSKIS, E. J. & EL-GAFY, M. 2014. Improving predictability of construction project outcomes through intentional management of indirect construction costs. *Journal of Construction Engineering and Management,* 140**,** 04014014.

BINGHAM, E. & GIBSON, G. 2010. *Development of the project definition rating index (PDRI) for infrastructure projects.* Arizona State University.

BINGHAM, E. & GIBSON, G. E. J. 2016. Infrastructure Project Scope Definition Using Project Definition Rating Index. *Journal of Management in Engineering***,** 04016037.

BOCCHINI, P., FRANGOPOL, D. M., UMMENHOFER, T. & ZINKE, T. 2013. Resilience and sustainability of civil infrastructure: Toward a unified approach. *Journal of Infrastructure Systems,* 20**,** 04014004.

BOSFIELD, R. & GIBSON JR., G. E. 2012. Data Analysis on the Implementation of Successful Front End Planning Processes. . *CII Research Report 268-12. Austin, TX: Construction Industry Institute.*

BURKE, R., PARRISH, K. & GIBSON JR., G. E. Defining Small Projects in Developing the PDRI for Small Infrastructure Projects. Construction Research Congress 2016, 31 May - 2 June 2016 Puerto Rico. ASCE, 10 pp.

CALDAS, C. H., MENCHES, C. L., REYES, P. M., NAVARRO, L. & VARGAS, D. M. 2014. Materials Management Practices in the Construction Industry. *Practice Periodical on Structural Design and Construction,* 20**,** 04014039.

CANNING, D. 1998. A database of world stocks of infrastructure, 1950–95. *The World Bank Economic Review,* 12**,** 529-547.

CHESTER, M., PARRISH, K., COSGROVE, J. & ELZOMOR, M. 2017. *Urban Sustainablility Lab* [Online]. http://urbansustainability.lab.asu.edu/index.php: asu.edu. [Accessed 2017].

CHO, C.-S. & GIBSON, G. 2001. Building project scope definition using project definition rating index. *Journal of architectural engineering,* 7**,** 115-125.

CHO, C.-S. & GIBSON, G. E. J. 1999. Development of a Project Definition Rating Index (PDRI) for General Building Projects By

CII 1991. Manual for Special Project Management: A Special Publication. Report from Small Projects Action Team. Austin, TX.

CII 1994a. "Analysis of Pre-Project Planning Effort and Success Variables For Capital Facility Projects". Source Document 105 prepared for Construction Industry Institute, University of Texas at Austin, Austin Texas.

CII 1994b. Pre-Project Planning: Beginning A Project the Right Way. Publication 39-1, Austin, TX. *Construction Industry Institute*.

CII 1995. Research Report 113-11. Project Definition Rating Index (PDRI) for Industrial Projects. . *Construction Industry Institute.* Austin, TX.

CII 1997. Pre-Project Planning Tools: PDRI and Alignment Research Summary 113-1. Austin, TX.

CII 1999. Research Report 155-11. Development of the Project Definition Rating Index (PDRI) for Building Projects. *Construction Industry Institute.* Austin, TX.

CII 2001. Small Project Execution. Research Summary 161-1. Austin, TX.

CII 2002. Research Report 161-11. Factors Impacting Small Capital Project Execution. *Construction Industry Institute.* Austin, TX.

CII 2006. Front End Planning: Break the Rules, Pay the Price. Research Summary 213-1. Austin, TX.

CII 2008. Implementation Resource 155-2 PDRI: Project Definition Rating Index - Building Projects (3rd ed.). Austin, TX. *Construction Industry Institute*.

CII 2010a. Development of the Project Definition Rating Index for Infrastructure Projects. *Construction Industry Institute.* Austin, TX.

CII 2010b. Research Resource 268-11 PDRI: Project Definition Rating Index - Infrastructure Projects. *Construction Industry Institute.* Austin, TX.

CII 2013. Integrated Project Risk Assessment. Implementation Resource 181-2. Austin, TX.

CII 2014a. Front End Planning for Renovation and Revamp, Version 1.1. Implementation Resource 242-2. Austin, TX.

CII 2014b. Research Summary 305-1: Measuring Project Complexity and Its Impact. *Construction Industry Institute.* Austin, TX.

CII 2015. Implementation Resource 314-2 PDRI: Project Definition Rating Index - Small Industrial Projects. . *Construction Industry Institute.* Austin, TX.

CII 2017. Implmentation Resource 314a-2. Project Definition Rating Index - Small Infrastructure Projects.

CLEVENGER, C. M., OZBEK, M., GLICK, S. & PORTER, D. Integrating BIM into construction management education. EcoBuild Proceedings of the BIM-Related Academic Workshop, 2010.

COLLINS, W., PARRISH, K. & EDWARD GIBSON JR, G. Comparison of Front End Planning Practices for Small and Large Industrial Construction Projects. Construction Research Congress 2016, 2016. 150-158.

COLLINS, W., PARRISH, K. & GIBSON, G. E. 2015. Development and utilization of the project definition rating index for index for small industrial projects.

ELZOMOR, M., BURKE, R., PARRISH, K. & GIBSON, G. E. J. 2016a. Development of the Project Definition Rating Index (PDRI) for Small Infrastructure Projects. Research Report 314a-11. Austin, TX.: Construction Industry Institute.

ELZOMOR, M., PARRISH, K., MANN, C. & CHESTER, M. Positioning students to understand urban sustainability strategies through vertical integration: Years 1 through 3. 2016 ASEE Annual Conference and Exposition, 2016b New Orleans. American Society for Engineering Education.

GAO, Z., SMITH, G. R. & MINCHIN JR, R. E. 2002. Budget and schedule success for small capital-facility projects. *Journal of Management in Engineering,* 18**,** 186-193.

GEORGE, R. 2007. Information flow to support front end planning.

GHOSH, A., PARRISH, K. & CHASEY, A. 2015. Implementing a Vertically Integrated BIM Curriculum in an Undergraduate Construction Management Program. *International Journal of Construction Education and Research,* 11**,** 121-139.

GIBSON, G. & DUMONT, P. R. 1996. Project definition rating index (PDRI) for industrial projects. *Construction Industry Institute Implementation Resource***,** 113-2.

GIBSON, G., KACZMAROWSKI, J. & LORE, H. 1993. Modeling Pre-Project Planning for the Construction of Capital Facilities–Source Document 94. *Construction Industry Institute, Austin, TX*.

GIBSON, G. E. J. & HAMILTON, M. R. 1994. Analysis of Pre-Project Planning Effort and Success Variables for Capital Facility Projects. *Construction Industry Institute, the University of Texas at Austin, source document 102*.

GIBSON JR, G. E. & WHITTINGTON, D. A. 2009. Charrettes as a method for engaging industry in best practices research. *Journal of Construction Engineering and Management,* 136**,** 66-75.

GOKHALE, S., HASTAK, M. & OH, E. 2009. Optimizing construction input in front end planning. *Report RR241-11, Construction Industry Institute, University of Texas at Austin, Austin, Texas*.

GRIFFITH, A. & GIBSON, G. E. J. 2001. Alignment during preproject planning. *Journal of Management in Engineering,* 17**,** 69-76.

GRIFFITH, A. & HEADLEY, J. D. 1995. Developing an effective approach to the procurement and management of small building works within large client organizations. *Construction Management and Economics,* 13**,** 279-289.

HAIMES, Y. Y. & JIANG, P. 2001. Leontief-based model of risk in complex interconnected infrastructures. *Journal of Infrastructure systems,* 7**,** 1-12.

HAMILTON, M. & GIBSON, G. E. J. 1996. Benchmarking preproject planning effort. *Journal of Management in Engineering,* 12**,** 25-33.

KARLAFTIS, M. G. & PEETA, S. 2009. Infrastructure planning, design, and management for big events. *Journal of Infrastructure Systems,* 15**,** 1-2.

KE, Y., WANG, S. & CHAN, A. P. 2010. Risk allocation in public-private partnership infrastructure projects: comparative study. *Journal of Infrastructure Systems,* 16**,** 343-351.

KRATHWOHL, D. R. 2010. A Revision of Bloom's Taxonomy: An Overview. *Theory Into Practice,* 41**,** 212-218.

LIANG, L., THOMAS, S. R. & GIBSON, G. E. Is a small project really different? Construction Research Congress 2005: Broadening Perspectives, 2005. ASCE, 1-10.

MORRISON, J. 2009. *Statistics for engineers: an introduction*, John Wiley & Sons.

NASIR, H., HAAS, C. T., CALDAS, C. H. & GOODRUM, P. M. 2015. An Integrated Productivity-Practices Implementation Index for Planning the Execution of Infrastructure Projects. *Journal of Infrastructure Systems,* 22**,** 04015022.

RAJENDRAN, S., CLARKE, B. & ANDREWS, R. 2012. Quality Management in Construction. *Professional Safety,* 57**,** 37.

SONG, L., MOHAMED, Y. & ABOURIZK, S. M. 2009. Early contractor involvement in design and its impact on construction schedule performance. *Journal of Management in Engineering,* 25**,** 12-20.

SOROLA, C. & MOORE, D. S. 2010. *Student Solutions Manual for Practice of Statistics for Business and Economics*, Macmillan.

THOMAS, H. R., SANVIDO, V. E. & SANDERS, S. R. 1989. Impact of material management on productivity-A case study. *Journal of Construction Engineering and Management,* 115**,** 370-384.

WAISSI, G. 2015. Applied Statistical Modeling. 2nd Addition. . Tempe, AZ. .

WESTNEY, R. E. 1985. *Managing the engineering and construction of small projects*, Dekker New York; Basel.

WILCOX, R. R. 2009. *Basic statistics*, Oxford Univ. Press.

APPENDIX A

PARTICIPATING ORGANIZATIONS

PDRI – Small Infrastructure Projects Research Team

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Mike Davidson	PTAG
Mohamed Elzomor	Student, Arizona State University
G. Edward Gibson, Jr.	Arizona State University
Dustin Giles	Burns & McDonnell
Shannon Grey	Occidental Oil and Gas
Paul Katers	American Transmission Company, Owner Chair
Robert Mitrocsak	Architect of the Capitol
Tom Nelson	Hargrove Engineers + Constructors
Charles Obi	Smithsonian Institute
Kristen Parrish	Arizona State University
Luis Pinto	Faithful + Gould
David Sonntag	DTE Energy
Derek Wedel	Global Infrastructure Partners
Leroy Yong	The Williams Company
Michael Burns	

Former Members:

Brad Lynch	TransCanada
Scott Penrod	Walbridge

Organizations Participating in Small Project Definition Survey

AZCO Inc
Bentley Systems
Burns & McDonnell (x3)
CBI
Chicago Bridge and Iron
CSA Group (x2)
Day & Zimmermann
Eichleay Inc.
Fluor
Hargrove Engineers + Constructors, Inc. (x2)
Hazen and Sawyer
IHI E&C
Leidos
Markham Contracting Co., Inc.
Parsons (x2)
PFI
PTAG INC
SBM Offshore
Supreme Group
Wade Trim
Walbridge
Wood Group Mustang, Inc.
Zachry Holdings, Inc

Architect of the Capitol
Astrazeneca
DTE Energy
Eastman Chemical Company
GIP
Huntsman
Maricopa County
MBP
ONEOK
OPG
PSE&G
SABIC
SI
Smithsonian Institution (x2)
Southern Company (x2)
The Williams Companies, Inc.
U.S. Department of Energy, Office of Science

Organizations Participating in Weighting Workshops

AECOM
Arcadis (x2)
Barton Malow Company (x2)
Bechtel Infrastructure (x3)
Black & Veatch (x3)
Burns & McDonnell (x3)
CB&I Environmental & Infrastructure, Inc.
D & B Engineers
Dragados USA (x2)
Eichleay Inc.
Engineering Design Technologies, Inc.
Faithful & Gould
Hargrove Engineers + Constructors (x2)
JS VIG Construction
L.S Brinker Company
Markham Contracting
MWH
S & B Infrastructure
Siemens
Sunland Construction, Inc.
Sunland Field Service, Inc
Wade Trim
Walbridge

BP
City Of Phoenix (x2)
City Of Peoria
City Of Surprise
Con Edison (x2)
Consumers Energy (x2)
DTE Energy (x4)
Edinburgh Airport (x2)
Gatwick airport (x2)
Greater Toronto Airports Authority (x2)
Huntsman Corporation
Maricopa County Department of Transportation
Mount Sinai Hospital
Occidental Oil & Gas Corporation (x10)
Smithsonian Institution
The Williams Companies, Inc. (x3)
Town of Gilbert
NYC DOT

Organizations Providing Testing Data for In-Process Projects

American Transmission Company (x2)	Hargrove Engineers & Constructors
DTE Energy	Burns & McDonnell
Smithsonian Institution	Gatwick Airport

APPENDIX B

PDRI FOR SMALL INFRASTUCTURE PROJECTS DOCUMENTS

SECTION I - BASIS OF PROJECT DECISION						
	Definition Level					
CATEGORY Element	**0**	**1**	**2**	**3**	**4**	**5**
A. PROJECT ALIGNMENT						
A.1 Need & Purpose Statement						
A.2 Key Project Participants						
A.3 Public Involvement						
A.4 Project Philosophies						
A.5 Project Funding						
A.6 Preliminary Project Schedule						
B. PROJECT REQUIREMENTS						
B.1 Functional Classification & Use						
B.2 Physical Site						
B.3 Dismantling & Demolition Requirements						

Definition Levels
0 = Not Applicable 1 = Complete Definition 2 = Minor Deficiencies 3 = Some Deficiencies
4 = Major Deficiencies 5 = Incomplete or Poor Definition

SECTION II - BASIS OF DESIGN						
	Definition Level					
CATEGORY Element	0	1	2	3	4	5
C. DESIGN GUIDANCE						
C.1 Lead/Discipline Scope of Work						
C.2 Project Codes and Standards						
C.3 Topographical Surveys & Mapping						
C.4 Project Site Assessment						
C.5 Environmental & Regulatory Considerations						
C.6 Value analysis						
C.7 Construction Input						
D.PROJECT DESIGN PARAMETERS						
D.1 Capacity						
D.2 Design for Safety & Hazards						
D.3 Civil and Structural						
D.4 Mechanical and Equipment						
D.5 Electrical and Controls						
D.6 Operations and Maintenance						
E. LOCATION AND GEOMETRY						
E.1 Schematic Layouts						
E.2 Alignment and Cross-Section						
E.3 Control of Access						
F. ASSOCIATED STRUCTURES & EQUIPMENT						
F.1 Support Structures						
F.2 Hydraulic Structures						
F.3 Miscellaneous Elements						
F.4 Equipment List						

Definition Levels
0 = Not Applicable 1 = Complete Definition 2 = Minor Deficiencies 3 = Some Deficiencies
4 = Major Deficiencies 5 = Incomplete or Poor Definition

SECTION III - EXECUTION APPROACH						
CATEGORY Element	**Definition Level**					
	0	**1**	**2**	**3**	**4**	**5**
G. EXECUTION REQUIREMENTS						
G.1 Land Acquisition Strategy						
G.2 Utility Adjustment Strategy						
G.3 Procurement Strategy						
G.4 Owner Approval Requirements						
G.5 Intercompany and Interagency Coordination						
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS						
H.1 Design/Construction Plan & Approach						
H.2 Project Cost Estimate and Cost Control						
H.3 Project Schedule and Schedule Control						
H.4 Project Quality Assurance & Control						
H.5 Safety, Work Zone & Transportation Plan						
H.6 Project Commissioning/Closeout						

Definition Levels
0 = Not Applicable 1 = Complete Definition 2 = Minor Deficiencies 3 = Some Deficiencies
4 = Major Deficiencies 5 = Incomplete or Poor Definition

SECTION I - BASIS OF PROJECT DECISION							
	Definition Level						
CATEGORY Element	**0**	**1**	**2**	**3**	**4**	**5**	**Score**
A. PROJECT ALIGNMENT (Maximum Score = 189)							
A.1 Need & Purpose Statement		2	16	29	42	55	
A.2 Key Project Participants		1	6	11	16	21	
A.3 Public Involvement		1	6	11	15	20	
A.4 Project Philosophies		1	9	16	23	30	
A.5 Project Funding		2	9	16	23	29	
A.6 Preliminary Project Schedule		3	11	19	26	34	
CATEGORY A TOTAL							
B. PROJECT REQUIREMENTS (Maximum Score = 86)							
B.1 Functional Classification & Use		1	7	12	18	23	
B.2 Physical Site		3	12	21	30	39	
B.3 Dismantling & Demolition Requirements		2	8	13	19	24	
CATEGORY B TOTAL							
Section I Maximum Score = 275						**SECTION I TOTAL**	

Definition Levels

0 = Not Applicable   1 = Complete Definition   2 = Minor Deficiencies   3 = Some Deficiencies
4 = Major Deficiencies   5 = Incomplete or Poor Definition

SECTION II - BASIS OF DESIGN							
CATEGORY Element	Definition Level						
	0	1	2	3	4	5	Score
C. DESIGN GUIDANCE (Maximum Score = 187)							
C.1 Lead/Discipline Scope of Work		2	9	17	24	31	
C.2 Project Codes and Standards		2	8	14	20	26	
C.3 Topographical Surveys & Mapping		2	9	15	22	28	
C.4 Project Site Assessment		2	10	17	25	32	
C.5 Environmental & Regulatory Considerations		2	9	16	23	31	
C.6 Value analysis		1	4	8	11	14	
C.7 Construction Input		2	8	14	19	25	
						CATEGORY C TOTAL	
D.PROJECT DESIGN PARAMETERS (Maximum Score = 132)							
D.1 Capacity		2	8	14	21	27	
D.2 Design for Safety & Hazards		2	7	12	17	22	
D.3 Civil and Structural		2	7	12	17	22	
D.4 Mechanical and Equipment		2	7	12	17	22	
D.5 Electrical and Controls		1	7	12	17	23	
D.6 Operations and Maintenance		1	5	9	12	16	
						CATEGORY D TOTAL	
E. LOCATION AND GEOMETRY (Maximum Score = 72)							
E.1 Schematic Layouts		1	8	15	22	29	
E.2 Alignment and Cross-Section		2	8	14	20	26	
E.3 Control of Access		1	5	9	13	17	
						CATEGORY E TOTAL	
F. ASSOCIATED STRUCTURES & EQUIPMENT (Maximum Score = 79)							
F.1 Support Structures		1	7	12	16	22	
F.2 Hydraulic Structures		2	6	10	14	18	
F.3 Miscellaneous Elements		1	5	9	12	16	
F.4 Equipment List		2	7	13	18	23	
						CATEGORY F TOTAL	
Section II Maximum Score = 470						**SECTION II TOTAL**	

Definition Levels
0 = Not Applicable 1 = Complete Definition 2 = Minor Deficiencies 3 = Some Deficiencies
4 = Major Deficiencies 5 = Incomplete or Poor Definition

SECTION III - EXECUTION APPROACH							
CATEGORY Element	Definition Level						
	0	1	2	3	4	5	Score
G. EXECUTION REQUIREMENTS (Maximum Score = 122)							
G.1 Land Acquisition Strategy		2	10	18	27	35	
G.2 Utility Adjustment Strategy		2	8	14	19	25	
G.3 Procurement Strategy		2	7	13	18	24	
G.4 Owner Approval Requirements		1	5	9	13	17	
G.5 Intercompany and Interagency Coordination		1	6	11	16	21	
						CATEGORY G TOTAL	
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS (Maximum Score = 133)							
H.1 Design/Construction Plan & Approach		2	7	13	18	23	
H.2 Project Cost Estimate and Cost Control		3	9	15	22	28	
H.3 Project Schedule and Schedule Control		2	9	15	22	28	
H.4 Project Quality Assurance & Control		2	7	11	16	21	
H.5 Safety, Work Zone & Transportation Plan		2	6	10	14	18	
H.6 Project Commissioning/Closeout		2	5	8	12	15	
						CATEGORY H TOTAL	
Section III Maximum Score = 255						**SECTION III TOTAL**	

PDRI TOTAL SCORE

(Maximum Score = 1000)

Definition Levels

0 = Not Applicable 1 = Complete Definition 2 = Minor Deficiencies 3 = Some Deficiencies
4 = Major Deficiencies 5 = Incomplete or Poor Definition

PDRI ELEMENT DESCRIPTIONS

RT 314a developed the following descriptions to help generate a clear understanding of the terms used in the un-weighted project score sheet. Some descriptions include checklists of sub-elements. These sub-elements clarify concepts and facilitate ideas, to make the assessment of each element easier. (Note that these checklists are not all-inclusive and that the user may supplement them when necessary.)

The descriptions follow the order in which they are presented in the un-weighted or the weighted project score sheets; they are organized in a hierarchy by section, category, and then element. The score sheet consists of three main sections, each of which contains a series of categories broken down into elements. Note that some of the elements have issues listed that are specific to projects that are renovations and revamps or part of a repetitive program. Identified as "Additional items to consider for renovation & revamp projects" and "If this is an instance of a repetitive program," these issues should be used for discussion if applicable. Users generate the score of each element by evaluating its definition level.

It should be noted that RT 314a developed this tool and these descriptions to address a variety of types of small infrastructure projects that are "horizontal" in nature and connect nodes in different types of infrastructure systems. Three basic varieties of projects are addressed in this tool: 1.) projects that convey people and freight, such as highways and roads, 2.) projects that convey fluids, such as pipelines and open channels, and 3.) projects that convey energy, such as transmission lines or microwave corridors. Throughout the descriptions, the user will see sub-elements that relate to this range of projects. These sub-elements appear in the order in which they are discussed. If a sub-element is not applicable to the project that the user is assessing, then it should be ignored. Note: the PDRI—Buildings Projects (Implementation Resource 152-2) and the PDRI—Industrial Projects (Implementation Resource 113-2) should be used singly or combined for the vertical (node) aspects of the infrastructure project as deemed appropriate. Detailed user information is provided in Chapter 1 of this document. Particular focus should be maintained to ensure that no gaps develop at the interfaces of the vertical and horizontal elements during the project management team's FEP process. The sections, categories and elements are organized as discussed below.

SECTION I: BASIS OF PROJECT DECISION

This section consists of information necessary for understanding the project objectives. The completeness of this section indicates whether the project team is aligned enough to fulfill the project's business objectives and drivers.

Categories:

A – Project Alignment

B – Project Requirements

SECTION II: BASIS OF DESIGN

This section addresses processes and technical information elements that should be evaluated for a full understanding of the engineering/design requirements necessary for the project.

Categories:

C – Design Guidance

D – Project Design Parameters

E – Location and Geometry

F – Associated Structures & Equipment

SECTION III: EXECUTION APPROACH

This section consists of elements that should be evaluated for a full understanding of the owner's strategy and required approach for executing the project construction and closeout.

Categories:

G – Execution Requirements

H – Engineering/Construction Plan and Agreements

The following pages contain detailed descriptions for each element in the PDRI.

SECTION I – BASIS OF PROJECT DECISION

This section consists of information necessary for understanding the project objectives. The completeness of this section indicates whether the project team is aligned enough to fulfill the project's business objectives and drivers.

A. PROJECT ALIGNMENT

The elements in this category align key stakeholders around "whys, whats, and hows" of the project in order to meet the needs of the organization.

A1. Need & Purpose Statement

This statement defines why the project is necessary, or being proposed, and its objectives. The statement should outline the relative priority among cost, schedule, and quality and address alternatives. All team members need to understand the objectives and constraints related to the project. The need and purpose statement should document:

- ☐ Project drivers (e.g., profitability, value/benefit, regulatory, safety, security)
- ☐ Desired project results (e.g., compliance, capacity, efficiency, refurbishment)
- ☐ Project constraints (e.g., community, geographic, governmental concerns)
- ☐ Preliminary project schedule of sufficient detail for alternative duration comparison
- ☐ Alternative considerations (e.g., routing(s), acquisition strategy(ies), technology(ies))
- ☐ Stakeholder identification and management process
- ☐ Preliminary surveys (e.g., population, land use, infrastructure)
- ☐ Location of nodes such as interchanges, stations, control points and depots
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Renovation & revamp project's compatibility with existing facilities

**** If this is an instance of a repetitive program****

- ☐ Ensure alignment of project statement with program statement.

A2. Key Project Participants

The roles and responsibilities of the key project participants should be identified and documented. Establishing a positive team relationship among all key project participants helps to ensure shared understanding of project objectives and facilitate an efficient, successful project. All key participants must be competent in their roles in the project at hand, informed of the project decisions and given the opportunity to attend project-planning meetings as appropriate. Key project participants may include:

- ☐ Project sponsor
- ☐ Project, design, and construction engineers, managers, and leads
- ☐ Project management support (e.g., project controls personnel, procurement, and budget officers)
- ☐ Operations & maintenance personnel
- ☐ Internal support groups (e.g., environmental, regulatory, economists, land and right-of way planners, marketing)
- ☐ Health, Safety and Environment personnel (including Hazard and Operability Study (HAZOP), Hazard Identification Study (HAZID))
- ☐ External (e.g., local, regional, and national governmental authorities, agencies and officials, customers, business partners)
- ☐ Other (user-defined)

**** If this is an instance of a repetitive program****

- ☐ Establish communication and identify synergies with other teams performing related projects within the repetitive program.

A3. Public Involvement

Most infrastructure projects require informing the public of the project's scope and measuring their attitude regarding the development process. The required level and type of public involvement for the project should be documented. Community involvement efforts may include meetings with key stakeholders as well as public meetings and hearings. Issues to consider should include:

- ☐ Policy determinations regarding mandatory vs. voluntary public involvement, including notification procedures, types (e.g., press releases, public meetings/hearings), and responsibilities
- ☐ Input of public involvement information into any deliverables (Environmental Impact Statements, Public Hearing Notices, or other)
- ☐ Local support/opposition

- ☐ Available website content
- ☐ Other (user-defined)

**** If this is an instance of a repetitive program****

- ☐ Leverage public outreach efforts for the program; ensure the project is aligned with program outreach efforts

A4. Project Philosophies

A list of general design philosophies should be developed and documented to inform the overall design, ensure the desired levels of service and lay out guidelines to maintain adequate and safe operations. Philosophies should include:

- ☐ Design philosophy
  - ☐ Design life and life cycle cost studies, including compatibility with long-range goals and other infrastructure improvement programs and technology upgrades
  - ☐ Configuration strategy, including geometric/alignment, access, and utilities; compatibility with other uses or adjacent projects and facilities
  - ☐ Reliability and safety requirements
- ☐ Operating philosophy
  - ☐ Daily level of service or capacity requirements including operating schedules
  - ☐ Alternative or redundant operating procedures
  - ☐ Operational security and risk mitigation
- ☐ Maintenance Philosophy
  - ☐ Maintenance and repair cycles (e.g., monitoring requirements, warranties, use of third-party maintenance personnel, preventative, funding sources)
  - ☐ Equipment access needs and provisions
  - ☐ Government regulated maintenance (includes safety) and environmental considerations
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Potential impacts to existing and adjacent operations, buildings and facilities
- ☐ Maintenance impact of renovation

- ☐ Common/spare parts (repair versus replace existing components)
- ☐ Compatibility of maintenance philosophy for new systems and equipment with existing use and maintenance philosophy
- ☐ Coordination of the project with any maintenance projects

**** If this is an instance of a repetitive program****

- ☐ Ensure alignment of project philosophies with program philosophies

(For more information on design, operating and maintenance philosophies, see CII IR 268-2, *PDRI—Infrastructure Projects*, Category B.)

A5. Project Funding

Funding of projects can come from various sources and must be identified, budgeted and documented for the project. Preliminary cost estimates are required to determine how much funding a project needs, and in turn, whether or not the project is worth pursuing. Items to consider should include:

- ☐ Congruity with local infrastructure projects and programs
- ☐ Comparison of funding options (public vs. private, expense vs. capital)
- ☐ Cash flow, spend plan, funding participants, cost drivers and contingencies
- ☐ Initial estimates (e.g., engineering, construction, right-of-way, and operating costs)
- ☐ Input into any required funding approval documents

A6. Preliminary Project Schedule

A preliminary project schedule should be developed, identifying the primary critical path, including major risk components. It should be documented, analyzed and agreed upon by the key project participants. Issues to consider should include:

- ☐ Milestones (e.g., funding approval, environmental, permitting, contracts, engineering, construction, commissioning and start up)
- ☐ The procurement plan (long-lead or critical pacing of equipment/material and contracting)
- ☐ Required submissions and approvals (e.g., environmental, regulatory)
- ☐ Contingencies (e.g., weather, site conditions, scope change, float, unusual schedule considerations)

**** Additional items to consider for renovation & revamp projects****

R&R projects require a high level of planning to minimize risk because they interface with existing operations and are many times performed in conjunction with other on-going projects. Shutdowns/turnarounds/outages are special cases in that they are particularly constrained in terms of time and space, requiring very detailed plans and schedules.

- ☐ The schedule should contain input from appropriate personnel to coordinate required disruptions

**** If this is an instance of a repetitive program****

- ☐ Ensure alignment of project schedule with program schedule.

B. PROJECT REQUIREMENTS

The elements in this category address high-level requirements informing the basis of design. These elements should define success criteria.

B1. Functional Classification & Use

An essential step in understanding the overall project requirements is the determination and documentation of the functions that the project is to serve. Examples of functional types could include:

- ☐ Types of product(s) to be conveyed (e.g., people, freight, fluids, energy, data)
- ☐ Location (e.g., interstate/intrastate, domestic/international, urban/rural, underground/above ground, on-shore/off-shore)
- ☐ Modes and types of conveyance:
  - ☐ Transportation (i.e., automobiles, aircraft, ships)
  - ☐ Conveyors (e.g., gravity, power, belt)
  - ☐ Pressure or gravity – pipelines
  - ☐ Heat or energy transfer (e.g., conduction or electromagnetic)
- ☐ Other (user-defined)

B2. Physical Site

The project should have a documented assessment comparing the project-specific requirements with the available site characteristics for any and all sites considered for the project in order to determine a site's feasibility, including high level requirements for adaptation and future growth. Items to consider should include:

- ☐ Utility considerations (e.g., existing utility identification, access and adjustment; additional or different utilities)
- ☐ Type of buildings/structures
- ☐ Land area (terrain, laydown, turn around, temporary workspace, camp, parking, stockpile, borrow pits, storage facilities)
- ☐ Accessibility during and after construction (e.g., roads, approaches, bridges)
- ☐ Amenities (e.g., food service, change rooms, medical, recreation, emergency)
- ☐ Security (setbacks, sight lines, clear zones, access and egress, fencing, gates, barriers, goal posts, lighting)
- ☐ Existing utility identification and adjustment (utility corridors, alignment with existing right-of-way, timelines for agreements and relocation, required clearances and boundaries, access points, associated permits and regulations)
- ☐ Possible expansion or alteration of current project (e.g., vertical/horizontal expansion, increase in capacity, future quality constraints)
- ☐ Potential compliance issues (e.g., stormwater, natural resource surveys, cultural resource surveys, pollutants and environmental compliance issues, climatic data)
- ☐ Existing plans, codes, and standards (e.g., coastal zone management, intracoastal and navigable waterways, railroad, regional transportation authorities, special private land issues, jurisdictional plans)

**** Additional items to consider for renovation & revamp projects****

- ☐ Complete condition assessment of existing facilities and above- and below-ground infrastructure
- ☐ As-built accuracy and availability (i.e., update/verify as-built documentation prior to project initiation)
- ☐ Temporary service provisions and detours
- ☐ Uncertainty of "as-found" conditions (e.g., structural integrity; sub-base conditions; hazardous materials; location, condition and capacity of piping, electrical system components, installed equipment, and existing safety devices)
- ☐ Other (user-defined)

B3. Dismantling & Demolition Requirements

A scope of work should be defined and documented for the decommission and removal of existing infrastructure that is associated with the project. This scope of work should list specific items that will be decommissioned/dismantled and be comprehensive enough to inform decision making. Evaluation criteria should include:

- ☐ Timing/sequencing
- ☐ Regulatory procedures and standards; health, safety and security requirements (e.g., decontamination and purge requirements, de-energize and isolation)
- ☐ Handling of dismantled equipment/ materials (including hazardous)
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Ensure that existing conditions (e.g., asphalt condition, pipe condition) and their impact on scope are clearly documented
- ☐ Potential reuse of existing dismantled or demolished equipment and material
- ☐ Physical identification of extent of demolition to clearly define limits
- ☐ Segregation of demolition activities from new construction, and operations (e.g., physical disconnect or "air gap")

**** If this is an instance of a repetitive program****

- ☐ Compatibility of this project with program's dismantling/demolition requirements

SECTION II – BASIS OF DESIGN

This section addresses processes and technical information elements that should be evaluated for a full understanding of the engineering/design requirements necessary for the project.

C. DESIGN GUIDANCE

The elements in this category identify items to be considered to support detailed design.

C1. Lead/Discipline Scope of Work

A complete, generally discipline-oriented, narrative description of the project should be documented that lays out the major components of work to be accomplished. This narrative should be tied to a high-level work breakdown structure (WBS) for the project. Items to consider should include:

- ☐ Sequencing of both product and project work, including engineering deliverables supporting pre-commissioning, commissioning, and expedited start-up
- ☐ Interface issues for various contractors, contracts, or work packages
- ☐ Any ancillary or temporary equipment required for installation and commissioning, regulatory compliance, or reporting
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Identification of specific interface or coordination efforts with operations and owner's staff

C2. Project Codes and Standards

The codes, standards, and guidelines that govern the project design have been identified and documented, as well as evaluated, for schedule and cost impact. Items to consider should include:

- ☐ National, local or organizational/corporate codes
- ☐ Local, state/provincial, and national government permits
- ☐ Regulatory and utility commissions, including construction
- ☐ Marine, waterway, and wetland

- ☐ Air quality
- ☐ Transportation, including road, railroad, air space or ports
- ☐ Security and fire
- ☐ Utilization of design standards (e.g., owner's, contractor's, mixed)
- ☐ Alignment of criteria between the project and existing system/facilities
- ☐ Health, Safety and Environment (HS&E)
- ☐ Future expansion considerations
- ☐ Other (user-defined)

****Additional items to consider for renovation & revamp projects****

- ☐ Evaluation of original intent of codes and regulations, and any "grandfathered" requirements
- ☐ Setting design goals to take advantage of system or facility outages/shutdowns
- ☐ Verification of accuracy of as-built drawings
- ☐ Reconciliation of as-built specifications against current specifications

****If this is an instance of a repetitive program****

- ☐ Applicability of existing criteria and permits for this project
- ☐ Compatibility of project's specifications with program's specifications

C3. Topographical Surveys & Mapping

A reconnaissance of the corridor/site should be conducted. This study should document the details of the preferred corridor/location, (or in some cases develop locational options). The study should include:

- ☐ Verify existing geographic, topographic, mapping, and right-of-way information, including geographical information system (GIS) data
- ☐ Requirements for right-of-entry and surveying consultants
- ☐ Preliminary topographic survey, including recovery of existing monuments
- ☐ Above and below ground utility information (e.g., crossing and/or parallel corridor)
- ☐ Existing conflicting structures
- ☐ Sensitive areas (e.g., environmental, historical, cultural, archaeological)
- ☐ Property descriptions and exhibits, including landowners, land use and zoning
- ☐ Inherent parcel issues that may cause difficulties in right-of-way acquisition, including special property owner concerns
- ☐ Other (user-defined)

C4. Project Site Assessment

The actual conditions pertaining to the selected project corridor, access or site should be identified and documented. Geotechnical or hydrological characteristics that can affect the project should be considered. Items to evaluate and consider should include:

- ☐ All previous and new geotechnical information
- ☐ Soil compaction, seismic, and foundation requirements (i.e., rock)
- ☐ Soil treatment or removal/replacement requirements
- ☐ Existing access issues with corridor/site (i.e., overhead interferences)
- ☐ Factors such as light, dust, noise, emissions, and erosion control
- ☐ Weather and climate impact
- ☐ Hydraulic information with corridor/site:
  - ☐ Surface, groundwater, and meteorological characteristics
  - ☐ Waves, tides and currents
  - ☐ Ground cover and erosion concerns
  - ☐ Flood plain characteristics
- ☐ Potential impacts of future development and affected communities/agencies
- ☐ Other (user-defined)

C5. Environmental & Regulatory Considerations

Environmental and regulatory considerations affecting the project design approach have been defined and documented. Items to evaluate and consider should include:

- ☐ Identification of national, regional, and local jurisdictional environmental assessment requirements
- ☐ Environmental documentation (e.g., waterway, wetland, flora, fauna, noise implications in documents such as an environmental impact statement if required)
- ☐ Environmental requirements (e.g., stormwater runoff, air quality, monitoring)
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Project requirements within existing environmental commitments (e.g., avoidance, compensation, enhancements, minimization)

- ☐ Existing environmental mitigation and remediation plans affecting current project

(For more information on environmental and regulatory issues, see CII IR 268-2, *PDRI—Infrastructure Projects*, Elements F4 and F5.)

C6. Value Analysis

The process for conducting value analysis studies (e.g., value engineering (VE), value management, value methodology, design simplification studies, material alternatives selection) should be documented. Items to consider should include:

- ☐ Policy requirements, accountabilities, procedures, and deliverables
- ☐ Assessment of redundancies and overcapacity
- ☐ Commonality, flexibility, and/or discretionary scope items
- ☐ Controls simplification
- ☐ Cost effective materials and construction techniques
- ☐ Sustainability considerations (e.g., use of local materials, pollution abating concrete, recycled materials, LED lighting, and so on)
- ☐ Use of modularized and prefabricated components
- ☐ Life-cycle analysis, including operations and maintenance considerations
- ☐ Other (user-defined)

(For more information on value analysis issues, see CII IR 268-2, *PDRI—Infrastructure Projects*, Elements E1, E2 and E3.)

C7. Construction Input

A structured process for constructability analysis has been documented. This process should be initiated in front end planning and include early identification of project team participants for constructability analysis, potentially including contractors. Elements of constructability to consider should include:

- ☐ Construction knowledge/experience involved in project planning and design, including contracting strategy, value engineering, and WBS development
- ☐ Developing a construction-sensitive project schedule
- ☐ Considering construction methods in design (e.g., modularization/pre-assembly, and off-site fabrication)

- ☐ Developing site layouts in relation to surveys for construction infrastructure and logistics, including laydown areas and hoisting requirements (e.g., construction equipment placement, lift paths, rigging, and line of sight)
- ☐ Developing a detailed installation plan for infrastructure including oversized loads and equipment
- ☐ Other (user-defined)

****Additional items to consider for renovation & revamp projects****

- ☐ "Installability" (e.g., small components/modules/pre-assembly to facilitate installation in congested areas)
- ☐ Opportunities to perform as much work as possible outside, low-congestion periods, shutdowns and outages

D. PROJECT DESIGN PARAMETERS

The elements in this category focus on items that support and inform detailed design. (For more information on project design parameters, see Category I in the PDRI—Infrastructure Projects.)

D1. Capacity

Design output or benefits to be gained from this project should be evaluated and documented. Capacity requirements should include:

- ☐ Details of required flows (vehicles, people, fluids, electrical power) related to the type of project:
  - ☐ People and freight (e.g., traffic capacity, number of lanes, pavement thickness, interchanges, tolling, runway orientation)
  - ☐ Fluids (e.g., piping, flow rate, friction and head loss, hydraulic profile)
  - ☐ Energy (e.g., transmission line capacity, bandwidth capacity, telecommunication media, transformers and switching gear)
- ☐ Redundancy and provisions for future expansion
- ☐ Major equipment requirements, availability and limitations
- ☐ Integration into and limitations of existing infrastructure
- ☐ Communication/control requirements
- ☐ Capacity/availability of support systems
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Tie-in points
- ☐ Accuracy of existing capacity information

D2. Design for Safety & Hazards

A formal process for identifying and mitigating safety and environmental hazards of the final project should be documented. This process is used to identify potential risk of injury to the environment or populace for certain types of infrastructure projects. Many jurisdictions, or organizations, will have their own specific compliance requirements; for example, in the United States, OSHA Regulation 1910.119 compliance is required for oil and gas conveyance. The owner should clearly communicate the requirements, methodology, and responsibility for the various activities to the project team. Issues to consider include:

- ☐ Handling of hazardous materials (i.e., nuclear, hydrocarbon, explosives)
- ☐ Operational Safety features
  - ☐ People and Freight (i.e., clear zones, barrier placement, sight distances)
  - ☐ Fluids (i.e., anti-corrosives, explosives, carcinogens)
  - ☐ Energy (i.e., setbacks, electromagnetic pulse, microwave exposure)
- ☐ Containment requirements
- ☐ Confined space
- ☐ Air monitoring
- ☐ Hazard and Operability Study (HAZOP) requirements
- ☐ Other (user-defined)

D3. Civil and Structural

A clear statement of civil and structural requirements should first be identified or developed and then documented as the basis of design. This documentation should include:

- ☐ Owner specifications/standards (e.g., basis for design loads, capacity, material procurement, vulnerability and risk assessments)
- ☐ Physical and seismic requirements
- ☐ Overall project site plan including future expansion

☐ Construction materials (e.g., concrete, steel) meet client and jurisdictional standards
☐ Sustainability considerations, including certification
☐ Interim traffic or by-pass control plans
☐ Definition of nomenclature and documentation requirements for civil drawings (e.g., grading/drainage/erosion control/landscaping, corrosion control/ protective coatings, minimum clearances)
☐ Other (user-defined)

****Additional items to consider for Renovation & Revamp projects****

☐ Existing structural conditions (e.g., foundations, building framing, harmonics/vibrations)
☐ Potential effect of noise, vibration, and restricted headroom
☐ Underground interference

****If this is an instance of a repetitive program****

☐ Compatibility of project's civil and structural requirements with program's requirements

D4. Mechanical and Equipment

Mechanical and equipment design requirements should first be identified or developed, and then documented as the basis of design. This documentation should include:

☐ Owner specifications/standards, material sourcing requirements
☐ Life cycle cost/sustainability considerations
☐ Environmental condition requirements for equipment (e.g., air quality, operating temperatures)
☐ System monitoring (e.g., cameras, sensors, monitors, electronic signage, conveyor systems)
☐ System redundancy requirements
☐ Support system requirements (e.g., water treatment, fire protection requirements, emissions control, utility support requirements, traffic control devices/signals)
☐ Piping requirements
☐ Seismic requirements
☐ Other (user-defined)

****Additional items to consider for Renovation & Revamp projects****

- ☐ Renovation projects' alteration of existing mechanical design assumptions
- ☐ Potential reuse of existing equipment and systems for renovation project
- ☐ New bypasses and tie-in requirements

****If this is an instance of a repetitive program****

- ☐ Compatibility of project's mechanical and equipment requirements with program's requirements

D5. Electrical and Controls

A clear statement of electrical design and control requirements should be identified or developed, and then documented as the basis of design. This documentation should include:

- ☐ Owner specifications/standards, material sourcing requirements
- ☐ Life cycle cost/sustainability considerations
- ☐ Power sources with available voltage/amperage
- ☐ Electrical substations, location of electrical service and distribution equipment
- ☐ Uninterruptable power source (UPS) and/or emergency power requirements
- ☐ Lightning/grounding requirements
- ☐ Voice, data, and video communications requirements
- ☐ Security/access control systems
- ☐ Other (user-defined)

****Additional items to consider for Renovation & Revamp projects****

- ☐ Integration of new technology with existing systems, including interface issues
- ☐ Safety systems compromised by new technology
- ☐ Renovation projects' alteration of existing electrical design assumptions
- ☐ Potential reuse of existing equipment and systems for renovation project

****If this is an instance of a repetitive program****

- ☐ Compatibility of project's electrical and controls requirements with program's requirements

D6. Operations and Maintenance

A clear statement of operations and maintenance design requirements should first be identified or developed, and then documented as part of the basis of design. Items to consider include:

- ☐ Accessibility and egress requirements for operations and maintenance (e.g., manholes, platforms, vaults)
- ☐ Required provisions for safe maintenance/operation including out of service
- ☐ Temporary structures for maintenance
- ☐ Storage and fabrication facilities for repair parts
- ☐ Surface finishes (e.g., paint and hot-dip galvanized)
- ☐ Right-of-way vegetative clearing and maintenance
- ☐ Remote monitoring/operating capabilities
- ☐ Other (user-defined)

E. Location and Geometry

This category considers schematic layouts, horizontal and vertical alignment, cross-sectional elements, and control of access all contain key location and geometric information important to the design success of the project.

E1. Schematic Layouts

Schematic layouts show the plan view that includes basic information necessary for the proper review and evaluation of the proposed improvement should be documented. The schematic is essential for use in public meetings and coordinating design features. Issues to consider include:

- ☐ General project information (e.g., boundary limits, speed or volume, and classification)
- ☐ Location of structures (e.g., interchanges, main lanes, frontages, ramps, levees, channels, ditches, towers, utilities, coordinates, and drainage structures)
- ☐ Integration and compatibility with existing facilities
- ☐ Right-of-way limits, including overhead and underground impacts
- ☐ Master plan showing zoning and jurisdictional boundary information
- ☐ Location/arrangement drawing to identify the location of each major project item (e.g., location, including coordinates, coordination of location among all items and interfaces with existing facilities)
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Renovation work in relation to existing structures

- ☐ Clear identification of existing systems and equipment to be removed, rearranged, or to remain in place
- ☐ Known detours or bypasses

E2. Alignment and Cross-Section

Horizontal and vertical alignment along with cross sectional elements of the final design help establish the project boundaries. It is important that the proper alignment be selected according to the system's design speed, pressure pipe hydraulics, open channel hydraulic parameters, existing and future roadside or adjacent development, subsurface conditions, and topography, among other parameters. Optimized cross-sections are also important design elements to reduce right-of-way width and control cost and schedule. Issues to evaluate and consider should include:

- ☐ Horizontal and vertical geometry referenced to a surveying control system
- ☐ Design exceptions or waivers identified and validated
- ☐ Pipeline or power line corridors and easements
- ☐ Crossover grades and profiles
- ☐ Vertical lift
- ☐ Vertex data
- ☐ Upstream and downstream control structures/parameters
- ☐ Constrained right-of-way zones areas (i.e., choke points, cut and fill slopes, retaining walls)
- ☐ Horizontal and vertical clearances to obstructions
- ☐ Horizontal directional drilling (HDD)/tunneling feasibility
- ☐ Other (user-defined)

E3. Control of Access

Permanent access requirements for maintenance and operations need to be defined and documented. Access control should be coordinated with right-of-way acquisition, including access deeds and restrictions. Issues to consider should include:

- ☐ Entrance/exit locations and length
- ☐ Growth capacity

- ☐ Safety and security of access
- ☐ Controlled access systems, including life safety requirements
- ☐ Split-parcel and other access requirements
- ☐ Access to pumping or support stations, valves, bypasses and other tie-ins
- ☐ Manholes and cleanouts
- ☐ Pretreatment, including bar screens, grit removal, grinders, and compactors access
- ☐ Utility access requirements (temporary and permanent)
- ☐ People and freight access (e.g., bypasses, runways, trunk tie-ins)
- ☐ Other (user-defined)

F. Associated Structures & Equipment

Infrastructure projects have associated structures and equipment that must be considered in the project for inclusion in design and to determine right-of-way requirements.

F1. Support Structures

Support structure requirements for the project should be defined and documented. Infrastructure projects often require support structures for conveyance requirements along the extent of the right-of-way, e.g., bridges for freight, fluids, or pipelines. Issues to consider should include:

- ☐ Structure locations
- ☐ Materials of construction as well as foundation requirements
- ☐ Details of required structures related to the type of project:
  - ☐ People and freight (e.g., retaining walls and abutments, toll plazas)
  - ☐ Fluids (e.g., thrust blocks, pipe racks, valve and pumping stations, bridges)
  - ☐ Energy (e.g., towers, duct banks, switching substations)
- ☐ Safety tolerances (e.g., maximum height, loads and capacities, minimum clearances)
- ☐ Vertical and horizontal alignment
- ☐ Special load requirements (e.g., seismic, ice, wind, thermal and heavy load)
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Current condition and life expectancy
- ☐ Temporary signage

- ☐ Maximum construction bridge loading
- ☐ Bypasses or temporary conveyance
- ☐ Detour bridge requirements or lane rerouting

F2. Hydraulic Structures

In the analysis or design of drainage facilities, the relative importance of the facility will determine the appropriate investment of time, expense, concentration, and completeness. Basic data components inherent in a design or analysis of any pipeline, channel, or highway drainage facility should be documented and include:

- ☐ Surveys of existing characteristics/estimates of future characteristics
- ☐ Discharge estimates
- ☐ Constraints

When documenting hydraulic structure requirements, issues to consider include:

- ☐ Open channels, tunnels, and outfall structures (right-of-way and environmental impacts)
- ☐ Storm drain systems, including inlets/outlets
- ☐ Emergency spillways/collection basins/culverts
- ☐ Fluid energy abatement
- ☐ Hydraulic routing/hydraulic channel controls
- ☐ Life-cycle maintenance considerations and costs
- ☐ Other (user-defined)

**** Additional items to consider for renovation & revamp projects****

- ☐ Condition and life expectancy of existing structures
- ☐ Bypasses or temporary conveyance

F3. Miscellaneous Elements

In addition to typical pipeline, water channel, energy, and/or roadway design elements, the following features may require consideration and planning. These items should be identified and listed, and should include:

- ☐ Details of required miscellaneous elements related to the type of project:
  - ☐ People and freight (e.g., noise abatement or blast deflection walls, border and immigration facilities, toll plazas, sidewalks, signage)

- ☐ Fluids (e.g., hazardous material traps, emergency spillway area, storm septors)
- ☐ Energy (e.g., fencing, berms or containment structures, visual architectural blending structures)

☐ Longitudinal barriers, rip-rap/gabions/soil retaining structures

☐ Maintenance and storage yards/parking facilities

☐ Extended shoulders for service

☐ Other (user-defined)

F4. Equipment List

Project-specific installed equipment should be defined and listed. The purchaser of equipment should be clearly identified in the equipment list. Items to consider should include:

☐ Details of required equipment related to the type of project:

- ☐ People and freight (e.g., benches, bus shelters, signs, traffic control devices)
- ☐ Fluids (e.g., turbines/compressors/pumps, grinders/clarifiers/tanks/basins)
- ☐ Energy (e.g., transformers, electrical substations, breakers, disconnect switches, protection and control equipment)

☐ Modularized control rooms

☐ Emergency generators

☐ A tabulated list of utility requirements for all major installed equipment (e.g., power, water, fuel, air, specialty gasses)

****Additional items to consider for renovation & revamp projects****

☐ Identification of systems and equipment as new, existing or relocate, remove

☐ Clear definition of any modifications to existing systems and equipment, and verification of compliance with existing codes

SECTION III – EXECUTION APPROACH

This section consists of elements that should be evaluated for a full understanding of the owner's strategy and required approach for executing the project construction and closeout.

G. EXECUTION REQUIREMENTS

The elements in this category focus on ensuring successful land acquisition, procurement, owner approvals and key project participant coordination.

G1. Land Acquisition Strategy

A plan and process for attaining land or other real estate rights should be established and documented, as these items are almost always on the critical path. The execution of contractual agreements may be required with local public agency (LPA) participants and establishes responsibilities for the acquisition of right-of-way, particularly those parcels that may cause delay. In some cases, an agreement must be entered into before a project is released for right-of-way acquisition. Issues to consider should include:

- ☐ Identification and prioritization of long-lead parcels and easements
- ☐ Acquisition plan (e.g., responsible parties, acquisition process, relocations, abatements, appraisal responsibility and process)
- ☐ Advance land acquisition requirements (e.g., protective buying, hardship acquisition, land donations, multi-owner parcels)
- ☐ Master agreement that governs local agency and joint venture advance funding (including supporting documentation and transmittal memos)
- ☐ Cost participation and work responsibilities between the owner and LPAs or others to include reimbursement for purchased parcels, appraisals, property acquisitions and improvements
- ☐ Prerequisites to secure right-of-way project release on non-federal-aid projects
- ☐ Coordination of hydraulic design with requirements for land acquisition
- ☐ Construction needs (e.g., spoil disposal, temporary access, easements, private roads, other land owner requirements)
- ☐ Other (user-defined)

(For more information on land acquisitions, see CII IR 268-2, PDRI—Infrastructure Projects, Elements J1, J2, J4 and J5.)

G2. Utility Adjustment Strategy

A strategy to address utility adjustment for the project should be developed and documented. Items to address should include:

- ☐ Identification and prioritization of long-lead utilities, public or private
- ☐ Utility adjustment plan (e.g., responsible parties, adjustment process, payment responsibility, relocations, abatements, quality control responsibility)
- ☐ Compatibility with local regulations and procedures to include crossing permits, encroachment permits, and approval process
- ☐ Agreement that governs local agency or joint venture advance funding and cost participation (including supporting documentation and transmittal memos)
- ☐ Long-term operation and maintenance responsibility to include utility agreements
- ☐ Other (user-defined)

(For more information on utility strategy, see CII IR 268-2, PDRI—Infrastructure Projects, Elements J2 and J3.)

G3. Procurement Strategy

A procurement strategy should be developed and documented that identifies the methods for design and construction delivery, identifies all equipment and materials to be delivered to the site and, then, validates and documents that it can be delivered in the required timeframe and at the required quality level. The team should also consider streamlining procurement processes to address the short duration of a small project. The identification and delivery of long lead/critical equipment and material are especially important. This strategy should also include procuring professional services. Issues to consider should include:

- ☐ Procedures and plans for procuring professional services (e.g., design, consulting, testing) and construction services (e.g., design/build, construction management (CM) at risk, design-bid-build)
- ☐ Bid evaluation, terms and conditions, and selection of vendors/suppliers
- ☐ Specific guidelines for small, disadvantaged business and local content requirements

- ☐ Identification, tracking and expediting of long lead time equipment and material, including vendor data to support design
- ☐ A procurement responsibility matrix (including authority and responsibility for engineering, design and professional services, construction, materials, commissioning and start-up materials)
- ☐ Quality requirements of materials and services, including acceptance testing and onsite vendor support service
- ☐ Other (user-defined)

G4. Owner Approval Requirements

Owner requirements including deliverables, submittals, approvals, and major interactive review meetings should be defined and documented. Items to consider should include:

- ☐ Project deliverables list including frequency, due dates and timing of submittal/approvals
- ☐ Project Responsible, Accountable, Consulted and Informed (RACI) Matrix
- ☐ Computer hardware, software, computer aided drafting and design (CADD), and physical model requirements
- ☐ Document review and approval processes for issuing subcontracts, purchase orders, changes or modifications
- ☐ Define specific hold points for owner reviews, inspections and/or witness to testing
- ☐ Invoicing process, scheduling process, change management procedures, reporting format, and timing
- ☐ Other (user-defined)

**** If this is an instance of a repetitive program****

- ☐ Compatibility of this project with program's owner approval process.

G5. Intercompany and Interagency Coordination

Public and private coordination may be required during project execution, and agreements should be in place to ensure efficient project delivery, and coordinated at the appropriate levels. Coordination entities to consider should include:

- ☐ Owners/funding sources
- ☐ Key contractors and suppliers

- ☐ Local and state historic, natural resources, environmental, air quality, fish & wildlife, habitat conservation, parks, flood control, preservation offices
- ☐ Emergency management organizations (e.g., law enforcement or the U.S. Federal Emergency Management Agency)
- ☐ Transportation, railroad agencies, utility companies
- ☐ Other (user-defined)

H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS

The elements in this category focus on ensuring successful design, engineering, construction and closeout.

H1. Design/Construction Plan & Approach

The methodology for engineering and constructing the project should be documented. These items should include:

- ☐ Project work breakdown structure (WBS)
- ☐ Contracting plans (e.g., logistics, labor/resource availability, partnering/strategic alliances, work week schedule/restrictions)
- ☐ Project staffing plans (e.g., definition of roles, responsibilities, experience, licenses/registrations, and other special skills/credentials, critical personnel)
- ☐ Project risk mitigation plan and contingency forecast/allowance
- ☐ Integration of other plans into construction execution (right-of-way management, environmental monitoring/controls, stormwater pollution prevention, utility adjustment, safety and health program, public space plan)
- ☐ Other (user-defined)

**** If this is an instance of a repetitive program****

- ☐ Compatibility of this project with program's engineering and construction plan and approach

H2. Project Cost Estimate and Cost Control

Project teams should develop and document cost estimates throughout planning and execution that include the required level of detail and accuracy for the project phase. The estimates should be used to manage contingencies, and track and control costs. Budget management responsibilities should be outlined and assigned in a formal project controls plan. Issues to consider should include:

- ☐ Direct and indirect design, engineering, construction, commissioning and contingency costs
- ☐ Right-of-way and utility adjustment cost
- ☐ Incentives, disincentives, penalties, and liquidated damages
- ☐ Environmental, permitting, and public communication costs
- ☐ Taxes, financing fees, and utility consumption costs
- ☐ Procedures for cost control have been developed and may include information sources, cash flow, payment schedules, cost breakdown structure, change management, estimate forecast and budget tracking, project and financial control software
- ☐ Other (user-defined)

H3. Project Schedule and Schedule Control

An appropriately detailed project schedule, for use during design and construction, has been developed, documented, and analyzed. A method for measuring and reporting progress should be established and documented, with responsibilities assigned in accordance with organizational requirements. Key stakeholders should agree upon this schedule. Items to consider should include:

- ☐ Input from appropriate project personnel (e.g., owner/operations/third party, design/engineering, construction/estimating, procurement, environmental/permitting, right-of-way, utility adjustments)
- ☐ Conformance with preliminary project schedule including milestones and appropriate contingency
- ☐ Specific schedule considerations (e.g., tracking of outage dates, hourly schedule, commissioning, procurement of long lead items, right-of-way land acquisition, required submissions and approvals)
- ☐ Schedule control procedures (e.g., software, responsibility, resource loading, reporting requirements)
- ☐ Other (user-defined)

****Additional items to consider for renovation & revamp projects****

- ☐ A schedule should contain input from traffic or flow control management personnel to coordinate disruptions

H4. Project Quality Assurance & Control

Quality assurance and quality control (QA/QC) procedures for the project should be established and documented, and should include assignment of responsibilities for approvals. The QA/QC plan should incorporate owner requirements, design review, material origin/sourcing/traceability requirements, shop/source inspection plans, definition of owner witness/hold points, material management plans, field inspections and documentation requirements/inspections for governing authorities/permits/local codes. These procedures should include:

- ☐ Assurance of contracted professional services
- ☐ Responsibility for QA/QC during design and construction
- ☐ Quality management system requirements, including audits (i.e., International Organization for Standardization (ISO) 9000)
- ☐ Environmental quality control
- ☐ Oversight of submittals, Requests for Information (RFIs), changes and modifications, progress photos, redlines/conformed to construction/as-builts
- ☐ Performance testing to assure conformance to specifications (e.g., coating, welding, slump test, compression test)
- ☐ Correction of non-conforming materials, equipment, and construction
- ☐ Other (user-defined)

H5. Safety, Work Zone & Transportation Plan

A plan should be developed and documented that establishes a full understanding of project logistics and safety, clearly showing provisions for safe and efficient operation of all modes of transportation that are adjacent to or concurrent with the project during construction. It should include considerations for the safety of construction workers, inspection personnel and the general public. It should be compliant with organizational, national, regional, and local jurisdictional and permitting requirements. Issues to consider should include:

- ☐ Transportation agency requirements for traffic control devices and routing or other compliance publications
- ☐ Traffic and work zone control plan (e.g., signage, safety equipment, clear zone protection devices)

- ☐ Special permitting and logistics (e.g., equipment or materials transport, oversize loads or barges, rail, special space permits)
- ☐ Safety for motorists and workers (e.g., work zone safety, safety personnel requirements, safety orientation, planning, communication and incentives)
- ☐ Requirements for maintenance and operation for construction access
- ☐ Staging area for material handling, and plan for hazardous material movement and handling
- ☐ Other (user-defined)

H6. Project Commissioning/Closeout

A project commissioning and closeout plan should be documented to make sure that the project has a smooth transition to operations. The owner's/user's operations and maintenance personnel should be involved in the development of this plan. Items to consider should include:

- ☐ Sequence of turnover tied to schedule, including system identification and priority
- ☐ Contractor's and owner's required level of involvement in pre-commissioning, training and testing
- ☐ Start-up process defined with responsibilities (e.g., start-up goals, leadership, sequencing of start-up, quality assurance/quality control, work force)
- ☐ Commissioning and closeout documentation (e.g., project data books, turnover manuals, as-built drawings, warranties)
- ☐ Training requirements
- ☐ Lessons learned feedback
- ☐ Administrative closeout (e.g., final payments, contractual closeout)
- ☐ Other (user-defined)

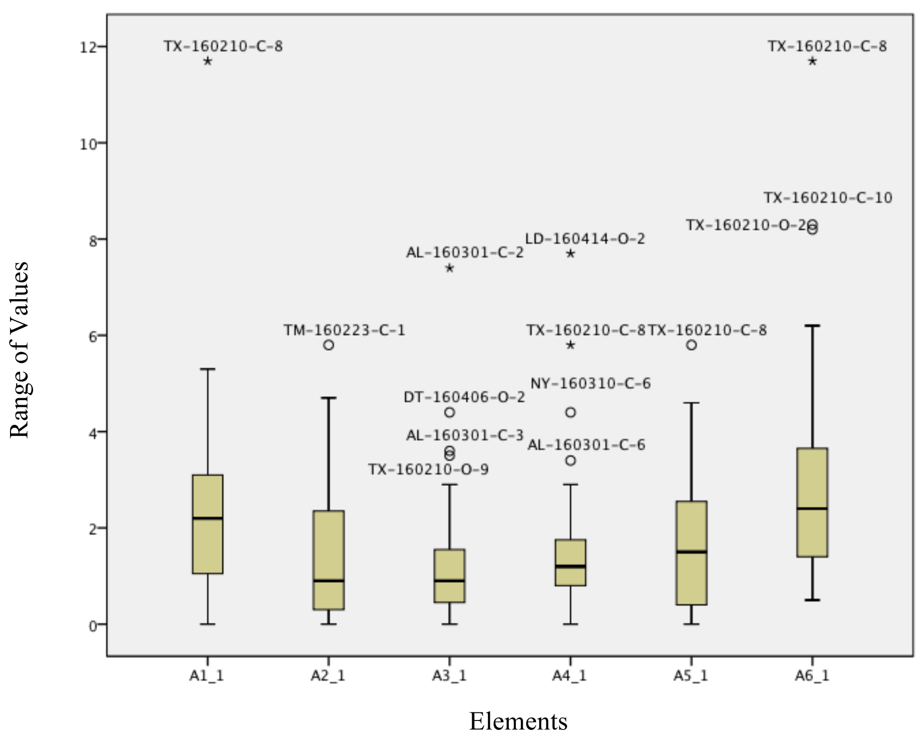
APPENDIX C

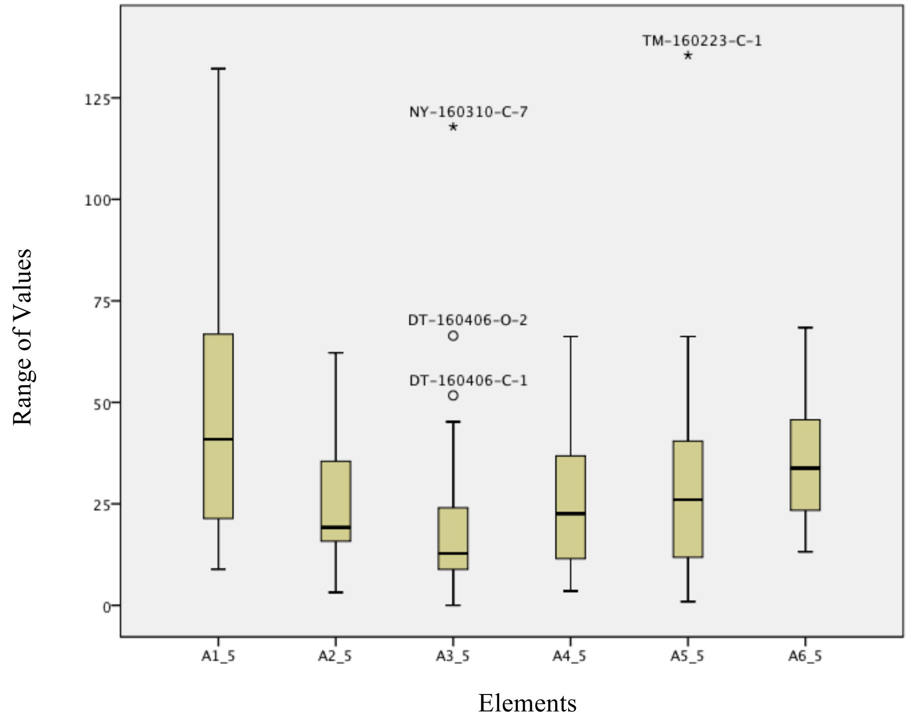
DESCRIPTIVE STATISTICS FROM WEIGHTING WORKSHOPS

DESCRIPTIVE STATISTICS FOR ELEMENTS A.1 – A.6

	A.1		A.2		A.3		A.4		A.5		A.6	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	2.71	55.58	1.43	21.81	1.30	19.23	1.59	28.79	1.52	27.35	2.84	34.98
Standard Deviation	3.08	46.94	1.46	14.12	1.44	21.36	1.50	21.37	1.41	23.19	2.17	17.31
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.98	22.79	0.35	11.18	0.43	6.87	0.74	12.03	0.00	10.60	1.27	23.07
Median	2.13	41.40	0.92	18.62	0.89	12.14	1.24	23.28	1.33	24.17	2.36	32.71
Q3	3.10	75.73	2.33	29.27	1.55	24.05	1.75	40.05	2.53	37.13	3.58	44.05
Maximum	18.18	285.34	5.83	62.23	7.37	117.92	7.67	108.99	5.83	135.50	11.67	92.56
Range	18.18	285.34	5.83	62.23	7.37	117.92	7.67	108.99	5.83	135.50	11.67	92.56
IQR	2.12	52.94	1.98	18.09	1.11	17.18	1.00	28.02	2.53	26.54	2.30	20.97
Mode	0.00	#N/A	0.00	#N/A	0.00	#N/A	0.00	0.00	0.00	#N/A	0.00	#N/A
Skewness	3.08	2.32	1.31	0.97	2.22	2.80	2.03	1.27	0.78	2.10	1.77	0.86
Kurtosis	11.95	8.65	1.43	0.76	6.55	10.33	4.88	2.34	0.31	7.53	4.25	1.23
Upper Extreme Value	9.47	234.54	8.26	83.55	4.88	75.58	4.76	124.12	10.11	116.74	10.49	106.96
Upper Outlier Value	6.28	155.13	5.30	56.41	3.21	49.82	3.25	82.09	6.32	76.94	7.03	75.50
Lower Outlier Value	-2.20	-56.62	-2.61	-15.96	-1.23	-18.90	-0.76	-30.00	-3.79	-29.20	-2.18	-8.39
Lower Extreme Value	-5.39	-136.02	-5.58	-43.10	-2.90	-44.66	-2.27	-72.03	-7.58	-69.01	-5.64	-39.84

BOXPLOTS FOR ELEMENTS A.1 – A.6 (LEVEL 1 AND LEVEL 5)

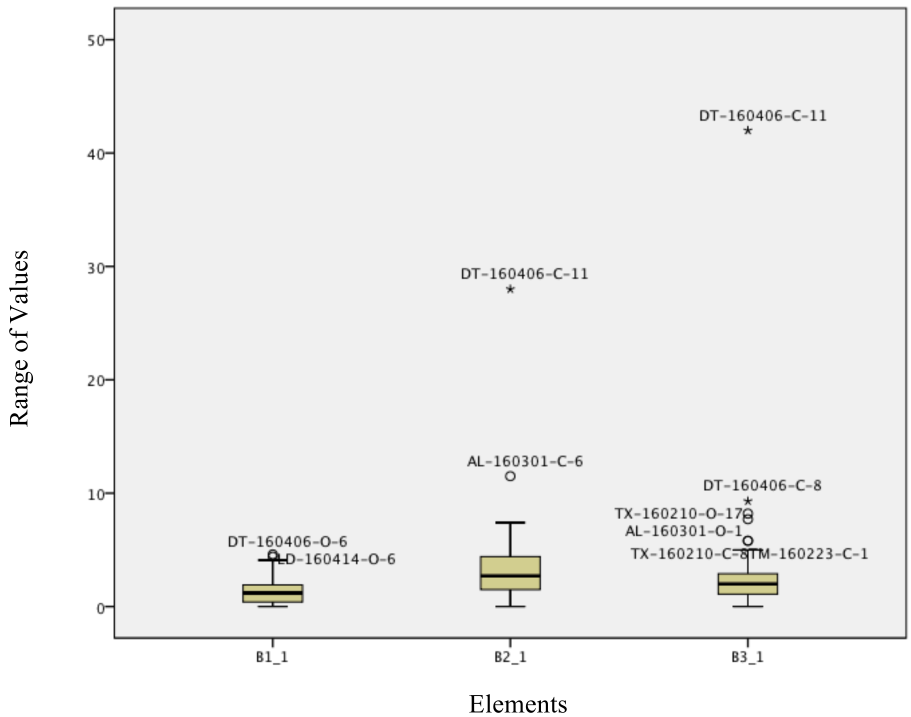


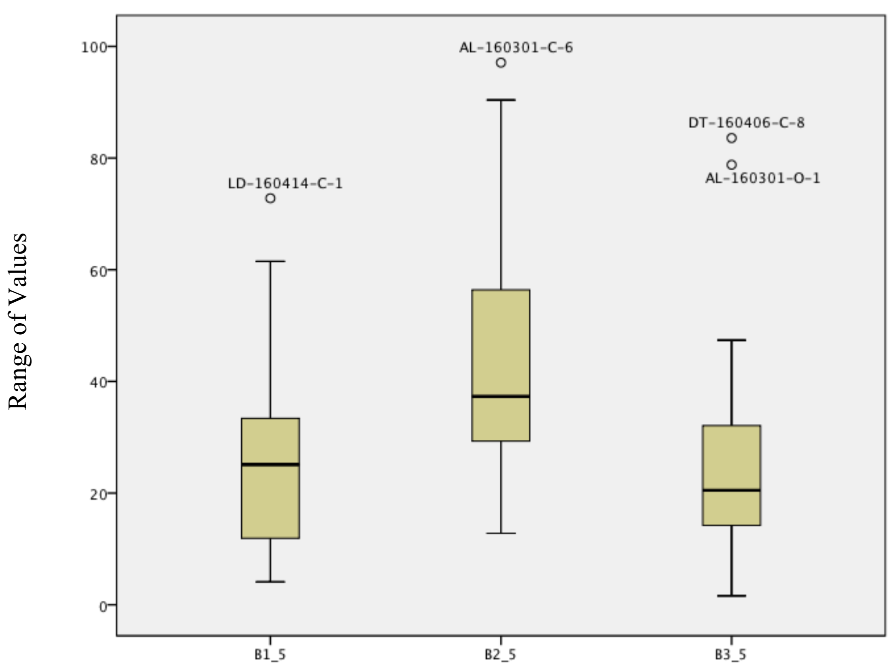


DESCRIPTIVE STATISTICS FOR ELEMENTS B.1 – B.3

	B.1		B.2		B.3	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	1.22	23.00	3.29	40.56	3.12	24.73
Standard Deviation	1.19	15.65	3.87	20.75	5.83	18.75
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.23	9.61	1.49	24.60	0.89	13.34
Median	0.95	22.51	2.40	35.56	1.86	19.31
Q3	1.71	32.13	4.22	56.01	2.91	32.14
Maximum	4.59	72.85	28.00	97.09	42.00	92.56
Range	4.59	72.85	28.00	97.09	42.00	92.56
IQR	1.48	22.53	2.72	31.41	2.02	18.81
Mode	0	0	0	#N/A	0	#N/A
Skewness	1.1382	0.9304	4.769	0.6562	5.9515	1.894
Kurtosis	0.9238	0.9321	29.119	0.1828	39.645	4.5127
Upper Extreme Value	6.1629	99.707	12.381	150.24	8.9783	88.557
Upper Outlier Value	3.9368	65.92	8.2985	103.12	5.9437	60.349
Lower Outlier Value	-1.999	-24.18	-2.589	-22.51	-2.149	-14.87
Lower Extreme Value	-4.226	-57.97	-6.672	-69.62	-5.183	-43.08

BOXPLOTS FOR ELEMENTS B.1 – B.3 (LEVEL 1 AND LEVEL 5)

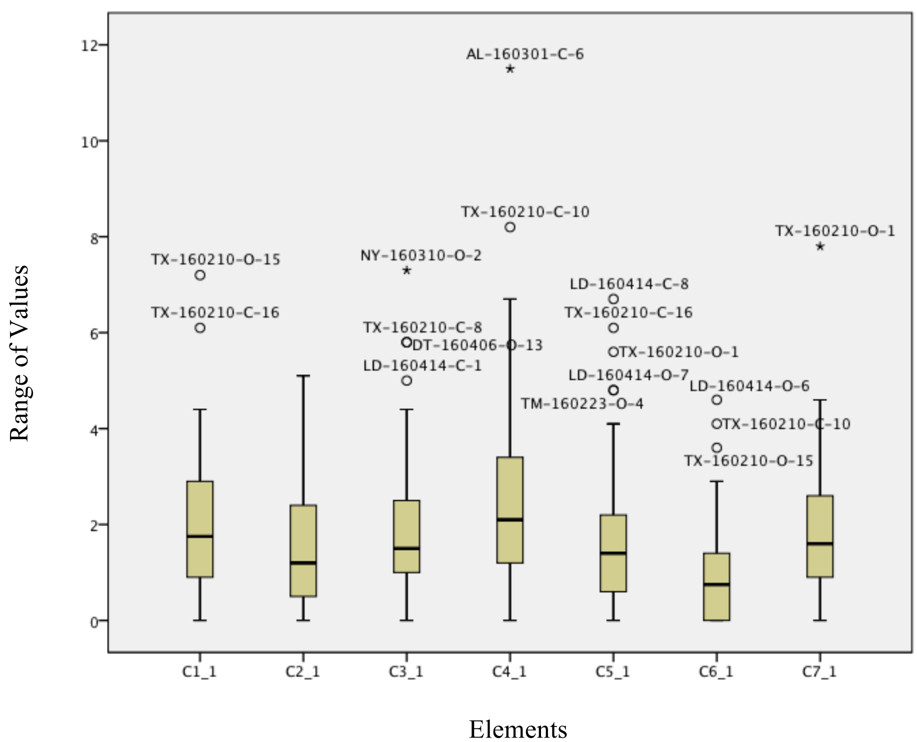


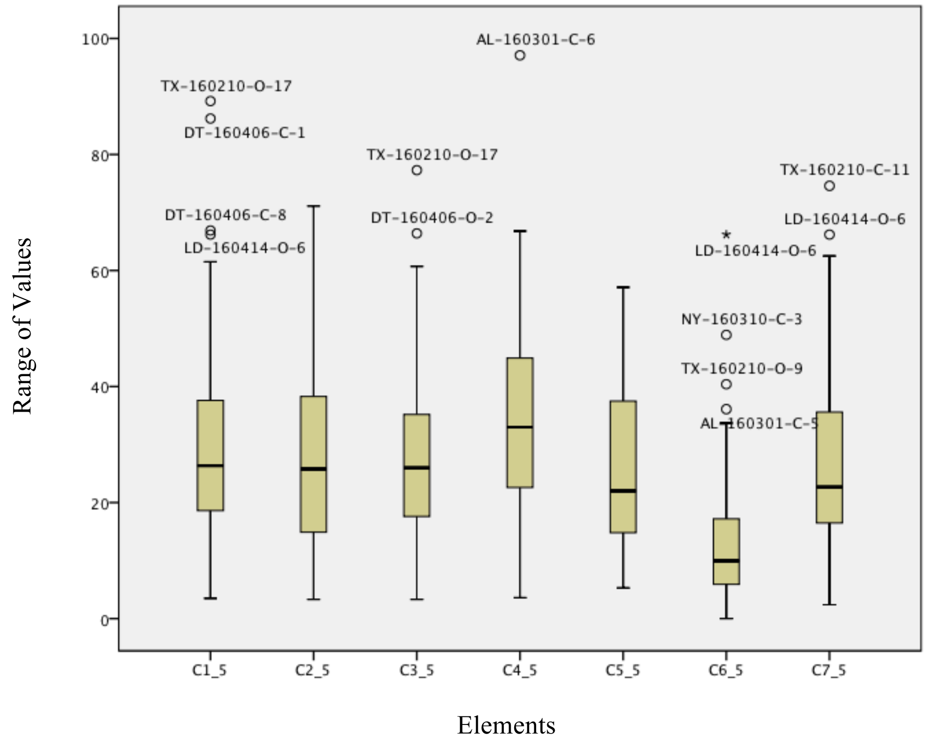


DESCRIPTIVE STATISTICS FOR ELEMENTS C.1 – C.7

	C.1		C.2		C.3		C.4		C.5		C.6		C.7	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	1.86	29.98	1.51	26.81	1.91	27.20	2.34	34.10	1.82	28.62	0.96	13.84	1.99	26.34
Standard Deviation	1.54	18.56	1.36	16.15	1.67	16.52	2.15	19.84	1.64	22.40	1.07	12.93	1.52	15.85
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.67	18.48	0.43	12.24	0.93	16.36	0.97	18.18	0.70	15.72	0.00	5.92	0.96	16.45
Median	1.70	26.34	1.24	24.90	1.50	24.12	1.85	32.13	1.46	22.40	0.75	9.96	1.77	22.72
Q3	2.68	36.30	2.39	38.12	2.53	34.85	2.91	44.69	2.42	38.89	1.41	16.76	2.69	35.57
Maximum	7.23	89.18	5.59	71.12	7.28	77.29	11.48	97.09	6.67	141.63	4.59	66.18	7.78	74.63
Range	7.23	89.18	5.59	71.12	7.28	77.29	11.48	97.09	6.67	141.63	4.59	66.18	7.78	74.63
IQR	2.01	17.82	1.96	25.88	1.60	18.49	1.94	26.50	1.71	23.17	1.41	10.83	1.74	19.12
Mode	0	#N/A	0	#N/A	0	#N/A	0	#N/A	0	#N/A	0	0	0	#N/A
Skewness	1.0961	1.1635	0.9419	0.6973	1.2248	0.9286	1.9102	0.8557	1.2587	2.5064	1.518	1.9072	1.0839	0.920719
Kurtosis	1.7134	1.8246	0.5597	0.2098	1.3183	0.7584	5.1196	1.3431	1.2089	10.669	2.5058	4.4756	2.2255	0.910529
Upper Extreme Value	8.7164	89.772	8.2607	115.76	7.3224	90.304	8.7321	124.2	7.5587	108.42	5.62	49.259	7.9026	92.9396
Upper Outlier Value	5.6989	63.038	5.3251	76.939	4.926	62.576	5.8221	84.442	4.9875	73.654	3.5125	33.008	5.298	64.2549
Lower Outlier Value	-2.348	-8.252	-2.503	-26.59	-1.464	-11.37	-1.938	-21.57	-1.869	-19.04	-2.108	-10.33	-1.648	-12.23762
Lower Extreme Value	-5.365	-34.99	-5.438	-65.41	-3.861	-39.09	-4.848	-61.33	-4.44	-53.8	-4.215	-26.58	-4.252	-40.92232

BOXPLOTS FOR ELEMENTS C.1 – C.7 (LEVEL 1 AND LEVEL 5)

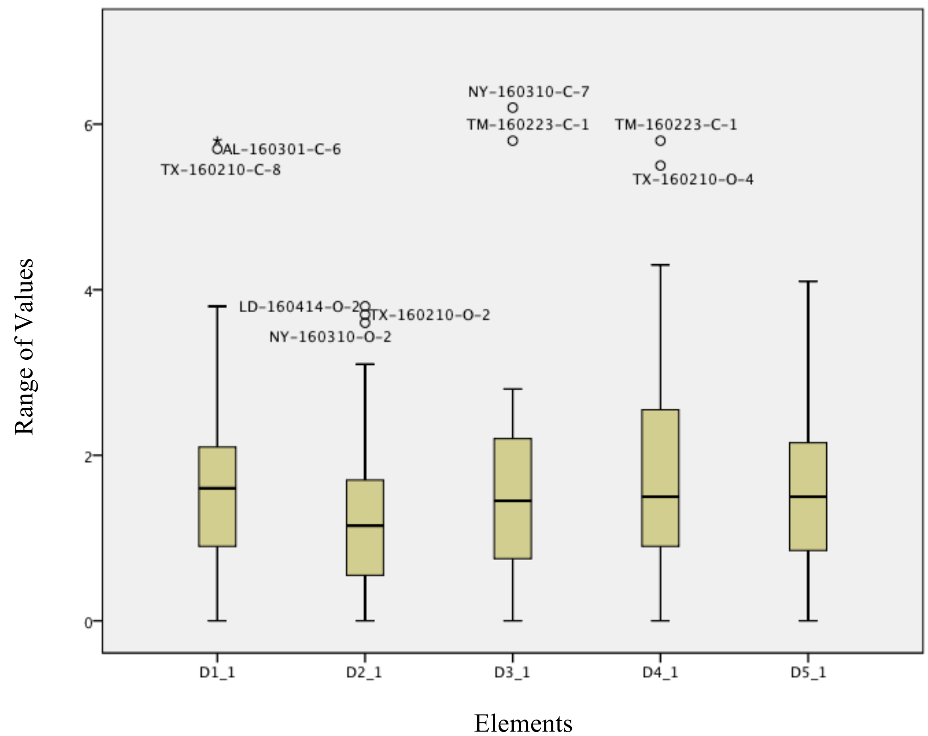


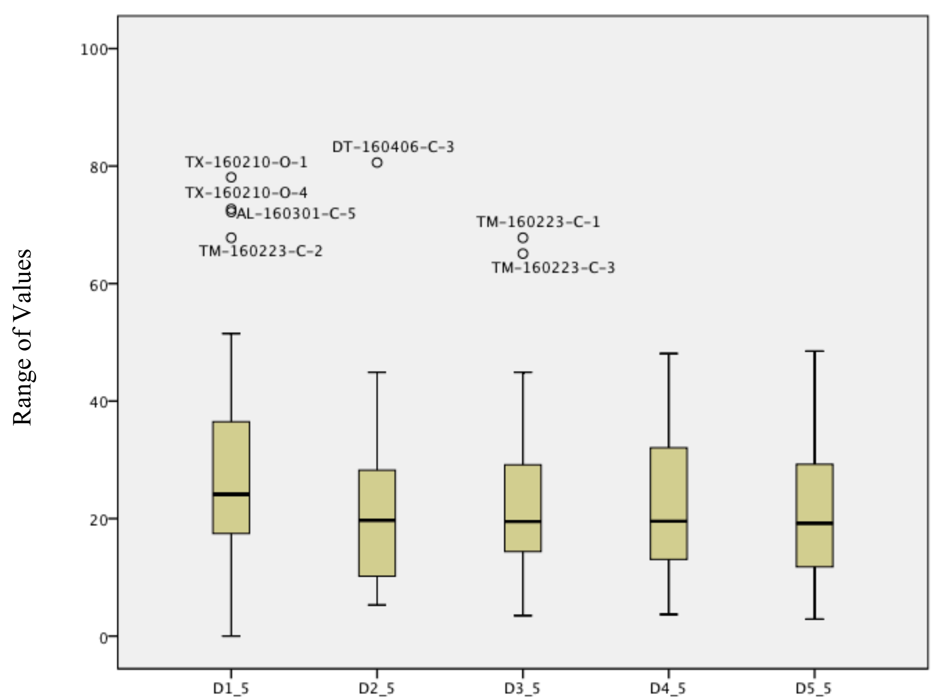


DESCRIPTIVE STATISTICS FOR ELEMENTS D.1 – D.5

	D.1		D.2		D.3		D.4		D.5	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	1.71	28.57	1.34	20.28	1.45	22.45	1.73	22.22	1.50	21.71
Standard Deviation	1.88	18.99	1.17	13.92	1.26	13.09	1.33	12.26	0.95	14.80
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.71	13.55	0.50	10.37	0.65	13.37	0.88	12.95	0.83	11.63
Median	1.46	24.11	1.15	18.29	1.34	20.14	1.49	19.57	1.47	19.08
Q3	2.07	37.31	2.02	25.51	2.10	29.05	2.55	31.91	2.11	29.83
Maximum	12.06	78.13	4.79	80.58	6.19	67.75	5.83	48.08	4.12	66.89
Range	12.06	78.13	4.79	80.58	6.19	67.75	5.83	48.08	4.12	66.89
IQR	1.36	23.76	1.52	15.14	1.45	15.68	1.67	18.96	1.27	18.20
Mode	0	0	0	#N/A	0	#N/A	0	#N/A	0	#N/A
Skewness	3.3642	0.9365	0.8954	1.8885	1.5691	1.2431	1.0664	0.2863	0.2563	1.0727
Kurtosis	16.157	0.4341	0.3771	5.6	4.1884	2.665	1.4252	-0.718	-0.135	1.1768
Upper Extreme Value	6.1449	108.6	6.5752	70.919	6.4353	76.097	7.5519	88.798	5.9287	84.443
Upper Outlier Value	4.1078	72.958	4.2964	48.214	4.2676	52.574	5.0491	60.355	4.0183	57.138
Lower Outlier Value	-1.324	-22.09	-1.78	-12.33	-1.513	-10.15	-1.625	-15.49	-1.076	-15.68
Lower Extreme Value	-3.361	-57.74	-4.059	-35.04	-3.681	-33.68	-4.128	-43.94	-2.987	-42.98

BOXPLOTS FOR ELEMENTS D.1 – D.5 (LEVEL 1 AND LEVEL 5)

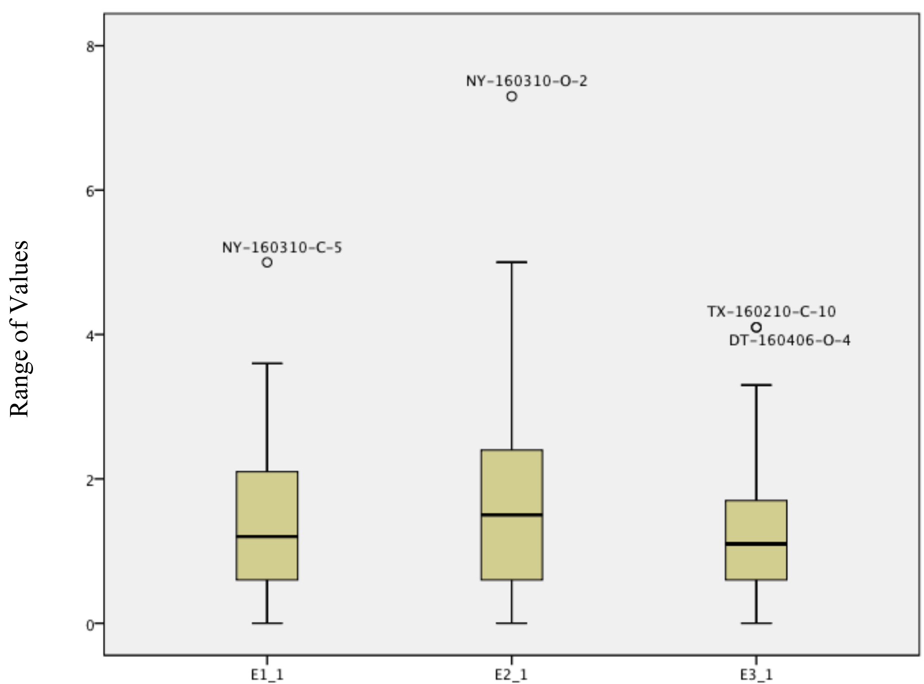




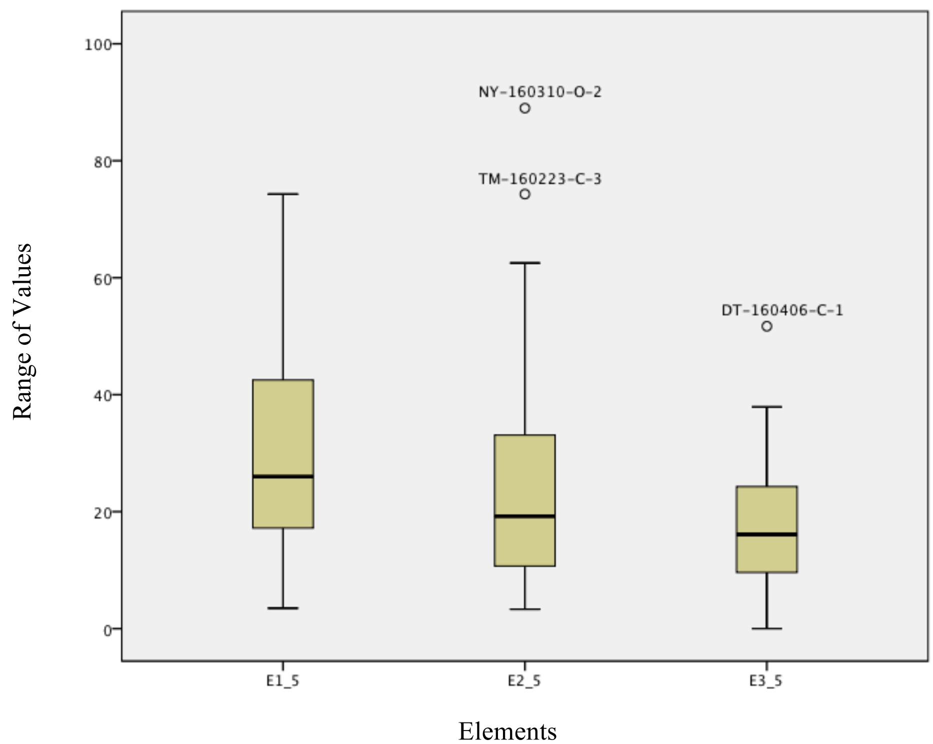
DESCRIPTIVE STATISTICS FOR ELEMENTS E.1 – E.3

	E.1		E.2		E.3	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	1.40	27.76	1.64	25.17	1.15	16.29
Standard Deviation	1.14	16.00	1.46	18.55	1.01	10.66
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.60	16.05	0.60	10.69	0.41	9.39
Median	1.22	26.02	1.47	19.23	1.05	13.82
Q3	2.13	38.19	2.36	33.99	1.55	22.08
Maximum	4.96	74.35	7.28	88.99	4.14	51.71
Range	4.96	74.35	7.28	88.99	4.14	51.71
IQR	1.52	22.15	1.76	23.30	1.14	12.69
Mode	0	#N/A	0	#N/A	0	6.4103
Skewness	0.7866	0.655	1.4612	1.3421	1.0459	0.9851
Kurtosis	0.4779	0.254	3.2973	2.1521	1.1793	0.9619
Upper Extreme Value	6.7039	104.63	7.6246	103.9	4.9689	60.133
Upper Outlier Value	4.4165	71.41	4.9915	68.948	3.2585	41.105
Lower Outlier Value	-1.683	-17.17	-2.03	-24.26	-1.303	-9.638
Lower Extreme Value	-3.971	-50.39	-4.663	-59.22	-3.013	-28.67

BOXPLOTS FOR ELEMENTS E.1 – E.3 (LEVEL 1 AND LEVEL 5)



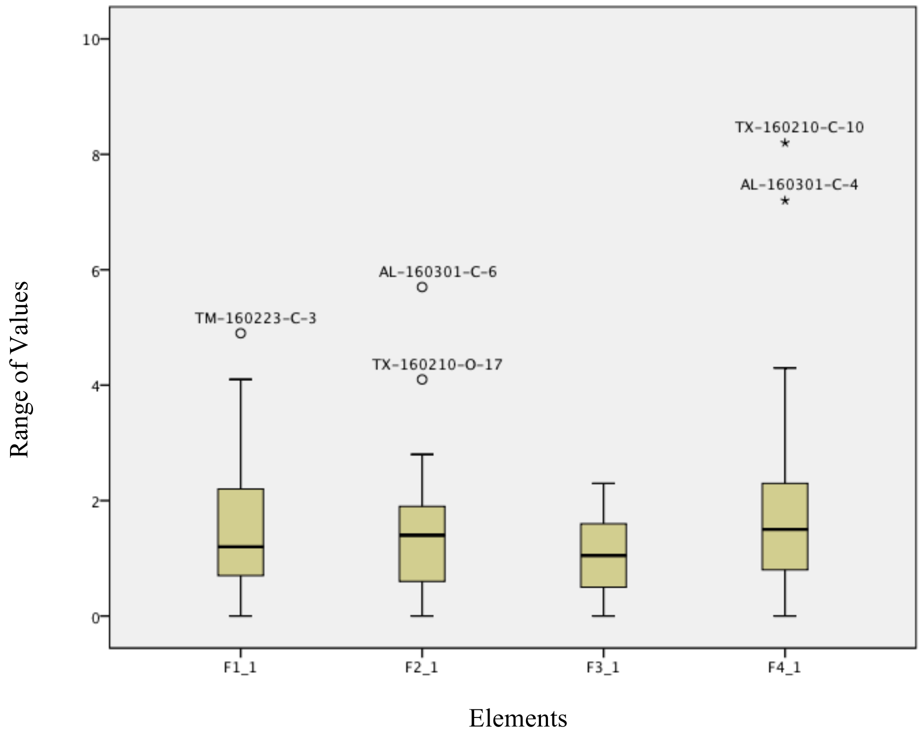
Elements

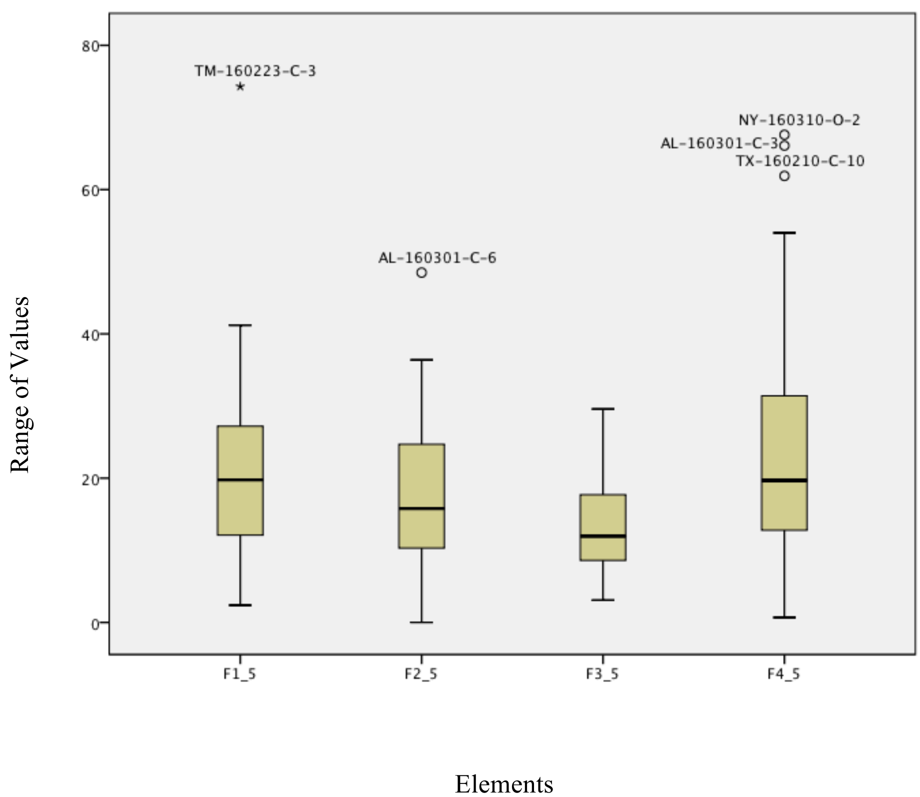


DESCRIPTIVE STATISTICS FOR ELEMENTS F.1 – F.4

	F.1		F.2		F.3		F.4	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	1.43	20.45	1.30	16.06	1.06	13.74	1.81	23.75
Standard Deviation	1.22	12.63	1.13	10.27	0.77	6.99	1.65	16.50
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.73	11.72	0.58	9.58	0.47	8.53	0.89	12.81
Median	1.33	19.23	1.22	14.16	1.14	12.04	1.46	20.22
Q3	1.90	26.72	1.78	19.08	1.54	18.20	2.30	32.13
Maximum	5.84	74.35	5.74	48.54	2.92	29.59	8.24	67.63
Range	5.84	74.35	5.74	48.54	2.92	29.59	8.24	67.63
IQR	1.17	15.00	1.20	9.51	1.07	9.68	1.41	19.32
Mode	0	#N/A	0	0	0	#N/A	0	#N/A
Skewness	1.4842	1.5954	1.4888	0.9719	0.0952	0.4664	1.964	0.9291
Kurtosis	3.2114	5.229	4.0332	1.0639	-0.746	-0.651	4.891	0.417
Upper Extreme Value	5.4176	71.708	5.3815	47.6	4.739	47.231	6.5221	90.101
Upper Outlier Value	3.6594	49.213	3.5816	33.342	3.1389	32.717	4.4086	61.116
Lower Outlier Value	-1.029	-10.77	-1.218	-4.68	-1.128	-5.987	-1.227	-16.18
Lower Extreme Value	-2.787	-33.27	-3.018	-18.94	-2.728	-20.5	-3.341	-45.16

BOXPLOTS FOR ELEMENTS F.1 – F.4 (LEVEL 1 AND LEVEL 5)

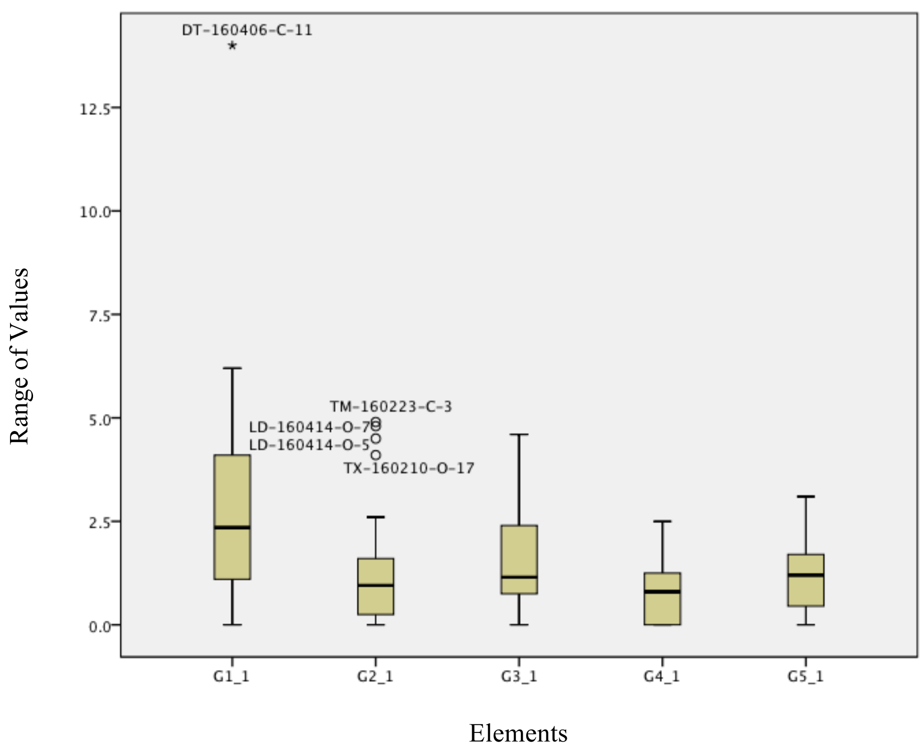


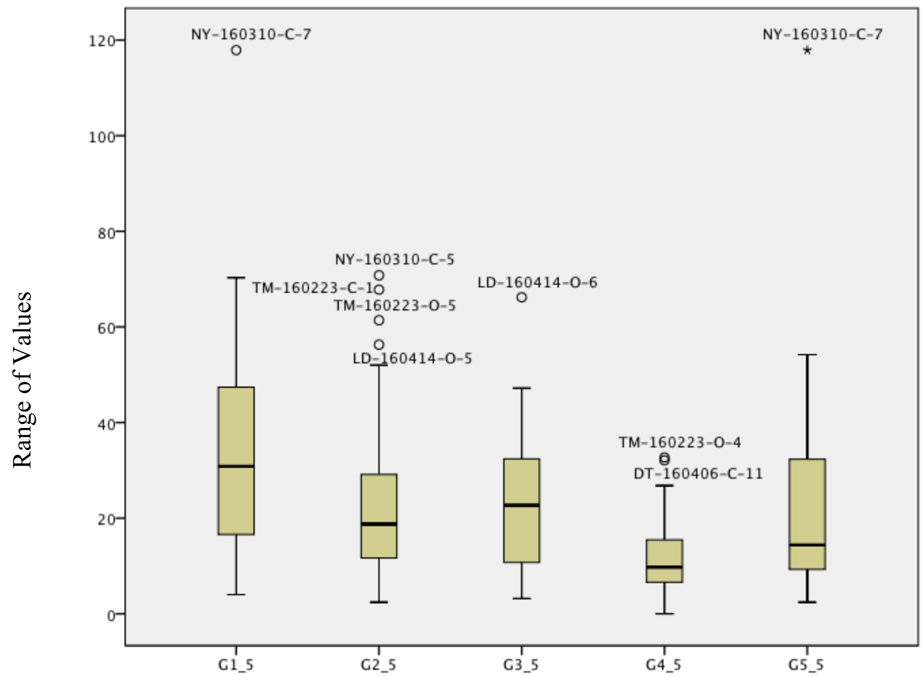


DESCRIPTIVE STATISTICS FOR ELEMENTS G.1 – B.5

	G.1		G.2		G.3		G.4		G.5	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	2.75	33.34	1.63	23.75	1.57	21.99	1.11	15.16	1.28	19.73
Standard Deviation	2.56	21.88	1.53	16.83	1.20	14.58	1.12	11.14	1.00	18.93
Minimum	0.00	4.03	0.00	2.42	0.00	0.00	0.00	0.00	0.00	2.35
Q1	0.96	17.12	0.66	11.65	0.73	10.54	0.00	7.06	0.48	8.33
Median	2.31	29.26	1.23	19.23	1.29	21.42	0.93	10.79	1.20	13.01
Q3	3.95	46.47	2.08	29.11	2.47	31.19	1.53	24.62	1.91	23.89
Maximum	14.00	117.92	6.11	70.81	4.59	70.96	4.11	48.85	3.83	117.92
Range	14.00	113.90	6.11	68.40	4.59	70.96	4.11	48.85	3.83	115.58
IQR	2.98	29.35	1.42	17.46	1.74	20.65	1.53	17.56	1.44	15.56
Mode	0	#N/A	0	#N/A	0	#N/A	0	0	0	#N/A
Skewness	2.4547	1.6639	1.1578	1.278	0.6708	1.0974	1.0011	0.9704	0.5236	2.9298
Kurtosis	9.4418	4.8684	0.8028	1.1254	-0.309	1.8369	0.4099	0.1301	-0.307	12.8
Upper Extreme Value	12.895	134.51	6.349	81.5	7.7027	93.146	6.1379	77.31	6.2187	70.556
Upper Outlier Value	8.4213	90.49	4.2147	55.307	5.0874	62.17	3.8362	50.967	4.0651	47.221
Lower Outlier Value	-3.509	-26.9	-1.477	-14.54	-1.887	-20.43	-2.302	-19.28	-1.678	-15
Lower Extreme Value	-7.983	-70.92	-3.611	-40.73	-4.502	-51.41	-4.603	-45.62	-3.831	-38.34

BOXPLOTS FOR ELEMENTS G.1 – G.5 (LEVEL 1 AND LEVEL 5)



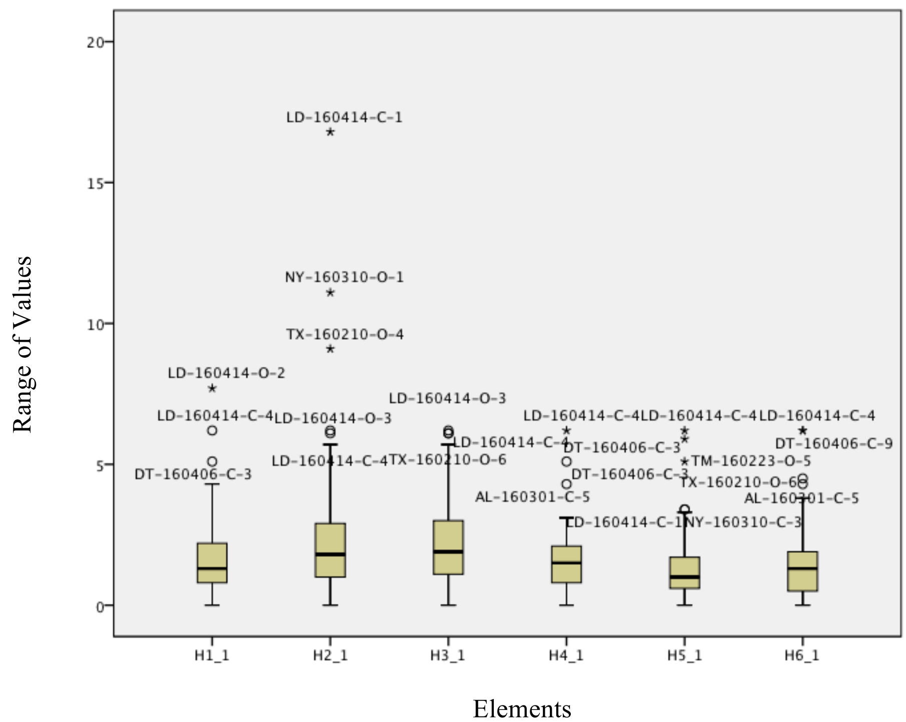


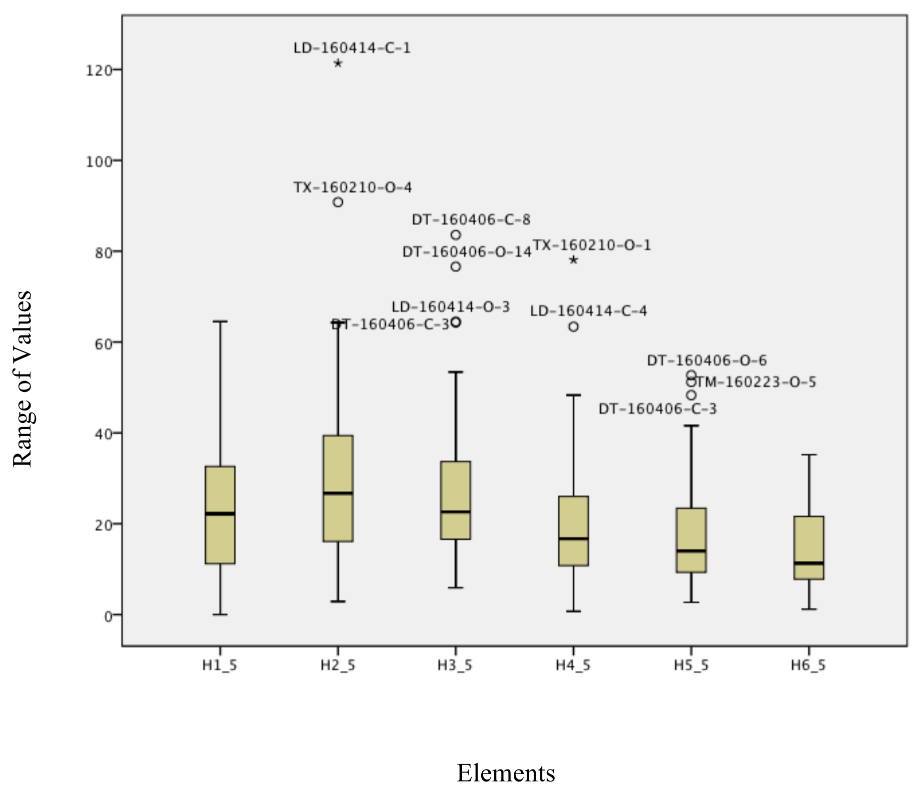
Elements

DESCRIPTIVE STATISTICS FOR ELEMENTS H.1 – H.6

	H.1		H.2		H.3		H.4		H.5		H.6	
	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5	LEV. 1	LEV. 5
Mean	1.70	22.53	2.45	30.33	2.17	27.66	1.57	20.35	1.42	17.41	1.55	14.05
Standard Deviation	1.54	14.15	2.84	22.18	1.61	16.88	1.32	14.82	1.44	13.02	1.47	8.97
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.74	10.93	0.94	15.84	1.06	16.54	0.74	10.55	0.59	8.98	0.49	7.40
Median	1.35	21.94	1.80	25.07	1.99	23.01	1.46	16.74	0.96	13.95	1.29	11.27
Q3	2.25	32.72	2.78	40.44	3.00	33.96	2.15	26.19	1.73	23.61	1.88	21.69
Maximum	7.67	64.46	16.83	121.41	6.24	83.61	6.24	78.13	6.24	52.72	6.24	35.22
Range	7.67	64.46	16.83	121.41	6.24	83.61	6.24	78.13	6.24	52.72	6.24	35.22
IQR	1.51	21.78	1.84	24.59	1.94	17.42	1.40	15.64	1.13	14.63	1.39	14.30
Mode	0	0	0	#N/A	0	#N/A	0	#N/A	0	#N/A	0	#N/A
Skewness	1.7002	0.5754	2.9742	1.603	0.8959	1.3792	1.3472	1.7247	1.6829	1.2737	1.3947	0.6233
Kurtosis	3.7347	0.0349	11.553	4.0212	0.3605	2.0325	2.4969	3.8611	2.832	1.0328	1.908	-0.537
Upper Extreme Value	6.7685	98.07	8.3182	114.22	8.8124	86.209	6.3511	73.104	5.123	67.499	6.0361	64.587
Upper Outlier Value	4.5091	65.393	5.5514	77.328	5.9071	60.083	4.2488	49.647	3.4245	45.553	3.958	43.14
Lower Outlier Value	-1.516	-21.75	-1.826	-21.05	-1.84	-9.586	-1.357	-12.9	-1.105	-12.97	-1.584	-14.05
Lower Extreme Value	-3.775	-54.42	-4.593	-57.94	-4.746	-35.71	-3.46	-36.36	-2.803	-34.91	-3.662	-35.5

BOXPLOTS FOR ELEMENTS H.1 – H.6 (LEVEL 1 AND LEVEL 5)

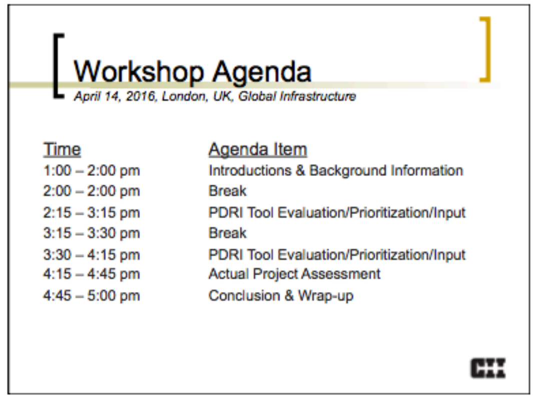




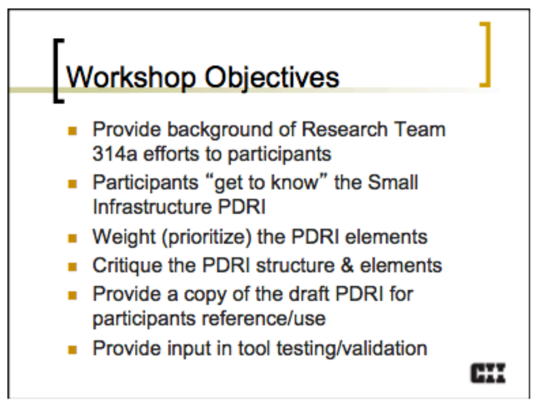
APPENDIX D

WEIGHTING WORKSHOP PRESENTATION AND EVALUATION FORMS


Small Infrastructure PDRI Workshop
CII Research Team 314a
London
April 14, 2016
CII


Workshop Agenda
April 14, 2016, London, UK, Global Infrastructure
Time
Agenda Item
1:00 – 2:00 pm
Introductions & Background Information
2:00 – 2:00 pm
Break
2:15 – 3:15 pm
PDRI Tool Evaluation/Prioritization/Input
3:15 – 3:30 pm
Break
3:30 – 4:15 pm
PDRI Tool Evaluation/Prioritization/Input
4:15 – 4:45 pm
Actual Project Assessment
4:45 – 5:00 pm
Conclusion & Wrap-up
CII


Introductions
Briefly
Name
Organization
Experience with front end planning and small infrastructure projects
CII


Workshop Objectives
Provide background of Research Team 314a efforts to participants
Participants "get to know" the Small Infrastructure PDRI
Weight (prioritize) the PDRI elements
Critique the PDRI structure & elements
Provide a copy of the draft PDRI for participants reference/use
Provide input in tool testing/validation
CII

CII Mission

Add value for members by enhancing the business effectiveness and sustainability of the capital facility life cycle through CII research, related initiatives, and industry alliances.

Expand the global competitive advantage realized through active involvement and effective use of research findings, including CII Best Practices.

RT 314a, Project Definition Rating Index (PDRI) for Small Infrastructure Projects

Objectives

1. Identify issues unique to front end planning for small infrastructure projects, such as:
   - how to address site investigations
   - construction/execution strategy
   - contracting approaches
   - task force organization
   - cost and schedule estimating methods
2. Enhance or supplement current CII FEP documentation, including a "PDRI- like tool" for these types of projects
3. Produce documents to assist project teams in developing effective FEP for small infrastructure projects
4. Set the stage for future work that could address a small building project PDRI tool

CII

Research Team 314 Members

Paul Katers, Co-chair	American Transmission Co.
Eskil Carlsson, Co-chair	CSA Group

Mike Davidson	PTAG
Dustin Giles	Burns & McDonnell
Shannon Gray	Occidental Petroleum
Brad Lynch	TransCanada
Robert Mitroczak	Architect of the Capitol
Tom Nelson	Hargrove Engineers + Constructors
Charles Obi	Smithsonian

G. Edward Gibson, Jr.	Arizona State University
Kristen Parrish	Arizona State University

Luis Pinto	Faithful-Gould
David Sonntag	DTE Energy
Derek Wedel	Global Infrastructure Partners
Leroy Yong	Williams

Rebekah Burke, Student	Arizona State University
Mohamed Elzomor, Student	Arizona State University

Confidentiality

- Responses coded
- Only ASU team members know who filled out
- Not attributable to any individual
- If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

CII

RT 314a Milestones

- 09/16/15 Team kick-off
- 01/14/16 Draft PDRI complete
- 02/10/16 Workshop – Houston
- 02/23/16 Workshop – Tempe
- 03/01/16 Workshop - Mobile
- 03/10/16 Workshop – New York
- 03/30/16 Workshop – Tempe
- 04/06/16 Workshop – Detroit
- 04/14/16 Workshop – London
  - Minimum 60 qualified responses
- 4Q, 2016 Publish PDRI

Typical Small Infrastructure Projects

Total Installed Cost	Less than $20 Million
Engineering Effort	Less than 10,000 man-hours
Construction Duration	6-12 months
Number of Core Team Members	<8 core team members
Availability of Core Team Members	Part time availability of core team members

These can/will vary from organization to organization, and from project to project

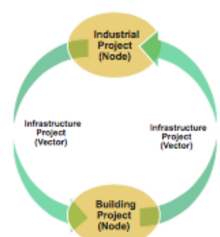
These attributes may be more "consequences" of projects being small as opposed to differentiators between large and small projects

Examples of Typical Small Infrastructure Projects

- People and Freight
  - ex. (airport runway resurfacing, intersection rebuild, install railroad track on new/existing roadbed, repairs and paving, security bollards)
- Energy
  - ex. (transmission line, fiber optic line and conduit, electrical ductbank insulation, natural gas pipeline service feeder)
- Fluids
  - ex. (install pipeline, recondition and recoat pipeline, utility pipeline asbestos abatement and reinsulation, fire protection water line relocation)

Project Systems

- Vector of node-vector system
- Infrastructure projects
  - Transportation
  - Transmission
  - Distribution
  - Collection
- Integrated system

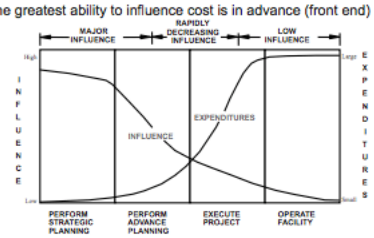


BACKGROUND

What is Front End Planning?

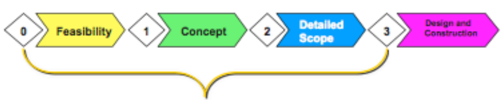
BACKGROUND

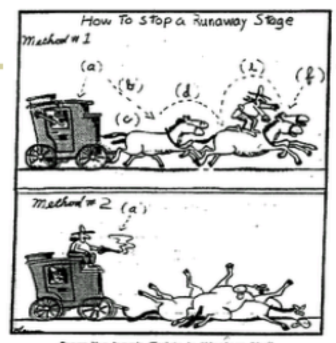
The greatest ability to influence cost is in advance (front end) planning



Influence and expenditures curve for the project life cycle

Front End Planning Defined

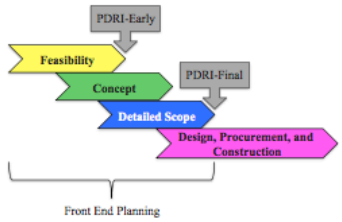




From the book Guide to Western Stuff

16

Compressed Front End Planning Process



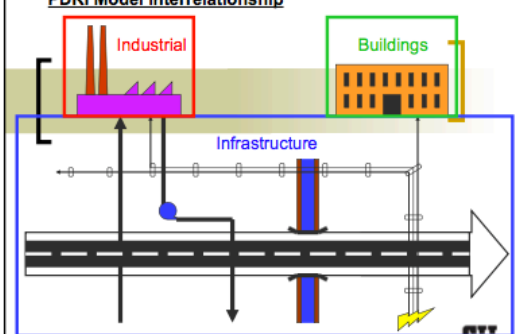
BACKGROUND

- Tools have been developed and widely used for industrial, small industrial, building and infrastructure projects during front end planning phase: Project Definition Rating Index (PDRI)
- Greater advance planning efforts = greater project success
  - Lower cost variance
  - Less schedule slippage
  - Fewer change orders

PDRI – The Definition

- An Acronym
  - Project Definition Rating Index
- An Index
  - Score along a continuum representing the level of scope definition
- A Risk Management Tool
  - Identifies and measures risks related to project scope definition

PDRI Model Interrelationship



Weighted Score Sheet
(Example)

See page 45 of IR 268-2

SECTION I – BASIS OF PROJECT DECISION							
CATEGORY Element	Definition Level 0	1	2	3	4	5	Score
A. PROJECT STRATEGY (Maximum Score = 112)							
A1. Need & Purpose Documentation	0	2	13	24	35	44	
A2. Investment Studies & Alternatives Assessments	0	1	8	15	22	28	
A3. Key Team Member Coordination	0	1	6	11	16	19	
A4. Public Involvement	0	1	6	11	16	21	
CATEGORY A TOTAL							
B. OWNER/OPERATOR PHILOSOPHIES (Maximum Score = 67)							
B1. Design Philosophy	0	2	7	12	17	22	
B2. Operating Philosophy	0	1	5	9	13	16	
B3. Maintenance Philosophy	0	1	4	7	10	12	
B4. Future Expansion & Alteration Considerations	0	1	5	9	13	17	
CATEGORY B TOTAL							
C. PROJECT FUNDING AND TIMING (Maximum Score = 70)							
C1. Funding & Programming	0	1	6	11	16	21	
C2. Preliminary Project Schedule	0	2	7	12	17	22	
C3. Contingencies	0	2	8	14	20	27	
CATEGORY C TOTAL							
D. PROJECT REQUIREMENTS (Maximum Score = 143)							
D1. Project Objectives Statement	0	1	6	11	16	19	
D2. Functional Classification & Use	0	1	6	11	16	19	
D3. Evaluation of Compliance Requirements	0	1	6	11	16	19	
D4. Existing Environmental Conditions	0	1	6	11	16	19	
D5. Site Characteristics Available vs. Required	0	1	5	9	13	18	
D6. Dismantling & Demolition Requirements	0	1	4	7	10	11	
D7. Determination of Utility Impacts	0	1	6	11	16	19	
D8. Lead/Discipline Scope of Work	0	1	4	7	10	13	
CATEGORY D TOTAL							
E. VALUE ANALYSIS (Maximum Score = 45)							
E1. Value Engineering Procedures	0	1	3	5	7	10	
E2. Design Simplification	0	0	3	6	9	11	
E3. Material Alternatives Considered	0	1	3	5	7	9	
E4. Constructability Procedures	0	1	5	9	13	15	
CATEGORY E TOTAL							
Section I Maximum Score = 437	SECTION I TOTAL						

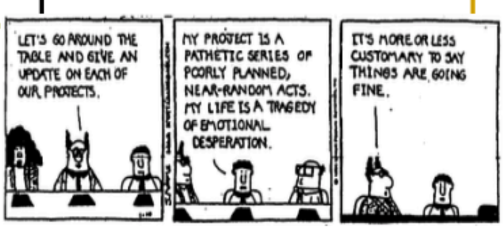
Definition Levels
0 = Not Applicable 2 = Minor Deficiencies 4 = Major Deficiencies
1 = Complete Definition 3 = Some Deficiencies 5 = Incomplete or Poor Definition

PDRI Element Descriptions
(Example)

B2. Operating Philosophy
A list of general design principles should be developed to preserve the level of service desired at a sufficient capacity over an extended period of time. This list focuses particularly on developing strategic operations plans to prevent problems related to sub-optimal capacity. Issues to consider include the following:

- ❑ Daily level of service requirements
- ❑ Capacity change requirements
- ❑ Technological needs assessment
- ❑ Future improvement schedule
- ❑ Flexibility to change layout
- ❑ Third party operations personnel
- ❑ Safety strategy for hazards mitigation
- ❑ Training requirements
- ❑ Control requirements
- ❑ Personnel and equipment requirements
- ❑ Alternative operating procedures, (i.e., consideration of manual versus automated modes)
- ❑ Utilities location in relation to facility

IR 268-2; Each element can be considered a written deliverable



Tool Format
Project Definition Rating Index

*The crucial elements that need to be included in a scope definition for **industrial** projects.*

Composition:
- 3 Sections
  - 15 Categories
    - 70 Elements

44 pages of detailed element descriptions;

Rate each of the 70 elements to obtain a project score of up to 1000 points--the lower the better.

Tool Format
Project Definition Rating Index

*The crucial elements that need to be included in a scope definition for **building** projects.*

Composition:

- 3 Sections
  - 11 Categories
    - 64 Elements

37 pages of detailed element descriptions;

Rate each of the 64 elements to obtain a project score of up to 1000 points--the lower the better.

CII

Tool Format
Project Definition Rating Index

*The crucial elements that need to be included in a scope definition for **infrastructure** projects.*

Composition:

- 3 Sections
  - 13 Categories
    - 68 Elements

71 pages of detailed element descriptions;

Rate each of the 68 elements to obtain a project score of up to 1000 points--the lower the better.

CII

Tool Format
Project Definition Rating Index

*The crucial elements that need to be included in a scope definition for **small industrial** projects.*

Composition:

- 3 Sections
  - 8 Categories
    - 41 Elements

25 pages of detailed element descriptions;
Rate each of the 41 elements to obtain a project score of up to 1000 points--the lower the better.

CII

Tool Format
Project Definition Rating Index

*The crucial elements that need to be included in a scope definition for **small infrastructure** projects.*

Composition:

- 3 Sections
  - 8 Categories
    - 40 Elements

28 pages of detailed element descriptions;

Rate each of the 40 elements to obtain a project score of up to 1000 points--the lower the better.

CII

Weighting Small Infrastructure PDRI Elements

PDRI INFORMATION PACKAGE*

*Color Coded

- Brief introduction to the PDRI Research and Agenda (White)
- Background information and detailed project information (Yellow)
- PDRI weighting factor evaluation forms (Green)
- PDRI element descriptions (White)
- Un-weighted project score sheet (White)
- Project Assessment sheet (Blue)
- Suggestions for improvement (Pink)

WE NEED YOUR HELP...

- Research team identified 40 risk issues, grouped into 8 categories and 3 sections
- Not all elements are equally important

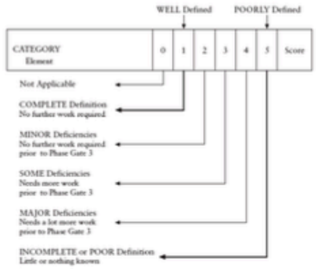
Therefore:

- We desire to prioritize or "weight" the issues according to their relative importance
- We need input from experienced project managers and project development subject experts to help us determine the issues' "weights"
- Then, we need to test the PDRI on real projects to assess its validity

WEIGHTING THE PDRI ELEMENTS

- Consider your recently completed project (type and size); on your background sheet
- Evaluate the *level of definition* of each element in the PDRI and apply an appropriate **contingency** to that element **(i.e., its individual impact on TIC stated as a percentage of the overall estimate)**
- Consider:
  - When detailed design is about to commence
  - **Consider both cost and time impacts**
  - Two levels of definition:
    - 1 = Complete Definition
    - 5 = Incomplete or Poor Definition

Which definition level at end of Front End Planning?



CII

What is N/A?

- Not Applicable to the specific "Typical Project" you chose for this workshop
- If you are unsure
  - Rely on your experience
  - Estimate a weight
  - Don't check N/A

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WEIGHTING THE PDRI ELEMENTS

Example:

CATEGORY Element	Definition Level						Comments
	N/A	1	2	3	4	5	
F. Associated Structures & Equipment							
F4. Equipment List							

Definition Levels:

1 = Complete Definition

5 = Incomplete or Poor Definition

PDRI Element Description

F4. Equipment List

Project-specific installed equipment should be defined and listed. The purchaser of equipment should be clearly identified in the equipment list. Items to consider should include:

- ❑ Details of required equipment related to the type of project:
  - ❑ People and freight (e.g., benches, bus shelters, signs, traffic control devices)
  - ❑ Fluids (e.g., turbines/compressors/pumps, grinders/clarifiers/tanks/basins)
  - ❑ Energy (e.g., transformers, electrical substations, breakers, disconnect switches, protection and control equipment)
- ❑ Modularized control rooms
- ❑ Emergency generators
- ❑ A tabulated list of utility requirements for all major installed equipment (e.g., power, water, fuel, air, specialty gasses)

****Additional items to consider for renovation & revamp projects****

- ❑ Identification of systems and equipment as new, existing or relocate, remove
- ❑ Clear definition of any modifications to existing systems and equipment, and verification of compliance with existing codes

WEIGHTING THE PDRI ELEMENTS

Example:

CATEGORY Element	Definition Level						Comments
	N/A	1	2	3	4	5	
F. Associated Structures & Equipment							
F4. Equipment List		2%				30%	

Please use integers only

Definition Levels:

1 = Complete Definition

5 = Incomplete or Poor Definition

2,3,4 = Interpolated Later

Path Forward

- Incorporate your comments and input
- Normalize input from all respondents
- Develop "weighted" score sheet
- Test on:
  - On-going projects
  - After the fact projects
- Develop Excel Spreadsheet
- Deploy

CII

Questions?

CII

SUGGESTIONS FOR IMPROVEMENT

Name:____

Date:____

Please answer the following questions regarding the PDRI.

Is the list of elements complete? If not, please list all others that should be added.

Are any of the elements redundant?

If so, please list and provide any recommended changes.

Are any of the definitions unclear or incomplete?

If so, please list and provide any recommended changes.

Do you have any other suggestions for improving the PDRI or the instruction sheet?

Please answer the following questions regarding the Background Information Sheet.

Are any of the questions unclear? If so, which ones and how should they be reworded?

Are there any other questions not included in the information sheet that may provide the research team with important information regarding the experience of the project managers and estimators? If so, please list the ones that should be added.

General Comments:

APPENDIX E

EXAMPLE OF COMPLETED WEIGHTING WORKSHOP ASSESSMENT

Name

PROJECT SCORE SHEET - UNWEIGHTED						
SECTION I - BASIS OF PROJECT DECISION						
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**
A. PROJECT ALIGNMENT						
A.1 Need & Purpose Statement			X			
A.2 Key Project Participants			X			
A.3 Public Involvement				X		
A.4 Project Philosophies			X			
A.5 Project Funding		X				
A.6 Preliminary Project Schedule			X			
B. PROJECT REQUIREMENTS						
B.1 Functional Classification & Use			X			
B.2 Physical Site			X			
B.3 Dismantling & Demolition Requirements			X			

Definition Levels

N/A = Not Applicable
1 = Complete Defintion
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

Name

SECTION II - BASIS OF DESIGN						
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**
C. DESIGN GUIDANCE						
C.1 Lead/Discipline Scope of Work		X				
C.2 Project Codes and Standards		X				
C.3 Surveys & Mapping		X				
C.4 Project Site Assessment		X				
C.5 Environmental & Regulatory Consideration		X				
C.6 Value analysis				X		
C.7 Construction Input			X			
D. PROJECT DESIGN PARAMETERS						
D.1 Capacity		X				
D.2 Design for Safety & Hazards		X				
D.3 Civil and Structural		X				
D.4 Mechanical and Equipment		X				
D.5 Electrical and Controls		X				
D.6 Operations and Maintenance			X			
E. LOCATION AND GEOMETRY						
E.1 Schematic Layouts			X			
E.2 Alignment and Cross-Section			X			
E.3 Control of Access			X			
F. ASSOCIATED STRUCTURES & EQUIPMENT						
F.1 Support Structures			X			
F.2 Hydraulic Structures			X			
F.3 Miscellaneous Elements			X			
F.4 Equipment List		X				

Definition Levels

N/A = Not Applicable
1 = Complete Defintion
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

PDRI For Small Infrastructure Projects

Name

SECTION III - EXECUTION APPROACH						
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**
G. EXECUTION REQUIREMENTS						
G.1 Land Acquisition Strategy		X				
G.2 Utility Adjustment Strategy		X				
G.3 Procurement Strategy		X				
G.4 Owner Approval Requirements		X				
G.5 Intercompany & Interagency Coordination & Agreements		X				
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS						
H.1 Design/Construction Plan and Approach		X				
H.2 Project Cost Estimate and Cost Control		X				
H.3 Project Schedule and Schedule Control		X				
H.4 Project Quality Assurance & Control			X			
H.5 Safety, Work Zone & Transportation Plan		X				
H.6 Project Commissioning/Closeout		X				

Definition Levels

N/A = Not Applicable
1 = Complete Defintion
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

Name

PROJECT SCORE SHEET - UNWEIGHTED

SECTION I - BASIS OF PROJECT DECISION							
		%				%	
CATEGORY Element	NA	1	2	3	4	5	Comments
A. PROJECT ALIGNMENT							
A.1 Need & Purpose Statement		2				30	
A.2 Key Project Participants		2				20	
A.3 Public Involvement		1				5	
A.4 Project Philosophies		1				20	
A.5 Project Funding		1				15	
A.6 Preliminary Project Schedule		2				20	
B. PROJECT REQUIREMENTS							
B.1 Functional Classification & Use		1				30	
B.2 Physical Site		1				30	
B.3 Dismantling & Demolition Requirements		1				10	

Definition Levels

N/A = Not Applicable 1 = Complete Defintion 5 = Incomplete or Poor Definition

PDRI For Small Infrastructure Projects

Name

SECTION II - BASIS OF DESIGN							
		%				%	
CATEGORY Element	NA	1	2	3	4	5	Comments
C. DESIGN GUIDANCE							
C.1 Lead/Discipline Scope of Work		2				25	
C.2 Project Codes and Standards		1				[illegible]	20
C.3 Surveys & Mapping		1				20	
C.4 Project Site Assessment		1				20	
C.5 Environmental & Regulatory Consideration		1				10	
C.6 Value analysis		1				5	
C.7 Construction Input		1				15	
D. PROJECT DESIGN PARAMETERS							
D.1 Capacity		1				10	
D.2 Safety & Hazards		1				5	
D.3 Civil/Structural		1				10	
D.4 Mechanical/Equipment		1				5	
D.5 Electrical/Controls		1				2	
D.6 Operations/Maintenance		1				10	
E. LOCATION AND GEOMETRY							
E.1 Schematic Layouts		1				10	
E.2 Alignment ad Cross-Section		1				10	
E.3 Control of Access		1				5	
F. ASSOCIATED STRUCTURES & EQUIPMENT							
F.1 Support Structures		1				10	
F.2 Hydraulic Structures		1				5	
F.3 Miscellaneous Elements		1				5	
F.4 Equipment List		1				10	

Definition Levels

N/A = Not Applicable 1 = Complete Defintion 5 = Incomplete or Poor Definition

PDRI For Small Infrastructure Projects

Name

SECTION III - EXECUTION APPROACH								
			%				%	
CATEGORY Element		NA	1	2	3	4	5	Comments
G. EXECUTION REQUIREMENTS								
G.1	Land Acquisition Strategy		2				20	
G.2	Utility Adjustment Strategy		1				5	
G.3	Procurement Strategy		1				15	
G.4	Owner Approval Requirements		1				5	
G.5	Intercompany and Interagency Coordination & Agreements		1				20	
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS								
H.1	Design/Construction Plan & Approach		1				15	
H.2	Project Cost Estimate and Cost Control		1				15	
H.3	Project Schedule and Schedule Control		1				15	
H.4	Project Quality Assurance & Control		1				10	
H.5	Safety, Work Zone & Transportation Plan		1				5	
H.6	Project Commissioning/Closeout		1				5	

Definition Levels

N/A = Not Applicable   1 = Complete Defintion   5 = Incomplete or Poor Definition

APPENDIX F
PDRI TESTING QUESTIONNAIRES

ARIZONA STATE UNIVERSITY

A BRIEF OVERVIEW OF THE PDRI FOR SMALL INFRASTRUCTURE PROJECTS RESEARCH PROJECT

The members of the CII PDRI for Small Infrastructure Projects Research Team (RT 314a) have been working since August of 2015 to develop a ***Project Definition Rating Index (PDRI)*** tool to be used specifically for evaluating front end planning (FEP) efforts on **small infrastructure projects**. The intent of the PDRI is for a FEP team to rate the scope of a project according to the elements that are defined in the tool. The rating process will quantify the planning effort and yield a score that can be evaluated in various ways to determine the project's probability for success. The small infrastructure projects PDRI is still in the developmental stages, and will be complementary to previously created PDRI tools.

To date, the research team has defined 40 elements as being important areas for consideration in the FEP effort for small infrastructure projects. We realize that not all of the elements defined are equally important. Therefore, we are asking that experienced project managers, estimators and planners help us define which elements could have a greater impact on overall project success by determining ***weighting factors*** that should be assigned to each element. Several workshop sessions will be held throughout 2016 where industry professionals will be asked to evaluate previously completed small infrastructure projects based on the elements that the research team has identified.

To ensure applicability and correct usage of the new tool, the research team has sought to determine an appropriate definition of what constitutes a "small project" in the infrastructure sector. The matrix below details the results of a survey (created by the research team and completed by over 40 infrastructure owners and contractors) that highlights some of the typical attributes of small infrastructure projects. Projects that closely meet these attributes should be used as reference during the workshop.

Total Installed Cost	Less than $20 Million
Engineering Effort	Less than 10,000 man-hours
Construction Duration	6-12 months
Number of Core Team Members	<8 core team members
Availability of Core Team Members	Part time availability of core team members

We appreciate any assistance you can provide in developing the PDRI. This tool should be a valuable resource for improving FEP efforts on small infrastructure projects. We intend to have a completed version ready for industry distribution by Fall 2016. We will provide a copy of the completed tool to you at that time. Thank you very much for your time and effort.

School of Sustainable Engineering and the Built Environment
Del E. Webb School of Construction
PO Box 870204 Tempe, AZ 85287-0204
(480) 965-3589 FAX: (480) 965-1769

A. Background Information					
Name					
Date					
Company					
Company Position					
Department/Division					
Company Address					
City		State		Zip	
Phone					
Email					
Years of Project Management/Estimating Experience					
Please describe some projects that you have recently completed:					
Percentage of Experience Spent on the Following Types of Projects:					
Industrial		Commercial Buildings			
Infrastructure		Other (Please Specify)			
What percentage of your experience has been spent on small projects?					
Annual dollar value of projects worked on or estimated over the last 3 years:					
Percentage of Experience Spent on the Following Types of Projects:					
New Construction					
Renovation/Revamp/Add-on					

B. Assessed Project Background Information					
Name of Project					
City		State/Province		Zip	
Brief Project Description:					
Was the project new construction, renovation/revamp, or both?					
Would the project be considered *People and Freight* (highways, railroads, security fencing), *Energy* (electricity transmission/distribution, fiber optics networks, electrical substations/switch gears), or *Fluids* (pipelines, aqueducts, lock weirs, meters and regulator stations)?					
Please describe the driver for this project (e.g. necessary maintenanace or replacement, innovation, technology upgrade, governmental regulation, other):					

C. Project Schedule Information		
Please provide the following schedule information (if known)		
Item	**Planned (Date - Month/Year)**	**Actual (Date - Month/Year)**
Start Date of Detailed Design		
Completion Date of Detailed Design		
Start Date of Construction		
Completion Date of Construction		
Do you have an comments regarding any causes or effects of schedule changes (e.g., special causes, freak occurances, etc.)?		

D. Project Cost Information		
Please provide the following cost information to the nearest $10k		
Item	**Budgeted Costs at Start of Detailed Design**	**Actual Cost at End of Project**
Total Design Costs*		
Construction Costs		
Owner's Contigency		
Other**		
Total Installed Cost		
Please describe any 'Other' costs listed above that were realized on the project:		
** - Total design costs include all engeineering and architect fees, including feasability studies, planning, programming, etc.*		
*** - Other costs may include major equipment procurement, owner's project management costs, etc.*		

E. Project Change Information	
What were the total number of change orders issued (during both detailed design and construction)?	
What was the total dollar amount (US Dollars) of all positive dollar amount change orders?	
What was the total dollar amount (US Dollars) of all negative dollar amount change orders?	
What was the net project duration change resulting from change orders? (+/- in days)	
Do you have any comments regarding any causes or effects of significant change orders (e.g., special causes, freak occurances, etc.)?	
E. Financial Information	
What level of approval was required for the project? (e.g., local, regional, corporate, board of directors, other)	
On a scale of 1 to 5 (1 being far short of expections, 5 being far exceeding expectations at authorization), how well was the actual financial performance of the project matched expectations?	
F. Customer Satisfaction	
Reflecting on the overall project, rate the success of the project using a scale of 1 to 5, with 1 being very unsuccessful and 5 being very successful	
Do you have any additional comments regarding customer satisfaction?	

Name____

PROJECT SCORE SHEET - UNWEIGHTED

SECTION I - BASIS OF PROJECT DECISION							
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**	**Comments**
A. PROJECT ALIGNMENT							
A.1 Need & Purpose Statement							
A.2 Key Project Participants							
A.3 Public Involvement							
A.4 Project Philosophies							
A.5 Project Funding							
A.6 Preliminary Project Schedule							
B. PROJECT REQUIREMENTS							
B.1 Functional Classification & Use							
B.2 Physical Site							
B.3 Dismantling & Demolition Requirements							

Definition Levels
N/A = Not Applicable 1 = Complete Defintion 5 = Incomplete or Poor Definition

Name____

SECTION II - BASIS OF DESIGN							
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**	**Comments**
C. DESIGN GUIDANCE							
C.1 Lead/Discipline Scope of Work							
C.2 Project Codes and Standards							
C.3 Surveys & Mapping							
C.4 Project Site Assessment							
C.5 Environmental & Regulatory Consideration							
C.6 Value analysis							
C.7 Construction Input							
D. PROJECT DESIGN PARAMETERS							
D.1 Capacity							
D.2 Safety & Hazards							
D.3 Civil/Structural							
D.4 Mechanical/Equipment							
D.5 Electrical/Controls							
D.6 Operations/Maintenance							
E. LOCATION AND GEOMETRY							
E.1 Schematic Layouts							
E.2 Alignment ad Cross-Section							
E.3 Control of Access							
F. ASSOCIATED STRUCTURES & EQUIPMENT							
F.1 Support Structures							
F.2 Hydraulic Structures							
F.3 Miscellaneous Elements							
F.4 Equipment List							

Definition Levels
N/A = Not Applicable 1 = Complete Defintion 5 = Incomplete or Poor Definition

Name____

SECTION III - EXECUTION APPROACH							
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**	**Comments**
G. EXECUTION REQUIREMENTS							
G.1 Land Acquisition Strategy							
G.2 Utility Adjustment Strategy							
G.3 Procurement Strategy							
G.4 Owner Approval Requirements							
G.5 Intercompany and Interagency Coordination & Agreements							
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS							
H.1 Design/Construction Plan & Approach							
H.2 Project Cost Estimate and Cost Control							
H.3 Project Schedule and Schedule Control							
H.4 Project Quality Assurance & Control							
H.5 Safety, Work Zone & Transportation Plan							
H.6 Project Commissioning/Closeout							

Definition Levels

N/A = Not Applicable 1 = Complete Defintion 5 = Incomplete or Poor Definition

Name________________________

PROJECT SCORE SHEET - UNWEIGHTED						
SECTION I - BASIS OF PROJECT DECISION						
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**
A. PROJECT ALIGNMENT						
A.1 Need & Purpose Statement						
A.2 Key Project Participants						
A.3 Public Involvement						
A.4 Project Philosophies						
A.5 Project Funding						
A.6 Preliminary Project Schedule						
B. PROJECT REQUIREMENTS						
B.1 Functional Classification & Use						
B.2 Physical Site						
B.3 Dismantling & Demolition Requirements						

Definition Levels

N/A = Not Applicable
1 = Complete Defintion
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

Name________________________

SECTION II - BASIS OF DESIGN						
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**
C. DESIGN GUIDANCE						
C.1 Lead/Discipline Scope of Work						
C.2 Project Design Criteria						
C.3 Surveys & Mapping						
C.4 Project Site Assessment						
C.5 Environmental & Regulatory Consideration						
C.6 Value analysis						
C.7 Construction Input						
D. PROJECT DESIGN PARAMETERS						
D.1 Capacity						
D.2 Safety & Hazards						
D.3 Civi/Structural						
D.4 Mechanical/Equipment						
D.5 Electrical/Controls						
D.6 Operations/Maintenance						
E. LOCATION AND GEOMETRY						
E.1 Schematic Layouts						
E.2 Alignment and Cross-Section						
E.3 Control of Access						
F. ASSOCIATED STRUCTURES & EQUIPMENT						
F.1 Support Structures						
F.2 Hydraulic Structures						
F.3 Miscellaneous Elements						
F.4 Equipment List						

Definition Levels

N/A = Not Applicable
1 = Complete Defintion
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

Name________________________

SECTION III - EXECUTION APPROACH						
CATEGORY Element	**NA**	**1**	**2**	**3**	**4**	**5**
G. EXECUTION REQUIREMENTS						
G.1 Land Acquisition Strategy						
G.2 Utility Adjustment Strategy						
G.3 Procurement Strategy						
G.4 Owner Approval Requirements						
G.5 Intercompany & Interagency Coordination & Agreements						
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS						
H.1 Design/Construction Plan and Approach						
H.2 Project Cost Estimate and Cost Control						
H.3 Project Schedule and Schedule Control						
H.4 Project Quality Assurance & Control						
H.5 Safety, Work Zone & Transportation Plan						
H.6 Project Commissioning/Closeout						

Definition Levels

N/A = Not Applicable
1 = Complete Defintion
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

APPENDIX G
IN-CLASS WORKSHOP ACTIVITY AND FINAL PROJECT RUBRIC

Project Definition Rating Index (PDRI) Workshop

Project Guide **Workshop Assessment: Thursday, April 6th, 2017**

SECTION III - EXECUTION APPROACH	MATERIAL, METHODS AND EQUIPMENT Consideration
G. EXECUTION REQUIREMENTS	
G2. Utility Adjustment Strategy	
G3. Procurement Strategy	
G4. Owner Approval Requirements	
G5. Intercompany and Interagency Coordination	
H. ENGINEERING/CONSTRUCTION PLAN AND AGREEMENTS	
H1. Design/Construction Plan & Approach	
H2. Project Cost Estimate and Cost Control	
H3. Project Schedule and Schedule Control	
H4. Project Quality Assurance & Control	
H5. Safety, Work Zone & Transportation Plan	
H6. Project Commissioning/Closeout	

Construction Proposal Project: Written Report

Rubric **DUE: Thursday, May 2nd, 2017**

Attribute	Developing (C-level)	Developed (B-level)	Excellent (A-level)
Content			
Did you clearly state the five (5) required scope elements of your proposed concept?	Concept is not presented, nor is it obvious in reading the paper	Concept is not explicitly presented, but is obvious from reading paper	Concept is clearly presented
Did you explain the relevance of the project goals on your proposed concept?	Relevance must be inferred by the reader	Relevance is not explicitly explained, but is somewhat clear from context of report	Relevance is clearly stated and is clear from the context of the report
In addition to your proposed concept, do you clearly state the five (5) required scope elements for the alternative concepts considered but not selected?	Concept is not presented, nor is it obvious in reading the paper; three or more scope elements missing from alternatives	Concept is not explicitly presented, but is obvious from reading paper; at most two scope elements are missing from alternatives	Alternative concepts are fully described in terms of all 5 scope elements and discussed.
Did you explain the **methods** used to construct each of the three concepts you present?	Methods are absent or are only included for the proposed concept	Methods are described well for the proposed concept and mentioned for alternatives	All three concepts include a comprehensive discussion of the construction methods
Did you explain how heat resilience, in particular, impacted your choices?	No discussion of heat resilience appears in the proposal	Resilience is not explicitly explained, but is somewhat clear from context of report	Heat resilience is defined and its impact on the team's choices is explicit
Do you use references when appropriate/necessary?	References are missing where necessary or are not formatted correctly	Two or fewer references are missing or incorrectly formatted	References are formatted correctly and used as necessary
Is appropriate project context for MAG and the building type presented?	There is either no context material presented or it is irrelevant	The context material is *mostly* relevant, though some may be superfluous or lacking	Appropriate context is provided and clearly presented
Can the reader draw the same conclusions as you given your data or arguments?	The reader is unclear about data or conclusions	The reader understands your data and conclusions, but does not see the link	The reader would draw the same conclusions given your data

Do you explain necessary topical background for your team regarding building type? (Do you refer back to the alternative tables in the appendices?)	Building type information is not present nor do you refer to tables	The building type material presented is *mostly* relevant, though some may be superfluous or lacking. Material properties charts may be ignored	Appropriate background is provided about the building type and the alternative considered; material clearly presented
Does the report sell your team?	The report meanders and sounds more like an explanation of different elements of a given building system than a proposal	The report discusses a couple of building systems clearly, but does not explain the link to a proposed concept and why your team should win	The report clearly describes elements of a building system, or discusses multiple proposed concepts clearly as well as why your team is best
Do you effectively sell your concept and team?	The team and concept are presented but not argued for	Some "sell" of concept and team mentioned, but may not be relevant or convincing	Report clearly sells the concept and team as the best choice for the mayor/City of Mesa
Do you draw appropriate conclusions?	A conclusion is either missing or not supported	A conclusion is stated, but is insufficiently supported	The conclusion is clearly stated and well-supported
Organization			
Do you provide an introduction?	No introduction is provided	Introduction is provided and then ignored	The introduction gives the reader a guide to the remainder of the report
Does your report flow clearly?	Reader is confused by flow of presentation	Flow is clear, but not logical	Report flows logically
Does each paragraph support the focus or main topic of each section?	Paragraphs seem disjointed from their own topic sentence and the report section	Paragraphs support their topic sentence, but may not all support the report section	Each paragraph supports the given report section
Writing Mechanics and Grammar			
Did you use proper grammar?	Grammar is poor and distracting for the reader	Few grammatical errors that do not impact general readability	Grammar is excellent, which makes the report easy to read
Is the tense consistent?	The tense varies throughout the report	The tense switches ONCE in the report	The tense is consistent
Is the report readable?	The sentence structure and language make the report difficult to read	At times, the report seems "choppy", but overall, it is readable	The report is easy (even enjoyable!) to read

Formatting			
Is report formatting neat and orderly?	Format is distracting to reader	Format is generally good and does not distract the reader	Format is excellent and enhances readability
Does report follow specified format?	Report does not include required sections	Report includes most, but not all, of the required sections	Report includes all required sections
Figures			
Are figures/charts used effectively?	Figures are either not present or not referenced in the text nor given captions	Figures are captioned, but not explained or referred to in the text	Figures *illustrate* a concept explained in the writing

Content	**Organization**	**Format**	**Mechanics**	**Figures**	**TOTAL**
30	**30**	**10**	**20**	**10**	**100**

APPENDIX H

INFRASTUCTURE PDRI SELECTION GUIDE

To determine which PDRI to use for your infrastructure project, i.e., PDRI – Infrastructure Projects or PDRI – Small Infrastructure Projects, review the table shown below and compare your individual answers to those of typical projects that are assessed with each of the tools. By comparing your answers, you should be able to discern which tool will be best suited to assess your project. For example, if your project fits most of the characteristics in the "Small Projects" column, then most likely the PDRI – Small Infrastructure Projects will be appropriate for use. If your project aligns better with the characteristics in the "Large Projects" column, then the PDRI – Infrastructure Projects would be most appropriate.

The table below provides suggestions about how to determine the appropriate PDRI tool for use on an infrastructure project, but should not be used as a strict guideline. Note the complexity factors appear according to order of importance reported by survey respondents; that is, total installed cost is the most important factor for differentiating small projects from large, while the number of Right of Way (ROW) parcels required is the least important differentiator. While the table below provides guidance as to factors to consider, the values that serve as delineators between small and large projects will vary from one organization to another. For instance, in some organizations, projects with total installed costs of $20 million may be considered very small, while in other organizations, projects of this caliber would be considered very large. In choosing a suitable tool for a specific project, users are urged to consider such factors and let common sense prevail. If project team members feel that a certain project should be considered small based on their experiences in their organization, it probably is. The same can be said about large projects.

Users of PDRI – Small Infrastructure should keep in mind that RT 314a developed the tool only for assessing small projects. The tool is not intended as a short cut to use in lieu of assessing a project with PDRI – Infrastructure Projects. Some organizations may wish to base the selection criteria on the characteristics of their typical projects; however, RT 314a's research validated the PDRI – Small Infrastructure Projects for projects meeting the criteria presented in the table below.

Table H.1: PDRI Infrastructure Selection Guide

Complexity Factor	Small Projects	Large Projects
Total Installed Cost*	<$20 Million	>$20.1 Million
Engineering Effort*	< 5000 Hours	> 5000 Hours
Construction Duration**	6-12 Months	>18 Months
Number of Core Team Members**	<10 individuals	>10 individuals
Availability of Core Team Members**	Part-time availability	Combination of part-time and full-time to completely full-time
Project Visibility External to Organization (Public)	Moderate	Significant
Extent of Permitting	None to moderate permitting	Significant permitting
Number Jurisdictions Involved	1-3 jurisdiction	> 5 jurisdictions
Existing Utility Provider Interface & Coordination	Minimal to Moderate	Significant
Sources of Funding	Singular	Multiple
Types of Permits	None to local/state permits	Local/state to national permits
Number of Trade Contractors	3-4 separate trade contractors	7-8 separate trade contractors
Extent of Public Outreach Effort	Minimal to Moderate	Significant
Management of Public Outreach Effort	Project Team	Corporate Executives
Right Of Way (ROW) procurement effort	Minimal to Moderate	Significant
Right Of Way (ROW) parcels required	1-2 parcels	>5 parcels

* More than 50% of respondents reported this factor as a differentiator between small and large projects

** More than 48% of respondents reported this factor as a differentiator between small and large projects