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# Applying The PDRI in Project Risk Management

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# APPLYING THE PDRI IN PROJECT RISK MANAGEMENT

**by**

**YU-REN WANG, B.S., M.S.**

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# Dedication

To my family,

especially my parents,

for their support and love.

To my friends,

for their companion and friendship,

with love and appreciation.

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# APPLYING THE PDRI IN PROJECT RISK MANAGEMENT

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Research conducted by the Construction Industry Institute (CII) shows that adequate pre-project planning benefits project in the areas of cost, schedule, and operational characteristics. Pre-project planning is the project phase encompassing all the tasks between project initiation to detailed design. The development of a project scope definition packages is one of the major tasks in the pre-project planning process. Project scope definition is the process by which projects are defined and prepared for execution. It is at this crucial stage where risks associated with the project are analyzed and the specific project execution approach is defined. Development of the Project Definition Rating Index (PDRI) in 1996 provided an effective and easy-to-use tool for project scope development for industrial projects. A complementary PDRI was developed for building projects in 1999. Since introduction, the PDRI (both versions) have been widely used by the construction industry and serve as an important tool for measuring project scope definition. The PDRI helps a project team to quickly analyze the scope definition package and predict factors that may impact project risk. However, since its introduction, little additional analyses have been conducted looking at the PDRI.

Data from 140 capital projects representing approximately $5 billion in total construction cost were used for this research analysis. The relationship between good scope definition and enhanced project performance were demonstrated. Analysis of PDRI scores identified poor definition scope elements and quantified their potential impact to project outcomes. Risk control procedures were examined and recommended to mediate high risk areas, such as poorly defined scope elements. A systematic risk management approach was proposed and explained in detail. Research limitations, conclusions and recommendations are also discussed in this dissertation. This research effort extends the use of PDRI as a project management tool in the process of capital facility projects delivery.

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# Chapter 1 Introduction

Pre-project planning is "….the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project" (CII 1995). One of the key tasks of pre-project planning is to develop a detailed scope definition for the project. Research has shown that a complete scope definition improves project performance in the areas of cost, schedule, quality, and operational characteristics. Extraordinary risks are many times the result of unresolved scope issues or unforeseen conditions (Smith and Bohn 1999). At a point of time right before detailed design, poorly defined scope definition elements are identified during the PDRI evaluation process within the owner's organization. These poorly defined scope definition elements should be treated as potential risk factors that might cause negative impact to project outcomes.

A need exists to integrate previous research results on pre-project planning and project risk management. This dissertation investigates the potential risk impact caused by poorly defined scope elements and proposes a risk management process using the Project Definition Rating Index (PDRI) in the early stage of the project life cycle.

The Project Definition Rating Index is a project scope definition tool developed under the guidance of Construction Industry Institute (CII). It is a powerful and easy-to-use tool that offers a method to measure project scope definition for completeness. Research has shown that PDRI allows a project team to evaluate the completeness of scope definition prior to detailed design or construction and helps a project team to quickly analyze the scope definition package and predict factors that may impact project risk (Gibson and Dumont 1996). According to a national survey of top 100 U.S. large contractors, Kangari (1995) identified 'defective design' as one of the most important risks ranked by the survey participants. Poor scope definition often results in delayed design and in some cases contributes to poor design. By identifying potential risk factors early in a project, the project team can quickly respond to the risks and thus reduce the possible negative impact on design and construction.

The construction industry, perhaps more than most, is plagued by high amounts of risk (Flanagan and Norman 1993), but often this risk is not dealt with adequately, resulting in poor performance with increased costs and time delays (Thompson and Perry 1992). Several methods have been developed to model construction risk (Ibbs and Crandall 1982, Ashley et al. 1988, CII 1989, Boyer and Kangari 1989, Touran 1992, Paek et al. 1993). While most of these methods were developed to help contractors estimate or evaluate their risk exposure, there has been little effort to estimate or evaluate risk from the owner's/client's perspectives. Mak and Picken (2000) looked into risk to the client/owner and used risk analysis to determine construction project contingency. Their study results showed improvement in the estimate of contingency after implementing the risk analysis technique in estimation. Nevertheless, available literature provides little information as to how the owner/investor should identify project risk factors and quantify potential risk impacts during the early stage of a project.

This chapter will present a brief overview of the context under which the research was conducted. Background information related to PDRI and how it relates to the investigation are presented. Previous research is discussed as well as the research objectives. Finally, the dissertation organization is outlined in this chapter.

## 1.1. BACKGROUND

It has long been recognized by the industry practitioners the importance of pre-project planning in the capital facility delivery process and its potential impact on project success. Nevertheless, the pre-project planning process varies significantly throughout industry from one organization to another. Because of this inconsistency, the Construction Industry Institute (CII) and others chartered several studies in the 1990's to look at this area.

### 1.1.1. Pre-Project Planning Research

The research presented in this dissertation is the latest in a related series of studies that have been performed at the University of Texas since 1991. The following sections give a brief overview of those studies. A more in-depth treatment is given in the next chapter.

**Pre-Project Planning Research**

In 1991, CII chartered a research project "to find the most effective methods of project definition and cost estimating for appropriation approval". The research team was composed of two faculty members and 16 industry practitioners (nine from owner organization and seven from contractor). This team helped map the pre-project planning process by using IDEF0, Structured

Analysis and Design Techniques (Gibson et al. 1995). Pre-project planning was defined as "the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project" (CII 1994). The research team summarized the pre-project planning process into four major steps: organize for pre-project planning, select project alternative(s), develop a project definition package (which is the detailed scope definition of the project), and decide whether to proceed with the project (Gibson et al. 1995). The research results also indicated that the pre-project planning effort level directly affects the cost and schedule predictability of the project (Hamilton 1994).

**Front End Planning Research**

CII constituted another research team in 1994 to produce effective, simple, and easy-to-use pre-project planning tools that extend previous research efforts so that owner and contractor companies can better achieve business, operational, and project objectives (CII 1996). The goal of this study was to develop effective and easy-to-use pre-project planning management tools. In order to reach this goal, the objectives were set up to 1) quantify pre-project planning efforts, and 2) analyze the impact of alignment. This effort produced the Project Definition Rating Index (PDRI) for Industrial Projects as a scope definition tool.

The PDRI is a weighted matrix with 70 scope definition elements (issues that need to be addressed in pre-project planning) grouped into 15 categories and further grouped into three main sections. The PDRI allows a project team to measure the completeness of a project's scope definition and a project can score up to 1000 points, with a lower score being better (Gibson and Dumont 1996). The tool is applicable to process and manufacturing facilities such as chemical plants, paper mills, manufacturing assembly plants, petroleum refineries and so on. In addition to the development of the industrial PDRI, this research investigation also analyzed the impact of alignment between business, project management, and operations personnel of owner companies, as well as the alignment between owners and contractors during pre-project planning. The research results showed that achieving and maintaining alignment is a key factor in project planning and in achieving project success (Griffith and Gibson 2001).

**OFPC Project**

In response to the University of Texas (UT) System Board of Regent's recommendation to revise the process of capital improvement projects, the UT Office of Facility Planning and Construction (OFPC) commissioned this study to address early project planning on University of Texas System capital projects. The objective of this effort was to 1) describe the performance of OFPC capital projects completed from 1990 to 1995 and use the results as a baseline for improvement, 2) describe the extent of pre-project planning performed on these projects, and 3) provide recommendations for improving early planning of U.T. System capital projects (Gibson et al. 1997). The study specifically investigated the relationship between the pre-project planning effort expended and project performance metrics. Some of the key conclusions from the research were that project cost estimates and schedules submitted for approval were often unrealistic and poorly defined, and that many design and construction changes were user requested because of lack of early requirements determination between planners and project sponsors.

**PDRI for Building Research**

The first PDRI was developed specifically for industrial sector projects to measure the completeness of project definition and has been widely used as a planning tool and highly recognized by the industry. In response to requests from the building industry for a similar tool, CII commissioned a study in 1997 to develop a user-friendly and generic tool for measuring project scope definition for commercial and institutional buildings and then to validate the tool through testing on sample projects (Cho et al. 1999). A data sample of 33 projects from 10 owner organizations was collected and the relationship between PDRI scores and project performance was analyzed using regression analysis, ANOVA, and qualitative assessments. Analysis results revealed a significant difference between projects with lower PDRI score (better pre-project planning efforts) and projects with higher PDRI scores in terms of cost, schedule and change order performance. Overall, the PDRI-Buildings effectively assists project teams in determining the completeness of scope definition for building-type projects such as schools, apartments, office buildings, hospitals, and so on (Gibson 1999).

**Institutional Organization Project**

One institutional organization (which prefers to remain anonymous) approached researchers at UT in 2000 and expressed interest in modifying and deploying the PDRI for their large capital program. The objective of this research effort was to slightly modify the PDRI to reflect the needs of this organization and to develop an extensible benchmarking database and path forward for implementation. The project studied a total of 45 projects representing $261 million in total installed cost.

A workshop was held to modify the PDRI-Buildings toward the organization's specific needs. A detailed project questionnaire and a user survey were developed and sent to respective project managers and end users. From the survey data collected from the 45 projects, it was proven for this sample that projects with better-defined scope definition have better performance in terms of cost, schedule, and change orders. Poor alignment (lack of user involvement) was also commonly seen as a problem on the sample projects. The study is part of the research effort embodied in this dissertation and will be discussed in more depth later.

### 1.1.2. Construction Project Risk

Just as any other industry, construction has a sizable risk built into its profit structure. Nevertheless, rarely do construction practitioners quantify uncertainty and systematically assess the risk involved in a project (Al-Bahar and Crandall 1990). Furthermore, even if risk is addressed, it is even less frequently used to evaluate the consequences (potential impact) associated with these risks. The risk management process contains risk identification, risk quantification and risk control. Several analytical models have been developed to offer a systematic approach for identifying and quantifying construction risks (Ibbs and Crandall 1981, Ashley, Stokes, and Perng 1988, Paek and Young 1992, Kangari 1995, Smith and Bohn 1999, Mak and Picken 2000). The purpose of risk modeling is to help construction practitioners identify project risks and systematically to analyze and manage them. Through risk modeling, this dissertation research tries to extend the usage of PDRI as a project risk management tool at the pre-project planning.

## 1.2. RESEARCH OBJECTIVES

Both the PDRI for Industrial and Building Projects have been widely accepted within the construction industry as valid tools to help with project scope definition. The purpose of this research is to extend the usage of the PDRI within the project management field. The four primary objectives of this research are:

1. To further validate the PDRI through testing by measuring the level of project scope definition and comparing to the degree of actual project success using a more robust sample
2. To identify the specific impact of PDRI elements using statistical analysis methods
3. To develop a systematic project risk management approach based on the PDRI
4. To establish a baseline methodology and database for follow up research

The first objective is a continuous effort from previous pre-project planning research projects using the PDRI. Risk factors that might have negative impacts on project outcomes are identified through the PDRI evaluation process. The data collected from actual industrial/building projects and statistical analysis methods are used to evaluate the effect that these risk factors have on project cost and schedule performances. It is the primary objective of this research to develop a systematic project risk management approach based on PDRI. A systematic approach will be suggested to help the project team manage project risks early in the project life cycle. The proposed systematic risk management approach would establish a baseline methodology and database for future PDRI and project risk management research.

### 1.3. ORGANIZATION OF THE DISSERTATION

This dissertation is organized into nine chapters and a set of appendices containing supporting information and results of data collection and analysis. Following this introductory chapter, Chapter Two provides a literature review of research work related to pre-project planning, scope definition, Project Definition Rating Index (PDRI), PDRI benchmarking, risk identification, risk quantification and risk control. Chapter Three presents the research problem statement and research hypotheses. Research methodology is presented in Chapter Four, including development of survey questionnaire, data collection methods employed, statistical analysis procedures used, and implementation of risk management techniques. Chapter Five provides descriptive characteristics of sample projects as well as results of statistical analysis. In-depth analysis for the 45 institutional projects is presented in Chapter Six due to the uniqueness of these sample projects. Chapter Seven discusses the identification of cost and schedule risk indicators using PDRI characteristics. In Chapter Eight, statistical analysis models for risk quantification are developed and the analysis results from the model are applied for risk control. A systematic risk management approach using PDRI is proposed and limitations of the approach are discussed as well. Chapter Nine discusses the research summary, achievement of research objectives, recommendations for future research and research conclusions.

# Chapter 2 Literature Review

An extensive literature review provides background information on current knowledge related to the research topic. Prior to investigating the application of PDRI in project risk management, previous research and topics related to the PDRI and risk management were studied in detail. This literature review is used in support development of the problem statement, research hypotheses, and the methodologies used to test those hypotheses.

## 2.1. PRE-PROJECT PLANNING AND SCOPE DEFINITION

The early planning phase of capital facility projects is the main focus of the research covered in this dissertation. Significant project decisions are made by the project team during this early stage. How well pre-project planning is performed will affect cost and schedule performance, operating characteristics of the facility, as well as the overall financial success of the project (Gibson and Hamilton 1994). The process of pre-project planning constitutes a comprehensive framework for detailed project planning and includes scope definition. Project scope definition, the process by which projects are selected, defined and prepared for definition, is one key practice necessary for achieving excellent project performance (Merrow and Yarossi 1994).

### 2.1.1. Pre-Project Planning

Pre-project planning is a major phase of the project life cycle. This phase begins after a decision is made by a business unit to proceed with a project concept and continues until the detailed design is begun. In general, industry practitioners perceive that early planning efforts in the project life cycle have a greater influence on project success than planning efforts undertaken later in the project delivery process. Figure 2.1 identifies the conceptual relationship between influence and expenditure in a project life cycle. The curve labeled "influence" in Figure 2.1 reflects a company's ability to affect the outcome of a project during various stages of a project. The diagram illustrates that it is much easier to influence a project's outcome during the project planning stage when expenditures are relatively minimal than it is to affect the outcome during project execution or operation of the facility when expenditures are more significant (CII 1995).

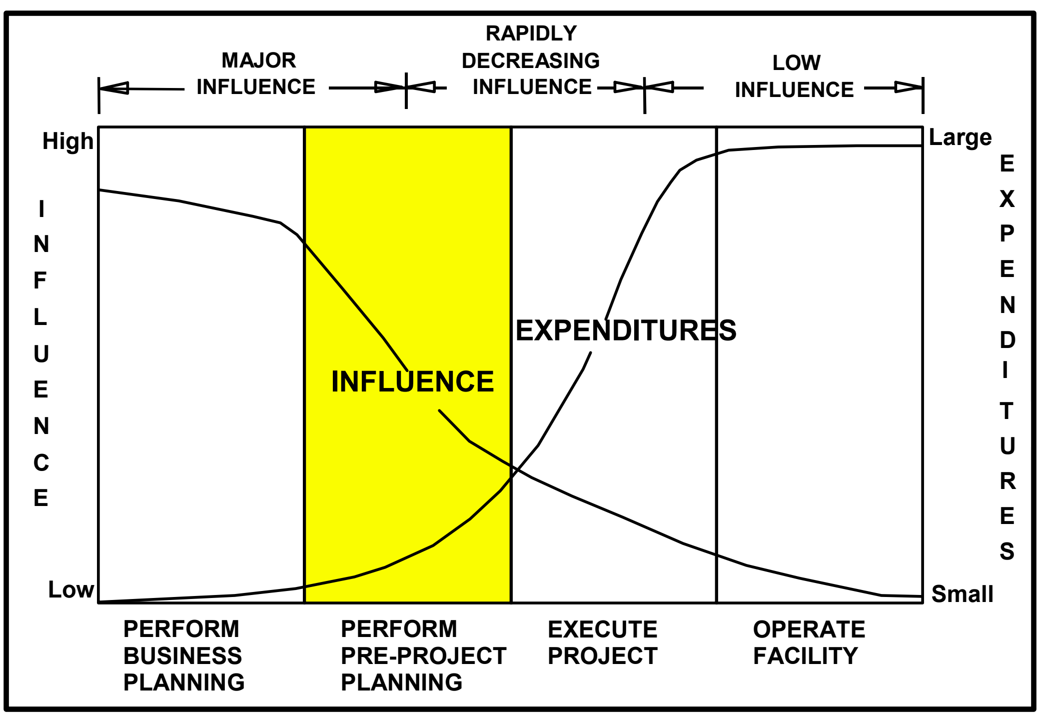


Figure 2.1. Influence and Expenditure Curve for the Project Life Cycle

As previously mentioned, to further investigate early planning efforts for capital facility projects, CII chartered a research project to determine the most effective methods of project definition and cost estimating for appropriation approval in 1991. The research team helped map the pre-project planning process by using IDEF0, Structured Analysis and Design Techniques (Gibson et al. 1995). Their development work also included a review of 62 capital projects that were randomly selected from a nominated pool of projects from 24 owner organizations. A detailed questionnaire was used to determine current practice of pre-project planning and the performance outcomes on these projects. In addition, 131 structured interviews and three case studies were conducted (Hamilton and Gibson 1996; Griffith et al. 1999).

The CII research team defined pre-project planning as "the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project" (CII 1994). Other aliases for pre-project planning include front-end loading, front-end planning, feasibility analysis, programming/schematic design, and conceptual planning. The research team looked further into the pre-project planning process and developed a process map as shown in Figure 2.2. The pre-project planning process can be summarized into four major steps: organization for pre-project planning, selection of project alternative(s), development of a project definition package (which is the detailed scope definition of the project), and decision on whether to proceed with the project (Gibson et al. 1995).

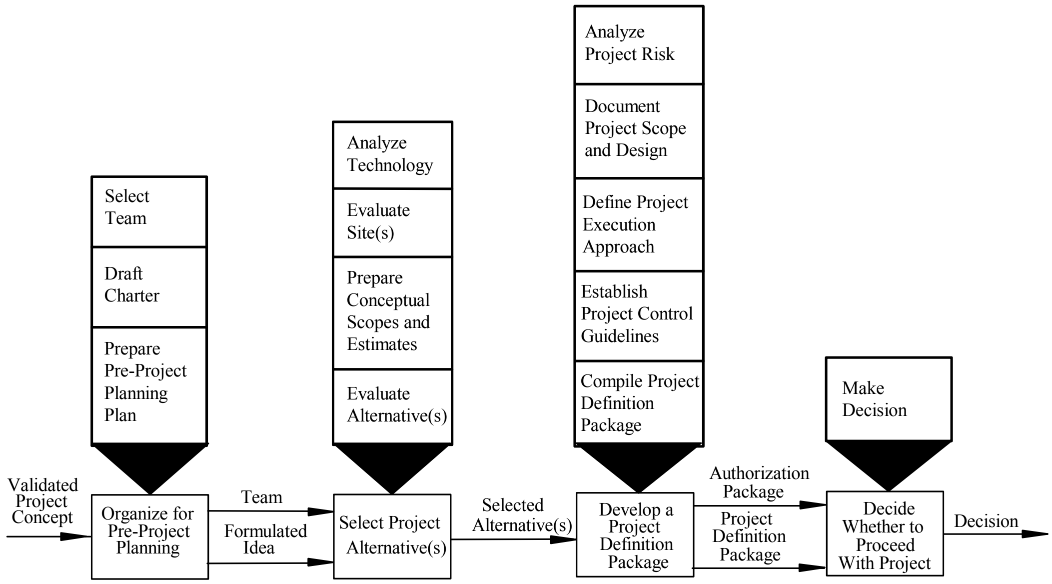


Figure 2.2. Pre-Project Planning Process Flow Map

This investigation showed the relationship between pre-project planning and project success through survey research and data analysis. The data sample represented $3.4 billion (USD) in total project costs, and the projects included chemical, petro-chemical, power, consumer produces, petroleum refinery and other manufacturing facilities. A regression analysis showed that a higher pre-project planning index (i.e., more effort in pre-project planning) translates into a more successful (predictable) project in terms of cost, schedule, attainment of nameplate capacity, and plant utilization (Hamilton and Gibson 1996). Further analysis showed that facilities with a high level of pre-project planning experienced fewer scope-based change order costs on average than projects with low pre-project planning efforts. A scope definition package which encompasses the results of the pre-project planning efforts is developed for each project. Scope definition will be discussed in the next section.

### 2.1.2. Scope Definition

As defined by the Project Management Institute (PMI), project scope definition occurs early in the project life cycle when the major project deliverables are decomposed into smaller, more manageable components in order to provide better project control (PMI 1996). Project scope definition is the process where projects are defined and prepared for execution and is a key component of pre-project planning. During this process, information such as general project requirements, necessary equipment and materials, environmental concerns, and construction methods or procedures are identified and compiled in the form of a project definition package. This document consists of a detailed formulation of continuous and systematic strategies to be used during the execution phase of the project to accomplish the project objectives. It also includes sufficient supplemental information to permit effective and efficient detailed engineering to proceed (Gibson et al. 1993).

Inadequate or poor scope definition, which negatively correlates to the project performance, is recognized as one of the most serious problems on a construction project (Smith and Tucker 1983). As stated in the Business Roundtable's Construction Industry Cost Effectiveness (CICE) Project Report A-6 (Business Roundtable 1982), two of the most frequent contributing factors to cost overrun are: poor scope definition at the estimate (budget) stage and loss of control of project scope. Therefore, the result of a poor scope definition is that final project costs can be expected to be higher because of the inevitable changes which interrupt project rhythm, cause rework, increase project time, and lower the productivity as well as the morale of the work force (O'Connor and Vikroy 1986). As a result, success during the detailed design, construction, and start-up phases of a project highly depends on the level of effort expended during the scope definition phase as well as the integrity of project definition package (Gibson and Dumont 1996).

For architectural practice, the total project delivery system is comprised of programming, schematic design, design development, construction documents, bidding, and construction (Peña et al. 1987). The architectural programming process provides the client and designer with a clear definition of the scope of a project and the criteria for a successful solution (Cherry 1999) and it is similar to the scope definition phase for industrial projects mentioned earlier in this section. Peña (1987) pointed out that good programming is the prelude to a good design. The ability to influence the project outcome rapidly diminishes as the schematic design and design development phases end, whereas the expenditures start to dramatically increase as the development of construction documents is completed and construction begins. Therefore, preparing well-developed design documents based on complete scope definition is indispensable to project success (Cho 2000).

Several studies focusing on the project performance and success identified the major factors that cause project failure. These studies suggest that poor scope definition is one of the primary causes of unsuccessful projects (Merrow et al. 1981, Myers and Shangraw 1986, Merrow 1988, and Broaddus 1995). According to these studies, cost growth and inaccurate estimates, as well as schedule slippage on most of the process plant projects are due to inadequate scope definition. These studies further conclude that the more time and effort invested in scope definition prior to authorization (within reason), the more accurate the construction estimation and scheduling.

## 2.2. PROJECT DEFINITION RATING INDEX (PDRI)

### Development of PDRI

In a study of capital costs estimating and controls, Hackney (1992) categorized items that are most important in a project definition package and proposed a detailed checklist for project planning. He assigned maximum weights to each of the items in his checklist. Each weight represented the relative ability of an item to affect the degree of uncertainty in the project estimate. This definition checklist was intended to be used as a means for improving areas of uncertainty and predicting project performance. Hackney's Definition Rating Checklist was found to be the most comprehensive and detailed attempt for quantifying project scope definition and was used extensively for the development of the PDRI for industrial projects.

Due to the needs for development of a tool to determine the adequacy of scope definition and to assess pre-project planning efforts, CII constituted a research team in 1994 to produce effective and easy-to-use pre-project planning tools that extended previous research efforts so that owner and contractor companies would be able to better achieve business, operational, and project objectives (CII 1996). This team was made up of 15 industry practitioners (eight owner companies and seven contractors) and the academic research team. Their goal was to develop effective and easy-to-use pre-project planning management tools. In order to reach this goal, two objectives were set up. First, pre-project planning efforts were to be quantified. Second, the impact of alignment was to be analyzed.

The development of the Project Definition Rating Index (PDRI) was a logical extension of the pre-project planning research efforts outlined in the previous section. Developed by the Front-End Research Team in CII, the PDRI serves as a scope definition tool for industrial projects. The PDRI is a weighted matrix with 70 scope definition elements (issues that need to be addressed in pre-project planning) grouped into 15 categories and further grouped into three main sections. A complete list of the PDRI's element breakdown is shown in Figure 2.3. Each of the elements has a corresponding detailed description. Figure 2.4 gives an example of element description for element A1 of the industrial PDRI. A more detailed review of the scope definition element descriptions can be found in *Project Definition Rating Index (PDRI)*, CII Research Report 113-11 (Gibson and Dumont 1996).

**SECTION I. BASIS OF PROJECT DECISION**

- **A. Manufacturing Objective Criteria**
  - A1. Reliability Philosophy
  - A2. Maintenance Philosophy
  - A3. Operating Philosophy
- **B. Owner Philosophies**
  - B1. Products
  - B2. Market Strategy
  - B3. Project Strategy
  - B4. Affordability/Feasibility
  - B5. Capacities
  - B6. Future Expansion Considerations
  - B7. Expected Project Life Cycle
- **C. Project Requirements**
  - C1. Technology
  - C2. Processes
- **D. Site Information**
  - D1. Project Objective Statement
  - D2. Project Design Criteria
  - D3. Site Characteristics Available vs. Req'd
  - D4. Dismantling and Demolition Req'mts
  - D5. Lead/Discipline Scope of Work
  - D6. Project Schedule
- **E. Building Programming**
  - E1. Process Simplification
  - E2. Design & Material Alts. Considered/Rej.
  - E3. Design for Constructability Analysis

**SECTION II. BASIS OF DESIGN**

- **F. Site Information**
  - F1. Site Location
  - F2. Surveys & Soil Tests
  - F3. Environmental Assessment
  - F4. Permit Requirements
  - F5. Utility Sources with Supply Conditions
  - F6. Fire Protection & Safety Considerations
- **G. Equipment**
  - G1. Process Flow Sheets
  - G2. Heat & Material Balances
  - G3. Piping & Instrumentation Diagrams
  - G4. Process Safety Management
  - G5. Utility Flow Diagrams
  - G6. Specifications
  - G7. Piping System Requirement List
  - G8. Plot Plan
  - G9. Mechanical Equipment List
  - G10. Line List
  - G11. Tie-in List
  - G12. Piping Specialty Item List
  - G13. Instrument Index
- **H. Equipment Scope**
  - H1. Equipment Status
  - H2. Equipment Location Drawings
  - H3. Equipment Utility Requirements
- **I. Civil, Structural, & Architectural**
  - I1. Civil/Structural Requirements
  - I2. Architectural Requirements
- **J. Infrastructure**
  - J1. Water Treatment Requirements
  - J2. Loading/Unloading/Storage Facility Req't
  - J3. Transportation Requirements
- **K. Instrument & Electrical**
  - K1. Control Philosophy
  - K2. Logic Diagrams
  - K3. Electrical Area Clasifications
  - K4. Substation Req'mts Power Sources Iden.
  - K5. Electric Single Line Diagrams
  - K6. Instrument & Electrical Specifications

**SECTION III. EXECUTION APPROACH**

- **L. Project Execution Plan**
  - L1. Identify Long lead/Critical Equip. & Mtls
  - L2. Procurement Procedures and Plans
  - L3. Procurement Responsibility Matrix
- **M. Deliverables**
  - M1. CADD/Model Requirements
  - M2. Deliverables Defined
  - M3. Distribution Matrix
- **N. Project Control**
  - N1. Project Control Requirements
  - N2. Project Accounting Requirements
  - N3. Risk Analysis
- **P. Project Execution Plan**
  - P1. Owner Approval Requirements
  - P2. Engineering/Construction Plan
  - P3. Shut Down/Turn Around Requirements
  - P4. Pre-Commiss. Turnover Sequence Re'q
  - P5. Startup Requirements
  - P6. Training Requirements

Figure 2.3. Sections, Categories and Elements of PDRI for Industrial Projects

**A1. Reliability Philosophy**

A list of the general design principles to be considered to achieve dependable operating performance from the unit. Evaluation criteria should include:

- ❑ Justification for spare equipment
- ❑ Control, alarm, and safety system redundancy
- ❑ 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, etc.)

Figure 2.4. Example Description for Element A1: Reliability Philosophy

The development effort for this tool included input from over 70 individuals, and encompassed three workshops and the use of scope definition documents from 14 companies in addition to Hackney's materials (Gibson and Dumont 1996). Differing weights were assigned to all elements for that it is recognized that not all PDRI scope elements are equally important in terms of their potential impact on a project's overall success. The weights were determined using input from 54 experienced project managers and estimators.

The PDRI allows a project team to measure the completeness of a project's scope definition. A score is assigned to each project and the maximum score is 1000 points, with a lower score indicating a more well-defined scope (Gibson and Dumont 1996). The tool can be used in process and manufacturing facilities such as chemical plants, paper mills, manufacturing assembly plants, and petroleum refineries.

The PDRI was validated as an effective scope definition tool using a sample of 40 industrial projects representing approximately $3.3 billion (USD) in authorized cost (Dumont et al., 1997). Project performance and PDRI data were collected from the sample projects and a statistical analysis showed that PDRI score and project success were linearly related. That is, a low PDRI score, representing a better-defined project scope definition package, corresponds to an increased probability for project success. Project success was judged from cost performance, schedule performance, percentage design capacity obtained at six months, and plant utilization attained at six months.

In addition to the development of PDRI, this research investigation also analyzed the impact of alignment between business, project management, and operations personnel of owner companies, as well as the alignment between owners and contractors during pre-project planning. Alignment is defined 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). This effort included three workshops, a review of sample projects, and structured interviews. Over 100 industry participants (representing 19 contractor and owner companies) were interviewed and 20 capital projects evaluated in depth. Ten critical alignment issues were identified to have major impact on project alignment and potential project success. These ten critical alignment issues were further grouped into four groups: execution processes, culture, information and tools. Both project success and alignment information was collected for 20 industrial capital projects.

A linear regression analysis demonstrated that alignment effort is positively related to project success for this sample of 20 projects. The research results showed that achieving and maintaining alignment is a key factor in project planning and in achieving project success (Griffith and Gibson, 2001).

With the success of the PDRI for industrial projects, many building industry planners wanted a similar tool to address scope development of buildings. Therefore, CII formed a team and funded a research effort to facilitate this development effort in 1998. This team was made up of 14 industry practitioners (11 owner companies and three contractors) and the academic research team. The research effort included input from approximately 30 industry experts as well as extensive use of published sources for terminology and key scope element refinement. As developed, the PDRI for Building Projects consists of 64 elements, which are grouped into 11 categories and further grouped into three main sections. A complete list of the three sections, 11 categories, and 64 elements is given in Figure 2.5. Figure 2.6 gives an example of element description of element A1 of the Building PDRI. The 64 elements are arranged in a score sheet format and supported by 38 pages of detailed descriptions and checklists (CII 1999).

**SECTION I. BASIS OF PROJECT DECISION**

**A. Business Strategy**
- A1. Building Use
- A2. Business Justification
- A3. Business Plan
- A4. Economic Analysis
- A5. Facility Requirements
- A6. Future Expansion/Alteration Considerations
- A7. Site Selection Considerations
- A8. Project Objectives Statement

**B. Owner Philosophies**
- B1. Reliability Philosophy
- B2. Maintenance Philosophy
- B3. Operating Philosophy
- B4. Design Philosophy

**C. Project Requirements**
- C1. Value-Analysis Process
- C2. Project Design Criteria
- C3. Evaluation of Existing Facilities
- C4. Scope of Work Overview
- C5. Project Schedule
- C6. Project Cost Estimate

**SECTION II. BASIS OF DESIGN**

**D. Site Information**
- D1. Site Layout
- D2. Site Surveys
- D3. Civil/Geotechnical Information
- D4. Governing Regulatory Requirements
- D5. Environmental Assessment
- D6. Utility Sources with Supply Conditions
- D7. Site Life Safety Considerations
- D8. Special Water and Waste Treatment Requirements

**E. Building Programming**
- E1. Program Statement
- E2. Building Summary Space List
- E3. Overall Adjacency Diagrams
- E4. Stacking Diagrams
- E5. Growth and Phased Development
- E6. Circulation and Open Space Requirements
- E7. Functional Relationship Diagrams/ Room by Room
- E8. Loading/Unloading/Storage Facilities Requirements
- E9. Transportation Requirements
- E10. Building Finishes
- E11. Room Data Sheets
- E12. Furnishings, Equipment, & Built-Ins
- E13. Window Treatment

**F. Building/Project Design Parameters**
- F1. Civil/Site Design
- F2. Architectural Design
- F3. Structural Design
- F4. Mechanical Design
- F5. Electrical Design
- F6. Building Life Safety Requirements
- F7. Constructability Analysis
- F8. Technological Sophistication

**G. Equipment**
- G1. Equipment List
- G2. Equipment Location Drawings
- G3. Equipment Utility Requirements

**SECTION III. EXECUTION APPROACH**

**H. Procurement Strategy**
- H1. Identify Long Lead/Critical Equipment and Materials
- H2. Procurement Procedures and Plans

**J. Deliverables**
- J1. CADD/Model Requirements
- J2. Documentation/Deliverables

**K. Project Control**
- K1. Project Quality Assurance and Control
- K2. Project Cost Control
- K3. Project Schedule Control
- K4. Risk Management
- K5. Safety Procedures

**L. Project Execution Plan**
- L1. Project Organization
- L2. Owner Approval Requirements
- L3. Project Delivery Method
- L4. Design/Construction Plan & Approach
- L5. Substantial Completion Requirements

Figure 2.5. Sections, Categories and Elements of PDRI for Building Projects

**A1. Building Use**

Identify and list building uses or functions. These may include uses such as:

| | | |
|---|---|---|
| ❑ Retail | ❑ Research | ❑ Storage |
| ❑ Institutional | ❑ Multimedia | ❑ Food service |
| ❑ Instructional | ❑ Office | ❑ Recreational |
| ❑ Medical | ❑ Light manufacturing | ❑ Other |

A description of other options which could also meet the facility need should be defined. (As an example, did we consider renovating existing space rather than building new space?) A listing of current facilities that will be vacated due to the new project should be produced.

Figure 2.6. Example Description for Element A1: Building Use

It was hypothesized that all elements are not equally important with respect to their potential impact on overall project success and each element needed to be weighted relative to the others. Higher weights were to be assigned to those elements whose lack of definition could have the most serious negative effect on the project performance. To develop the weights, seven "weighting" workshops were held and 69 workshop participants consisted of 30 engineers, 31 architects, and eight other professionals directly involved in planning building projects participated in the workshops. The element weights of the PDRI for building projects were established using the input provided by 35 owner and contractor organizations from the building sector (CII 1999).

During the development of the Building PDRI, a logic flow diagram was developed by the researchers to assist with the application of the PDRI. The

PDRI for buildings is intended as a “point in time” tool with elements grouped by subject matter, not in time-sequenced logic. Therefore, the logic flow diagram was set up to identify the embedded logic that the scope elements might have and to tie to the quantitative score of the PDRI for buildings (Furman 1999; Cho, Furman, and Gibson 1999). As part of the early research effort for this dissertation, a logic flow diagram was developed for the Industrial PDRI to demonstrate the embedded logic between the scope elements. A prototype was first sent out to 73 industry practitioners for feedback. With inputs from several industry practitioners, a logic flow diagram was finalized for the Industrial PDRI and is given in Appendix A.

The PDRI for building projects was validated through a total of 33 projects varying in authorized cost from $0.7 million to $200 million (representing approximately $896 million in construction cost). PDRI scores were calculated for each of these projects and compared to project success criteria, such as cost and schedule performance. The results showed that validation projects scoring below 200 outperformed those scoring above in three important areas: cost performance, schedule performance, and the relative value of change orders compared to budget (CII 1999).

Overall, the PDRI for building projects is a user-friendly checklist that identifies and describes the critical element in a project scope definition package to assist project managers in understanding the scope of work. It provides a means for an individual or team to evaluate the status of a building project during preproject planning with a score corresponding to the project’s overall level of definition. The PDRI helps the stakeholders of a project to quickly analyze the scope definition package and to predict factors that may impact project risk specifically with regard to buildings (CII 1999; Cho 2000).

**Scope Definition Level and PDRI Element Weights**

The PDRI element weights were assigned to reflect the fact that not all of the elements within the PDRI were equally important with respect to their potential impact on overall project success. The data collected for determining the PDRI element weights were based upon the subjective opinions of industrial representatives.

The pre-assigned weights were developed through a series of workshops to gather inputs from a broad range of construction industry experts. Higher weights were to be assigned to those elements whose lack of definition could have the most serious negative effect on project performance (CII 1996 and CII 1999). The workshop participants were asked to consider each element individually and evaluate the worst case scenario. If that element was incomplete or poorly defined base on the description (definition level 5), the participants were instructed to assess what percent contingency they would deem appropriate for that element. Then the weights were normalized and converted so that the highest score obtained from using the PFRI would be 1000 (CII 1996 and CII 1999). It should be noted that both version of the PDRI share a similar weighting scheme and scoring methodology.

In the PDRI score sheets, the element's state of definition was to be evaluated using the following five-level scale:

1 = Complete Definition

2 = Minor Deficiencies

3 = Some Deficiencies

4 = Major Deficiencies

5 = Incomplete or Poor Definition

For each PDRI element, different weights were given to all five levels of definition. If one element were not applicable to a particular project, a definition level of 0 with zero weight can be applied. Please refer to Appendix B and Appendix C for complete PDRI score sheets.

In the process of pre-project planning evaluation using PDRI, the project team first read the description of each element, collect all data that is needed to evaluate and then select the definition level for each element. Each element has five pre-assigned weights for the possible five definition levels for that element. The project team can look up the corresponding weight for the definition level they chose for that scope element. This weight represents potential impact of the scope element to the project performance based on the weights developed by the industry experts input. For illustration, Section I – Category A of the PDRI for building projects (both elements and their weights) is shown in Figure 2.7. Hypothetical PDRI scope definition evaluations are circled in the figure as well. Please refer to Figures 4.4 and 4.6 for PDRI element description examples.

To score an element, the project team should first read the descriptions for each element and then collect all data needed to properly evaluate and select the definition level for each element. After the definition level is selected, the score that corresponds to its level of definition was recorded in the "Score" column. The element scores are summed to obtain a total PDRI score.

| SECTION I - BASIS OF PROJECT DECISION | | | | | | | |
|---|---|---|---|---|---|---|---|
| CATEGORY<br>Element | **Definition Level** | | | | | | **Score** |
| | **0** | **1** | **2** | **3** | **4** | **5** | |
| A. BUSINESS STRATEGY (Maximum = 214) | | | | | | | |
| A1. Building Use | 0 | 1 | (12) | 23 | 33 | 44 | 12 |
| A2. Business Justification | 0 | (1) | 8 | 14 | 21 | 27 | 1 |
| A3. Business Plan | 0 | 2 | (8) | 14 | 20 | 26 | 8 |
| A4. Economic Analysis | 0 | 2 | 6 | (11) | 16 | 21 | 11 |
| A5. Facility Requirements | 0 | 2 | 9 | 16 | (23) | 31 | 23 |
| A6. Future Expansion/Alteration Considerations | 0 | 1 | 7 | 12 | (17) | 22 | 17 |
| A7. Site Selection Considerations | 0 | (1) | 8 | 15 | 21 | 28 | 1 |
| A8. Project Objectives Statement | 0 | 1 | 4 | 8 | 11 | (15) | 15 |

**<u>Definition Levels</u>**
**0 = Not Applicable** **2 = Minor Deficiencies** **4 = Major Deficiencies**
**1 = Complete Definition** **3 = Some Deficiencies** **5 = Incomplete or Poor Definition**

Figure 2.7. Buildings PDRI Category A

From Figure 2.7, the definition levels for the eight scope elements are 2, 1, 2, 3, 4, 4, 1, and 5. The corresponding weights for these eight elements are 12, 1, 8, 11, 23, 17, 1, and 15. The definition levels indicate the completeness of each scope definition and from this example; the total score obtained from Category A is 88 for this particular project evaluation (out of a possible total score of 214).

**PDRI Benchmarking**

Since its introduction, the PDRI for building projects has been widely used in industry and has proven to be an effective tool for building sector capital project scope definition. One institutional organization (which prefers to remain anonymous) approached researchers at the University of Texas and expressed interest in modifying and deploying the PDRI for their large capital program. The objective of this research effort was to slightly modify the PDRI scope definition to reflect the needs of this organization's budgeting cycle and a procedure manual, and to develop an expansible benchmarking database and path forward for implementation.

A workshop was therefore held to modify the PDRI-Buildings toward the organization's specific needs. A detailed project questionnaire and a user survey were developed and sent to the respective project managers and end users. Data from a total of 45 building projects were collected and studied. It should be noted that 42 of these 45 projects were essentially identical and constructed in many locations around the world. It was proven for this sample that projects with better-defined scope definition had better performance in terms of cost, schedule, and change orders. Poor alignment (lack of user involvement) was also commonly seen as a problem on the sample projects. Data collected from these projects were analyzed and conclusions and recommendations were provided for the organization's future capital project development.

The average PDRI score for the 45 sample projects was 346 points. The sample projects with a PDRI score under 300 (average 262 for this sub-sample) outperformed projects with PDRI scores above 300 (average of 388 for this sub-sample) in cost, schedule and change order performance. When 33 CII building projects were added to the sample, analysis showed that projects performed by the institutional organization still had room for improvement. Further analysis of the PDRI details shows that future projects should focus on improving project definition for PDRI Category C: (Project Requirements), Category F: (Project Design Parameters), Category G: (Equipment) and Category H: (Procurement Strategy) prior to the beginning development of construction documents (CDs). The research recommended a benchmarking PDRI score of 300 or less for future capital project development. However, they also strongly recommend that once these goals are consistently achieved that the benchmarking scores be lowered to 200 or less. This study will be outlined in more detail later in Chapter Six.

### 2.3. MANAGING CONSTRUCTION PROJECT RISK

The definition for risk is elusive, and its measurement is controversial (Lifson and Shaifer 1982). There is no consistent or uniform usage of the term risk. Often times, risk is interpreted in association with uncertainty. In this sense, risk implies that there is more than one possible outcome for the event, where the uncertainty of outcomes is expressed by probability (Al-Bahar 1988). In project management, risks are typically associated with cost, schedule, safety and technical performance (Rao et al. 1994). For the purpose of this study, risk is defined as *the exposure to the chance of occurrences of cost or schedule growth as a consequence of uncertainty*. Risk will be studied as it relates to growth caused by incomplete scope definition.

Risk management is a quantitative systematic approach used to manage risks faced by project participants. It deals with both foreseeable as well as unforeseeable risks and the choice of the appropriate technique(s) for treating those risks. The process of risk management includes three phases: risk identification, risk quantification, and risk control. The process is a continuous cycle that consists of risk analysis, strategy implementation, and monitoring (CII 1989, Minato and Ashley 1998).

### 2.3.1. Identifying Construction Project Risk

Risk identification is the first process of the risk management. This process involves the investigation of all possible potential sources of project risks and their potential consequences. For construction projects, Al-Bahar and Crandall (1990) defined risk identification as the process of systematically and continuously identifying, categorizing, and assessing the significance of risks associated with a project. Several studies have been conducted to identify and categorize construction risk factors and allocate the ownership of risk (Ashley et al. 1988; Al-Bahar and Crandall 1990; Kangari 1995; Smith and Bohn 1999). From the owner's perspective, these risk factors include fears that (1) costs will escalate unpredictably; (2) structures will be faulty and need frequent repairs; and (3) the project will simply be abandoned and partially paid for but incomplete and useless (Strassman and Wells 1988).

A survey of the top 100 U.S. construction contractors classified risk factors to allocate ownership of the risk under three categories: owner, contractor, and shared risk (Kangari 1995). In this survey study, 23 risk factor descriptions are identified, including permits and ordinances, site access / right of way, defective design, changes in work, labor, equipment and material availability, safety, quality of work, and financial failure of any party. Most of these risk factors descriptions can be found or related to the element descriptions in the

PDRI. Accordingly, the scope definition elements in the PDRI can serve as a comprehensive list of potential risk factors for capital facility project development as addressed in pre-project planning. During the PDRI evaluation process, the project team can obtain knowledge about the completeness of pre-project planning efforts and also identify potential project risk factors by looking at poorly defined scope definition elements.

Risk Analysis and Management for Projects (RAMP) is a process which has been developed for the purpose of evaluating and controlling risk in major projects in the United Kingdom. It proposed that any risk identified should be entered in the "risk register". The risks in the risk register should be classified and if appropriate grouped to assist in their evaluation in turn to determine and record (ICE 2000):

- Possible cause or causes of the risk
- Trigger events giving risk to risk occurring
- Possible timing and potential frequency of occurrence
- Range of possible consequences – both physical and financial
- Asset component, factor or activity associated with the risk
- Objective, 'deliverable' or parameter impacted
- Other related risks
- Form of relationship with other risks
- Who currently owns the risk
- The initial response to the risk
- Whether there are any risks which should be eliminated because they duplicate or overlap with each other

The risk register not only identifies the potential impact but the relationship between each risk as well. After the identification process, the project team should determine the possible consequences resulting from the inadequately defined project scope.

### 2.3.2. Quantifying Construction Project Risk

The second process, risk quantification, is needed to determine the potential impact of the risk quantitatively. This process incorporates uncertainty in a quantitative manner to evaluate the potential impact of risk. In this process, an analyst integrates information from numerous sources through quantitative and/or qualitative modeling, while preserving the uncertainty and the complex relationships between the elements of information (Rao et al. 1994).

Several analytical models have been developed to estimate or evaluate risk exposure for construction projects. A risk decision model was developed by Ibbs and Crandall (1982) based on utility theory. A model using utility theory is able to represent human decision values in the form of mathematical formulation. By incorporating Bayesian probability analysis in this decision model, a contractor is able to estimate the impact of their risk decision. In their study, a theory is introduced which facilitates the analysis of complex decisions and the selection of consistent courses of action. In addition, an illustrative decision problem is solved, not only to explain the mechanics of the theory, but to demonstrate that construction risk is a function of competitive economics as well as of project-related characteristics (Ibbs and Crandall 1982). Nevertheless, most researches studied construction risk from the contractors' perspective.

Mak and Picken (2000) proposed a methodology to investigate risks to clients, persons or organizations investing in the construction of built facilities. It is a common practice that facility owners use a contingency allowance, a percentage addition on top of base estimates, to provide for uncertainties associated with construction projects. A methodology, estimating using risk analysis (ERA), was proposed to substance the contingency by identifying uncertainties and estimating their financial implications. The project team identifies risks and determined risk allowances (probability times cost). Their analysis results showed that the use of the ERA approach has improved the overall estimating accuracy in determining contingency amounts (Mak and Picken 2000). The proposed ERA method substantiates the contingency by identifying uncertainty and estimating their financial implications. Therefore, the risk implications for a capital facility development project for the owners can be expressed by project contingency amounts that account for project uncertainties.

In an effort to study estimating and contingencies, the late John Hackney (1992) used definition rating method to appraise project definition, assign contingency allowances, and predict estimate accuracy. The definition rating is obtained from a checklist and it reflects the degree to which a project is "pinned down" at a given stage of development. The contingency allowances are established in order to compensate for the unfavorable deviations from estimated cost that can be produced by poorly defined factors. Hackney (1992) further indicated that the most dependable guide in establishing proper contingency allowances is experience from past projects. With past project data, he plotted percentage overruns of estimates against the definition rating at the time of estimate and observed from the chart that there is a bias toward underestimating the cost of partially defined projects (Hackney 1992). A similar approach will be applied in this research to quantify the potential risk implications for partially defined projects based on historic project data and will be outlined later.

Having identified the risk factors, and evaluated their potential impact to the project, the next step is to manage the identified project risks as discussed in the next section.

### 2.3.3. Controlling Construction Project Risk

The third phase of the risk management process is risk control. Risk control involves measures aimed at avoiding or reducing the probability and/or potential severity of the losses occurring. The implementation of these measures should be monitored and be taken into account for future alternative risk management strategies development (Al-Bahar and Crandall 1990).

Risk control includes risk avoidance, risk reduction, risk sharing, risk transfer, insurance, risk acceptance by establishment of contingency accounts, risk acceptance without any contingency and risk containment (CII 1989). For example, risk avoidance is a common strategy for managing risk by avoiding risk exposures. An owner organization is able to avoid construction risks associated with a new technology by implementing proven technology. Although risk avoidance eliminates the risk exposures, it also prevents the possibility of benefiting from a new technology.

Risk reduction is a two-fold risk management technique. It decreases risk exposures by (1) reducing the probability of risk, and (2) reducing the financial consequences caused by the risk exposures. It is risk reduction that this dissertation research focuses on as the major risk control measure.

Hackney (1992) pointed out in his study that "consideration of individual ratings on the detailed checklist brings out those points where lack of definition presents the greatest potential threat. These items can be given priority in further definition of the project". That is, these poorly defined scope elements have potential negative impacts to the project and should be addressed later in the project. If these poorly defined elements are properly addressed, the chance and magnitude of the potential negative impact caused by these poorly defined elements can be reduced. Therefore, by improving the poorly defined scope elements (i.e. mitigating the risk) and thus lowering the PDRI score, the project team is able to increase the probability of better project performance. The PDRI score evaluation also serves as a good measure for monitoring the effectiveness of risk control techniques implemented.

## 2.4. LITERATURE REVIEW CONCLUSIONS

The literature review revealed a strong consensus that unresolved scope definition issues are many times associated with poor cost, schedule, safety and technical performance. However, there is little research into which unresolved scope elements lead to project risks early in the project life cycle from the owner's perspective. Mak and Picken (2000) proposed a methodology to substantiate the contingency by identifying uncertainty and estimating their financial implications. Nevertheless it is hard to determine risk allowance and probability for each identified risk factor. Hackney (1992) used definition rating method and graphic techniques to quantify contingency allowances.

The results of previous research revealed that decisions made early in the project have greater influence on project outcome with less costs associated comparing to decisions made later on in the project life cycle. As a pre-project planning tool, the PDRI helps the project team assess project scope definition as well as identify potential risk factors. Several published studies of risk management give useful information for developing a systematic risk management approach using the PDRI.

This research effort addresses application of PDRI evaluation in an attempt to provide additional information as to what potential project problems can occur based on actual data collected. The research will also address the development of a systematic risk management approach using the PDRI.

### 2.5. SUMMARY

This chapter presented the results of the literature review covering pre-project planning, PDRI, risk management and other related topics. The next chapter of this dissertation presents the research problem statement and the research hypotheses based on findings from the literature review.

# Chapter 3 Problem Statement and Research Hypotheses

The literature review discussed in Chapter Two provides a background of the current body of knowledge regarding pre-project planning and risk management. The information gathered in literature review was used in developing research objectives and in designing how to best conduct the research. The problem statement and research hypotheses are presented in the following section.

## 3.1. PROBLEM STATEMENT

It is evident from the literature review that it is important to identify and address potential project risk factors early in the project life cycle. However, there are few effective methods available to fulfill this need. Several problems have been identified in the literature review. The lack of an easy-to-use tool makes it difficult for the project teams to identify and address potential risk factors during early project phase. Limited research results are available to quantify the potential impact caused by unresolved scope issues. Finally, most of currently available risk management techniques are developed for the contractors; therefore, a systematic risk management approach geared towards addressing risks from the owner's perspectives is in great need. Based on the results of the literature review, the problem statement of this dissertation research is as follows:

*A need exists to identify and measure the effect that risk factors identified in the pre-project planning process have on project cost and schedule performance. There also exists a need to develop a systematic risk* *management approach for the owner's organization in the early project planning phase.*

### 3.2. RESEARCH HYPOTHESES

The primary purpose of this research study is to build on previous research concerning pre-project planning, including the Project Definition Rating Index, and risk management by developing a systematic risk management approach to identify and address potential risk factors during the pre-project planning phase. Major decisions regarding project scope are made during the pre-project planning phase of the project life cycle. PDRI is a simple and easy-to-use tool for measuring the degree of scope development on capital facility projects. This scope definition tool is intended to help project teams identify risk factors that may impact their project (Gibson and Dumont 1996).

Risk management contains three major processes: risk identification, risk quantification and risk control. As previous outlined, various authors have discussed and modeled construction project risks to address contractors' risk exposures in capital facility projects (Ibbs and Crandall 1982; Ashley et al. 1988; Al-Bahar and Crandall 1990; Kangari 1995; Ashley et al. 1998; Smith and Bohn 1999). Based on the literature review, two general research hypotheses are developed to meet the research objectives stated in Chapter One.

- H1: *A PDRI score indicates the current level of scope definition and corresponds to project performance. That is, PDRI scores correlate to measures of project success.*

Specifically, the first research hypothesis is that a low PDRI score would represent a scope definition package that is well defined and, in general, corresponds to a higher project success. Higher PDRI scores, on the other hand, would signify that certain elements in the scope definition package lacked adequate definition at the time of assessment, thus resulting in poorer project performance and lower project success. Although this hypothesis was proven in initial development efforts for both PDRI tools, it was done on an exploratory basis with a limited sample size. This hypothesis will be tested by conducting a regression analysis with the expanded sample project database.

- H2: *The PDRI is a reliable indicator of potential project risk factors and PDRI scores can be used to quantify risk impact on project outcomes based on collected data from actual projects.*

The first hypothesis was developed to analyze correlations between PDRI scores and project performance. This second hypothesis was established to examine the possibility of quantifying risk impacts with project schedule and cost performance using statistical analysis models and PDRI scores. In addition, developing a systematic risk management approach will be attempted to extend the usage of the PDRI to support decision-making process in the pre-project planning stage. The proposed risk management approach using PDRI will provide a systematic approach for the project team to identify, assess and manage project risks identified in the pre-project planning phase.

### 3.3. SUMMARY

This chapter outlines the problem statement and research hypotheses. The identified problem involves the need to identify and measure the effect that project risk factors identified during pre-project planning has on project outcome. The research hypotheses are focused on applying PDRI in the project risk management processes early in the project life cycle. The next chapter describes the research methodology, including literature review, administration of the surveys, data collection and analysis, development of statistical models, and application of risk management processes.

# Chapter 4 Research Methodology

The results of the literature review revealed the need for further research into risk analysis early in the project life cycle. Data collected for this research were collected from three main sources: previous PDRI research at the University of Texas, the CII Benchmarking & Metrics database, and through a pre-project planning benchmarking project for an institutional organization. The research also compiled inputs from project professionals representing various areas in the filed of capital facility construction, including projects from both industrial and building sectors.

The hypotheses for this research are based on three main concepts; antecedents to pre-project planning and scope definition, consequences of unresolved scope issues on project outcomes, and the project risk management process. In order to test these hypotheses, past project data were captured to conduct statistical analysis. This analysis will be used either to support or refute the research hypotheses depending on the results of the data analysis.

The specific methodology used for this dissertation research is presented in this chapter. It covers the development of the questionnaire, collection and analysis of data, and the development of risk management model as depicted in Figure 4.1. Each phase contains several steps that are described in the following paragraphs. Specific results of the data analysis, format of the risk management model and recommendations for applying of the risk management model are provided in subsequent chapters.

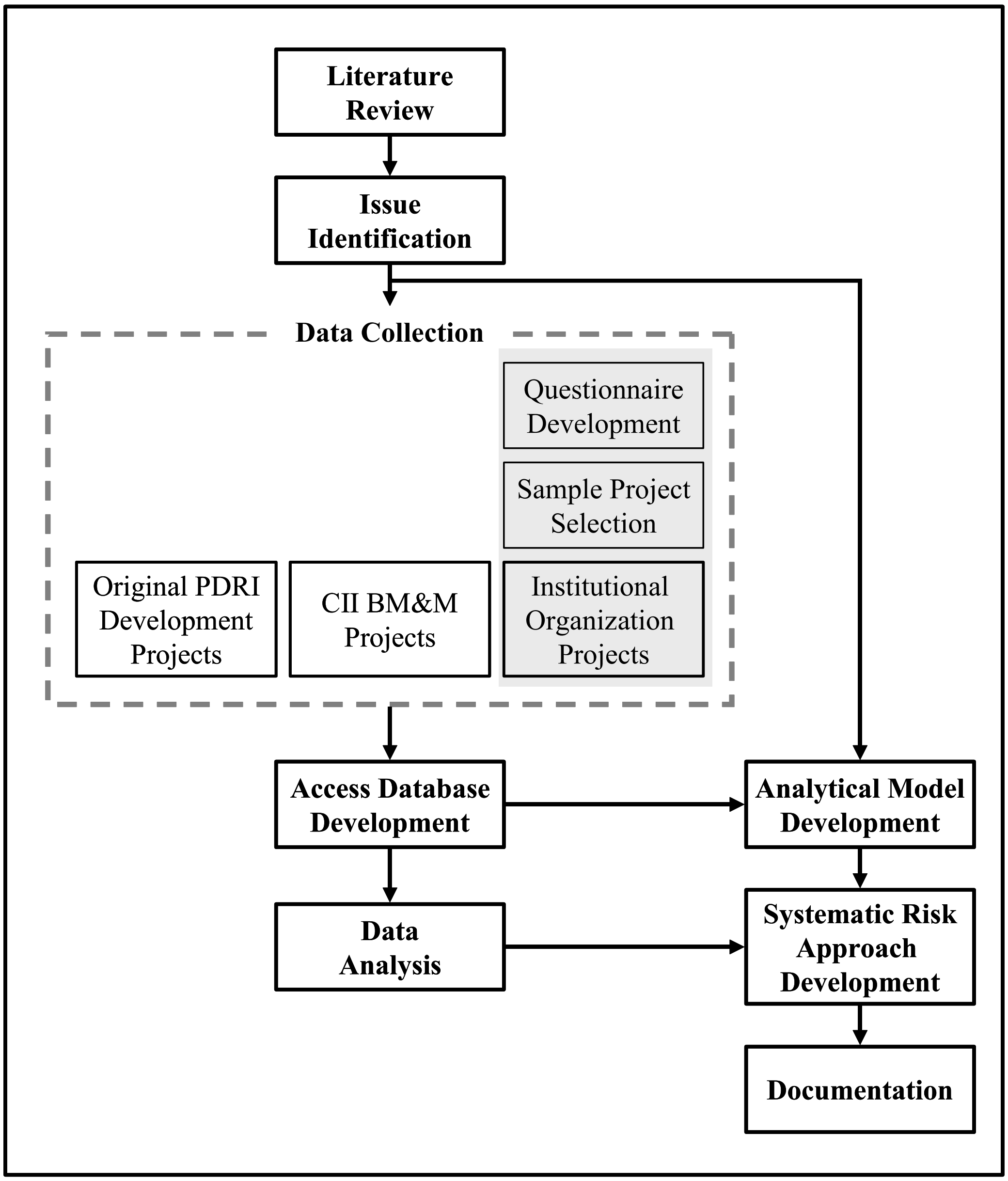


Figure 4.1. Research Methodology Flow Diagram

## 4.1. LITERATURE REVIEW AND ISSUE IDENTIFICATION

Extensive literature review was conducted to examine existing research that is significant to this dissertation research. This effort looked into research topics including pre-project planning, scope definition, the Project Definition Rating Index (PDRI), PDRI benchmarking, construction project risk, and project risk management processes. Critical issues concerning the application of the PDRI into project risk management were identified during literature review.

A literature review was first conducted looking at CII and other available references to identify documented studies on early project planning and scope definition. Numerous works were found concerning pre-project planning and the Project Definition Rating Index and these works served as stepping stones for this dissertation research on exploring the application of the scope definition tool into project risk management. Existing research topics related to construction risk and risk management processes were examined to identify the opportunities of applying PDRI in construction project risk management. The research proceeded with the identification of available statistical analysis methods to develop specific risk models for the purpose of this research. Risk modeling techniques were studied and several construction risk models were considered for the development of PDRI risk models. During the literature review process, issues related to early project planning and construction project risk management were identified as outlined in Chapter 2.

The research methodologies described in the following sections were based on the identified issues from the literature review.

## 4.2. QUESTIONNAIRE DEVELOPMENT AND FINALIZATION

Previous pre-project planning and PDRI research projects utilized survey research as their primary technique for data collection. For detailed reasoning behind the selection of survey research, please refer to CII (1996) and Cho et al. (1999). Retrospective case study questionnaires developed from previous PDRI research were adopted and refined to reflect specific needs for new data collection efforts with the institutional organization.

Babbie (1992) described five different modes of observation in social research: experimental research, survey research, field research, unobtrusive research and evaluation research. Among these different observation methods, survey research was chosen as the most appropriate method of data collection for previous research projects on both versions of PDRI (Cho 2000).

There are three basic procedures used to conduct a survey: questionnaires, personal interviews, and telephone interviews. Personal or telephone interviews were regarded not feasible due to the complicated nature of the questionnaire related to project performance and because of the time and geological constraints (Cho, 2000). As a result, questionnaires were developed during previous PDRI research project as a survey instrument to gather PDRI evaluation and project performance information. The questionnaire is a self-administered survey instrument consisting of questions to be answered by respondents. In the PDRI survey questionnaires, specific questions were intended to obtain historical and "after the fact" project information. The questionnaires included questions regarding project basics (location, type, budget and schedule), operating information, and evaluation using an unweighted PDRI score sheet.

Two sets of questionnaires (one for industrial projects and the other for general building projects) were developed during the initial PDRI development and these questionnaires were used without any changes for continuing sample data collection efforts. However, for the institutional organization projects, a modified PDRI survey questionnaire was employed for data collection process and is given in Appendix B. As part of the PDRI benchmarking research effort, a specific set of PDRI questionnaires were developed for the institutional organization to obtain information from both construction department and intended users within the organization. Developed by the author and research supervisor and approved by the sponsor, the user questionnaire was developed to gather user feedback and was sent to building users. The other questionnaire was developed to obtain project information and was sent to project managers who are in charge of building construction. This questionnaire was modified from PDRI-Buildings questionnaire to reflect specific needs of the organization. In order to obtain inputs from personnel in the institutional organization, a workshop with nine participants was held in November 2000. During the workshop, the descriptions of PDRI scope definition elements were modified to accommodate the specific terminologies and capital project delivery process of the institutional organization. The generic score sheet format and weights of the PDRI-Buildings remained unchanged.

After the development of user and project manager questionnaires, these questionnaires were sent to managers of user and construction departments for their review. Minor questionnaire modifications were suggested and then incorporated into the final version that was sent out to gather information from 45 projects.

The questionnaire development described earlier was geared toward the collection of project information for the institutional organization. The CII Benchmarking and Metrics research and PDRI development research used the questionnaires created for the initial PDRI-Buildings and the PDRI-Industrial research efforts.

## 4.3. DATA COLLECTION

After the development of survey instrument, the research proceeded with data collection. The data collected contains both successful and unsuccessful projects. Nevertheless, it is important to note that the sample selection for the study is based on organizations volunteering projects for the study and not on a random sample of a known population. Specific information concerning sources is given below.

Three different sources were used for data collection during this phase of the research project. Previous PDRI research, CII Benchmarking & Metrics research, and institutional organizational PDRI Benchmarking research were the three main resources of data. When both versions of PDRI were developed, sample projects of actual construction were collected for PDRI validation purpose. Initially, 23 industrial projects were surveyed to gather information regarding PDRI evaluation and project performance during the PDRI validation process (CII 1996). These projects were selected from companies represented by participants in the Front End Planning research project (described in Chapter Two). Following PDRI and project team alignment research efforts obtained 18 more industrial projects from CII owner and contractor member companies for a total of 41 industrial projects. Thirty-three sample projects surveyed during the PDRI-Buildings development effort were used for detailed analysis (CII 1999). These projects were selected from a pool of building projects nominated by the PDRI-Buildings research team member companies. The sample projects represented seven different owner organizations and three contractor organizations.

The CII Benchmarking & Metrics Program was established to provide industry performance norms, quantify the use and value of "best practices," and to help focus CII research and implementation efforts. A committee of industry representatives working with the CII staff has defined critical performance and practice use metrics and developed a strategic approach to CII's collection, analysis, and dissemination of industry data. Questionnaires developed by the committee were sent out to owner and contractor member companies to obtain benchmarking and metrics data. The data are collected by trained industry representatives, and screened by CII staff personnel prior to analysis (CII 2001). Practice use metrics such as safety, team building, constructability, pre-project planning, design/information technology, project change management, material management, planning for start-up, quality management and strategic alliances are evaluated through the CII Benchmarking and Metrics research program. The PDRI was included as part of the questionnaire evaluating the pre-project planning practice. Twenty-one projects with PDRI information were selected from the benchmarking database for this research. These projects represented nine contractor and 12 owner companies and they were all industrial projects.

The third PDRI data resource is PDRI-Buildings benchmarking research efforts for the institutional organization (described in Chapter 2). With the assistant of the consultant hired by the sponsor, modified questionnaires for the institutional organization were sent out to project managers and building users to collect information on PDRI evaluation, project performance and user satisfaction. Information from a total of 45 sample building projects was obtained for the same owner organization and these projects included both domestic (within U.S.) and international projects. Because of confidentiality concerns by the sponsor, certain information (building specific location and names of individuals filling out the questionnaire) was masked by the consultant before the information was sent to the author. The consultant not only assisted with the data collection but also helped clarify questions acting as a "go-between". Specific information such as user satisfaction and owner's contingency was captured due to the fact that questionnaires were specifically developed for this institutional organization. The homogeneous nature of the sample and enhanced quality of information allowed more detailed analysis of this sample, which will be discussed, in next chapter of this dissertation.

Although the data were collected by different researchers, the data collection methods remain consistent throughout the whole data collection period (1994 ~ 2001). That is, a questionnaire survey was used to collect the data and all the questionnaires are filled out by survey participants and followed up by researchers if necessary.

It also should be noted the PDRI is developed in a way that is flexible to treat non-applicable scope elements by assigning zero weights to those elements. Therefore, non-applicable elements will not affect the final total PDRI score. For this research, raw scores were used to conduct the analysis instead of adjusted score (non-applicable weights were taken out of the total maximum score of 1000). However, two industrial projects collected during the PDRI development were not included in this research because these two projects have more than one full category (greater than 10 elements) of "non-applicable" scope elements in their PDRI evaluation.

In summary, information from a total of 62 industrial projects representing a total budget cost of approximately \$3.8 billion dollars was obtained for the research. In the meantime, 78 building projects representing approximately \$1.1 billion dollars in total budget cost were also collected. A detailed breakdown of the projects is presented in Table 4.1.

Table 4.1. Sample Data Summary

| Sector | Resource | No. of Projects | Represented Cost (Billion) |
|---|---|---|---|
| **Industrial** | PDRI-Industrial Research (1996) | 23 | $1.6 |
| | Alignment Research (1998) | 18 | $1.9 |
| | CII BM&M Database (2001) | 21 | $0.4 |
| | ***Industrial Projects Total*** | ***62*** | ***$3.9*** |
| **Building** | PDRI-Buildings Research (1999) | 33 | $0.8 |
| | Institutional Organization Benchmarking (2001) | 45 | $0.3 |
| | ***Building Projects Total*** | ***78*** | ***$1.1*** |

## 4.4. DATA ANALYSIS

The data analysis started with an investigation of the descriptive characteristics of the sample and proceeded to an investigation of the research hypotheses. The purpose of survey was to produce data and statistical analysis permits researchers to reach tentative conclusions about the existence and strength of any relationships of concern (Knoke and Bohrnstedt 1994). For this research, several statistical analyses were performed to evaluate the relationship between PDRI scores and project performance. The establishment of this relationship would indicate the ability of PDRI score to represent project outcomes. The Statistical Package for Social Scientists (SPSS®), version 10.1 and Microsoft® Excel spreadsheets were used for the statistical analyses. The following sections describe several statistical techniques employed in this research study.

### 4.4.1. Descriptive Statistics Analysis

Using bar charts, histograms and pie charts, a profile of the sample projects was developed to determine the nature of the sample being analyzed. In addition to the two industry sectors, projects were profiled by the following classifications:

- Type of construction (greenfield, expansion, revamp, etc.)
- Contract type (lump sum, design build, etc.)
- Project location
- Total project schedule
- Total installed cost

Scatter plots and boxplots were used to display the summary information about the distribution of sample values. A scatter plot displays pairs of points on typical Cartesian (perpendicular) axes, and can reveal relationships or association between two variables in graphic. Scatter plots can provide answers to questions such as "Are the two variables related? If so, linear or non-linear related?" and "Does the variation of one variable depend on the other variable?"

Boxplots are an excellent tool for conveying location and variation information in data sets, particularly for detecting and illustrating location and variation changes between different groups of data. Figure 4.2 provides an annotated sketch of a boxplot. The boxplot presents the median, the 25$^{th}$ percentile, the 75$^{th}$ percentile, and values that are far removed from the rest. The lower boundary of the box is the 25$^{th}$ percentile and the upper boundary is the 75$^{th}$ percentile. The horizontal line inside the box depicts the median. Fifty percent of the cases have values within the box. The length of the box corresponds to the inter-quartile range. From the length of the box, one can determine the spread, or variability, of the observation. From the median, one can determine the central tendency or location. Special symbols used in the boxplot identify the position of outliers, if any. These extremes and outliers, which skew the distribution, are calculated based on Tukey's hinges (SPSS 2000). Results of the detailed descriptive analyses are provided in Chapter Five.

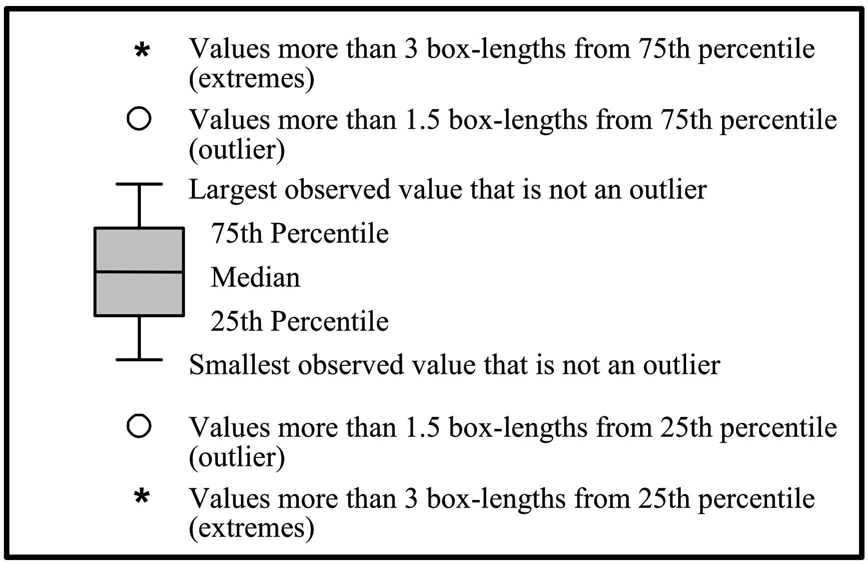


Figure 4.2. Annotated Sketch of the Boxplot

### 4.4.2. Regression Analysis

A regression analysis is a description of the probabilistic relationship between two or more random variables whose values are not necessarily uniquely related (Hamilton 1991). The regression model is represented as an equation for the linear (or non-linear) relationship between a continuous dependent variable and one or more independent variables, plus an error term. The independent variables can be either continuous or discrete. Mathematically, the regression model for the linear bivariate analysis is:

$$Y_i = b_0 + b_1 X_i + e_i$$

where:

$Y_i$ = dependent variable

$b_0$ = $Y_i$ axis intercept

$b_1$ = bivariate regression coefficient

$X_i$ = independent variable

$e_1$ = error term

A bivariate linear regression is a simple form of estimating the linear relationship between a dependable variable (Y) and an independent variable (X). The prediction equation, a regression equation without the error term, is used to predict the value of the dependent variable from the independent variable in the equation. As used in this study it is shown as:

$$\hat{Y}_i = b_0 + b_1 X_i$$

where:

$\hat{Y}_i$ = the predicted value of the dependent variable

The bivariate regression coefficient, $b_1$, or the slope of the regression line, and the intercept, $b_0$, are estimated using ordinary least squares. Ordinary least squares minimizes the error sum of squares, that is, the minimum value of the squared difference between the observed value, $Y_i$, and the value predicted by the regression equation, $\hat{Y}_i$.

The regression model produces two pieces of information that are useful to analyzing relationships between independent variables and a single dependent variable. The first is the regression coefficient, $b_1$ , which measures the amount of increase and decrease in the dependent variable for a one-unit difference in the independent variable.

The second important piece of information provided by the regression model is the coefficient of determination, R-squared ($R^2$). It represents the amount of variation in the dependent variable explained by the model's independent variable. The explained variation in a regression model represents the total sum of squares less the error sum of squares divided by the total sum of squares. The coefficient of determination is presented as:

$$R^2 = \frac{\sum (Y_i - \bar{Y})^2 - \sum (Y_i - \hat{Y})^2}{\sum (Y_i - \bar{Y})^2}$$

$$= \frac{SS_{Total} - SS_{Error}}{SS_{Total}}$$

where:

$\bar{Y}$ = the mean score of Y for all observations

A statistical significance test, F-statistic, is used to determine whether or not the linear regression model with its independent variable is a significant predictor of the dependent variable. That is, the $R^2$ value is statistically significant, or different from zero, if the computed F-statistic is greater than the F-critical value for the defined probability level. For this study, if the obtained significant level (p-value) associated with the F-statistic is less than 0.05 (at 95 percent confidence), the $R^2$ value is statistically significant. All of the above computations were carried out through the use of the SPSS for Windows™, version 10.0. Regression analyses were performed to verify the research hypothesis and to define the relationship between the PDRI score as a predictor and project performance variable.

### 4.4.3. Independent Samples *t*-Test and Effect Size

The *t*-test is the most commonly used method to evaluate the differences in means between two groups made up of small sample sizes. It can be applied to address hypotheses involving a single mean or differences between two means. The *t*-test is valid even if the sample sizes are very small as long as the variables are normally distributed within each group and the variation of scores in the two groups is not reliably different (Knoke 1994). For independent samples *t*-test, the grouping variable divides cases into two mutually exclusive or categories, while the test variable defines each case on some quantitative dimension. The *t*-test evaluates whether the mean value of the test variable for one group differs significantly from the mean value of the test variable for the second group.

The *p*-level reported with a *t*-test represents the probability of error involved in accepting our research hypothesis about the existence of a difference. Technically speaking, this is the probability of error associated with rejecting the hypothesis of no difference between the two categories of observations (corresponding to the groups) in the population when, in fact, the hypothesis is true. For this research, the *t*-test was used to investigate if the scope definition levels are significantly different between successful and less-than-successful projects.

However, if *t*-test was applied too many times, the probability of error associated with rejecting the hypothesis purely by chance might increase. This will be the case for this research study because the *t*-test was applied for all PDRI scope elements (70 for industrial PDRI and 64 for buildings PDRI). To prevent this, the measurement of Effect Size was employed to compare the means between two groups.

Effect Size (ES) is a name given to a family of indices that measure the magnitude of a treatment effect. Unlike significance tests, these indices are independent of sample size. The results of significance tests rely heavily on two aspects: the size of the effect and the size of the sample. One would get a 'significant' result either if the effect were very big (despite having only a small sample) or if the sample were very big (even if the actual effect size were tiny). It is important to know the statistical significance of a result, since without it there is a danger of drawing firm conclusions from studies where the sample is too small to justify such confidence. In the mean time, effect size quantifies the size of the difference between two groups, and may therefore be said to be a true measure of the significance of the difference (Coe, 2000).

Effect size can be conceptualized as a "standardized difference". In the simplest form, effect size is the mean difference between groups in a standard score form (i.e., the ratio of the difference between the means to the standard deviation). This concept is derived from a school of methodology named Meta-

Analysis, which was developed by Glass (1976). A meta-analysis is a quantitative approach to reviewing research literature in a specific area and is beyond the scope of this research. The equation for calculating Effect Size is given as follow:

$$Effective\,Size = \frac{Mean\ of\ Group\ 1 - Mean\ of\ Group\ 2}{Pooled\ Standard\ Deviation}$$

where Pooled Standard Deviation is calculated from:

$$SD_{Pooled} = \sqrt{\frac{(N_1 - 1)\,SD_1^{\,2} + (N_2 - 1)\,SD_2^{\,2}}{(N_1 + N_2 - 2)}}$$

Conventional values of effect size are Small: 0.20, Medium: 0.50, and Large: 0.80 (Welkowitz et al. 1982). Other researchers may have different values for small, medium, and large effect size. The magnitude of effect size depends on the subject matter. For example, in medical research d = .05 may consider a large effect size i.e. if the drug can save even five more lives, further research should be considered. Because there are no references to use of effect size in construction research, conventional values of effect size will be utilized for this research study when the scope definition levels for the sample projects were compared. The effect size analysis can be applied to both continuous and discrete variables (Heiman 1992). In this research, scope definition levels (discrete variable) were used to conduct the effect size analysis.

## 4.5. ANALYTICAL MODEL DEVELOPMENT

The purpose of this phase is to develop decision support models for project managers to use in efficiently assessing the project's scope definition and potential risk impact to the final project outcome. These models can be used by owners as a project risk management tool to maintain a high probability of success during the pre-project planning phase of the project. Furthermore, the models can be used by both owner and contractor project management to efficiently assess risk exposures that have the greatest impact on project success. Three approaches were explored to establish an analytical model for the purpose of this research: boxplots, bivariate linear regression and Hackney's accuracy range estimate method. The first two approaches have been discussed in previous sections. This section is focused on the introduction of the accuracy range estimate method proposed by Hackney (1992).

### Accuracy Range Estimate Method

Hackney (1992) developed a project definition checklist and gave each item an arbitrary maximum weight to indicate the general degree of uncertainty produced in the overall project if that particular item is completely unknown. Figure 4.3 gives an example of Hackney's checklist of definition rating. The assigned weights represent the sort of percentage overrun which might be expected if the item in question were completely misjudged.

| | Maximum Rating | This Project |
|---|---|---|
| A. *General Project Basis* | | |
| Product and by-products | 100 | |
| Raw materials | 100 | |
| Process background | 200 | ______ |
| Subtotal A | (400) | |
| Project basis multiplier (one plus 1% of subtotal A) | 5.0 | |
| B. *Process Design Status* | | |
| Flow balances (material, heat, power) | 70 | |
| Major equipment, type and size | 80 | |
| Materials of construction | 30 | |
| Review with research, development, and operations | 70 | ______ |
| Subtotal B | (250) | |
| C. *Site Information* | | |
| Surveys, including obstructions and subsoil | 45 | |
| Re-usable equipment | 25 | |
| Re-usable supports, piping and electrical | 25 | |
| Buildings available | 30 | |
| Utilities available | 25 | |
| Yard improvements available | 25 | |
| Climatological information | 20 | |
| Local ordinances and regulations | 20 | |
| Review with operations | 25 | ______ |
| Subtotal C | (240) | |
| D. *Engineering Design Status* | | |
| Layouts | 35 | |
| Line diagrams, including utilities | 50 | |
| Auxiliary equipment, type and size | 45 | |
| Buildings, type and size | 35 | |
| Yard improvements, type and size | 25 | |
| Hazard control | 25 | |
| Coating specifications | 10 | |
| Review with research, development, and operations | 70 | ______ |
| Subtotal D | (295) | |
| E. *Detailed Design* | | |
| Drawings and bills of material | 45 | |
| Drawing checks | 25 | ______ |
| Subtotal E | (70) | |
| F. *Field Performance* | (50) | ______ |
| Subtotal, Sections B through F | (905) | |
| Definition Rating (multiply subtotal of sections B through F by project basis multiplier); maximum, 905 × 5.0 | (4,525) | ______ |
| Recommended Contingency | | |
| Unlisted items (per cent of base cost) | | ______% |
| Restricted reserve (per cent of base cost plus unlisted items) | | ______% |

Figure 4.3. Hackney's Checklist of Definition Rating

It was shown that the definition rating can be used as a valid and valuable quantitative indication of the degree to which a project is “pinned down” at a given stage of development (Hackney 1992). Furthermore, the definition rating was applied for the estimation of contingency allowances.

Contingency allowances are established in order to compensate for the unfavorable deviations from estimated cost. Hackney (1992) pointed out six factors that can be accounted for these deviations: estimating error and oversights, imperfections in estimating methods, accidental events during construction, economic and other environmental conditions, effectiveness of project performance, and project deviation from estimate scope. He further indicated that the most dependable guide in establishing proper contingency allowances is experience from past projects. Actual and estimated cost for past projects is tabulated to organize and analyze this experience. He plotted percentage overruns of past estimates against the definition at the time of estimate and the plot is shown in Figure 4.4.

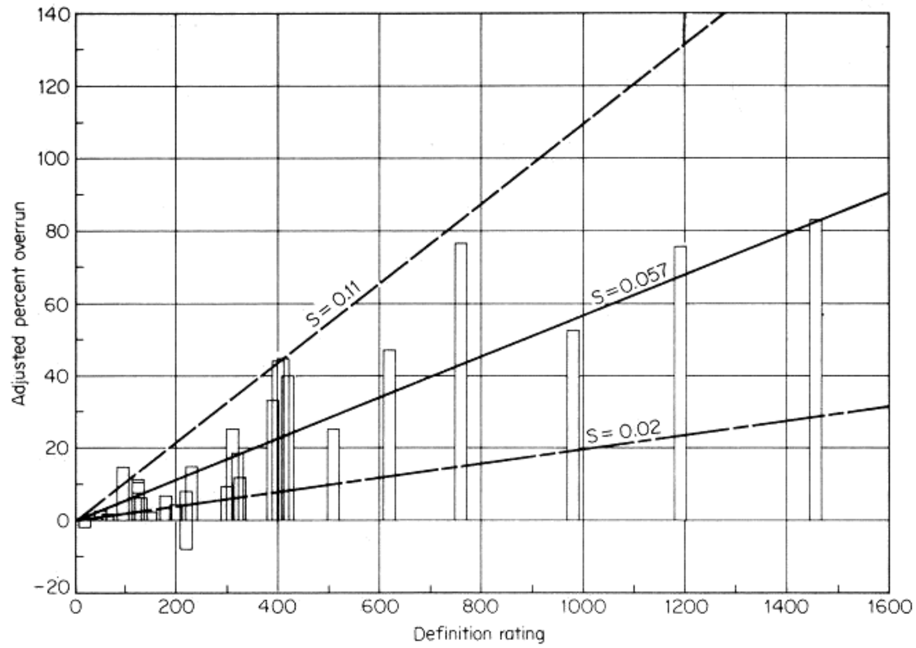


Figure 4.4. Definition Rating vs. Overruns

Figure 4.4 shows how definition ratings have related to the excesses of actual costs over base estimates, without contingency allowances, from approximately 30 projects of record (Hackney 1992). Figure 4.4 has a line drawn through the data with half the bar tops below and half above. This line has a slope of 0.057. If this coefficient is applied to the definition rating for a project at a given stage of its development, the result is the even-chance contingency allowance percentage. The even-chance contingency allowance is the amount that if added to the base estimate without contingency allowance, will provide a 50/50 chance of the actual cost overruning or underrunning the estimate (Hackney 1992). From Figure 4.4, a $90 MM project, for instance, with a definition rating of 630 will have an even-chance allowance of 35.9 (630 x 0.057) percent and the even-chance estimate is $122 MM ($90 MM x 1.359). This approach will be adopted for this research to establish a model to estimate the potential risk impact.

## 4.6. SYSTEMATIC RISK MANAGEMENT APPROACH

Al-Bahar (1988) proposed a model, Construction Risk Management System (CRMS), providing an effective systematic framework for quantitatively identifying, evaluating, and responding to risk in construction projects. The CRMS provides a formal, logical, and systematic tool that helps contractors in identifying, analyzing, and managing risks in a construction project. Based on his risk management system framework, this research will develop a new prototype risk management approach by incorporating the PDRI.

In the proposed risk management technique, PDRI will be used in all three of the risk management process: risk identification, risk quantification and risk control. Flowcharts will be created to graphically represent the systematic risk management that helps owners in identifying, quantifying and controlling risks in the pre-project planning stage of a construction project.

Using results from literature review and data analysis, the research findings are synthesized into a comprehensive risk management approach. The proposed systematic risk management approach using PDRI can be implemented by the project team in the pre-project planning phase of a project to increase the probability of a successful project.

## 4.7. STUDY LIMITATIONS

It is important to note some of the potential limitations of this study in terms of methodology and data collection. The sample selection for the study is based on organizations volunteering projects for the study and not on a random sample of a known population. Moreover, most of these organizations are CII member companies and, at least anecdotally, CII companies are typically larger in size and perform better than the average non-CII member companies. These organizations may have selected projects with a bias toward successful projects which tends to have lower PDRI scores and thus will influence the results. For the building projects, the institutional organization provided both successful and less than successful projects and made the building project sample less biased, since this represented their entire population of projects for a particular time period.

A second limitation relates to the nature of retrospective case studies. The respondents are required to think back to the initial planning and designing stage (just prior to Construction Documents development) and assess how well each scope element was defined at that time during the "after the fact" project data collection process. Regardless of how complete their project documentation was, this method may still have resulted in slightly inaccurate reporting since it is typically difficult to remember precise details. This data collection may also have lead to some bias in self-scoring the PDRI.

### 4.8. SUMMARY OF RESEARCH METHODOLOGY

This chapter outlined the development and administration of data collection instrument, data collection process, data analysis techniques, and development of analytical model and systematic risk management approach. Information from several reference resources that cover pre-project planning and risk management were used as the foundation for this research. Raw data obtained from previous research, CII Benchmarking and Metrics research, and data from the institutional organization were stored in a database. Several statistical analysis techniques were employed to conduct data analysis and to verify the research hypotheses. Descriptive analyses of the data collected are presented in the next chapter.

# Chapter 5 Project Data Characteristics and Data Analysis

Data collected for the research represent 62 industrial projects and 78 building projects. These 62 industrial projects represent approximately $3.9 billion in total construction costs from 30 owner and contractor companies. This sample included projects constructed in 11 different countries. The 78 building projects represent approximately $1.1 billion in total construction costs and are geographically dispersed in four regions (U.S.A., Canada, Latin America, and Australia/Pacific). These building projects were provided by 15 different owner and contractor companies. This chapter presents the summary of data collected from three main sources: previous PDRI research, CII Benchmarking & Metrics research, and institutional organizational PDRI Benchmarking research, as described in Section 4.3 in this dissertation. Tables and figures are used to present the sample characteristics. The various analyses performed on the data collected from the sample projects are also presented. The results of success index analysis, correlation analysis, and hypothesis validation are discussed.

## 5.1. GENERAL PROJECT CHARACTERISTICS

The 62 industrial projects had a wide range of facility types such as gas processing, petroleum refinery, power plant, chemical plant, pulp and paper, manufacturing facility, metal refining/processing, transmission and distribution, pharmaceutical, and wastewater treatment. The building projects cover schools, churches, border stations, research labs, offices, warehouses, shopping centers, recreational facilities, fire stations, and courthouses. Table 5.1 shows the sample projects by facility types. Due to the distinct natures of these two sectors, the industrial and building projects are described separately.

Table 5.1. Sample Data Facility Type

| Sector | Facility Type | No. of Projects |
|---|---|---|
| Industrial | Chemical Plants | 24 |
| | Oil/Gas Production or Processing Plants | 13 |
| | Metal Refining/Processing Plants | 7 |
| | Power Plants | 6 |
| | Pulp and Paper Mills | 5 |
| | Miscellaneous | 7 |
| | ***Total Industrial Projects*** | ***62*** |
| Building | Institutional Buildings | 46 |
| | Offices | 9 |
| | Research Labs | 5 |
| | Schools | 3 |
| | Recreational Facilities | 3 |
| | Miscellaneous | 12 |
| | ***Total Building Projects*** | ***78*** |

For each project, the survey participants were asked to identify the category that best describes their project. Figure 5.1 shows the sample of industrial projects divided into four categories: grassroots, retrofit/expansion, co-located and other. Projects started from greenfields are categorized as *Grassroots*. If more than 25 percent of the project was a retrofit, the project is classified as a *Retrofit/Expansion*. Projects are deemed as *Co-Located* if built adjacent to other facilities. More than half (40) of the industrial projects are *Retrofit/Expansion*, accounting for 65 percent of total projects.

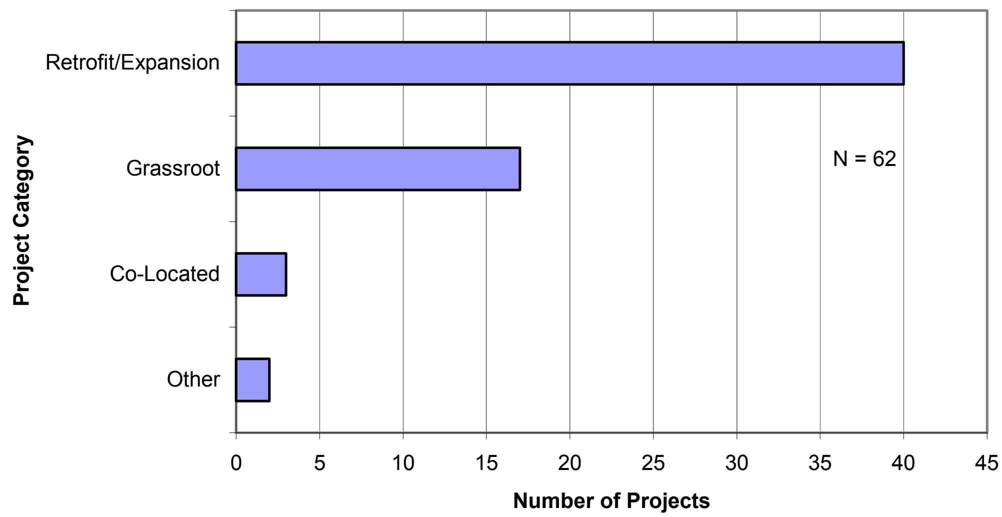


Figure 5.1. Industrial Project Type

Figure 5.2 shows the sample of building projects divided into two categories: new construction and renovation. If renovation cost was greater than 50 percent, the project is considered as a r*enovation* project. Eighty-eight percent (69 out of 78) of the building projects were *new construction*.

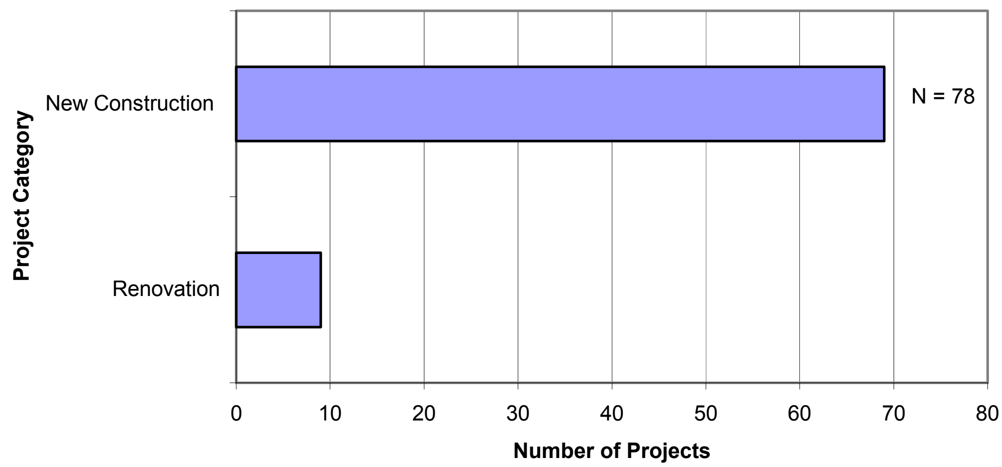


Figure 5.2. Building Project Type

In the survey, respondents were asked to identify what kind of contract was used for the project. These projects were categorized in three categories: Design-Bid-Build, Design-Build, and Other. Figure 5.3 shows the number of industrial sample projects in each contract type category along with their percentages. It should be noted that only 28 out of the 62 surveyed industrial projects provided sufficient project contract information. Among the 28 projects, more than half (64 percent) were Design-Bid-Build projects.

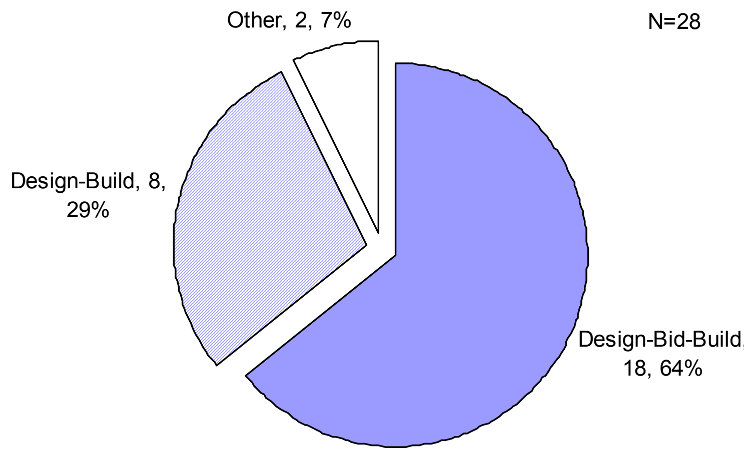


Figure 5.3. Industrial Project Contract Type

Figure 5.4 below shows the percentage of each contract type in three different contracting categories for the 68 building projects that provided this information. Fifty out of the surveyed 68 projects (74 percent) indicated usage of Design-Bid-Build contracts.

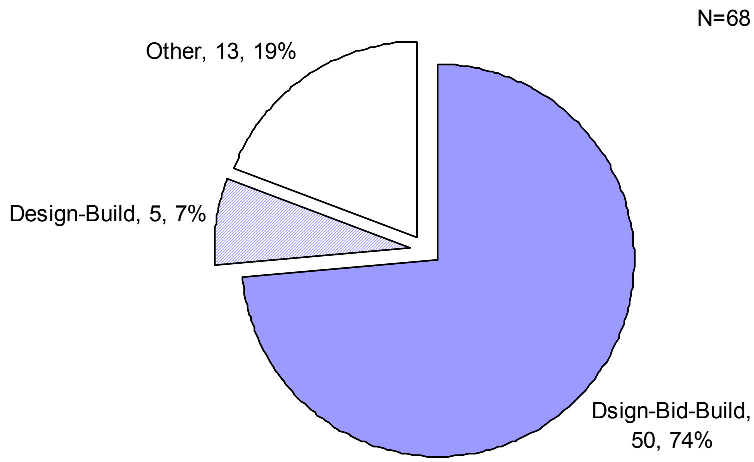


Figure 5.4. Building Project Contract Type

The location of each project was also provided by the participants during the survey. The industrial projects can be categorized into four geographic regions: North America, Central America, Europe and Asia. The building projects were categorized into three different regions, North America, Latin America and Australia/Pacific. It should be noted that there are four Canadian building projects in the North America region. As shown in Figures 5.5 and 5.6, a major portion of the sample projects collected for this research is in the North America region.

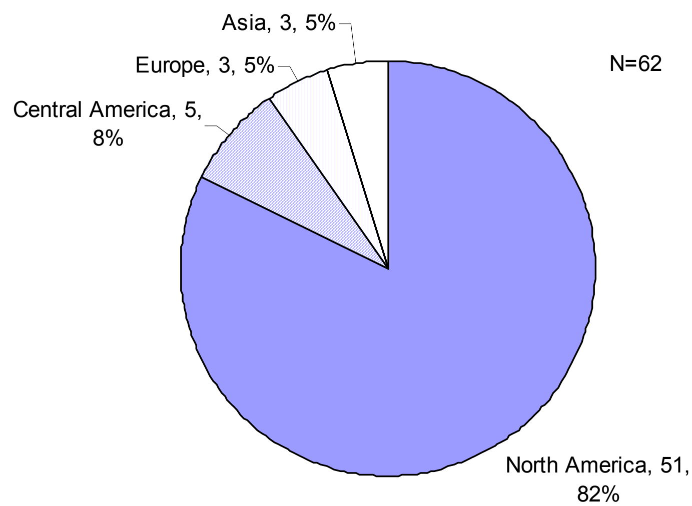


Figure 5.5. Industrial Project Locations

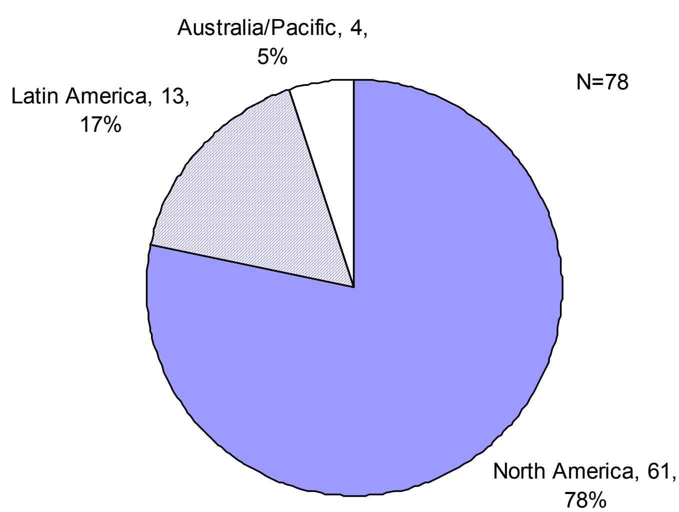


Figure 5.6. Building Project Locations

The average total project duration (design, construction and startup) for the 62 industrial projects was 33 months with a standard deviation of 24 months. The longest project took a total of 114 months to finish while the shortest project took only four months to complete. Figure 5.7 shows the distribution of total project durations for industrial projects. More than 50 percent of the industrial sample projects have total project durations of one to three years.

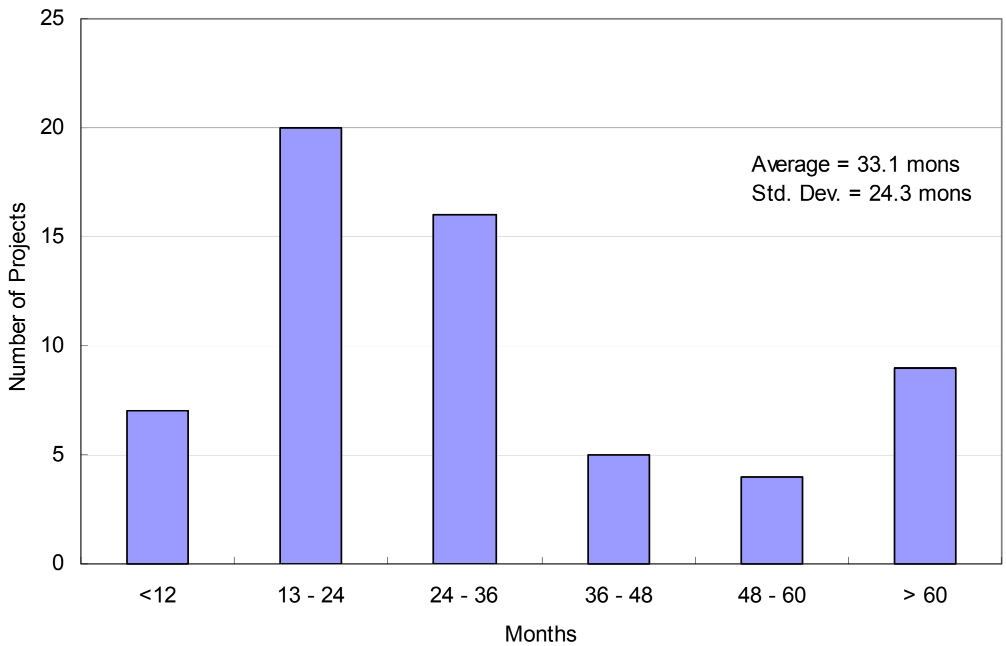


Figure 5.7. Industrial Project Total Schedule Durations, N=62

For the 78 building projects, it took an average of 21 months (design, construction and commissioning) to finish with a standard deviation of 18 months. The longest project duration was 98 months and the shortest project duration was seven months. The distribution of project durations is shown in Figure 5.8. More than 60 percent of building projects in the survey were finished within two years and the sample is skewed by the projects provided by the institutional owner.

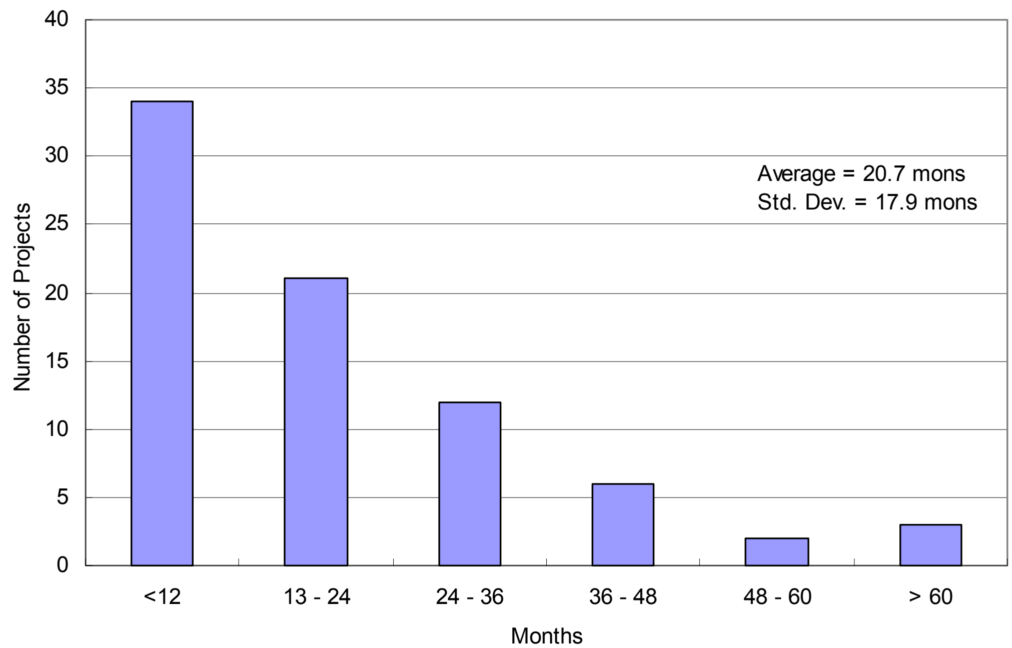


Figure 5.8. Building Project Total Schedule Durations, N=78

The total installed cost for industrial projects ranged from $0.9 million to $635 million with a standard deviation of $118 million. The mean project cost was approximately $65 million with half of the projects taking less than $25 million to complete. Figure 5.9 illustrates the distribution of total installed cost for industrial projects.

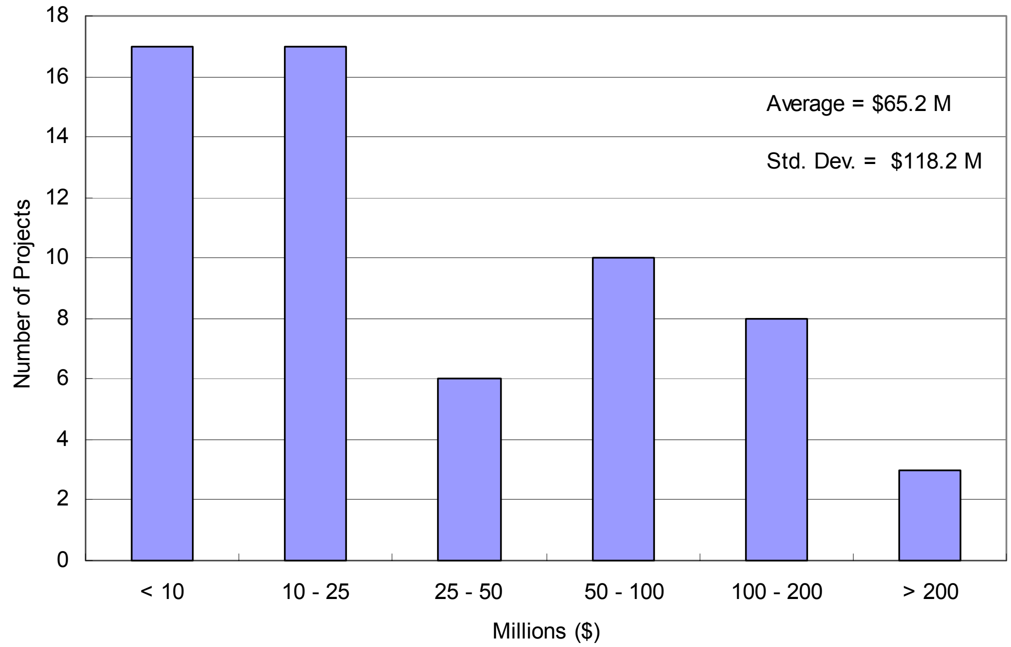


Figure 5.9. Industrial Project Total Installed Cost, N=62

Comparing by total installed cost, building projects are generally smaller in size (dollar amount) than industrial projects. The mean total installed cost for building projects was approximately $15 million with a standard deviation of $30 million. The total installed cost for building projects ranges from $0.7 million to $200 million. More than 60 percent of the building projects in the survey took less than $10 million to design and construct. Again, these data are skewed by the 45 projects of the one institutional owner.

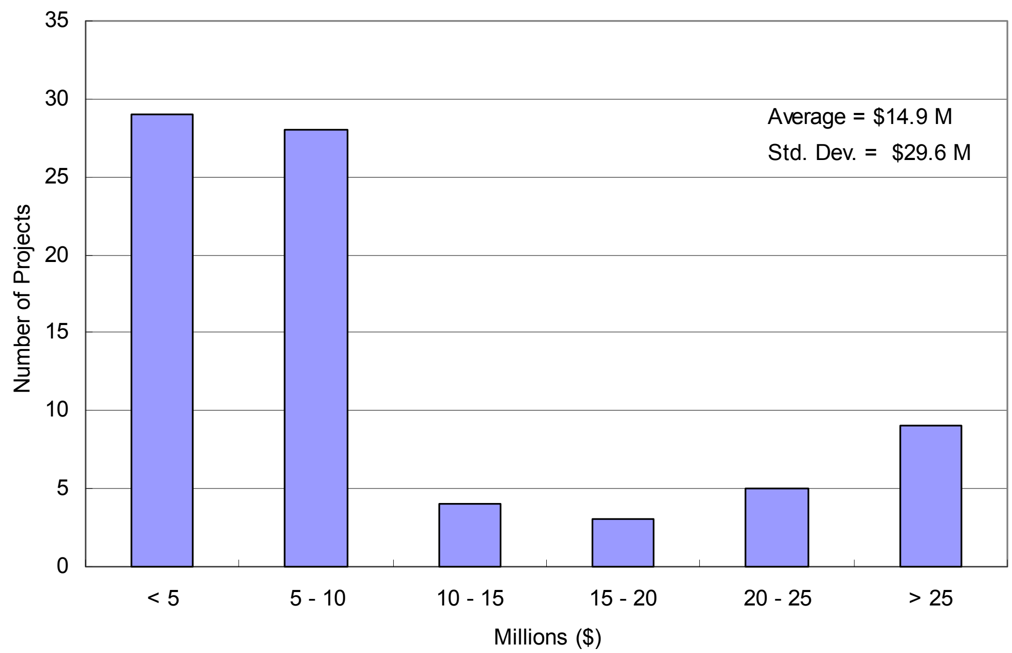


Figure 5.10. Building Project Total Installed Cost, N=78

## 5.2. PERFORMANCE CHARACTERISTICS

Two performance characteristics are of particular concern in this research, cost and schedule performance. In the survey, respondents were asked to provide estimated costs at the start of construction document development for detailed design and construction as well as the actual costs after construction completion. In addition, respondents were asked to provide the start date of construction document development and the date of final project completion. This information is used to examine the cost and schedule performance of surveyed projects.

### 5.2.1. Cost Performance

Total cost growth measures the total project cost growth as a percentage of the initial predicted project cost. Cost performance was measured by project cost growth metric obtained as follow:

$$\frac{\textit{Actual Total Project Cost} - \textit{Initial Predicted Project Cost}}{\textit{Initial Predicted Project Cost}}$$

Project cost growth measures the overall percent cost growth for many reasons, and therefore is a good overall measure of owner-contractor team performance (CII 1998). For industrial projects, the average cost growth calculated from the above equation was 2.6 percent over the initial predicted project cost with a standard deviation of 18.9%. Among these projects, the worst project was approximately 86 percent over budget, while another project was approximately 22 percent below the original estimated cost. Figure 5.11 gives a histogram for industrial project cost growth. Most of the projects fall within 20 percent above or below original budgeted cost with a few exceptions. In dollar terms, the highest cost growth on a project totaled \$58 million with a final cost of \$150 million, which translates to approximately a 62 percent cost growth. The largest savings was \$91 million below the budgeted cost with a final project cost of \$434 million, which translates to approximately 22% below budgeted cost.

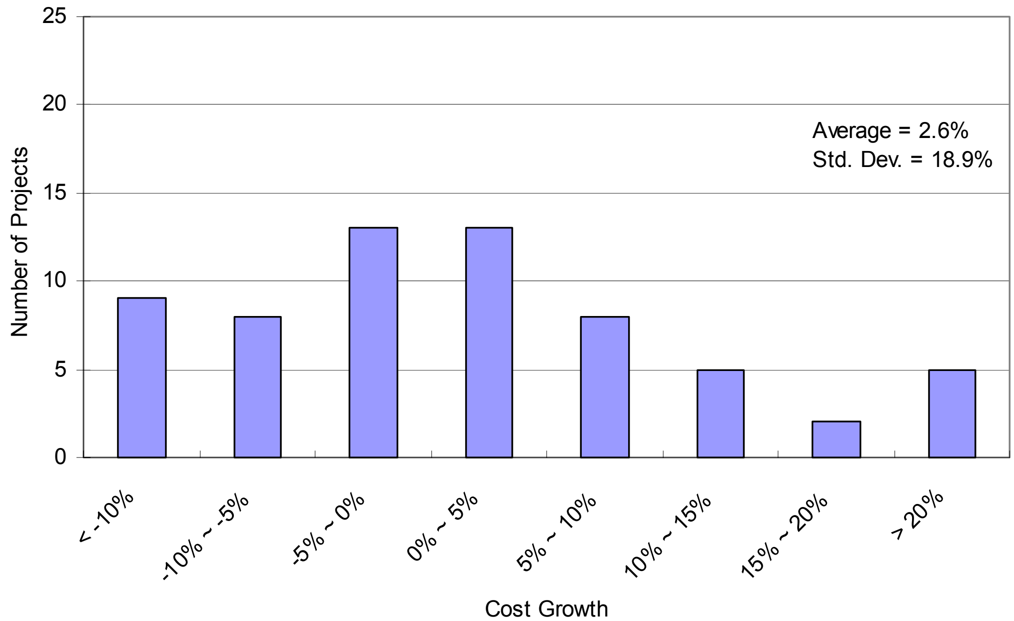


Figure 5.11. Industrial Project Cost Growth Histogram, N=62

Figure 5.12 illustrates the histogram of building projects cost growth. From the figure, it is found that most of the building projects reported less-than-successful cost performance (over budgeted cost) with the worst project reporting 54 percent over original budget and the best reporting 22 percent below budget. The largest cost growth in dollar terms was $29 million for a $124 million project in total, representing a 33 percent cost growth.

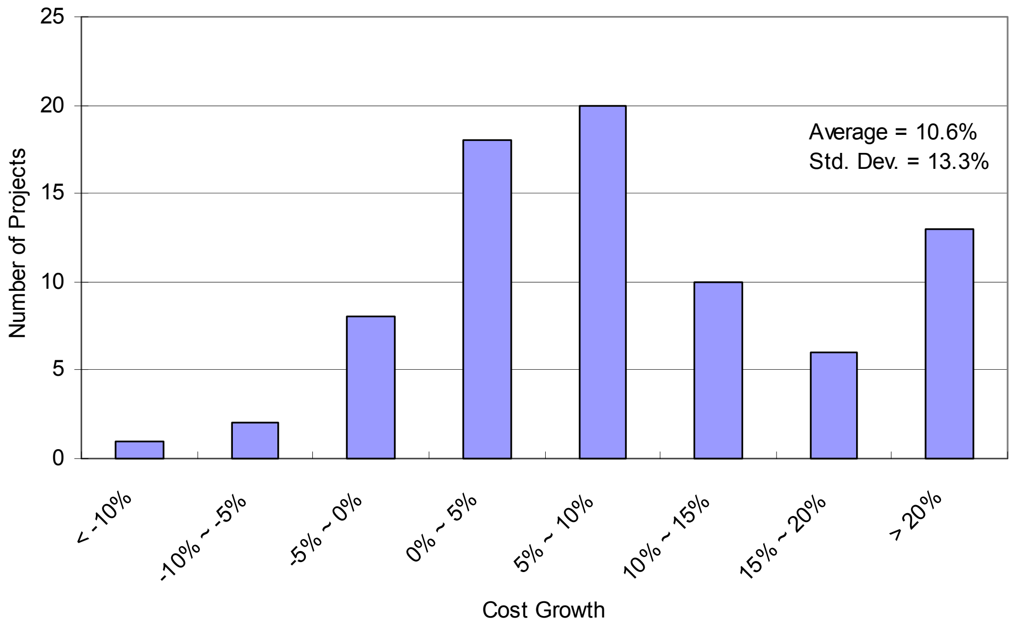


Figure 5.12. Building Project Cost Growth Histogram, N=78

### 5.2.2. Schedule Performance

The total project duration used to calculate project schedule growth was measured from the start date of construction documents development (or authorization for expenditure of detailed design funds for industrial projects) to the date of substantial completion (or mechanical completion in the case of industrial projects) in months. The following equation was used for computing project schedule performance:

$$\frac{\textit{Actual Total Project Schedule} - \textit{Initial Predicted Project Schedule}}{\textit{Initial Predicted Project Schedule}}$$

Project schedule growth measures the overall percent schedule growth for many reasons, and therefore is a good overall measure of owner-contractor team performance (CII 1998). Based on the above equation, schedule growth was obtained for all industrial projects and a histogram was plotted in Figure 5.13. Figure 5.13 shows that the sample projects have a wide range of schedule growth ranging from 65 percent behind schedule to 43 percent ahead of schedule. The longest project delay is 16 months for a project with an estimated duration of 41 months, which translates to a 40% schedule growth. One project finished 24 percent ahead of schedule with final project duration of 12.2 months.

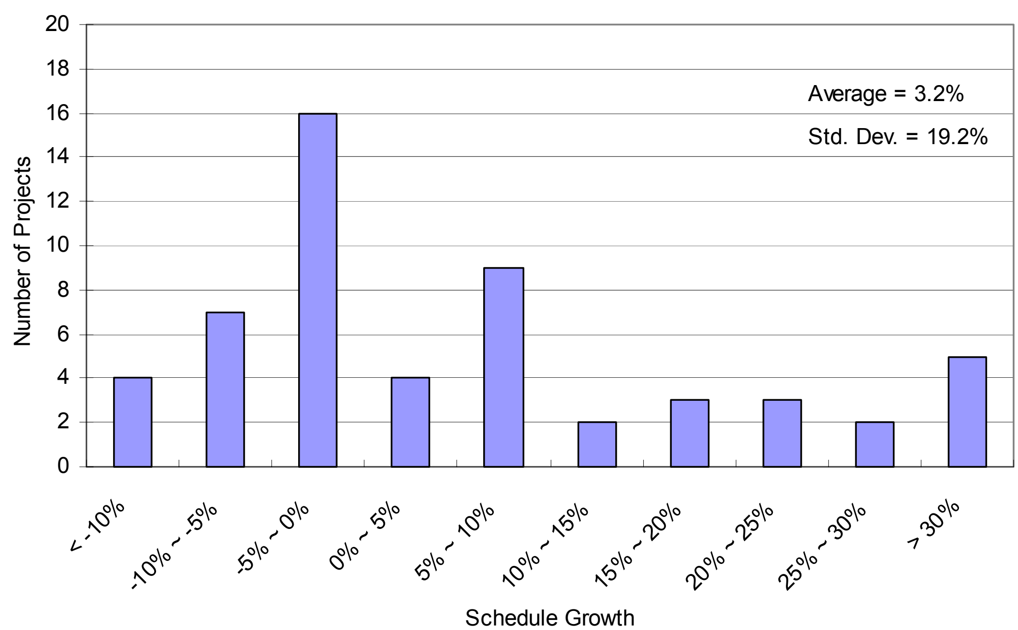


Figure 5.13. Industrial Project Schedule Growth Histogram, N=62

Similar to the distribution of building project cost growth, most of the building projects are behind the original estimated schedule. The 78 building projects have an average total project duration of 20.7 months with a standard deviation of 17.9 months. Figure 5.14 shows the histogram of building project schedule growths. The worst project had a schedule growth of 106 percent that doubled the original project duration to more than one year. One project finished three months ahead of schedule, which accounted for 25 percent of the original estimated project duration.

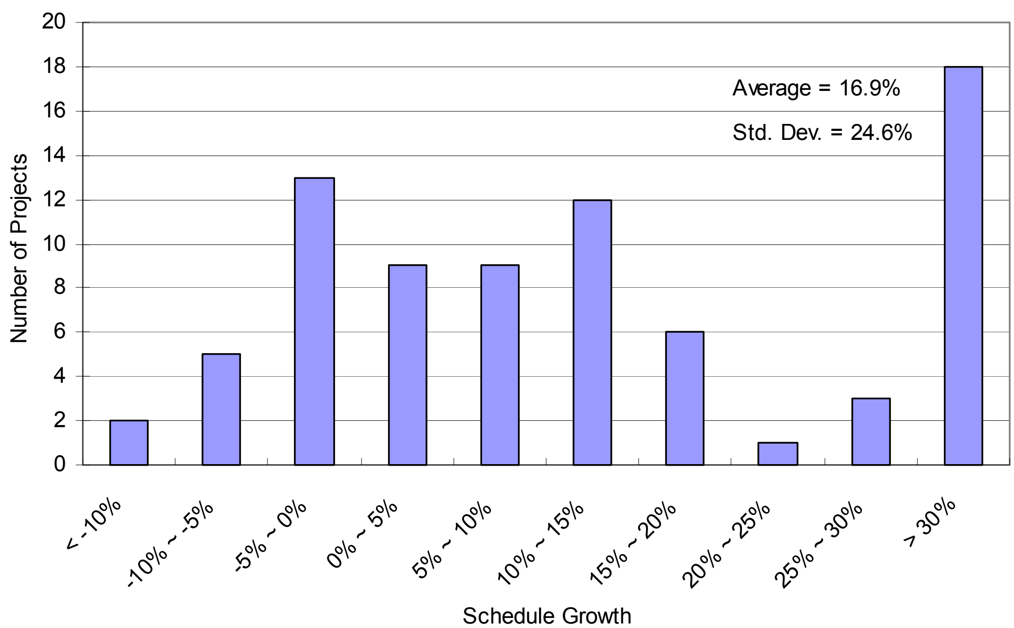


Figure 5.14. Building Project Schedule Performance Histogram, N=78

Table 5.2 summarizes the basic cost and schedule growth information for both industrial and building projects. Again, performance in this table was measured by comparing final cost/schedule against original estimated project cost or duration.

Table 5.2. Sample Project Performance Summary versus Estimated

| | Industrial Projects (N=62) | Building Projects (N=78) |
|---|---|---|
| **Cost Growth** | | |
| Average | 2.6% | 10.6% |
| Standard Deviation | 18.9% | 13.3% |
| Maximum | 86.0% | 54.4% |
| Minimum | -22.0% | -22.4% |
| **Schedule Growth** | | |
| Average | 3.2% | 16.9% |
| Standard Deviation | 19.2% | 24.6% |
| Maximum | 65.0% | 106.8% |
| Minimum | -43.3% | -24.8% |

### 5.3. PDRI SCORE CHARACTERISTICS

In the survey, participants were asked to fill out unweighted PDRI score sheet for their pre-project planning evaluation and they were asked to think back to a point prior to Construction Document development. Based on the evaluator's perception of how well one scope element has been addressed, only one definition level (0, 1, 2, 3, 4, or 5) for that element was chosen. According to this information, the PDRI scores were calculated by UT researchers by applying the weighted PDRI score sheet. The weights as applied are the developed weights for each PDRI scope element. For development and validation of PDRI element weights, please refer to previous CII studies (CII 1996, CII 1999).

As discussed earlier in Chapter 2, elements have five pre-assigned scores, one for each of the five possible levels of definition. The value of the score based on a chosen definition was obtained for each element. Each of the element scores within a category was added to produce a total score for that category. The scores for each of the categories within a section were added to arrive at a section score. Finally, the three section scores were added to achieve a total PDRI score. The Industrial PDRI scoresheet is provided in Appendix C and Building PDRI scoresheet is contained in the project manager questionnaire in Appendix B.

The histogram of 62 PDRI scores for industrial projects is shown in Figure 5.15. The average PDRI score was 221 with a standard deviation of 104. The distribution of PDRI scores is fairly widespread and range from 82 to 465. Note that these scores were measured for each project at the point in time just prior to authorization for expenditure for these industrial projects. At this point in time, scope definition should have been completed.

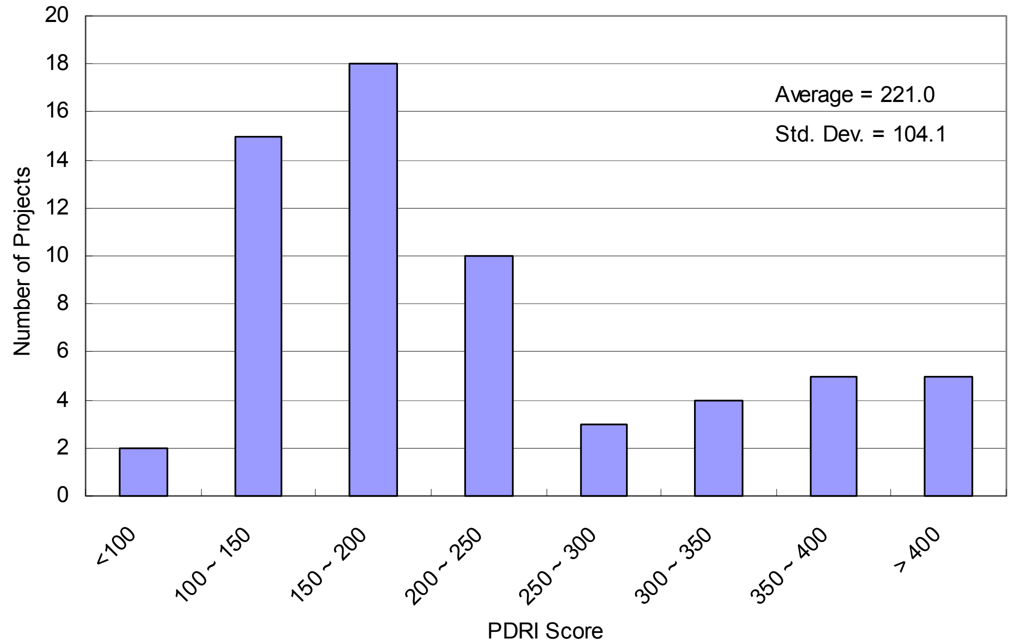


Figure 5.15. Industrial Project PDRI Score Histogram, N=62

Similarly, the distribution of building project PDRI scores is wide spread and the PDRI score histogram is presented in Figure 5.16. The average PDRI score for the 78 building projects was 285 with a standard deviation of 120. The PDRI scores range from 95 to 648. Again, these scores were calculated for each project at the end of design development and should correspond to the end of scope definition.

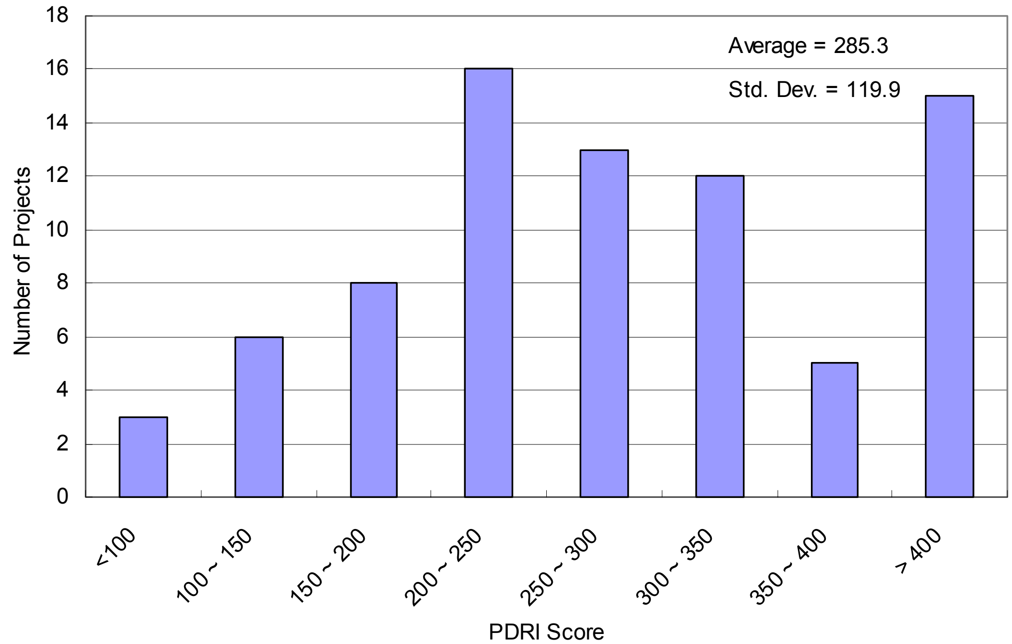


Figure 5.16. Building Project PDRI Score Histogram, N=78

## 5.4. PDRI AND PROJECT SUCCESS

Since one of the primary objectives of this research is to identify if positive relationships exist between project scope definition and project success, a measurement of project success was required. The section outlines the measurement of project success and correlation between PDRI scores and project success.

### 5.4.1. Project Success

Several studies have been conducted to measure project success (Ashley, Jaselskis, & Lurie 1987, Morris & Hough 1987, Freeman & Beale 1992, Gibson & Hamilton 1994, Pinto & Kharabanda 1996, and Tan 1996). The Project

Management Institute devoted the entire annual conference to the topic of measuring project success in 1986 (PMI 1986). There does not seem to be a universally accepted definition or measurement based on published literature. Nevertheless, a mechanism for measuring the success of the sample projects was desired for this research effort. Once the project success was measured and quantified, a bivariate regression analysis can be performed to explore the relationship between the PDRI score and project success.

The project success measurement method used to evaluate the sample projects in this investigation was adopted from previous research by the Construction Industry Institute's Pre-Project Planning Research Team. In their study of the relationship between pre-project planning effort and project success, they examined the success level attained on 53 capital projects and determined that a positive correlation existed between success and the amount of effort expended in pre-project planning. As part of their research, they developed an index for measuring project success based on four performance variables: Budget Achievement, Schedule Achievement, Design Capacity, and Plant Utilization (Gibson and Hamilton 1994).

These four variables were divided into two categories: Project Success variables and Operating Success variables. Budget Achievement and Schedule Achievement were categorized as Project Success variables, while Design Capacity and Plant Utilization were categorized as Operating Success variables. However, the Design Capacity and Plant Utilization are specific measurements for industrial projects and are therefore not applicable to building projects. For consistency, the author decided that only two Project Success variables (Budget Achievement and Schedule Achievement) were used to measure project success (both industrial and building projects) for this research. The definitions for Project Success variables are as follows (Gibson and Hamilton 1994):

**Budget Achievement:** Adherence to the authorized budget, measured by the percent deviation between the actual cost and the authorized cost (for design and construction).

**Schedule Achievement:** Adherence to the authorized schedule for mechanical completion, measured by the percent deviation between the actual project duration and the authorized project duration (for design and construction).

The Pre-Project Planning Research Team determined the relative level of importance of each variable in the success index through interviewing 131 industry representatives. An analysis of their responses indicated that the index variables should be weighted as shown in Table 5.3 (Gibson and Hamilton 1994).

Table 5.3. Success Index Variables and Weights (Gibson and Hamilton 1994)

| **Success Category** | **Variable** | **Variable Wt.** | **Category Wt.** |
|---|---|---|---|
| Project Success | | | 0.60 |
| | Budget Achievement | 0.55 | |
| | Schedule Achievement | 0.45 | |
| Total Variable Weight | | 1.00 | |
| Operating Success | | | 0.40 |
| | Design Capacity | 0.70 | |
| | Plant Utilization | 0.30 | |
| Total Variable Weight | | 1.00 | |
| **Total Category Weight** | | | 1.00 |

Combining the four variables and their corresponding weights yielded an equation for computing the Project Success Rating. The equation is shown as follow (Gibson and Hamilton 1994):

Project Success Rating = 0.60 x [0.55 (Budget Achievement Value) +
0.45 (Schedule Achievement Value)] +
0.40 x [0.70 (Design Capacity Attainment Value) +
0.30 (Plant Utilization Attainment Value)]

As discussed earlier, only Budget Achievement and Schedule Achievement were included in Project Success Ratings for this research. Since only two variables were considered in the success index, for simplicity a weight of 50 percent for each variables was used to represent the importance of these two factors in the success index (even though this may not be indicative of relative value for some projects). A project success index was then calculated by averaging the two variables (budget and schedule achievement). The equation for calculating Project Success Index is as follow:

Project Success Index = 0.50 (Budget Achievement Value) +
0.50 (Schedule Achievement Value)

When several categories are in the data, or the data are continuous in nature, it can become difficult to detect patterns and discover significant relationships. In this case, it may be necessary to combine categories or regroup the data into fewer and larger categories (Abdul-Raheem 1994). For this dissertation research, the large ranges of continuous variables (cost and schedule performance) were uniformly grouped by percentiles and recoded into nominal values ranging from one to five.

Descriptives of cost and schedule performance were examined for the industrial and building projects in order to recode the variables. The variable values were assigned for the projects based on the 20th percentile ranges for their performance. For example, the cost growth for the industrial project ranged from 40 percent below budget to 86 percent over the original budget. Each of the 11 projects within the first 20th percentile (-40% to -10%) was assigned a budget achievement value of five. It should be noted that bringing a project in far under budget is not necessarily a good performance outcome. Each of the 14 projects within the second 20th percentile (-9% to -1%) was assigned a budget achievement value of four. Projects within the third and fourth 20th percentile were assigned values of three and two, respectively. Finally, projects within the last 20 percentile (12% to 86%) were assigned values of one for their budget achievement.

Table 5.4 summarizes the recoded values of budget and schedule achievement for the industrial projects, while Table 5.5 summarizes the recoded values of budget and schedule achievement for the building projects. Performance was measured by determining if the project's final cost and schedule falls in one of the five ranges. The values for each variable obtained using this criterion were then entered into the equation above to compute a Project Success Index for the project. Potential values for the Project Success Index range between one and five, with one indicating the lowest level of success and five indicating the highest level of success.

Table 5.4. Industrial Project Achievement Variable Recoding, N=62

| Variable | Range (20th Percentile) | Recoded Value | No. of Projects |
|---|---|---|---|
| Budget Achievement (Measured against budget) | < -10.0% | 5 | 11 |
| | -10.0% < -1.0% | 4 | 14 |
| | -1.0% < 1.0% | 3 | 12 |
| | 1.0% < 10.0% | 2 | 13 |
| | > 10.0% | 1 | 12 |
| Schedule Achievement (Measured against budget) | < -10.0% | 5 | 12 |
| | -10.0% < -3.0% | 4 | 11 |
| | -3.0% < 4.0% | 3 | 14 |
| | 4.0% < 14.0% | 2 | 13 |
| | > 14.0% | 1 | 12 |

Table 5.5. Building Project Achievement Variable Recoding, N=78

| Variable | Range (20th Percentile) | Recoded Value | No. of Projects |
|---|---|---|---|
| Budget Achievement (Measured against budget) | < 1.6% | 5 | 16 |
| | 1.6% < 5.6% | 4 | 15 |
| | 5.6% < 9.5% | 3 | 16 |
| | 9.5% < 16.7% | 2 | 15 |
| | > 16.7% | 1 | 16 |
| Schedule Achievement (Measured against budget) | < 0.0% | 5 | 20 |
| | 0.0% < 6.3% | 4 | 11 |
| | 6.3% < 13.9% | 3 | 16 |
| | 13.9% < 31.8% | 2 | 15 |
| | > 31.8% | 1 | 16 |

Although the equation for computing a project's success index only includes two criteria for determining a project's level of success, it does give a reliable indication of project performance from a project controls perspective. The equation is both easy to understand and simple to use. In addition, it is relatively easy to obtain the information needed for determining the value of each variable. The rating also provides a good basis for comparing overall performance on various types of industrial and building projects. Note that the rating system was established by comparing the performance within the sample projects. Therefore, caution should be taken for the application of the rating system to projects beyond the sample.

This success index, which is based on cost and schedule performance variables, was used to evaluate the success of the 62 industrial and 78 building projects. For example, an industrial project has a cost growth of 0.5 percent and schedule growth of 13 percent. According to Table 5.4, the Budget Achievement for this particular project is three and Schedule Achievement is two. The success index, which is the average of these two, is 2.5 for this project. The success index, PDRI, cost performance in percent deviation from authorized, and schedule performance in percent deviation from authorized for both industrial and building projects are detailed in Appendix D.

### 5.4.2. Bivariate Correlation and Linear Regression Analysis

A bivariate correlation analysis examines the relationships among pairs of continuous variables (Knoke and Bohrnstedt 1994). The analysis assumes that the form of the relationship between the two variables is linear and that the dependent variable is distributed normally at every level of the independent variable. For this analysis, the dependent variables (industrial and building success indexes) were first tested for normality using SPSS™. The calculated Kolmogorov-Smirnov statistics for both the industrial and building success indexes were significant to the level of 0.05. The null hypothesis of non-normality was thus rejected. However, it should be noted that even when data violate these assumptions, the methods may still be quite robust and will seldom be wrong when making conclusions about statistically significant or insignificant results (Knoke and Bohrnstedt 1994).

The statistical software package SPSS™ was used to conduct the bivariate correlation tests. The independent variables tested in the bivariate analysis are PDRI scores for both industrial and building projects. The dependent variable is the success index. The correlation coefficients (R) between Success Index and

PDRI were -0.442 for industrial projects and -0.568 for building projects. Both correlations are statistically significant at the 0.01 level (2-tailed). The analysis results are based on a procedure that computes the Pearson product-moment and the significance test is based on a two-tailed analysis technique. The absolute value of the correlation coefficient indicates the strength of the linear relationship and the sign indicates the direction of the relationship (SPSS 2000).

To further investigate the relationship between PDRI score and Project Success, linear regression analyses were conducted using SPSS™. Tables 5.6 and 5.7 present a summary of the statistics for the regression analysis associated with ANOVA test results.

Table 5.6. Industrial Project Regression Results

| **Regression Results for PDRI and Project Success** | | |
|---|---|---|
| R = - 0.442 | $R^2$ = 0.195 | Adjusted $R^2$ = 0.182 |

**ANOVA**

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 16.74 | 1 | 40.07 | 14.56 | 3.23E-04 |
| Residual | 68.97 | 60 | 1.15 | | |
| Total | 85.71 | 61 | | | |

Table 5.7. Building Project Regression Results

| Regression Results for PDRI and Project Success | | |
|---|---|---|
| R = - 0.568 | $R^2$ = 0.323 | Adjusted $R^2$ = 0.314 |

**ANOVA**

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 34.99 | 1 | 34.99 | 36.20 | 5.83E-08 |
| Residual | 73.46 | 76 | 0.97 | | |
| Total | 108.45 | 77 | | | |

As can be seen in above tables, the correlations (R) between the project success and PDRI score are -0.442 and -0.568, which can be described as a moderate negative relationship between the two variables. That is, as the PDRI score increases, the Project Success Rating decreases and vice versa. The $R^2$ measures the amount of agreement between the predictor and criterion variables and reflects the accuracy of future predictions. The $R^2$ values of 0.195 for industrial projects and 0.323 for building projects, which are significantly different from zero, indicate that a linear relationship with the PDRI score explain about 19.5/32.3 respectively percent of the sample variance of the project success.

Scatter plots along with best-fit lines of "Success" vs. "PDRI Score" are shown in Figure 5.17 and 5.18 for industrial and building projects, respectively. Least-squared linear regression analyses performed on the plots in Figure 5.17 and 5.18 verify the hypothesis that low (good) PDRI scores correlate to high project success. The solid straight line denotes the linear trend between the two variables: Project Success and PDRI Score. Both linear equations and associated $R^2$ values are presented in the figures.

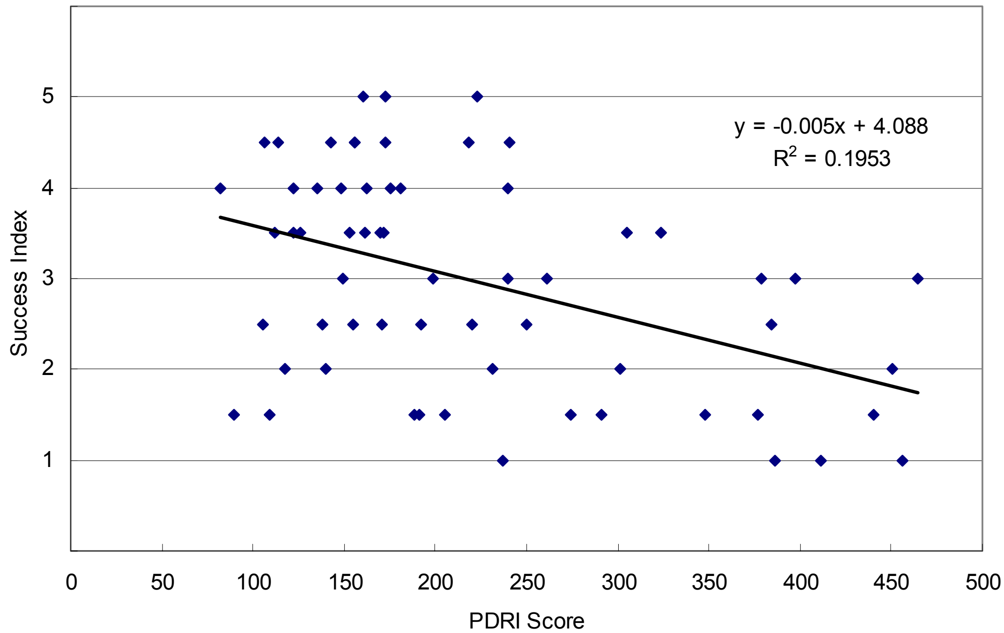


Figure 5.17. Industrial Project Success Index vs. PDRI Score

It is important to remember that many factors other than pre-project planning efforts contribute to project success. The lower correlation for the industrial PDRI score may simply reflect this reality. It should be noted that many factors may influence the project after pre-project planning and therefore, can contribute to cost growth and schedule slippage such as poor contract documents, unforeseen conditions, market conditions, strikes, Acts of God, and so on. The analyses of PDRI scores and performance variables (cost and schedule growth) will be presented in Chapter 7.

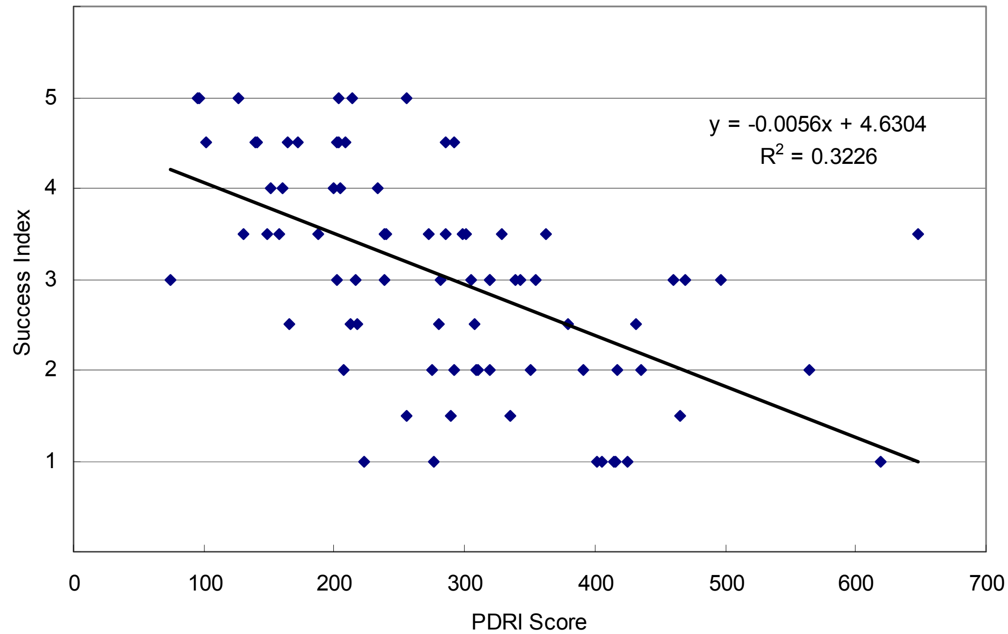


Figure 5.18. Building Project Success Index vs. PDRI Score

## 5.5. FINDINGS RELATED TO RESEARCH HYPOTHESIS

As described in previous sections of this dissertation, a number of different methods were used to collect and analyze data. The PDRI tool itself was developed under the guidance of the CII and had inputs from both industry and academia. Historical performance data were collected from 62 industrial and 78 building projects representing approximately $5 billion in total construction cost. This large amount of data was analyzed using various statistical techniques to validate the PDRI as a viable vehicle that can lead to project success.

The first research hypothesis was established to test where the PDRI is a reliable indicator of project success. In order to test this hypothesis and to find any existing correlation between these two variables (i.e. PDRI Score and Project Success), a mechanism for measuring the project success was developed. The results of the regression analysis using the PDRI scores and the project success measured by success rating index demonstrated a significant correlation for both industrial and building projects and thus supported the first research hypothesis. The PDRI had correlations (R) of negative 0.455 and negative 0.531 for industrial and building projects respectively. This indicates that as the PDRI score decreases, the probability of project success (as indicated by this index) increases.

### 5.6. SUMMARY

The data collected from the sample capital facility projects were presented in this chapter. Several different analysis techniques were used to evaluate the data collected from the 62 industrial and 78 building projects. Descriptive statistics, bivariate correlations, and linear regression analysis were all used in analyzing the data. The cost and schedule performance collected from the survey were used to develop a success rating index for each project. Bivariate correlation analyses were done to identify if PDRI scores were significantly correlated with project success as measured by the success index. For both industrial and building projects, it was found that PDRI scores are significantly correlated with a project success rating index.

The regression analysis also revealed correlations between the project success and the PDRI score. The regression analysis results support the hypothesis that low (good) PDRI score correlates to project success and vice versa.  In the next chapter, results from the institutional organization will be evaluated in more detail.

# Chapter 6 Institutional Organization Project Analysis

The 45 building projects provided by the institutional organization are unique in nature in that these projects were almost identical building construction projects (same functional requirements and similar footprint), they all belonged to one owner organization, they provided more detailed project information, and they were all completed within the past three years. The homogeneous nature of the sample and enhanced quality of information enabled a more in-depth analysis for this unique sample. The analysis results are presented in the following sections. It should be noted that most of the information provided is masked due to concerns of confidentiality by the research sponsor.

The institutional organization had a building program to construct 100 small buildings worldwide within a three-year time-frame. Management wanted the projects to be completed before the year of 2000. A standard building plan was developed for these building projects by the central design office and a typical project has a total area of 10,600 square feet. Once the location of the project is determined, a local architect was hired to adapt the standard plan to meet the site conditions and local building code requirements. The standard plan adaptation was accomplished through collaboration between the local architect and the central design office. Then a local contractor is hired to carry out the plan and construct the building. Similar execution approach was used to build the small building projects.

## 6.1. PROJECT SAMPLE CHARACTERISTICS

The 45 surveyed building projects consisted of 40 small buildings, three large buildings and two work-in-progress small buildings. The authorized cost varied from $2.2 million to $26.7 million, with a total authorized cost of $236.3 million for this project sample. It should be noted that the final cost of these project was approximately $261.4 million. These projects were built in regions such as Latin America, Canada, Australia/Pacific, and within the U.S.

The analyses looked at four specific characteristics: project cost, schedule, change orders, quality and PDRI scores. Table 6.1 provides an overview of project performance characteristics between small and large buildings.

Table 6.1. Institutional Organization Project Summary

| Performance Parameter (Mean) | Small Buildings (n=42) | Large Buildings (n=3) |
|---|---|---|
| Authorized Cost ($million) | 4.2 | 19.1 |
| Authorized Project Duration (month) | 8.9 | 22.1 |
| Cost Growth | 16.4% | 2.0% |
| Schedule Growth | 23.0% | 4.6% |
| Change Order Cost (% of budget cost) | 15.6% | 3.3% |

### 6.1.1. Construction Cost

The *authorized project costs* range from $2.2 million to $26.7 million for all 45 projects with an average project cost of $19.1 million for large building projects, $4.8 million for two work-in-progress small buildings and $4.1 million for the other small building projects. Given square footage of each project, the unit cost per square foot information (authorized unit cost, actual unit cost, actual plus first year alteration unit cost) is summarized in Table 6.2. Note that all units are normalized to mask actual cost per square foot.

Table 6.2. Unit Cost Comparison (Authorized, Actual, After 1st Year)

| | **Authorized** | **Actual** | | **After 1st Year** | |
|---|---|---|---|---|---|
| **Project Type** | **Unit Cost** | **Unit Cost** | **% Change from Auth.** | **Unit Cost** | **% Change from Auth.** |
| **Large Building (N=3)** | | | | | |
| **Domestic Average** | **3.9** | **4.0** | **+ 2.2%** | **4.0** | **+ 2.2%** |
| **Small Building (N=40)** | | | | | |
| Australia/Pacific (4) | 5.0 | 5.5 | + 10.7% | 5.6 | + 12.9% |
| Canada (4) | 3.9 | 4.3 | + 10.0% | 4.4 | + 12.2% |
| Domestic (19) | 4.0 | 4.4 | + 10.7% | 4.6 | + 13.8% |
| Latin America (13) | 3.6 | 4.5 | + 26.5% | 4.6 | + 28.5% |
| **Small Building Avg.** | **4.0** | **4.6** | **+ 15.3%** | **4.7** | **+ 17.8%** |
| **Work-in-Progress (N=2)** | | | | | |
| **Domestic Average** | **3.6** | **4.4** | **+ 23.1%** | **N/A** | **N/A** |
| **Overall Average** | ***3.9*** | ***4.5*** | ***+ 14.7%*** | ***4.6*** | ***+ 17.0%*** |

By examining the overall cost performances (budgeted vs. actual), the large building projects have better average cost growth (only 2.2 percent) while the small building and work-in-progress projects have average cost growth of 15.3 percent and 23.1 percent respectively versus authorized. Among them, the worst cases are in the Latin America region with an average cost growth of 26.5 percent, including three projects with growths of 54 percent, 53 percent and 50 percent. Alteration costs within the first year after project completion were included for the analysis as well. The results show that an average of 2.2 percent of authorized project cost was expended for alterations within the first year of project completion. Figure 6.1 breaks down all building projects into different regions and shows cost growths in different regions.

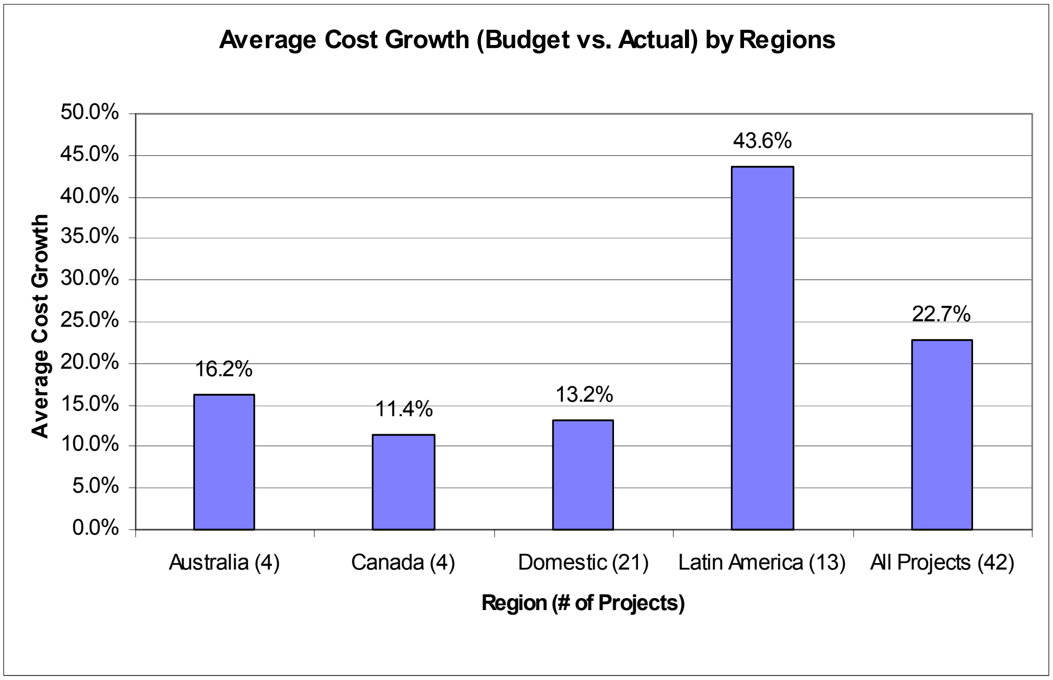


Figure 6.1. Average Cost Growth in Different Regions

### 6.1.2. Construction Schedule

For small building projects, the average schedule growth was 26 percent above the authorized schedule. The worst case was in Latin America where one project had a schedule growth of 83.1 percent while one domestic project came in 24.8 percent *ahead of* the scheduled completion estimate. Large building projects had better schedule growth (averaged 4.6 percent behind schedule) versus projected when compared to small building projects. Figure 6.2 shows average schedule growth in different regions for the sample.

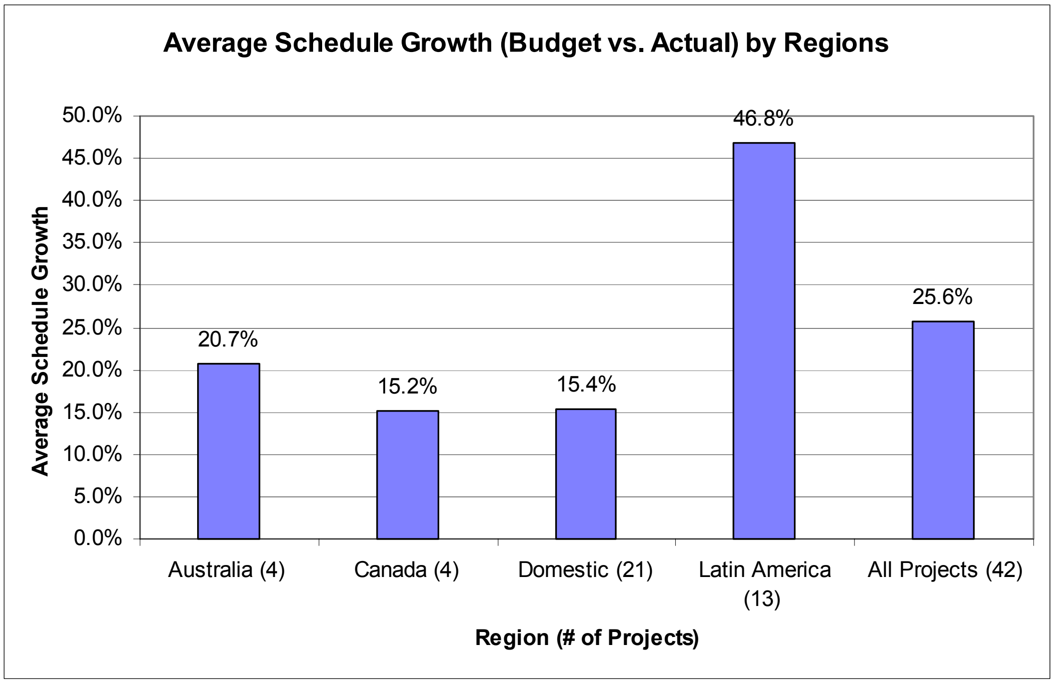


Figure 6.2. Average Schedule Growth in Different Regions

Similar to the results of cost analysis presented previously, the Latin America region was the worst performing region among the four (almost three times worse on average than the others). Analysis of the questionnaire indicated two main reasons contributing to the poor performances in the Latin America region:

1. *Poor site adaptation*. The standard plan was translated and converted to the local building code by a local architect. Often times, the site adaptation prepared by the local architect was poorly done and errors and omissions were found. Some buildings started construction while the local architect thought that the design was 80 percent complete but as it turned out that, according to the project manager, the design was only 50 percent to 60 percent complete. This seemed to be the main reason for poor cost and schedule growth. This also led to the large change order costs as identified in the next section.
2. *Inability of contractor to perform*. Poor contractor performance was another contributing factor to the poor performance of Latin America projects. In some cases, the contractor could not perform the tasks to meet the owner's requirement or the local material and equipment failed to meet owner's specifications. In some cases, American workers were brought in to finish the job and material and equipment were imported from America to finish the project.

Figure 6.3 shows the average total project time (from project announcement to substantial completion) for small building projects in different regions. The total project time ranges from 16 months for Domestic projects to 19 months for Australia/Pacific projects. The average total project time for 42 small building projects is 17 months. Table 6.3 further breaks the total project time into pre-construction time (project announcement to construction start) and construction time (construction start to substantial completion).

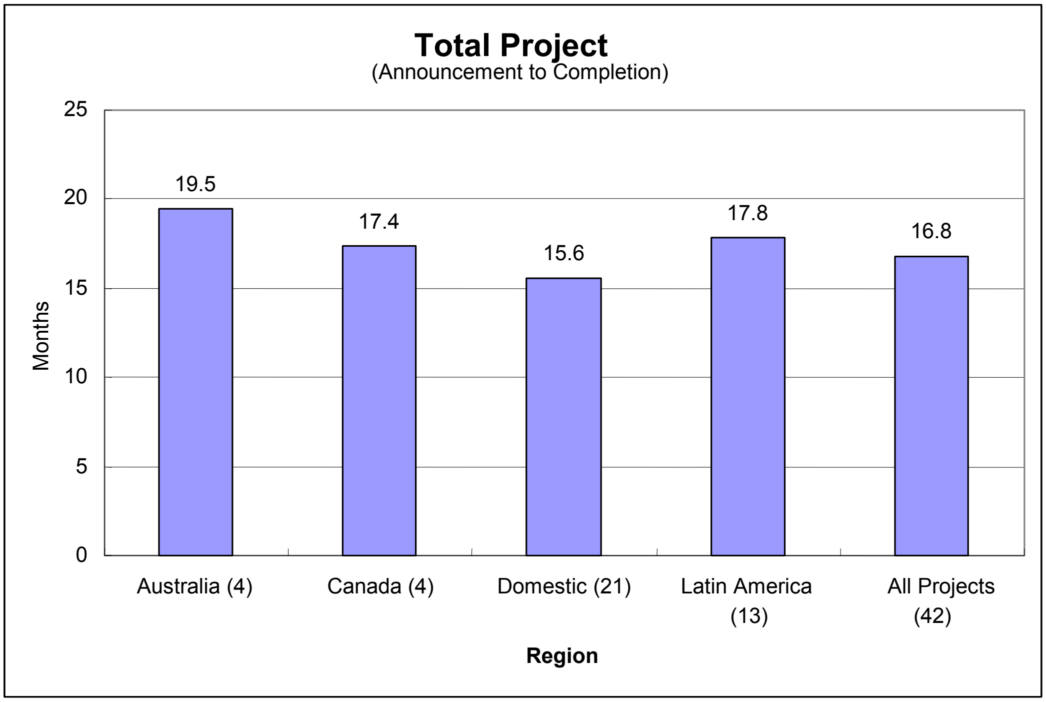


Figure 6.3. Total Project Time for Small Building Projects

Table 6.3. Small Building Project Time Breakdown

| | Pre-Construction Time | Construction Time | Total Time | Cost Performance |
|---|---|---|---|---|
| Australia/Pacific | 8.3 mos. | 11.2 mos. | 19.5 mos. | 10.7% |
| Canada | 6.2 mos. | 11.2 mos. | 17.4 mos. | 10.0% |
| Domestic | 5.9 mos. | 9.7 mos. | 15.6 mos. | 10.7% |
| Latin America | 4.7 mos. | 13.1 mos. | 17.8 mos. | 26.5% |

Australia/Pacific region has the longest pre-construction time of 8.3 months and Latin America has the shortest pre-construction time of 4.7 months. By examining the project performance and the pre-construction time, it was found that Australia/Pacific projects (longer pre-construction time) have better cost performance than Latin America projects (shorter pre-construction time). If longer pre-construction time can be translated to more pre-project planning efforts, it is recommended more time and efforts should be spent in pre-construction process. Although Australia/Pacific projects have longer pre-construction time, the project construction time is shorter than Latin America projects that spent less time in pre-construction. In summary, the total time was similar for all international projects and consistently longer than domestic projects.

### 6.1.3. Change Orders

Change orders are fairly common in construction and often times have negative impact on both schedule and cost performance of a project. On average in this sample, change orders increased the small building project schedule by 58 days (with an average schedule duration of 266 days) translating to 21.7 percent more than the original schedule duration. Among the small building projects, an average of 77 change orders occurred during construction and accounted for an average total of $0.6 MM (15.6 percent of authorized cost) in cost growth. Although the large building projects had more change orders, 173 on average, during construction, they accounted for a smaller percentage of total construction cost, 3.3 percent of total cost or $0.6 MM on average. In addition, 69 percent of all the projects had at least one change order that accounted for more than one percent of the total budgeted cost. Table 6.4 further breaks down change order costs into different regions for small building projects:

Table 6.4. Change Orders (COs) Information for Small Building Projects

| Item Average | Australia / Pacific | Canada | Domestic | Latin America | Total Average |
|---|---|---|---|---|---|
| Number of COs | 61 | 97 | 84 | 63 | 77 |
| Cost Increase by COs | 548 | 430 | 432 | 1,034 | 651 |
| % to Budgeted Cost | 10.3% | 10.2% | 10.3% | 27.5% | 15.6% |
| Days Delay by COs | 58 | 45 | 38 | 94 | 58 |
| % to Budgeted Schedule | 20.7% | 15.2% | 14.9% | 35.1% | 21.7% |
| % of Projects that have CO Cost over 1% of Budgeted Cost | 50% | 25% | 58% | 77% | 64% |

Table 6.4 shows that the number of change orders is not highly related to cost increases or schedule delays by change orders. The worst performing region was still Latin America, which had an average change order cost increase of 1,034 (27.5 percent of budgeted project cost), and project schedule extensions of 94 days (35.1 percent of budged schedule).

Three out of the four regions had greater than 50 percent of projects with at least one change order that accounted for more than one percent of the authorized cost. These "big" change orders should be and can be avoided with better pre-project planning. When asked for the reasons of these "big" change orders, 12 out of 23 (52 percent) of the responses stated that these change orders were requested from the home office. Further investigation of these changes may provide project lessons learned. Figure 6.4 breaks down the change order costs (percent of budget) into eight categories. Among them, field architect and home office request seem to contribute to most of the change order cost.

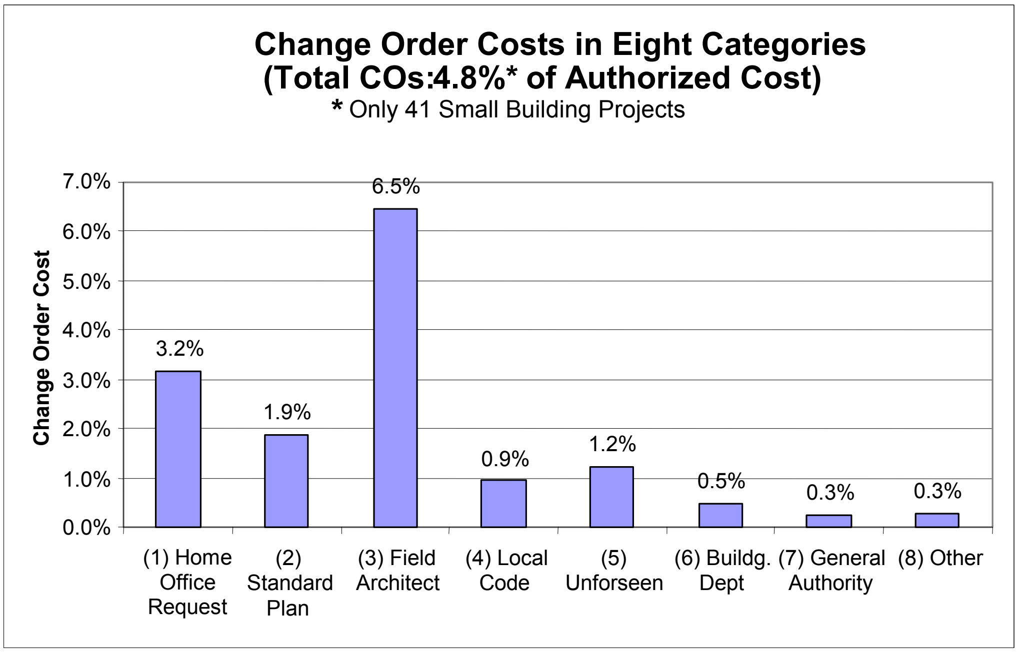


Figure 6.4. Detailed Change Order Costs in Eight Category

By looking further into the causes of change orders, the change order costs can be grouped into eight categories: Home Office Request, Standard Plan, Field Architect, Local Code, Unforeseen, Building Department, General Authority, and Other. Among them, Standard Plan, Field Architect, Local Code, Unforeseen and Building Department can be broadly viewed as pre-project planning related causes for change orders, which means that these issues can (and typically should) be dealt with in the pre-project planning stage. Looking at the small projects providing data, Figure 6.5 indicates that average change order costs account for approximately 15 percent of estimated cost. Within this 15 percent, approximately 11 percent of the cost is due to pre-project planning related change order costs. These changes added approximately a total of $18.5 million to the 41 projects.

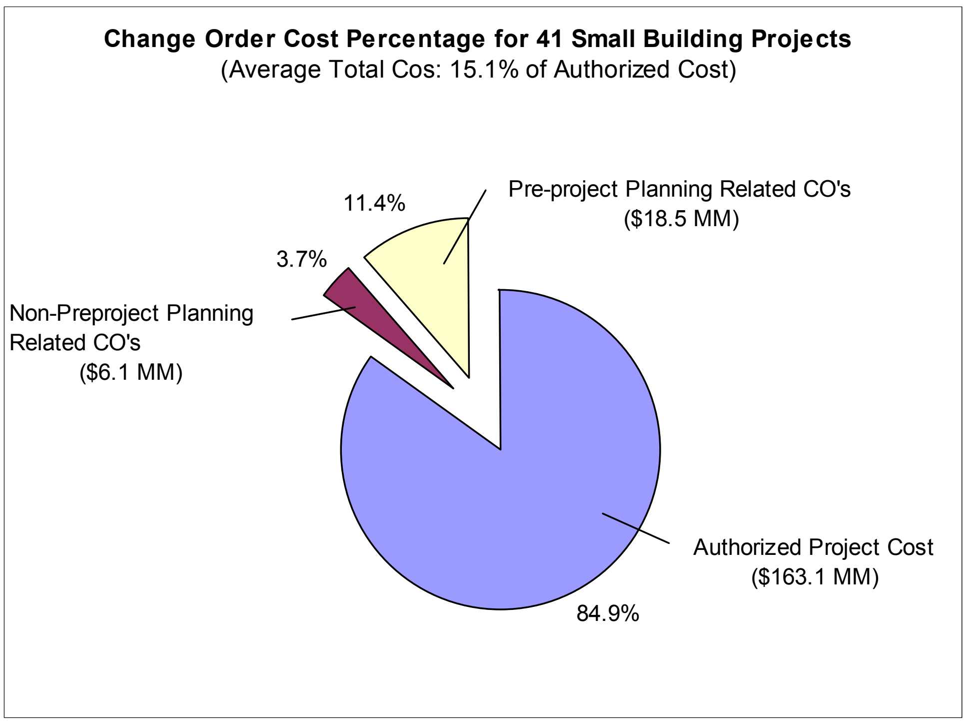


Figure 6.5. Change Order Cost Percentage

### 6.1.4. Quality

The best quality measure is customer satisfaction, in this case, building user's satisfaction. Users were asked to rate the overall smoothness of the project delivery on a Likert scale of 1 to 5, 1 being very difficult and 5 being very smooth. Fifty-five percent of the user respondents indicated that the overall smoothness of the project delivery was level 3, which means not so good and not so bad. Another 29 percent of the users rated the overall smoothness at level 2, which was less than satisfactory. Eighty-eight percent of the users therefore rated the overall project delivery smoothness, from their perspective, equal to or below level 3 and the total average on overall project "smoothness" was 2.7. This shows that the users were not satisfied with the project delivery process. At the same time, results from project manager's survey show that project managers gave the projects an average of 4.4, (using a Likert scale of 1 to 5 with 1 meaning very unsuccessful and 5 meaning very successful) when asking about how the project managers felt about the success of the project. Figure 6.6 shows the survey question and responses from project managers and users.

**User Survey**

Q: Reflecting on the overall project, rate how smoothly the project has proceeded from design to turnover, with 1 being very troubled to 5 being very smooth

| **Smoothness Level** | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Count | 3 | 11 | 23 | 2 | 0 |
| **Average** | | **2.7** | | | |

**PM Survey**

Q: Reflecting on the overall project, rate how successful you feel the project has been using a scale of 1 to 5, with 1 being very unsuccessful to 5 being very successful

| **Quality Level** | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Count | 0 | 0 | 3 | 14 | 28 |
| **Average** | | | | **4.6** | |

Figure 6.6. PM vs. User Quality Survey

The difference between user's and project manager's rating on project quality (4.4 to 2.7) indicates that those two have different sets of criteria concerning the quality of a project. It is apparent that project managers are satisfied with the outcome quality of the projects while the users have quite the opposite experience with the process. The best solution may be to have more user-input into the project from the early stage of the project life. The survey also indicated that users had little involvement during construction and only 13 percent of users were involved in program definition and scope development.

Another possible quality measure is to account for alteration within the first year of operation. Alteration costs occurring within the first year can be deemed as a sign of poor quality of the project delivery process. The survey results showed that 31 out of 39 (79 percent) of small building projects had alterations within the first year (three projects did not report). The alteration costs averaged 3.2 percent of budget per project and totaled $5.2 million. In addition, some of the small building projects are still anticipating more alteration costs. One major reason for this is lack of user participation in the project delivery process. Many alterations are user requested and perhaps can be avoided with more user input early in the process.

### 6.1.5. PDRI Scores

As discussed previously, the Project Definition Rating Index (PDRI) is a weighted scope definition package checklist in score sheet format. Project managers were asked (after the fact) to fill out the score sheet based on a point in time just prior to development of construction documents for their projects. The project managers evaluated the level of definition of each element and the total scores were calculated by the researchers at The University of Texas. One domestic large building project had the best PDRI score of 199 while the worst

PDRI score, 619, was from a small building project in Latin America. The average PDRI score for all projects surveyed was 346. The average PDRI scores for different regions are shown in Figure 6.7. Projects can be grouped into four geographic regions: Australia/Pacific, Canada, Domestic, and Latin America as shown in Figure 6.7.

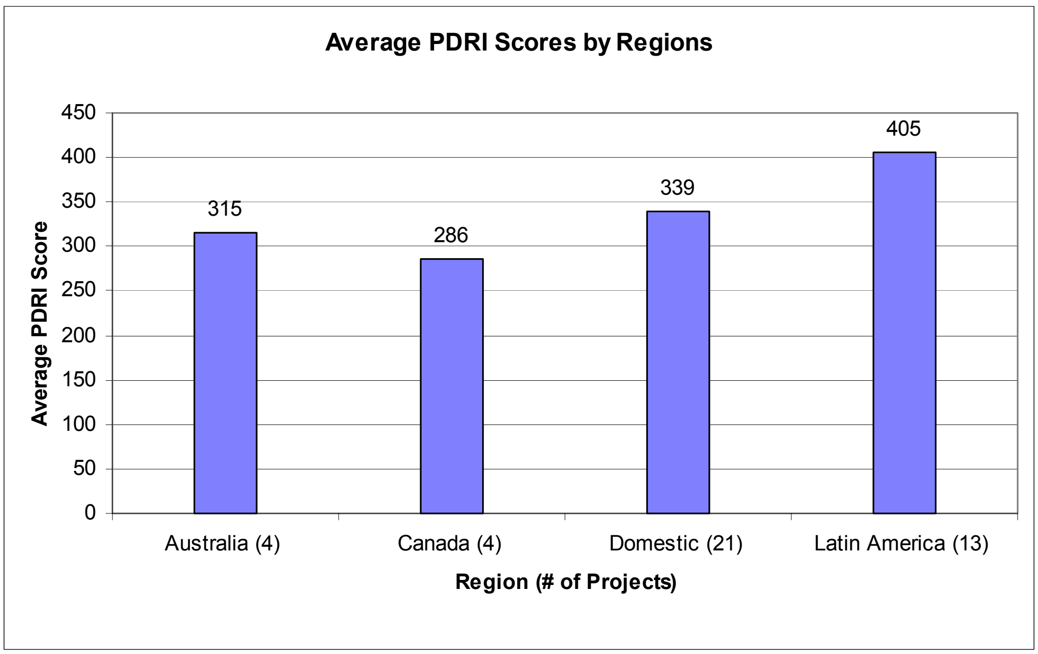


Figure 6.7. Average PDRI Scores in Different Region

## 6.2. PDRI SCORE EVALUATION

Overall PDRI scores were presented in previous sections and following sections will look further into the relationship between PDRI scores and project performance. A cutoff PDRI score will be determined to compare the performance between the projects. In addition, performance measures will be analyzed for the 45 building projects. Previous CII building projects will be used to compare with the institutional organization projects.

### 6.2.1. PDRI Score vs. Project Performance

Previously PDRI research indicated that a score of 200 or below (lower score is better) was a good indicator of a well-defined project (CII 1999). Analysis of the institutional organization project data has revealed a significant difference in performance between the sample projects scoring above 300 and the projects scoring below 300 prior to development of construction documents, as shown in Table 6.5. Several cutoff points (from 250 to 400) were evaluated to determine if there was significant statistical difference in performance between the two groups. It was found that a PDRI score of 300 for this sample was a good dividing line for differing statistical significance and contained a reasonable number of projects in both sub-samples. Variation data for the sample projects are given in Table 6.6. Cost growth is the mean percentage change in actual cost (contingency not included) and schedule growth is compared to that estimated prior to development of construction documents. The reported change order value represents the cost increase during design and construction due to change orders.

Table 6.5. Summary of Cost, Schedule, and Change Order Performance for the Building Projects Using a 300-point Cutoff

| Category | PDRI Score < 300 | PDRI Score > 300 | Difference |
|---|---|---|---|
| Cost Growth | 11% above budget | 18% above budget | 7% |
| Schedule Growth | 13% behind schedule | 26% behind schedule | 13% |
| Change Orders | +9% of budget | +18% of budget | 9% |
| User Satisfaction | 2.6<br>(1-5, 5: very satisfied) | 2.7<br>(1-5, 5: very satisfied) | 0.1 |
| | (N=15) | (N=30) | |

**Note:** all difference values were statistically significant to the level of 0.05 except for user satisfaction.

Table 6.6. Summary of Cost, Schedule, and Change Order Variation for the Building Projects Using a 300-Point Cutoff

| | PDRI Score < 300 | | PDRI Score >300 | |
|---|---|---|---|---|
| Category | Range | Std. Dev. | Range | Std. Dev. |
| Cost Growth | -1% to +37% | 10% | +2% to +54% | 15% |
| Schedule Growth | -25% to +45% | 19% | -2% to +83% | 24% |
| Change Orders | +2% to +22% | 6% | +2% to +55% | 15% |
| User Satisfaction | 1 to 3 | 0.69 | 1 to 5 | 0.84 |
| | (N=15) | | (N=30) | |

In summary, the sample projects scoring below 300 outperformed those scoring above 300 in three important areas: cost growth, schedule growth, and the relative value of change orders compared to budget. In addition to cost and schedule differences, the projects scoring less than 300 had lower percentage of projects having single change orders more than 1 percent of total budget cost as shown in Table 6.7.

Table 6.7. Summary of Percentage of Building Projects Having At Least One Change Order >1% of Project Cost Using a 300-Point Cutoff

| **Performance** | **PDRI Score** < 300 | **PDRI Score** > 300 |
|---|---|---|
| Average PDRI Score | 262 | 388 |
| Percentage of Projects with a Single Change Order > 1% of Budget Cost | 53% | 73% |
| | (N=15) | (N=30) |

In addition to the 45 building projects from this sub-sample, a total of 33 projects were added into the database for analysis from the earlier CII study. Table 6.8 and Table 6.9 show the analysis summary for the combined data. These 33 building projects (office, warehouse, laboratory facilities, schools, etc.) had authorized costs ranging from $0.7 million to $200 million and were from 10 CII owner organizations. The performance for the projects with PDRI scores above 300 does not change very much (less than 2 percent) comparing to the earlier analysis. This is because only 2 projects in the added database scored 300 or above. Nevertheless, the combined projects with PDRI scores less than 300 had much better performance than institutional projects (5 percent reduction in cost growth and 4 percent reduction in schedule growth). The results indicate that there is also opportunity for improvement for this institutional organization projects with PDRI scores under 300.

Table 6.8. Summary of Cost, Schedule, and Change Order Performance for ALL Projects Using a 300-point Cutoff

| Category | PDRI Score | | Difference |
|---|---|---|---|
| | **< 300** | **> 300** | |
| Cost Growth | 6% above budget | 17% above budget | 11% |
| Schedule Growth | 9% beyond schedule | 25% beyond schedule | 16% |
| Change Orders | +9% of budget | +17% of budget | 8% |
| | (N=46) | (N=32) | |

**Note:** all difference values were statistically significant to the level of 0.05 except for user satisfaction.

Table 6.9. Summary of Cost, Schedule, and Change Order Variation for ALL Projects Using a 300-point Cutoff

| Category | PDRI Score < 300 | | PDRI Score >300 | |
|---|---|---|---|---|
| | **Range** | **Std. Dev.** | **Range** | **Std. Dev.** |
| Cost Growth | -22% to +37% | 12% | +2% to +55% | 14% |
| Schedule Growth | -25% to +89% | 19% | -2% to +83% | 23% |
| Change Orders | +1% to +61% | 10% | +2% to +55% | 15% |
| Average PDRI | 207 (N=46) | | 398 (N=32) | |

Table 6.10 shows a comparison of the institutional sample to the CII database. Among the 33 CII building projects surveyed, 16 projects had PDRI scores under 200 with average cost growth of one percent above budget, schedule growth of two percent behind schedule and change orders of seven percent of budget. Only one building project from the institutional organization had score

under 200 and the average building project performance falls far above the average from the CII sample. It should be noted again that the CII sample is made of a diverse set of projects.

Table 6.10. Comparison between CII Projects PDRI Score <200 and Institutional Projects PDRI Score <300 and PDRI Score >300

| Category | PDRI Score | | |
|---|---|---|---|
| | **CII Projects < 200** | **Institutional Projects<300** | **Institutional Projects>300** |
| Cost Growth | 1% above budget | 11% above budget | 18% above budget |
| Schedule Growth | 2% behind schedule | 13% behind schedule | 30% beyond schedule |
| Change Orders | 7% of budget | 9% of budget | 18% of budget |
| | N=16 | N=15 | N=30 |

### 6.2.2. Unit Cost Analysis

Forty-two out of the 45 projects from the institutional organization were almost identical small building projects. When these buildings were constructed in different regions, a standard plan was utilized by the local architect for site adaptation. Based on the standard plan, the local architect was able to come up with a design that met the local building codes. The standard plan had to be adapted to the site conditions for different lots acquired by the institutional organization. The close similarity of these projects offers a unique opportunity to conduct an direct, value-based comparison for these projects.

As discussed in the previous section, a PDRI score of 300 was determined to be a good cutoff point for these sample projects. The authorized unit cost and actual unit cost were calculated for this sample and are summarized in Table 6.11.

Note that the unit cost was obtained by dividing the total building area (square feet) by the cost (U.S.D.).

Table 6.11. Unit Cost Comparison for All 42 Building Projects

| Average Unit Cost for Small Building Projects, N=42 | | | | | | |
|---|---|---|---|---|---|---|
| | PDRI Score < 300 N=13 | | PDRI Score > 300 N=29 | | All 42 Projects | |
| | Budgeted | Actual | Budgeted | Actual | Budgeted | Actual |
| **Average Unit Cost** | $402 | $451 | $390 | $457 | $393 | $455 |

The average unit cost after substantial completion for all 42 small building projects was $455 while the average unit cost authorized (estimated) at the beginning of the project was $393. Only 13 out of the 42 projects (31%) actually had final actual costs lower than $393. This might suggest that the authorized unit cost set by the institutional organization was too low. That is, the small building budgets were probably underestimated. In the mean time, projects with higher PDRI score cost an average of $457 per square foot to build while the projects with lower PDRI score cost $451 per square foot to build. This indicates that projects with better scope definition cost $6 ($457 – $451) per square foot less to construct and this can translate to a saving of $63,984 per building ($6 per square foot x 10,664 s.f.). That is, with an average building size of 10,664 square feet, projects with better scope definition costs approximately $64,000 less to build than projects with poor scope definition. If the 29 projects with higher PDRI scores could improve their scope definition, a potential total cost savings of approximately $1.9 MM (29 projects x $6 per square foot x 10,664 s.f. per building) could have been achieved. Note that this analysis does not control for regional location and the difference between the actual average costs is not statistically significant for two groups of projects. Therefore, caution should be taken when interpreting the analysis results.

As mentioned earlier, these small building projects were constructed in four different regions: Canada, U.S., Latin America, and Australia/Pacific. In order to differentiate the effect that regions may have on the unit cost, projects in North America (Canada and U.S.) were selected for similar unit cost analysis. A total of 25 small building projects were selected and the unit cost analysis for these projects was summarized in Table 6.12. Note that 22 out of the 25 projects had a footprint of 10,700 square feet, two projects had a footprint of 6,800 square feet and one project had a footprint of 16,000 square feet.

Table 6.12. Unit Cost Comparison for North America Building Projects

| **Average Unit Cost for North America Small Building Projects, N=25** | | | | | | |
|---|---|---|---|---|---|---|
| | PDRI Score < 300 N=11 | | PDRI Score > 300 N=14 | | All 25 Projects | |
| | Budgeted | Actual | Budgeted | Actual | Budgeted | Actual |
| **Average Unit Cost** | $382 | $433 | $408 | $449 | $396 | $442 |

The average actual unit cost for the 25 North America building projects was $442 per square foot while the budgeted unit cost was $396 per square foot. Again, the results show signs of underestimating as can be seen from the previous analysis. From Table 6.12, projects with better (lower) PDRI scores had an average actual cost of $433 per square foot while projects with poor (higher)

PDRI scores had an average actual cost of $449. The difference of $16 ($449 – 433) per square foot can be viewed as the results of improved scope. However, this difference is not statistically significant.

If the scope definition of a project were improved, a potential cost saving of $16 per square foot can be achieved. That is, the actual unit cost can be brought down from $449 per square foot to $433 per square foot. This cost saving can be translated to a total of $169,300 ($16 per square foot x 10,584 square feet) for these projects in North America. Research conducted by CII has indicated that approximately two percent of total project cost is spent on pre-project planning for building projects (CII 2002). For this project sample, approximately $93,600 ($442 per square foot x 10,584 square feet x 2%) per project should have been spent on effective pre-project planning according to the CII research results. In turn, the benefit/cost ratio for pre-project planning can be estimated. By dividing the cost of pre-project planning ($93,600) from the potential cost saving ($169,300), a benefit/cost ratio of 1.8 was obtained.

The mean actual cost per square foot for 17 international projects was $474 and the authorized unit cost was $389. Among the 17 projects, only two had a PDRI score of 300 or below. Therefore, the international projects were not analyzed. Again, the data show signs of poor estimation.

### 6.3. SUMMARY

This chapter presented the descriptive statistics of the institutional organization project sample and the analyses of PDRI versus project performance. General results showed that sample projects were suffering from poor scope definition and had poor cost and schedule performance. Further analysis showed that projects with better scope definition outperformed projects with poor scope definition. The unique sample also provided the opportunity for unit cost comparison analysis. Two conclusions were obtained from this sample project analyses:

1. Improved predictability of cost performance can be expected with better scope definition
2. Improved scope definition leads to real project cost savings

It should be noted that despite the repetitious nature of this particular building sample, no significant "learning effects" were observed when comparing the project performance through the three-year period. That is, the performance of projects built later in the three-year period is not significantly better than the performance of projects built earlier. The rationale behind this might be that only the home office had repetitive tasks when building these almost identical building projects and home office did not improve through time. Different local architects and contractors were hired to complete the projects and thus no learning effects occurred.

# Chapter 7 Risk Identification through PDRI Characteristics

The next phase of the research approach is focused on trends in pre-project planning, especially on specific scope elements that are not well-defined in surveyed projects. The data collected from the actual projects represented past practices and were used for analyzing the characteristics and trends of scope definition levels. This chapter covers the identification of poorly defined PDRI scope elements for both industrial and building projects and the examination of their relationship with project cost and schedule performance.

As discussed in Section 5.3, pre-assigned element weights were applied to survey responses in order to obtain a final PDRI score. The sample project PDRI score characteristics were described in Section 5.3 as well. In this chapter, original survey responses using only definition levels were used for analysis. By doing so, the trend of actual project scope definition can be analyzed without the bias of pre-assigned weights. This chapter presents a summary of the PDRI definition level characteristics and relationships between project performance and element definition levels.

## 7.1. Scope Definition Level Characteristics

The industrial PDRI contains 70 scope definition elements which are grouped into 15 categories and further grouped into three sections. Similarly, the building PDRI has 62 scope definition elements which are grouped into 11 categories and further grouped into three sections. Eight out of the 62 surveyed industrial projects did not provide sufficient information on detailed scope definition levels (i.e. they only provide rollup PDRI scores); therefore, only 54 industrial projects were analyzed for scope definition level characteristics. All 78 building projects were included in this definition level analysis. Please refer to Chapter 2 for PDRI elements definition level/weights and illustration of scoring PDRI. The following two sections summarize the PDRI element definition level characteristics for industrial and building projects.

### 7.1.1. Industrial Project Definition Level Characteristics

Each PDRI scope definition element has five definition levels with definition level 1 standing for complete definition, 2 for minor deficiencies, 3 for some deficiencies, 4 for major deficiencies and 5 for incomplete or poor definition. If the scope element is not applicable to the project, the respondent was asked to check definition level 0, which does not affect the total PDRI score. After receiving the survey responses, definition levels were averaged and total number of projects was counted for each of the 70 scope elements in the industrial PDRI or 64 elements for building projects. Appendix E summarizes the descriptive statistics of both industrial and building PDRI scope definition levels.

First, the PDRI scope element definition levels were examined to determine which elements were not well-defined for the 54 industrial projects. The mean definition levels were calculated for the 70 scope elements and then compared with each other. The 70 scope elements were sorted according to their mean definition levels and Table 7.1 presents a list of 15 scope definition elements with mean definition levels greater than 2.5 (which corresponds to some deficiencies). This list identifies scope elements that were poorly defined by the surveyed 54 industrial projects.

From the list, the worst-defined scope element (highest mean definition level) is element K2: Logic Diagrams. Logic diagrams provide a method of depicting interlock and sequencing systems for the startup, operation, alarm, and shutdown of equipment and processes (CII 1996). Twenty-seven (50%) out of the 54 sample projects indicated scope definition for element K2: Logic Diagrams was either incomplete or poorly defined (definition level 5).

Table 7.1. Worst Definition Level Averages for Industrial Projects

| **Definition Level Average from 54 Industrial Projects** | |
|---|---|
| *Definition Level Average Larger than 2.5* | |
| K2. Logic Diagrams | 3.1 |
| G13. Instrument Index | 2.9 |
| P5. Start Up Requirements | 2.8 |
| G11. Tie-in List | 2.8 |
| G12. Piping Special Item List | 2.8 |
| G10. Line List | 2.8 |
| P4. Pre-Commissioning Turnover Sequence Requirements | 2.7 |
| K6. Instrument & Electrical Specifications | 2.6 |
| N3. Risk Analysis | 2.6 |
| I1. Civil/Structural Requirements | 2.6 |
| E3. Design for Constructability Analysis | 2.6 |
| P6. Training Requirements | 2.5 |
| G3. Piping & Instrumentation Diagrams | 2.5 |
| G7. Piping System Requirements | 2.5 |

Six out of the 13 elements in Category G, Process/Mechanical, have definition level averages greater than 2.5. Similarly, 50% (3 out of 6) of the elements in Category P, Project Execution Plan, are poorly-defined. The results indicate that for this sample improvements were needed in scope definitions relating to Process/Mechanical and Project Execution Plan.

Another way to identify the worst defined scope elements is to identify scope elements with most "level 5" definitions. Definition level 5 indicates that the scope element is either incomplete or poorly defined. Table 7.2 shows a list of scope definition elements with most projects choosing definition level 5. Not surprisingly, K2: Logic Diagrams, was among the scope elements that were poorly defined by most sample projects (27 projects). Twenty projects had scope definition level 5 for scope element N3: Risk Analysis. The average scope definition for N3: Risk Analysis is 2.6, and this showed that these industrial projects were not doing as well in defining the Risk Analysis for their projects. Comparing Table 7.1 with Table 7.2, six elements have more than 10 projects evaluating them as definition level 5 (Table 7.2) but have an average definition level lower than 2.5 (Table 7.1). These elements were L3: Procurement Responsibility Matrix, M3: Distribution Matrix, D1: Project Objective Statement, E1: Process Simplification, E2: Design & Material Alterations Considered/Rejected, and P3: Shut Down/Turn-Around Requirements. One explanation for this would be that most of the sample projects did well in defining these elements while only a few projects did poorly in defining these elements.

Table 7.2. Scope Elements with Most Level 5 Definitions for Industrial Projects

| **Top 10 Industrial Elements with Most Level 5 Definitions** | |
|---|---|
| K2. Logic Diagrams | 27 |
| N3. Risk Analysis | 20 |
| L3. Procurement Responsibility Matrix | 18 |
| M3. Distribution Matrix | 14 |
| D1. Project Objective Statement | 12 |
| E1. Process Simplification | 12 |
| E2. Design & Material Alterations Considered/Rejected | 11 |
| G13. Instrument Index | 11 |
| P3. Shut Down/Turn-Around Requirements | 11 |
| P4. Pre-Commissioning Turnover Sequence Requirements | 11 |

From Table 7.1 and Table 7.2, it is shown that, in general, the sample projects needed to improve in defining scope elements relating to instrument & electrical, process/mechanical, project control and value engineering.

After reviewing scope elements that were poorly-defined by the sample projects, Table 7.3 lists scope elements with average definition levels lower than 2.0. Definition level 2 means that the scope definition only has minor deficiencies for this particular scope element. These elements are considered well-defined. Scope element F1: Site Location had an average scope definition level of 1.0, which means that all projects had completely defined the geographical location of the proposed project. The other well-defined scope element is B1: Products. This scope element deals with a list of products to be manufactured and their specifications and it should address items such as chemical composition, physical form, raw materials, allowable impurities, by-products, and wastes (CII 1996). Generally, these industrial projects did well in scope elements relating to site information, technology, business objectives, and project scope.

Table 7.3. Best Definition Level Averages for Industrial Projects

| **Definition Level Average from 54 Industrial Projects** | |
|---|---|
| *Definition Level Average Lower than 2.0* | |
| G9. Mechanical Equipment List | 1.9 |
| B3. Project Strategy | 1.9 |
| K3. Electrical Area Classifications | 1.9 |
| F4. Permit Requirements | 1.9 |
| D1. Project Objective Statements | 1.9 |
| E1. Process Simplification | 1.9 |
| F2. Surveys & Soil Tests | 1.9 |
| E2. Design & Material Alterations Considered/Rejected | 1.8 |
| M1. CADD/Model Requirements | 1.8 |
| K4. Substation Requirements Power Source Identification | 1.8 |
| J3. Transportation Requirements | 1.8 |
| B2. Market Strategy | 1.7 |
| G8. Plot Plan | 1.7 |
| G2. Heat & Material Balances | 1.7 |
| F3. Environmental Assessment | 1.7 |
| C2. Processes | 1.7 |
| G1. Process Flow Sheets | 1.6 |
| C1. Technology | 1.6 |
| L1. Identify Long Lead/Critical Equipments & Materials | 1.6 |
| B5. Capacities | 1.5 |
| D6. Project Schedule | 1.5 |
| D3. Site Characteristics Available and Required | 1.5 |
| B1. Products | 1.4 |
| F1. Site Location | 1.0 |

Table 7.4 identifies a list of 10 scope elements with the most projects choosing definition level 1. As mentioned earlier, scope element F1: Site Location had all responses rating definition level 1 (except four projects indicated not applicable for this scope element). It should be noted that 11 projects rated

E2: Design & Material Alterations Considered/Rejected as poorly-defined (definition level 5) while 42 projects rated E2 as completely defined (definition level 1). This indicated that the majority of the sample projects had a structured approach in place to consider design and material alternatives. The low definition level average of Scope element L1 indicated that most sample projects did well in defining scope elements relating to procurement strategy in during their pre-project planning process.

Table 7.4. Scope Elements with Most Level 1 Definitions for Industrial Projects

| **Top 10 Industrial Projects with Most Level 1 Definitions** | |
|---|---|
| F1. Site Location | 50 |
| D3. Site Characteristics Available & Required | 47 |
| D6. Project Schedule | 46 |
| E2. Design & Material Alterations Considered/Rejected | 43 |
| D1. Project Objective Statement | 42 |
| E1. Process Simplification | 42 |
| M3. Distribution Matrix | 40 |
| L3. Procurement Responsibility Matrix | 36 |
| L1. Identify Long Lead/Critical Equipment & Materials | 35 |
| J3. Transportation Requirement | 34 |

As shown in Tables 7.3 and 7.4, scope elements relating to site information, technology, business objectives, procurement strategy, and project scope were better defined according to the survey results from the 54 industrial projects.

### 7.1.2. Building Project Definition Level Characteristics

Similar to the PDRI for industrial projects, PDRI for building projects has 64 scope elements and each scope definition element has five definition levels with definition level 1 standing for complete definition, 2 for minor deficiencies, 3 for some deficiencies, 4 for major deficiencies and 5 for incomplete or poor definition. If this scope element is not applicable to the project, the respondent was asked to check definition level 0, which does not affect the total PDRI score. After receiving the survey responses, definition levels were averaged and then sorted to examine the level of pre-project planning for the surveyed 78 building projects. Appendix E summarizes the descriptive statistics of both industrial and building PDRI scope definition levels.

Table 7.5 illustrates a list of poorly-defined scope definition elements with average definition levels greater than 2.5. From the list, the most poorly-defined scope element (highest definition level average) for the 78 surveyed building projects is element E1: Program Statement. The Program Statement identifies the levels of the performance of the facility in terms of space planning and functional relationships. It should address the human, physical, and external aspects to be considered in the design (CII 1999). Category C deals with Project Requirements, and 4 out of the 6 elements in category C are on the list (poorly-defined). These four elements are C1: Value-Analysis Process, C4: Scope of Work Overview, C5: Project Schedule, and C6: Project Cost Estimate.

Surprisingly, project cost estimate and project schedule were among the poorly-defined elements as well. Normally, these two scope elements are assumed to be the basic requirements for project management. However, the survey results showed that the sample project participants did not focus as much on these two scope elements as perceived. The fact that limited time and resource availability might contribute to this.

Table 7.5. Worst Definition Level Averages for Building Projects

| **Definition Level Average from 78 Building Projects** | |
|---|---|
| *Definition Level Average Larger than 2.5* | |
| E1. Program Statement | 3.4 |
| A8. Project Objective Statement | 3.0 |
| C4. Scope of Work Overview | 3.0 |
| C6. Project Cost Estimate | 2.8 |
| C1. Value-Analysis Process | 2.7 |
| F7. Constructability Analysis | 2.7 |
| C5. Project Schedule | 2.7 |
| F4. Mechanical Design | 2.6 |
| E11. Room Data Sheets | 2.5 |

The scope definition elements with most projects choosing definition level 5 from the 78 building projects were identified and listed in Table 7.6. A definition level of 5 means the scope element is either incomplete or poorly defined. Not surprisingly, E1: Program Statement was the scope element that was poorly-defined by most sample projects. Comparing Table 7.5 with Table 7.6, the results were consistent. This means that certain scope elements are poorly defined by most of the surveyed building projects.

Table 7.6. Scope Elements with Most Level 5 Definitions for Building Projects

| Top 10 Building Projects with Most Level 5 Definitions | |
|---|---|
| E1. Program Statement | 30 |
| A8. Project Objective Statement | 17 |
| C1. Value-Analysis | 12 |
| C4. Scope of Work Overview | 11 |
| F4. Mechanical Design | 11 |
| F5. Electrical Design | 11 |
| F7. Constructability Analysis | 11 |
| J2. Documentation/Deliverables | 11 |
| E12. Furnishings, Equipments, and Built-ins | 9 |
| C6. Project Cost Estimate | 8 |

From Table 7.5 and Table 7.6, it is shown that, in general, the sample projects needed to improve in defining scope elements relating to project requirements, building programming, and building/project design parameters.

Although industrial and building sectors are two different sectors, it is interesting to find that the survey results showed that Project Objective Statement and Value Analysis are among the worst-defined scope elements for both building and industrial sample projects.

After reviewing scope elements that were poorly-defined by the sample building projects, Table 7.7 listed scope elements with average definition levels lower than 2.0. Definition level 2 means that the scope definition only has minor deficiencies for this particular scope element. These elements are considered well-defined. Generally, these building projects did well for scope elements relating to business strategy, site information, building programming, and project execution planning. It is important to note that in general, building projects did well in defining scope elements relating to Category E: Building Programming, except elements E1: Program Statement and E11: Room Data Sheet.

Table 7.7. Best Definition Level Averages for Building Projects

| **Definition Level Average from 78 Building Projects** | |
|---|---|
| *Definition Level Average Lower than 2.0* | |
| E5. Growth and Phased Development | 1.9 |
| E4. Stacking Diagrams | 1.9 |
| L5. Substantial Completion Requirements | 1.9 |
| B4. Design Philosophy | 1.9 |
| D8. Special Water and Waste Treatment Requirements | 1.9 |
| D1. Site Layout | 1.8 |
| E3. Overall Adjacency Diagrams | 1.8 |
| K1. Project Quality Assurance and Control | 1.7 |
| A4. Economic Analysis | 1.7 |
| A5. Facility Requirements | 1.7 |
| F6. Building Life Safety Requirements | 1.7 |
| J1. CADD/Model Requirements | 1.7 |
| B1. Reliability Philosophy | 1.7 |
| E6. Circulation and Open Space Requirements | 1.7 |
| E7. Functional Relationship Diagrams / Room by Room | 1.6 |
| E9. Transportation Requirements | 1.6 |
| D3. Civil/Geotechnical Information | 1.6 |
| L2. Owner Approval Requirements | 1.6 |
| L1. Project Organization | 1.6 |
| D7. Site Life Safety Considerations | 1.6 |
| A7. Site Selection Considerations | 1.6 |
| E8. Loading/Unloading/Storage Facilities Requirements | 1.6 |
| C3. Evaluation of Existing Facilities | 1.6 |
| D5. Environmental Assessment | 1.6 |
| A3. Business Plan | 1.5 |
| D4. Governing Regulatory Requirements | 1.5 |
| K5. Safety Procedures | 1.5 |
| D2. Site Surveys | 1.4 |
| A1. Building Use | 1.3 |
| A2. Business Justification | 1.3 |

Similar to Table 7.6, Table 7.8 identifies a list of 10 scope elements with most projects choosing definition level 1. Generally, Category A: Business Strategy was the best-defined scope category among the 11 PDRI categories for the 78 building projects. However, element A8: Project Objectives Statement was poorly-defined in many sample building projects. From Tables 7.7 and 7.8, it can be seen that scope elements relating to business strategy, site information, and building programming were better-defined for the 78 building projects.

Table 7.8. Scope Elements with Most Level 1 Definitions for Building Projects

| **Top 10 Building Projects with Most Level 1 Definitions** | |
|---|---|
| A1. Building Use | 63 |
| A2. Business Justification | 59 |
| K5. Safety Procedures | 52 |
| D2. Site Surveys | 50 |
| A3. Business Plan | 49 |
| L2. Owner Approval Requirement | 49 |
| D4. Governing Regulatory Requirements | 48 |
| E6. Circulation and Open Space Requirements | 48 |
| L1. Project Organization | 48 |
| A7. Site Selection Considerations | 47 |

## 7.2. IDENTIFYING RISK THROUGH PDRI

The previous sections examined general PDRI definition level characteristics from the survey data. Well and poorly-defined scope elements were identified for the sample projects. The results showed the general practice of scope definition level for the surveyed sample projects. The next step is to use the surveyed information to assist in identifying potential project risks during the pre-project planning phase. Al-Bahar and Crandall (1990) defined risk identification as the process of systematically and continuously identifying, categorizing, and assessing the significance of risks associated with a project. Two approaches can be used to identify potential project risk through the application of PDRI. The first approach is using the pre-assigned scope element weights as a reference for evaluating their potential impact on the project outcome. The second approach is to examine the historical project data and the project performance (actual project impacts) and identify scope elements that distinguish between successful and less-than-successful projects (based on cost and schedule performance). The following two sections outline the two approaches and examples are given for both applications.

### 7.2.1. Risk Identification through PDRI Element Weights

One obvious way to identify project risk with the PDRI is using the pre-assigned element weights during the pre-project planning evaluation process. During the development of the PDRI, higher weights were to be assigned to those elements whose lack of definition could have the most serious negative effect on project performance (CII 1996 and CII 1999). The pre-assigned weights were developed through a series of workshops to gather inputs from a broad range of construction industry experts. If that element was incomplete or poorly defined based on the description (definition level 5), the workshop participants were instructed to assess what percent contingency they would deem appropriate for that element. Therefore, it is logical to use the pre-assigned PDRI score as an indicator of potential risk impact for a particular scope element.

PDRI element weight development and how to conduct PDRI scoring were discussed in Chapter 2. For illustration purpose, Section I – Category A of the PDRI for building projects (both elements and their weights) is shown in Figure 7.1. Hypothetical PDRI scope definition level evaluations are circled in the figure as well.

| **SECTION I - BASIS OF PROJECT DECISION** | | | | | | | |
|---|---|---|---|---|---|---|---|
| CATEGORY<br>Element | **Definition Level** | | | | | | **Score** |
| | **0** | **1** | **2** | **3** | **4** | **5** | |
| A. BUSINESS STRATEGY (Maximum = 214) | | | | | | | |
| A1. Building Use | 0 | 1 | (12) | 23 | 33 | 44 | 12 |
| A2. Business Justification | 0 | (1) | 8 | 14 | 21 | 27 | 1 |
| A3. Business Plan | 0 | 2 | (8) | 14 | 20 | 26 | 8 |
| A4. Economic Analysis | 0 | 2 | 6 | (11) | 16 | 21 | 11 |
| A5. Facility Requirements | 0 | 2 | 9 | 16 | (23) | 31 | 23 |
| A6. Future Expansion/Alteration Considerations | 0 | 1 | 7 | 12 | (17) | 22 | 17 |
| A7. Site Selection Considerations | 0 | (1) | 8 | 15 | 21 | 28 | 1 |
| A8. Project Objectives Statement | 0 | 1 | 4 | 8 | 11 | (15) | 15 |

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

Figure 7.1. Buildings PDRI Category A

From Figure 7.1, the element with the highest score from the hypothetical evaluation is A5: Facility Requirements. For this particular scope element, the definition level chosen by the project team is four, which means there are major deficiencies in the scope definition for this element, and the corresponding weight for this element at definition level four is 23. Thus, the element A5 has a score of 23 for this project's PDRI evaluation. The scope definition for Element A8 is poor or incomplete and the PDRI score of A8 is 15. According to the element weights and PDRI scores, the performance impact of poorly-defined element A5, with definition level 4 of and weight of 23, might be larger than element A8, with definition level 5 and weight of 15.

A project team can quickly assess their potential project risk exposures by identifying scope elements with higher PDRI scores, since higher PDRI score indicates potential larger impact to project performance. In this hypothetical case, the element with highest score in Category A is element A5: Facility Requirement. Element A6: Future Expansion/Alteration Considerations has the second highest score and element A8: Project Objective Statement has the third highest. From the PDRI evaluation, these three elements (A5, A6, and A8) might potentially have greater negative impact on project outcome based on their PDRI scores. Therefore, these elements might pose greater risk comparing to other elements with lower PDRI scores. By examining the element PDRI scores, the project team can identify potential risk factors that might have negative impact to project performance and then take measures to better-define the scope elements to reduce potential risks exposures.

Table 7.9 summarizes the top 15 scope elements with highest level 5 definition weights for both industrial and building PDRI. These elements, if poorly-defined, could result in greater impact to project outcome and therefore, should be treated with more attention.

Table 7.9. Top 15 Elements with Highest Definition Level 5 Weights

| **INDUSTRIAL PDRI**<br>Element | Level 5<br>Weight |
|---|---|
| B1. Products | 56 |
| B5. Capacities | 55 |
| C1. Technology | 54 |
| C2. Process | 40 |
| G1. Process Flow Sheets | 36 |
| F1. Site Location | 32 |
| G3. Piping and Instrumentation Diagrams (P&ID's) | 31 |
| D3. Site Characteristics Available vs. Required | 29 |
| B2. Market Strategy | 26 |
| D1. Project Objective Statement | 25 |
| B3. Project Strategy | 23 |
| G2. Heat and Material Balance | 23 |
| D2. Project Design Criteria | 22 |
| F3. Environmental Assessment | 21 |
| A1. Reliability Philosophy | 20 |
| **BUILDING PDRI**<br>Element | Level 5<br>Weight |
| A1. Building Use | 44 |
| A5. Facility Requirement | 31 |
| A7. Site Selection Considerations | 28 |
| A2. Business Justification | 27 |
| C6. Project Cost Estimate | 27 |
| A3. Business Plan | 26 |
| C2. Project Design Criteria | 24 |
| C3. Evaluation of Existing Facilities | 24 |
| A6. Future Expansion / Alteration Considerations | 22 |
| F3. Architectural Design | 22 |
| A4. Economic Analysis | 21 |
| E2. Building Summary Space List | 21 |
| C5. Project Schedule | 20 |
| F4. Mechanical Design | 20 |
| B4. Design Philosophy | 19 |

Although the building and industrial projects are uniquely different in nature, there exists similar risk factors when evaluating the scope definitions. These aspects are site considerations, project design criteria, economic analysis, and mechanical considerations (Cho 1999).

To further investigate the potential impact of PDRI score on project performance, projects were grouped by their PDRI scores and average cost/schedule performance was compared. Previous PDRI research has statistically shown that projects with a PDRI score of 200 or lower outperformed projects scoring above 200. Table 7.10 shows the mean project performance for all the sample projects with PDRI score of 200 or below, and those projects with a PDRI score above 200. From the results, it is evident that projects with lower PDRI scores (better scope definition) outperform those with higher PDRI scores (poor scope definition) for both industrial and building projects in terms of estimate predictability.

Table 7.10. Summary of Mean Project Performance Using a 200-point Cutoff

| Category | PDRI Score < 200 | PDRI Score > 200 | Difference |
|---|---|---|---|
| **Industrial Projects** | | | |
| Cost Growth | 2.6% below budget | 9.3% above budget | 11.9% |
| Schedule Growth | 0.6% ahead of schedule | 8.0% behind schedule | 8.6% |
| PDRI Score | 147 (N=35) | 317 (N=27) | 170 |
| **Building Projects** | | | |
| Cost Growth | 2.6% below budget | 12.9% above budget | 15.5% |
| Schedule Growth | 2.7% ahead of schedule | 20.9% behind schedule | 23.6% |
| PDRI Score | 142 (N=17) | 325 (N=61) | 183 |

### 7.2.2. Risk Identification through Historical Data

Another approach to identify project risk through the PDRI is to examine the historical project data and compare the results with the current project. In order to do so, previous projects were first divided into two groups, successful and less-than-successful projects, based on their performance (cost and schedule). Then, the element scope definition level means for these two groups of projects were calculated and compared with each other. In addition to traditional statistical significance tests (i.e., *t*-test), Effect Size was measured to compare the difference between the mean definition levels for the two groups. As discussed in Chapter 4, the equation for calculating Effect Size is as follow:

$$Effect\ Size = \frac{Mean\ of\ Group\ 1 - Mean\ of\ Group\ 2}{Pooled\ Standard\ Deviation}$$

where Pooled Standard Deviation is calculated from:

$$SD_{Pooled} = \sqrt{\frac{(N_1 - 1)SD_1^2 + (N_2 - 1)SD_2^2}{(N_1 + N_2 - 2)}}$$

Using the above equations, the Effect Size was calculated for the 78 building projects. First, the building projects were divided into two groups based on their cost performance. The first cost performance group had 11 projects with cost underruns under 0% and the second group had 67 projects with cost growth above 0%. The definition level average and standard deviation were calculated for each scope element. Then the Effect Size was obtained using the above equations. For illustration purpose, Table 7.11 summarizes the Effect Size for the scope elements in building PDRI Category A: Business Strategy.

Table 7.11. Effect Size for Building PDRI Category A, example

| Category A: Business Strategy<br>Element | Mean<br>Difference* | Effect<br>Size* |
|---|---|---|
| A1. Building Use | 0.2 | 0.2 |
| A2. Business Justification | 0.0 | 0.0 |
| A3. Business Plan | -0.1 | -0.1 |
| A4. Economic Analysis | -0.2 | -0.2 |
| A5. Facility Requirements | 0.1 | 0.1 |
| A6. Future Expansion/Alteration Considerations | 0.3 | 0.3 |
| A7. Site Selection Considerations | 0.2 | 0.3 |
| A8. Project Objectives Statement | 1.5 | 1.0 |
| * Mean Difference and Effect Size were obtained by comparing two cost groups | | |

As an example, the Effect Size obtained from historic project data in Table 7.11 shows that the difference of definition level averages between the two cost performance groups was significant (greater than 0.80) for element A8: Project Objective Statement. This implies that, historically, projects with better cost performance did better in defining element A8 than projects with poor cost performance. Therefore, element A8: Project Objective Statement might serve as a cost risk indicator based on information collected from this sample. The project team should pay additional attention in defining this scope element in order to reduce the potential risk exposures if the element was poorly-defined.

Similarly, scope elements with effect size greater than 0.80 were identified for both building and industrial projects. Tables 7.12 and 7.13 summarize these scope elements (potential risk indicators) based on their schedule and cost performance, respectively. Note that no indicators were determined for schedule in the building project sample.

Table 7.12. Elements with Large Effect Size Based on Schedule Performance

| Building Projects (N1=20, N2=58)<br>Element | Mean Difference* | Effect Size* |
|---|---|---|
| N/A | | |
| | | |
| **Industrial Projects (N1=30, N2=24)<br>Element** | **Mean Difference*** | **Effect Size*** |
| A3. Operating Philosophy | 0.9 | 0.9 |
| G4. Process Safety Management (PSM) | 1.1 | 1.0 |
| G5. Utility Flow Diagrams | 0.9 | 0.9 |
| G7. Piping System Requirements | 1.2 | 1.1 |
| G13. Instrument Index | 1.1 | 0.8 |
| K1. Control Philosophy | 0.7 | 0.8 |
| K6. Instrument & Electrical Specifications | 0.9 | 0.8 |
| * Mean Difference and Effect Size were obtained by comparing two schedule groups | | |

The results show that differences between successful and less-than-successful building projects are not significant when the projects are divided based on schedule performance (ahead of schedule and behind schedule). When the industrial projects were grouped based on schedule performance, these scope elements (A3, G4, G5, G7, G13, K1, K6) with effect size larger than 0.80 can be regarded as performance indicators. That is, according to this sample, projects with better schedule performance did better in defining these scope elements.

Table 7.13. Elements with Large Effect Size Based on Cost Performance

| Building Projects (N1=11, N2=67) Element | Mean Difference* | Effect Size* |
|---|---|---|
| A8. Project Objectives Statement | 1.5 | 1.0 |
| B2. Maintenance Philosophy | 0.9 | 0.8 |
| B4. Design Philosophy | 0.7 | 0.8 |
| E1. Program Statement | 2.0 | 1.4 |
| E2. Building Summary Space List | 1.1 | 1.0 |
| E11. Room Data Sheets | 1.0 | 0.8 |
| E13. Window Treatment | 1.3 | 1.0 |
| F2. Architectural Design | 1.0 | 0.9 |
| F4. Mechanical Design | 1.2 | 1.0 |
| F5. Electric Design | 1.1 | 0.9 |
| F7. Constructability Analysis | 1.6 | 1.3 |
| H1. Identify Long-Lead/Critical Equipment and Materials | 1.1 | 0.9 |
| H2. Procurement Procedures and Plans | 1.0 | 0.8 |
| J2. Documentation/Deliverables | 1.3 | 0.9 |
| L3. Project Delivery Method | 1.0 | 0.8 |
| **Industrial Projects (N1=25, N2=29) Element** | **Mean Difference*** | **Effect Size*** |
| A1. Reliability Philosophy | 0.8 | 0.8 |
| A2. Maintenance Philosophy | 1.2 | 1.3 |
| A3. Operating Philosophy | 0.8 | 0.8 |
| B6. Future Expansion Considerations | 0.9 | 0.9 |
| B7. Expected Project Life Cycle | 1.4 | 1.2 |
| B8. Social Issues | 1.1 | 0.9 |
| D2. Project Design Criteria | 0.9 | 1.1 |
| D4. Dismantling and Demolition Requirements | 0.9 | 0.8 |
| F2. Surveys and Soil Tests | 0.7 | 1.0 |
| G4. Process Safety Management (PSM) | 1.2 | 1.2 |
| G5. Utility Flow Diagrams | 0.9 | 0.9 |
| G7. Piping System Requirements | 1.2 | 1.1 |
| G10. Line List | 1.2 | 0.9 |
| G11. Tie-In List | 1.2 | 0.9 |
| G12. Piping Specialty Items List | 1.2 | 0.8 |
| H2. Equipment Location Drawings | 0.8 | 0.9 |
| J2. Location/Uploading/Storage Facilities Requirements | 0.8 | 0.8 |
| P4. Pre-Commission Turnover Sequence Requirements | 1.2 | 0.8 |

* Mean Difference and Effect Size were obtained by comparing two cost groups

When grouped by cost performance, scope elements with an effect size larger than 0.80 were found for both industrial and building projects. The cost performance indicators for building projects are scope elements A8, B2, B4, E1, E2, E11, E13, F2, F4, F5, F7, H1, H2, J2, and L3. The cost performance indicators for industrial projects are: A2, A3, B6, B7, B8, D2, D4, F3, G4, G5, G7, G10, G11, G12, H2, J2, and P4.

For industrial projects, elements A3: Operating Philosophy, G4: Process Safety Management (PSM), G5: Utility Flow Diagrams, and G7: Piping System Requirements had large Effect Size both in cost and schedule performance evaluations. This indicates that the definition level average differences are significant for these four elements based on historic data and projects with successful outcomes (both cost and schedule performance) did a better job defining these elements than less-than-successful projects.

If the identified scope elements were not well-defined, the project is more likely to have a less-than-successful project performance (cost/schedule growth). Based on historical data, these elements should be viewed as potential risk indicators and deserve more attention for future project scope development. It should be noted that *t*-test results showed that the mean differences for these elements are statistically significant to the *p*-level of 0.01.

### 7.3. FINDINGS RELATED TO RESEARCH HYPOTHESIS

One of the objectives of this research is to identify performance risk indicators through PDRI analysis. Special attention was given to historical project data analysis. In the previous section, PDRI elements were identified as performance risk indicators by applying the Effect Size analysis. In order to investigate the legitimacy of these scope elements, mean project performance were calculated for each definition level. From Table 7.13, scope element A1, Reliability Philosophy, was identified as one of the cost performance indicator for industrial projects. Mean cost performance was taken for all projects with definition level 1 for scope element A1. Similarly, mean cost performances were calculated for projects with definition level 2, 3, 4 and 5 for scope element A1. The average cost growth was negative 1.6 percent for level 1 projects and 19.1 percent for level 4 projects. The results indicate that if scope element A1, Reliability Philosophy, were better-defined, it is more likely the industrial project will have a better cost performance than projects having poorly-defined scope element A1.

Following the same fashion, mean performances for selected scope elements (from Tables 7.12 and 7.13) were calculated for illustrative purpose for both industrial and building projects. The results are summarized in Tables 7.14 and 7.15.

Table 7.14. Mean Cost Performance Comparison for Cost Indicators

| Scope Element | Effect Size | No. of Projects | Average Cost Growth |
|---|---|---|---|
| **Industrial Projects** | | | |
| A1. Reliability Philosophy | 0.8 | | |
| Level 1 | | 16 | -1.6% |
| Level 2 | | 18 | 1.2% |
| Level 3 | | 11 | 7.2% |
| Level 4 | | 6 | 19.1% |
| Level 5 | | 1 | 2.3% |
| A2. Maintenance Philosophy | 1.3 | | |
| Level 1 | | 15 | -5.4% |
| Level 2 | | 20 | 1.4% |
| Level 3 | | 10 | 10.9% |
| Level 4 | | 7 | 20.9% |
| Level 5 | | 1 | 2.3% |
| F2. Surveys and Soil Tests | 1.0 | | |
| Level 1 | | 20 | -1.3% |
| Level 2 | | 16 | 6.9% |
| Level 3 | | 11 | 5.6% |
| Level 4 | | 1 | 14.6% |
| Level 5 | | 0 | |
| **Building Projects** | | | |
| A8. Project Objective Statement | 1.0 | | |
| Level 1 | | 20 | 4.1% |
| Level 2 | | 12 | 3.9% |
| Level 3 | | 8 | 11.1% |
| Level 4 | | 17 | 19.1% |
| Level 5 | | 17 | 16.2% |
| E1. Program Statement | 1.4 | | |
| Level 1 | | 14 | 0.8% |
| Level 2 | | 12 | 9.6% |
| Level 3 | | 5 | 6.5% |
| Level 4 | | 13 | 12.4% |
| Level 5 | | 30 | 17.0% |
| F5. Electrical Design | 0.9 | | |
| Level 1 | | 21 | 3.7% |
| Level 2 | | 29 | 8.6% |
| Level 3 | | 14 | 12.6% |
| Level 4 | | 2 | 28.7% |
| Level 5 | | 11 | 23.0% |

Table 7.15. Mean Cost Performance Comparison for Schedule Indicators

| Scope Element | Effect Size | No. of Projects | Average Schedule Growth |
|---|---|---|---|
| **Industrial Projects** | | | |
| A3. Operating Philosophy | 0.9 | | |
| Level 1 | | 15 | -2.5% |
| Level 2 | | 19 | 0.3% |
| Level 3 | | 12 | 7.1% |
| Level 4 | | 4 | 26.7% |
| Level 5 | | 2 | 15.7% |
| G4. Process Safety Management | 1.0 | | |
| Level 1 | | 16 | -1.1% |
| Level 2 | | 14 | 0.0% |
| Level 3 | | 12 | 6.5% |
| Level 4 | | 4 | 9.2% |
| Level 5 | | 3 | 35.2% |
| K1. Control Philosophy | 0.8 | | |
| Level 1 | | 14 | -3.4% |
| Level 2 | | 24 | 4.2% |
| Level 3 | | 13 | 8.9% |
| Level 4 | | 2 | 8.9% |
| Level 5 | | 1 | 7.7% |

From Tables 7.14 and 7.15, it is apparent that projects (both industrial and building) that did well in defining these elements outperformed those that did poorly in defining these elements. Note that Table 7.15 only contains industrial projects because no schedule performance indicator was identified for building projects according to the effective size analysis.

The second research hypothesis was established to test whether the PDRI is a reliable indicator of potential risk factors. The results of the effect size analysis using the historical project data and average project performance comparison demonstrates a significant relationship between certain scope elements and project performance and thus supports the second research hypothesis.

## 7.4. SUMMARY

This chapter examined the PDRI characteristics and related them to construction project risk identification process. First, the PDRI survey results were examined and element definition level averages were calculated. Poorly-defined scope definition elements were identified for both the building and industrial project samples. In addition, better-defined PDRI elements were identified. The results show that the Project Objective Statement and Value Analysis were among the most poorly-defined elements for both building and industrial projects.

Projects were divided into two groups based on their cost and schedule performance. The PDRI scope element definition level averages were calculated. Within each performance group, both better-defined elements and poorly-defined elements were identified. The results showed that projects with less-than-successful performance did worse in defining specific scope elements than successful projects.

Two approaches were explored to identify potential project risk through PDRI. The first approach tries to identify potential risk factors by comparing the pre-assigned level 5 definition weight. During the development of the PDRI, weights were assigned to each element to represent the relative potential impacts to project outcome based on the inputs from industry experts. In turn, the larger the weight for the level 5 definition, the larger the potential impact the element might have on the final project outcome. If these elements were not well-defined, the project is more likely to have less-than-successful outcomes.

Furthermore, an analysis of project performance using a 200-point cutoff PDRI score revealed that projects with lower PDRI scores (better scope definition) outperformed projects with higher PDRI scores (poor scope definition).

The second approach identified potential risk factors based on historic project data. The definition level averages were compared between the two performance groups and elements with significant average definition level differences were identified. These elements were viewed as potential performance indicators since historically they are better-defined in successful projects.

The results of these two approaches were compared and it was found that risk factors identified by historic data were different than those identified by PDRI weights. The results did not contradict one another per se because for that risk elements with high PDRI weights were recognized by industry practitioners and therefore, were oftentimes better defined. Therefore, the results from historical data analyses supplement the results from PDRI weights by identifying risk factors not generally recognized by the industry practitioners.

After risk identification, the next step in a risk management process is to quantify the potential risk impact. Chapter 8 outlines the development of risk quantification models and describes risk control procedures based on the model results.

# Chapter 8 Risk Quantification and Control through PDRI

The previous chapter presented two approaches to risk identification using the PDRI. The two approaches utilized different methods to identify the PDRI scope elements that have the greatest potential impact on project outcomes for the samples. This chapter outlines the development and application of three models for the data collected (linear regression, quartile analysis, and Hackney's method). Modeling refers to the development of mathematical expressions that describe in some sense the behavior of a random variable of interest (Rawlings, 1988). One major objective of this research is to describe project cost/schedule performance with information provided by PDRI scores. The chapter begins with a brief overview of the proposed models used to describe the cost and schedule performance data. By applying the proposed models, potential cost and schedule performance impacts were determined based on obtained PDRI scores. Possible risk control measures to reduce risk impact will be discussed and a risk management process using PDRI will be presented and also its application will be presented. Detailed project cost and completion time information is given in Appendix F.

## 8.1. MODEL DEVELOPMENT APPROACH

As previously discussed, the PDRI can be used as an effective tool for risk identification during the pre-project planning phase of the project life cycle. Information collected from the survey and previous research was used to establish models to describe the data. Three approaches were implemented to model the data: linear regression, quartile analysis, and Hackney's historic accuracy range method. Both industrial and building project data were used for the model development and models were developed specifically for cost and schedule performance. Two other methods, Bayesian Statistics and Artificial Neural Networks, were tried unsuccessfully for this sample.

### 8.1.1. Linear Regression Model

Regression, as one of many mathematically-based techniques available in statistical theory used to analyze relationships between variables, is a powerful quantitative research tool as described in Chapter 3. Regression analysis was used as the preliminary investigations of the relationships between the PDRI scores and cost/schedule performance. Individual project PDRI score, cost and schedule performance are provided in Appendix D for both industrial and building projects.

**Cost Performance Regression Analysis**

With cost growth as dependent variable and PDRI score as independent variable, bivariate linear regression analysis was performed for the industrial and building projects and the relationships shown in Figures 8.1 and 8.2 were revealed. Again, cost growth is the actual cost of the project for design and construction versus the cost estimate prior to project execution. It does not include contingency for these sample projects. The least squares regression line offers a graphical illustration of the association between cost growth and PDRI score and the prediction equation is a useful form for summarizing that association. Statistics shown in Tables 8.1 and 8.2 indicate a positive correlation between the two variables, meaning that, as the PDRI score increases so does cost growth. The R-Square ($R^2$) is 0.226 for the industrial projects and 0.150 for the building projects and both the levels of significance are 0.01.

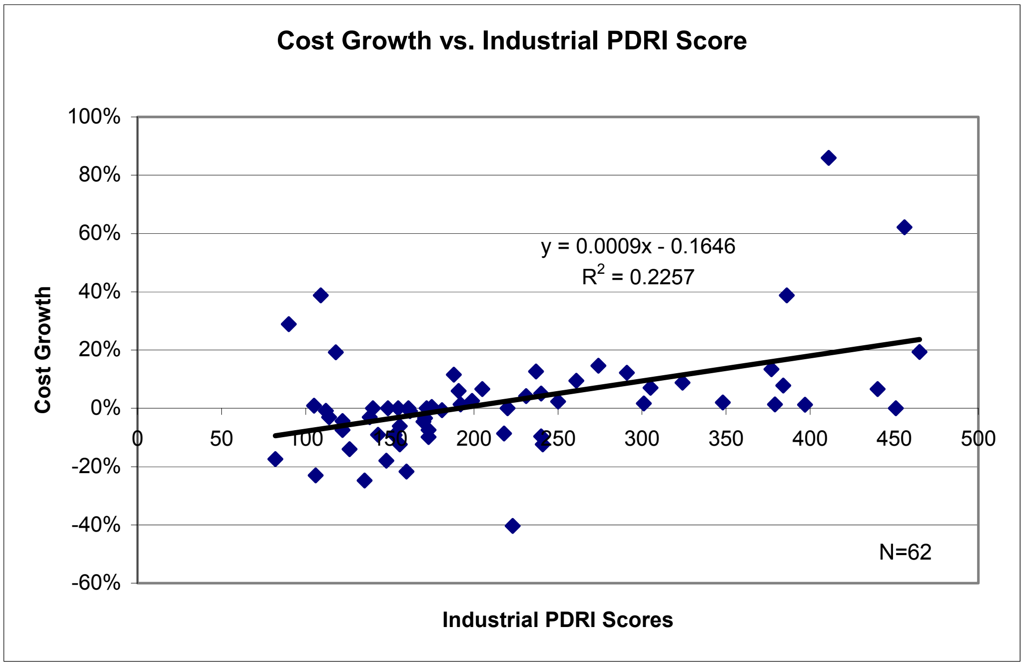


Figure 8.1. Linear Regression: Cost Growth vs. Industrial PDRI Score

Table 8.1. Regression Statistics: Cost Growth vs. Industrial PDRI Score

| **Regression Results for Industrial PDRI and Cost Growth** | | | | | |
|---|---|---|---|---|---|
| R = 0.475 | | $R^2$ = 0.226 | | Adjusted $R^2$ = 0.213 | |
| **ANOVA** | | | | | |
| Model | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | 0.491 | 1 | 0.491 | 17.489 | 9.56E-05 |
| Residual | 1.685 | 60 | 0.028 | | |
| Total | 2.175 | 61 | | | |

The R-Square ($R^2$) value is the coefficient of determination and can be interpreted as the proportion or percentage of the total variation in the dependent variable which can be attributed to its linear relationship with the independent variable. In this case, approximately 23 percent of the variation in the cost growth value can be "explained" (in a statistical rather than a causal sense) by the industrial PDRI score value.

The bivariate prediction equation for industrial cost performance is:

| |
|---|
| Cost Growth = 0.0009 [PDRI Score] – 0.1646 |

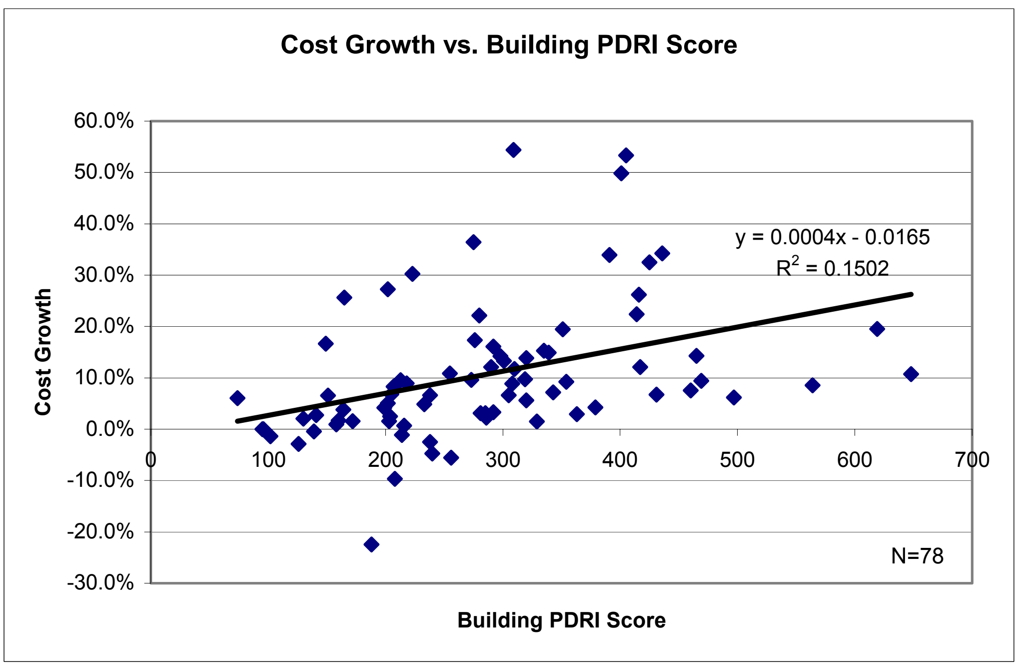


Figure 8.2. Linear Regression: Cost Growth vs. Building PDRI Score

Table 8.2. Regression Statistics: Cost Growth vs. Building PDRI Score

| Regression Results for Building PDRI and Cost Growth | | | | | |
|---|---|---|---|---|---|
| R = 0.388 | | $R^2$ = 0.150 | | Adjusted $R^2$ = 0.139 | |
| ANOVA | | | | | |
| Model | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | 0.205 | 1 | 0.205 | 13.434 | 4.55E-04 |
| Residual | 1.161 | 76 | 0.015 | | |
| Total | 1.366 | 77 | | | |

The bivariate prediction equation for building cost performance is:

$$\text{Cost Growth} = 0.0004\,[\text{PDRI Score}] - 0.0165$$

The R-Square ($R^2$) value is the coefficient of determination and can be interpreted as the proportion or percentage of the total variation in the dependent variable which can be attributed to its linear relationship with the independent variable. In this case, approximately 15 percent of the variation in the cost growth value can be "explained" (in a statistical rather than a causal sense) by the building PDRI score value.

The low R-Squared values obtained suggested that a major portion of the variation is left "unexplained". However, the scatter plots clearly point out that projects with lower PDRI scores have more predictable cost growth while projects with higher PDRI scores have less predictable growth. With the assistance of two straight lines drawn "free-hand" along the boundary of cost growth on the scatter plot, Figure 8.3 further demonstrates this "funnel" effect (low PDRI projects with less scattered cost performance and high PDRI projects with more scattered cost performance).

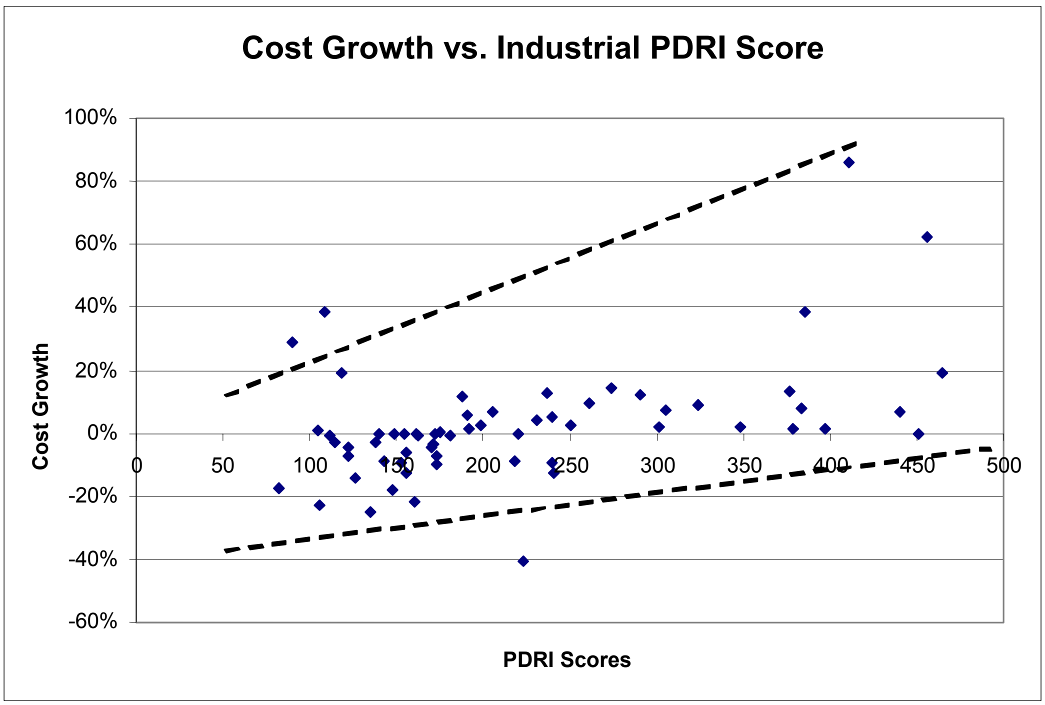


Figure 8.3. Funnel Effect of Cost Growth, Industrial

Similar relationships were observed for building cost growth versus PDRI scores as shown in Figure 8.4.

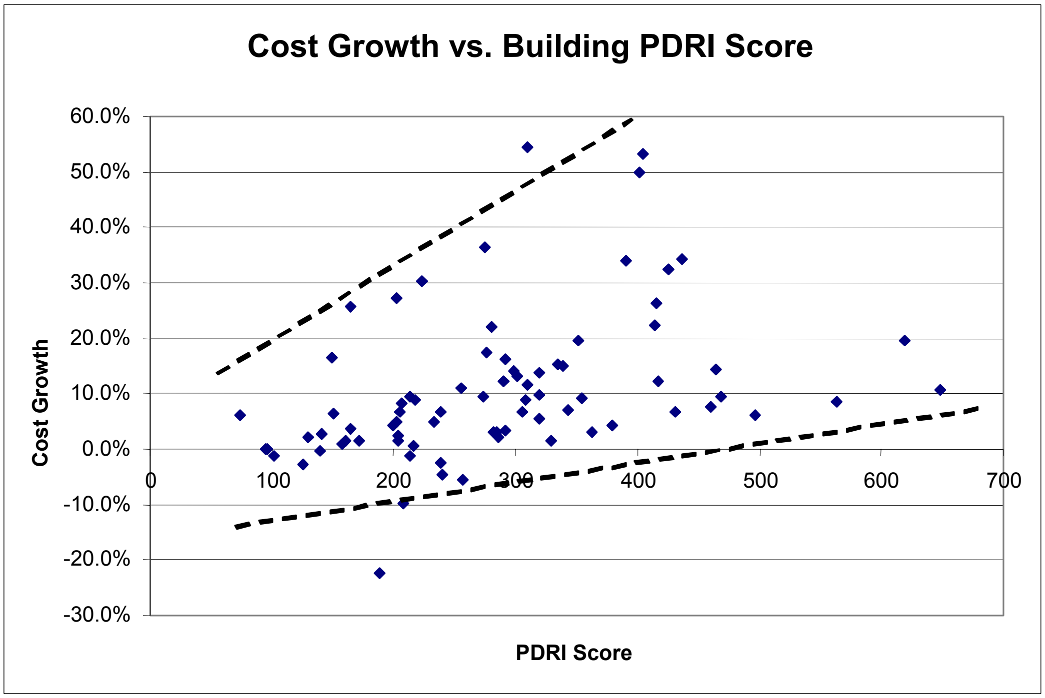


Figure 8.4. Funnel Effect of Cost Growth, Building

There are several possible reasons for the low R-Squared values obtained. First, the scope definition completeness during pre-project planning is not the only factor that contributes to cost growth. Many actions that occur after pre-project planning stage of the project life-cycle have a significant affect on cost growth and were not directly evaluated in this research. Controllable and "uncontrollable" factors that may influence the project and can contribute to cost growth such as poor contract documents, unforeseen conditions, market conditions, strikes, Acts of God, and so on. Next, measurement errors might occur during the data collection. The data were collected after-the-fact and the quality of the data relied greatly on the memory recollection of the survey participants. If project information was not well documented, it is likely that the survey might not reflect reality. The survey did not provide sufficient information to support the elimination of possible outliers. The existence of possible outliers might have negative impact to the regression analysis. Lastly, total PDRI score simply might not be an adequate indicator for cost growth. Total PDRI score was calculated by summing the score for each scope element, while some elements might have more impact on cost growth than others. Therefore, a modified PDRI score containing only part of the scope elements might be a better variable than total PDRI score.

Section 7.2.2 identified scope elements that distinguish successful and less-than-successful projects based on the effect size analysis. The scores for these elements were summed and used as modified PDRI scores for another linear regression analysis. From Table 7.13, the elements identified for industrial projects relating to cost performance are A1: Reliability Philosophy, A2: Maintenance Philosophy, A3: Operating Philosophy, B6: Future Expansion Considerations, B7: Expected Project Life Cycle, B8: Social Issues, D2: Project Design Criteria, D4: Dismantling and Demolition Requirements, F2: Survey and Soil Tests, G4: Process Safety Management (PSM), G5: Utility Flow Diagram, G7: Piping System Requirements, G10: Line List, G11: Tie-In List, G12: Piping Specialty Items List, H2: Equipment Location Drawings, J2: Location/Uploading/Storage Facilities Requirements, and P4: Pre-Commission Turnover Sequence Requirements. The elements identified for building projects relating to cost performance are A8: Project Objectives Statement, B2: Maintenance Philosophy, B4: Design Philosophy, E1: Program Statement, E2: Building Summary Space List, E11: Room Data Sheets, E13: Window Treatment, F2: Architectural Design, F4: Mechanical Design, F5: Electric Design, F7: Constructability Analysis, H1: Identify Long Lead/Critical Equipment and Materials, H2: Procurement Procedures and Plans, J2: Documentation / Deliverables, and L3: Project Delivery Method.

With cost growth as dependent variable and modified PDRI score (using pre-assigned weights for the selected elements) as independent variable, bivariate linear regression analysis was performed for the industrial and building projects and these relationships are shown in Figures 8.5 and 8.6. In addition, the regression statistics obtained were compared with results from total PDRI score analysis. Tables 8.3 and 8.4 summarized the comparison results.

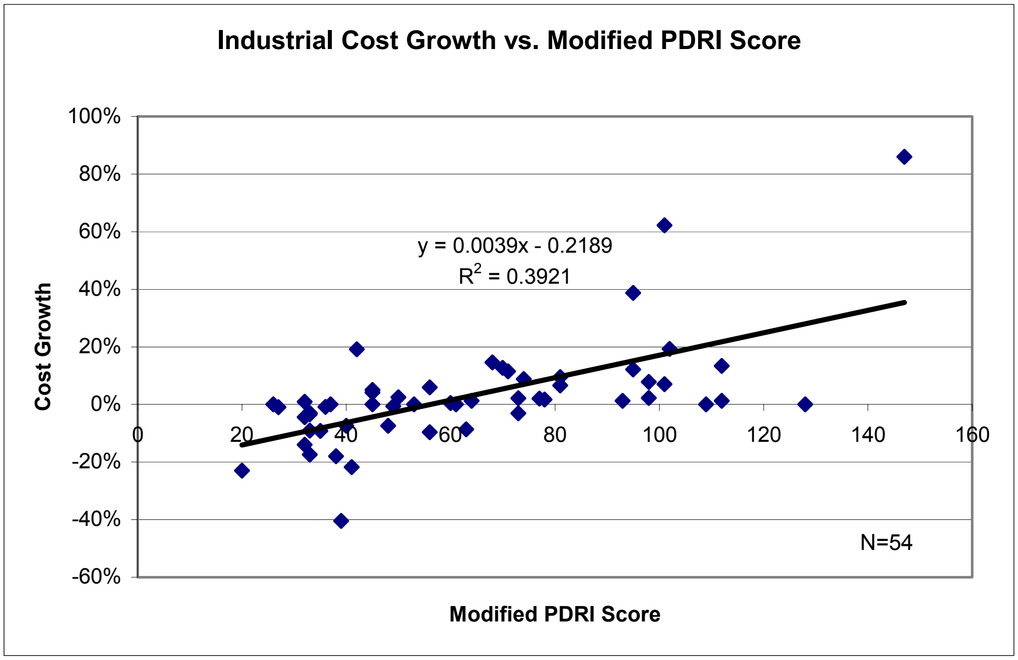


Figure 8.5. Industrial Cost Growth vs. Modified PDRI Score

Table 8.3. Regression Statistics: Industrial Total vs. Modified PDRI Score,

| Industrial Projects Regression Statistics | PDRI Score | |
|---|---|---|
| | Total | Modified |
| R-Squared ($R^2$) | 0.226 | 0.392 |
| Significant F | 9.56E-05 | 4.17E-07 |
| Degree of Freedom | 61 | 61 |

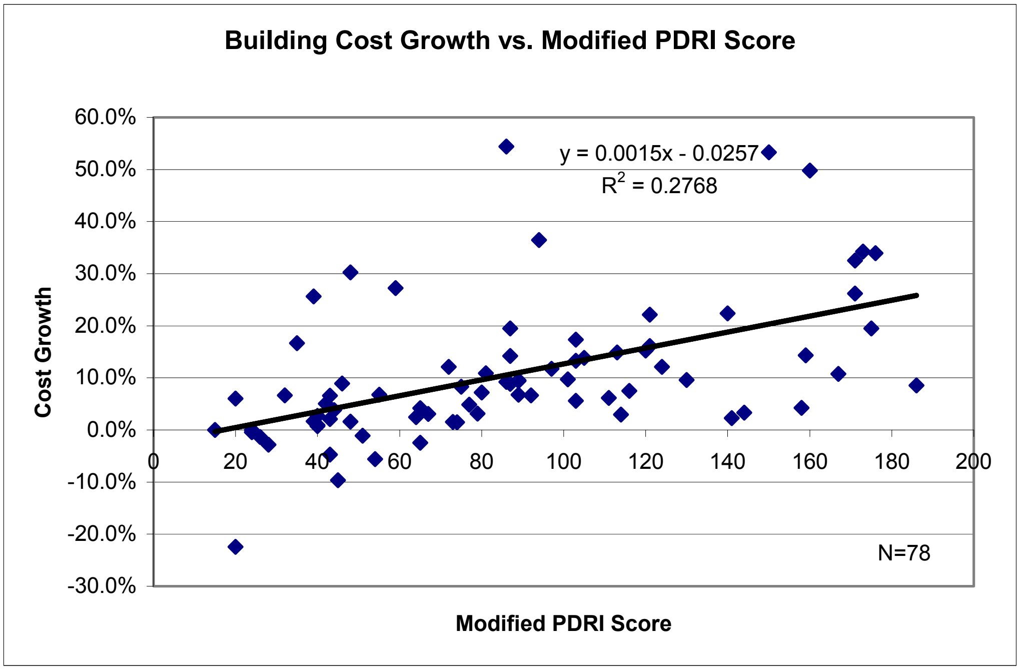


Figure 8.6. Building Cost Growth vs. Modified PDRI Score

Table 8.4. Regression Statistics: Building Total vs. Modified PDRI Score,

| Building Projects Regression Statistics | PDRI Score Total | PDRI Score Modified |
|---|---|---|
| R-Squared ($R^2$) | 0.150 | 0.277 |
| Significant F | 4.55E-04 | 7.56E-07 |
| Degree of Freedom | 77 | 77 |

Statistics comparisons shown in Tables 8.3 and 8.4 indicate improved R-Squared ($R^2$) values obtained with Modified PDRI scores. The results suggest that, with cost growth as the dependent variable, the modified PDRI score might serve as a better independent variable than total PDRI score in the bivariate linear regression analysis for both industrial and building projects, when addressing cost performance.

**Schedule Performance Regression Analysis**

A similar approach was used for schedule growth regression analysis. With schedule growth as dependent variable and PDRI score as independent variable, bivariate linear regression analysis was performed for the industrial and building projects and the relationships shown in Figures 8.7 and 8.8 were revealed. Again, schedule growth is the actual schedule of the project for design and construction versus the schedule estimate prior to project execution. The least squares regression line offers a graphic interpretation of the association between schedule growth and PDRI score and the prediction equation is a useful form for summarizing that association. Statistics shown in Tables 8.5 and 8.6 indicate a positive correlation between the two variables, meaning that, as the PDRI score increases so does the schedule growth. The R-Square ($R^2$) is 0.118 for the industrial projects and 0.150 for the building projects and both the levels of significance are 0.01.

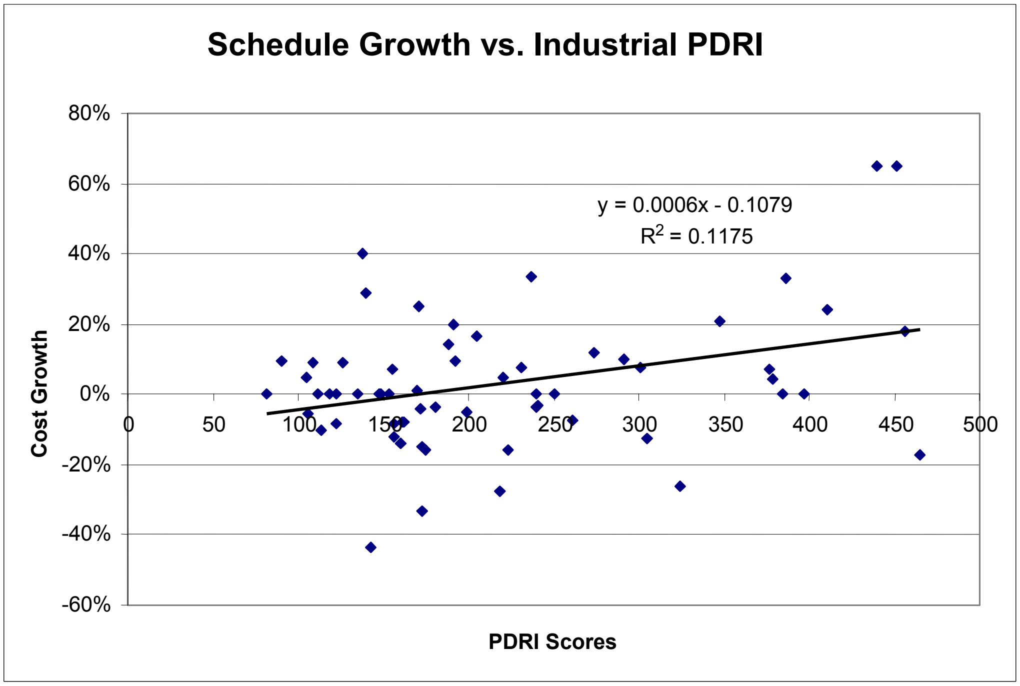


Figure 8.7. Linear Regression: Schedule Growth vs. Industrial PDRI Score

The bivariate prediction equation for industrial schedule performance is:

| |
|---|
| Schedule Growth = 0.0006 [PDRI Score] – 0.1079 |

The R-Square ($R^2$) value is the proportion or percentage of the total variation in the dependent variable which can be attributed to its linear relationship with the independent variable. In this case, approximately 12 percent of the variation in the schedule growth value can be "explained" (in a statistical rather than a causal sense) by the industrial PDRI score value.

Table 8.5. Regression Statistics: Schedule Growth vs. Building PDRI Score

| Regression Results for Building PDRI and Schedule Performance | | | | | |
|---|---|---|---|---|---|
| R = 0.343 | | $R^2$ = 0.118 | | Adjusted $R^2$ = 0.103 | |
| **ANOVA** | | | | | |
| Model | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | 0.265 | 1 | 0.265 | 7.990 | 0.0064 |
| Residual | 1.994 | 60 | 0.033 | | |
| Total | 2.259 | 61 | | | |

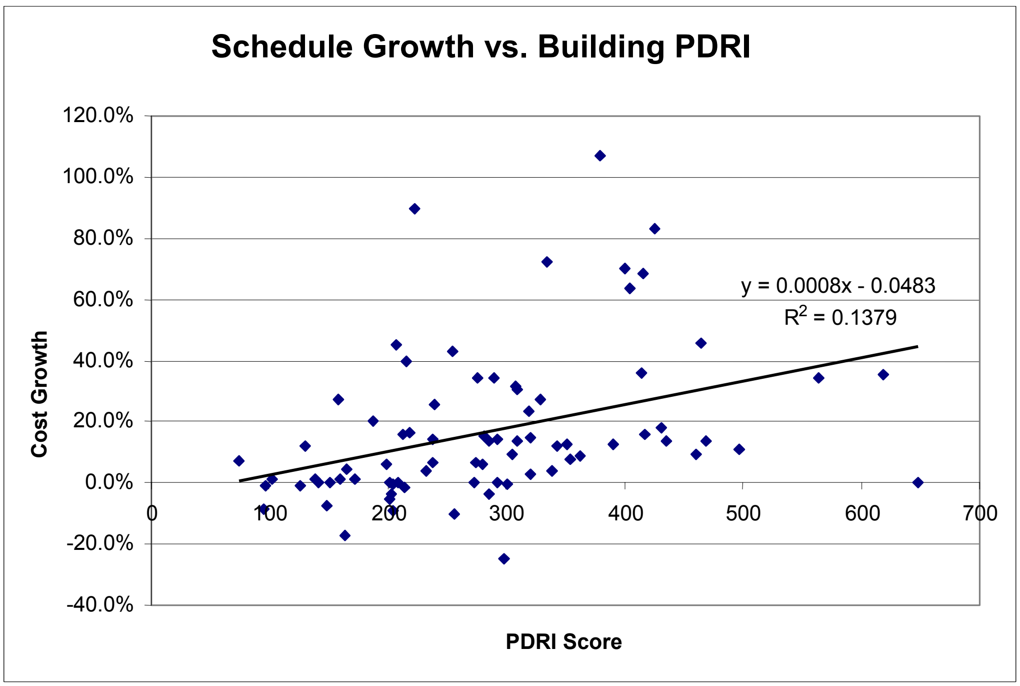


Figure 8.8. Linear Regression: Schedule Growth vs. Building PDRI Score

The bivariate prediction equation for building schedule performance is:

Schedule Growth = 0.0004 [PDRI Score] – 0.0483

Table 8.6. Regression Statistics: Schedule Growth vs. Building PDRI Score

| **Regression Results for Building PDRI and Schedule Growth** | | | | | |
|---|---|---|---|---|---|
| R = 0.371 | | $R^2$ = 0.138 | | Adjusted $R^2$ = 0.127 | |
| **ANOVA** | | | | | |
| Model | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | 0.644 | 1 | 0.644 | 12.159 | 8.15E-04 |
| Residual | 4.025 | 76 | 0.053 | | |
| Total | 4.669 | 77 | | | |

The R-Square ($R^2$) value is the proportion or percentage of the total variation in the dependent variable which can be attributed to its linear relationship with the independent variable. Again, approximately 14 percent of the variation in the schedule growth value can be “explained” (in a statistical rather than a causal sense) by the building PDRI score value.

The low R-Squared values obtained suggested that a major portion of the variation is left “unexplained”. When compared with cost growth analysis, the results from schedule analysis revealed less significant relationship between schedule growth and PDRI scores. This is consistent with previous observations that PDRI score is a better predicator for cost growth when comparing to schedule growth (Cho 1999).

Section 7.2.2 identified scope elements that distinguish successful and less-than-successful projects based on the effect size analysis. The scores for these elements were summed and used as modified PDRI scores for another linear regression analysis. From Table 7.12, the elements identified for industrial projects relating to schedule performance are A3: Operating Philosophy, G4: Process Safety Management (PSM), G5: Utility Flow Diagram, G7: Piping System Requirements, G13: Instrument Index, K1: Control Philosophy, K6: Instrument & Electrical Specifications.

With schedule growth as dependent variable and modified PDRI score as independent variable, a bivariate linear regression analysis was performed for the industrial projects and the relationships shown in Figure 8.9 were revealed. Since previous effect size analysis did not identify any scope elements that can distinguish schedule performance for building projects, only results from modified scores were compared for the industrial projects.

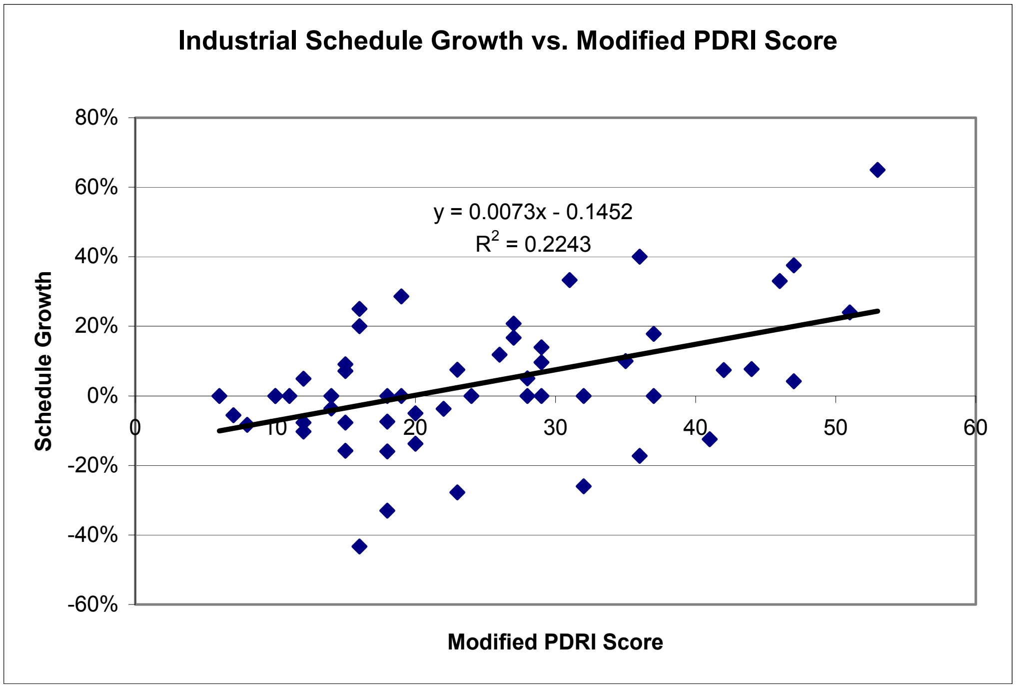


Figure 8.9. Industrial Schedule Growth vs. Modified PDRI Score

Analysis results obtained from modified PDRI score were compared to regression statistics obtained from total PDRI score, the comparison results are presented in Table 8.7.

Table 8.7. Regression Statistics: Industrial Total vs. Modified PDRI Score,

| Industrial Projects Regression Statistics | PDRI Score | |
|---|---|---|
| | Total | Modified |
| R-Squared ($R^2$) | 0.118 | 0.224 |
| Significant F | 0.0064 | 2.98E-04 |
| Degree of Freedom | 61 | 61 |

Table 8.7 shows that modified PDRI score offered better R-Squared ($R^2$) value for the regression analysis. That is, the modified PDRI score when compared with the analysis results from total PDRI score can explain a better portion of the total variation in schedule growth.

### 8.1.2. Boxplots Quartile Model

Boxplots present a visual display of summary information about the distribution of values. The boxplots, found in Figures 8.11 through 8.14, display the median, the 25th percentile, the 75th percentile, and values that are far removed from the rest. Fifty percent of the cases have values within the box. Figure 4.2 is reproduced below for the reference (Figure 8.10). Used in this section, boxplots will display summary information showing how the four PDRI score quartile-groups respond with the performance (cost/schedule growth). Both industrial and building projects are grouped into four quartile-groups based on their PDRI scores. All projects were first sorted by their PDRI scores. First quartile-group contained one-quarter of the projects with the lowest PDRI scores. The last quartile-group contained the 25 percent of projects that have highest PDRI scores.

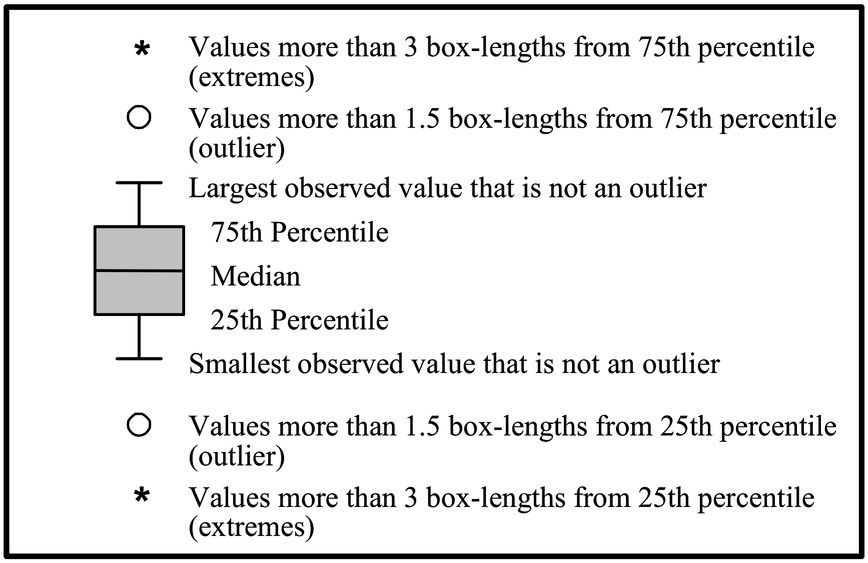


Figure 8.10. Annotated Sketch of the Boxplot

**Cost Performance Boxplot Analysis**

A boxplot of PDRI Score quartile-groups against cost growth was created for industrial projects and presented in Figure 8.11. The associated statistics were summarized in Table 8.8. As revealed by Figure 8.11 and Table 8.8, the PDRI score has a definite relationship with cost growth. Projects within the fourth quartile-group had significantly higher cost growth than those in the first and second quartile-groups. There are also more outliers and extremes in the fourth quartile-group. Most of the projects in the first and second quartile-groups had final costs under their authorized budget.

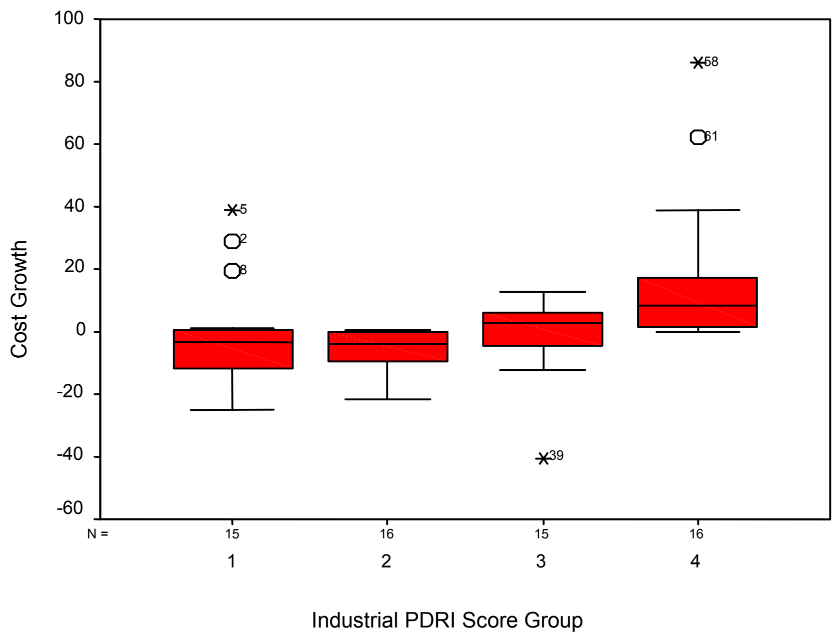


Figure 8.11. Industrial Cost Growth by PDRI Score Groups

Table 8.8. Summary Statistics for Industrial Cost Growth

| Cost Growth | PDRI Scores | Mean | Median | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| 1st Quartile (N=15) | 82-143 | -1.3% | -3.1% | -11.5% | 0.5% |
| 2nd Quartile (N=16) | 148-181 | -5.9% | -4.0% | -9.4% | 0.0% |
| 3rd Quartile (N=15) | 188-261 | -0.6% | 2.5% | -4.3% | 6.3% |
| 4th Quartile (N=16) | 274-465 | 17.7% | 8.3% | 1.9% | 15.8% |

A boxplot of PDRI Score quartile-groups against cost growth was created for building projects and presented in Figure 8.12. For building projects, cost growth was also significantly affected by the PDRI score. Figure 8.12 and Table 8.9 reveal this relationship. Once again, the projects within the fourth quartile-group had significantly higher cost growth than those in the first, second, and third quartile-groups. The results change acutely as the PDRI score gets lower. However, when compared with industrial project cost growth, more building projects had costs over their authorized budget. Only 25 percent of the building projects within the first quartile-group came in under budget cost while 50 percent of the industrial projects within the first and second quartile-groups came in under budget.

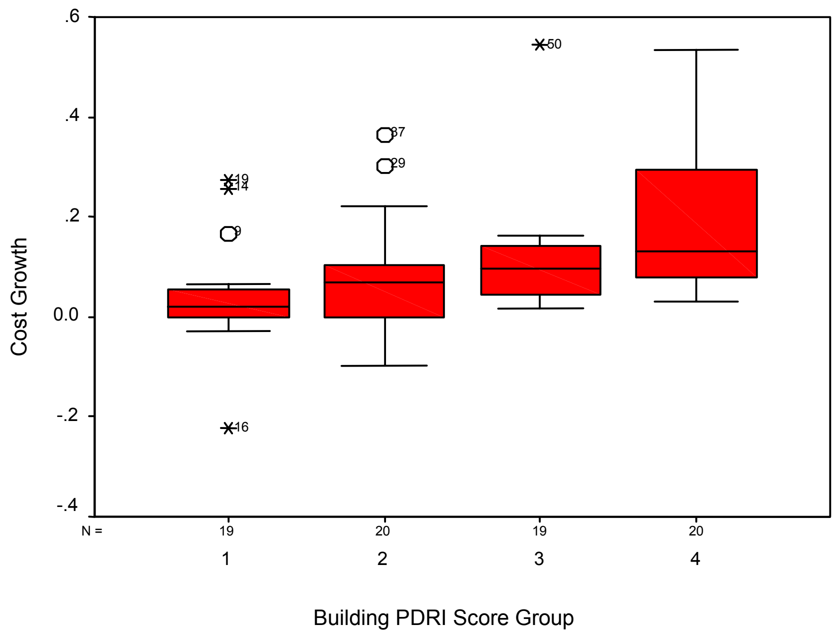


Figure 8.12. Building Cost Growth by PDRI Score Groups

Table 8.9. Summary Statistics for Building Cost Growth

| Cost Growth | PDRI Scores | Mean | Median | $25^{th}$ Percentile | $75^{th}$ Percentile |
|---|---|---|---|---|---|
| $1^{st}$ Quartile (N=19) | 74-202 | 4.2% | 2.1% | 0.0% | 5.5% |
| $2^{nd}$ Quartile (N=20) | 203-280 | 7.6% | 6.7% | 0.3% | 9.9% |
| $3^{rd}$ Quartile (N=19) | 281-343 | 11.4% | 9.7% | 4.5% | 14.0% |
| $4^{th}$ Quartile (N=20) | 351-648 | 19.2% | 13.2% | 8.3% | 27.8% |

**Schedule Performance Boxplot Analysis**

A boxplot of PDRI Score quartile-groups against schedule growth was created for industrial projects and presented in Figure 8.13. The associated statistics were summarized in Table 8.10. Interesting results were discovered when the distribution of values was analyzed for schedule growth. As shown in Figure 8.13, the mean schedule growth for the second quartile-group is lower than that obtained from the first quartile-group. Projects within the third and fourth quartile-groups had significantly larger schedule growth variations than those in the first and second quartile-groups.

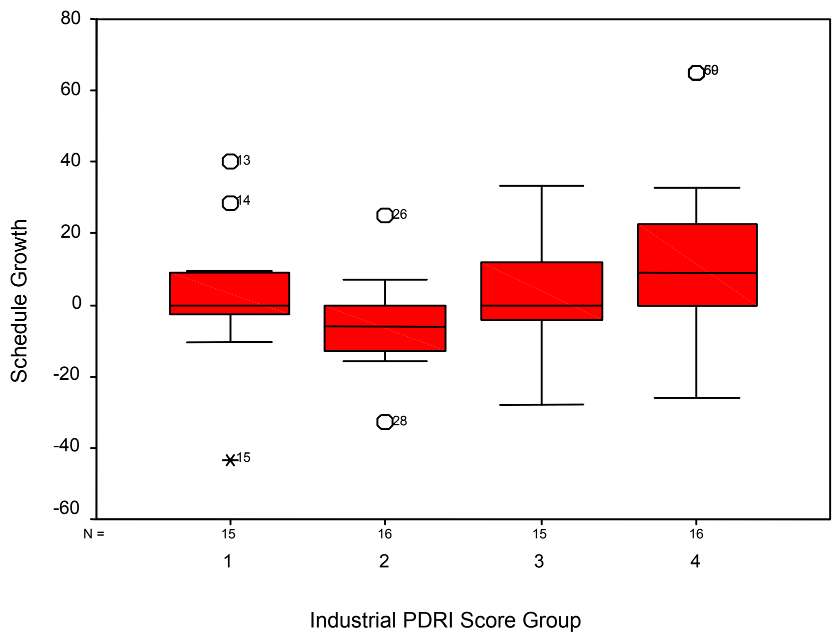


Figure 8.13. Industrial Schedule Growth by PDRI Score Groups

Table 8.10. Summary Statistics for Industrial Schedule Growth

| Schedule Growth | PDRI Scores | Mean | Median | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| 1st Quartile (N=15) | 82-143 | 2.2% | 0.0% | -2.8% | 9.0% |
| 2nd Quartile (N=16) | 148-181 | -5.5% | -5.9% | -12.5% | 0.0% |
| 3rd Quartile (N=15) | 188-261 | 2.9% | 0.0% | -4.3% | 11.8% |
| 4th Quartile (N=16) | 274-465 | 13.2% | 8.9% | 0.0% | 21.6% |

Results of building schedule growth were similar to those of building cost growth and are shown in Figure 8.14. The associated statistics are summarized in Table 8.11. The projects within the fourth quartile-group had significantly higher schedule growth than those in the first quartile-group. The results change acutely as the PDRI score gets lower. As can be seen in Figure 8.14, projects within the fourth quartile-group had significantly larger schedule growth variations than those in the first quartile-groups.

Once again, the results from schedule growth analysis showed that the PDRI score served as a better distinguisher for cost growth than schedule growth.

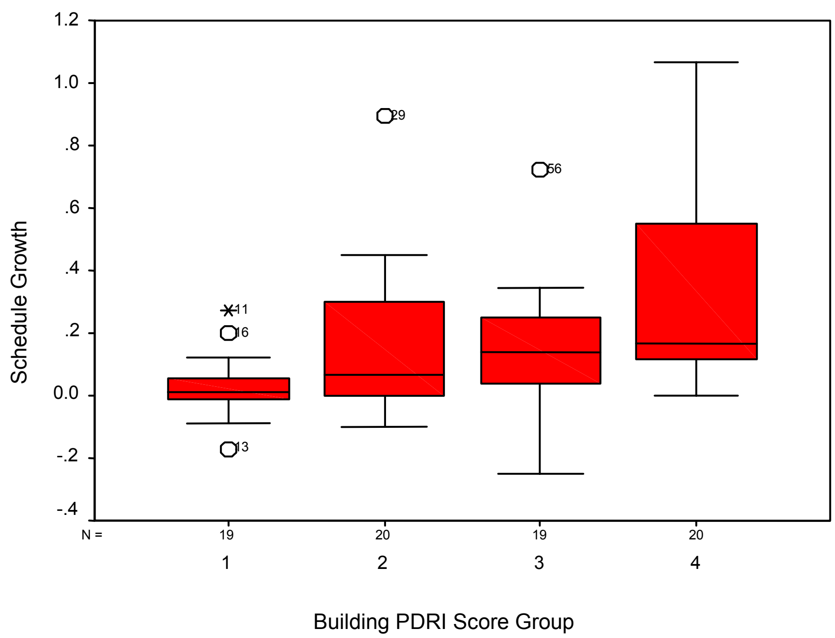


Figure 8.14. Building Schedule Growth by PDRI Score Groups

Table 8.11. Summary Statistics for Building Schedule Growth

| Schedule Growth | PDRI Scores | Mean | Median | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| 1st Quartile (N=19) | 74-202 | 2.2% | 1.0% | -1.0% | 5.5% |
| 2nd Quartile (N=20) | 203-280 | 16.2% | 6.8% | -0.1% | 27.8% |
| 3rd Quartile (N=19) | 281-343 | 15.3% | 13.9% | 3.6% | 25.2% |
| 4th Quartile (N=20) | 351-648 | 33.4% | 16.9% | 12.0% | 50.3% |

### 8.1.3. Hackney's Accuracy Range Estimate Method

As described in Section 4.5, Hackney's accuracy range estimate method is considered an appropriate approach for the purpose of this research. In order to apply the Hackney's method, it is assumed that linear relationships exist from the origin for this project sample (the starting point, the origin, is used in Hackney's method). With sample project performance and their corresponding PDRI scores, paired scatter plots were created for both building and industrial projects. Note that the projection lines are for projects that move ahead with detailed design and have PDRI scores at the values indicated. A line was drawn through the data with half the projects above and the other half below and the slope was determined. This coefficient can be used to obtain the even-chance contingency allowance, which is the amount that if added to the base estimate without contingency allowance, will provide a 50/50 chance of the actual performance overruning or underrunning the estimate (Hackney 1992). Similarly, lines that provide 10/90 and 90/10 chance of actual overrunning or underrunning were also drawn in the scatter plots. Figure 4.4 is reproduced below for reference (Figure

8.15). Used in this section, Hackney's charts will display summary information about contingency estimations using PDRI scores based on historical projects.

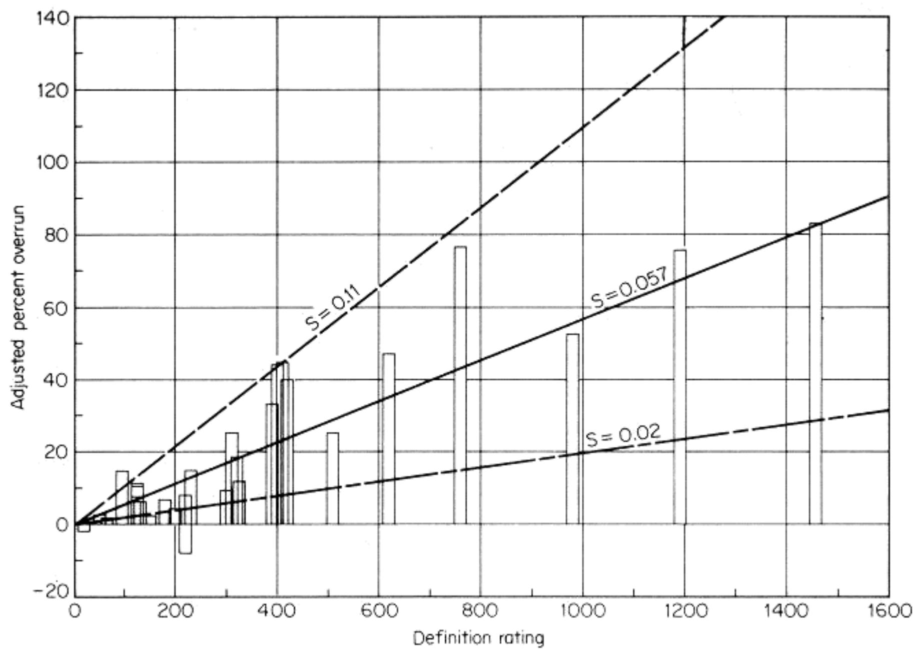


Figure 8.15. Definition Rating vs. Overruns

**Industrial Project Contingency Estimate Using Hackney's Method**

A scatter plot of PDRI scores and project cost growth was created for industrial projects and presented in Figure 8.16. Three lines were drawn through the project data in the scatter plot: 10%, 50% and 90% line. The 10% line was drawn such that 10 percent of the line tops above and 90 percent of the line tops below. Half line tops are above the 50% line and the other half line tops are below the line. The 90% line has 90 percent of line tops above it and 10 percent of line tops below it. The slopes obtained for these lines were 0.10, 0.00, and -0.12 for the 10%, 50%, and 90% lines respectively.

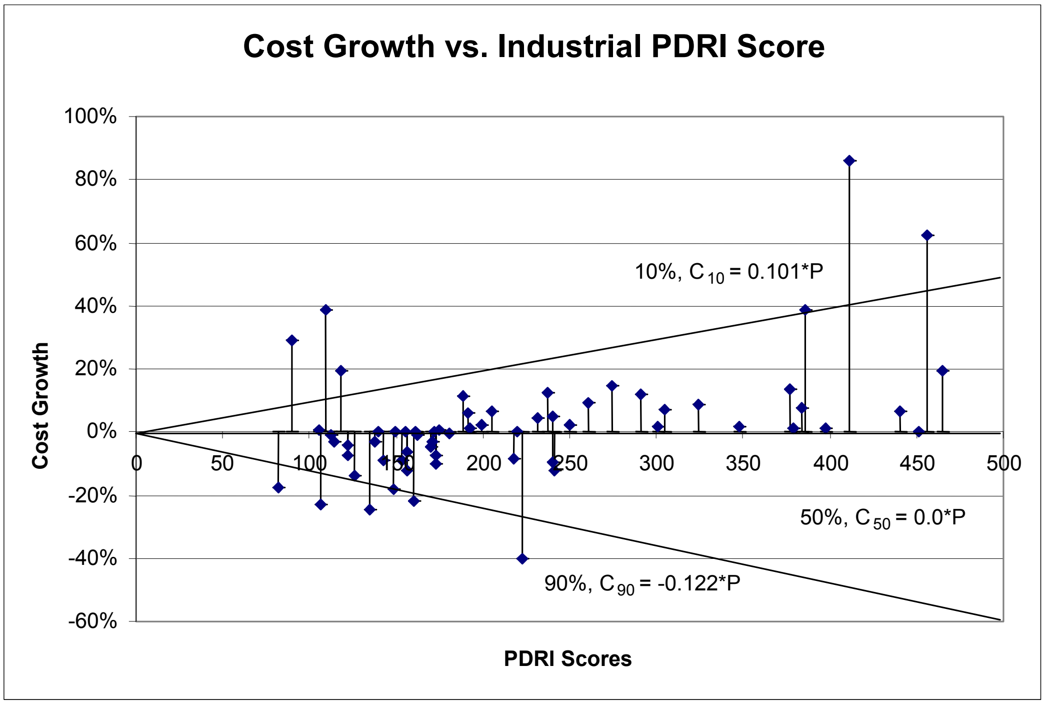


Figure 8.16. Scatter Plot: Cost Growth vs. Industrial PDRI Score

From Figure 8.16, a project with 0% cost contingency would have a 50 percent chance that the final project cost will be at or under authorized budget regardless its PDRI score. In the mean time, a project with a PDRI score of 386 and a 39 percent contingency would come in under authorized budget 90 percent of the time according to historical data. That is, if a project had a percentage contingency of approximately one-tenth of its PDRI score, there is merely a 10 percent chance that the project would come in over budget. If a project had a

PDRI score of 200 and an estimated contingency of 10%, the chance that the final project cost comes in under budget can be calculated from Figure 8.16. First, the point (200, 10%) was plotted in the scatter plot and a line that passes the origin and this point was drawn as shown in Figure 8.17.

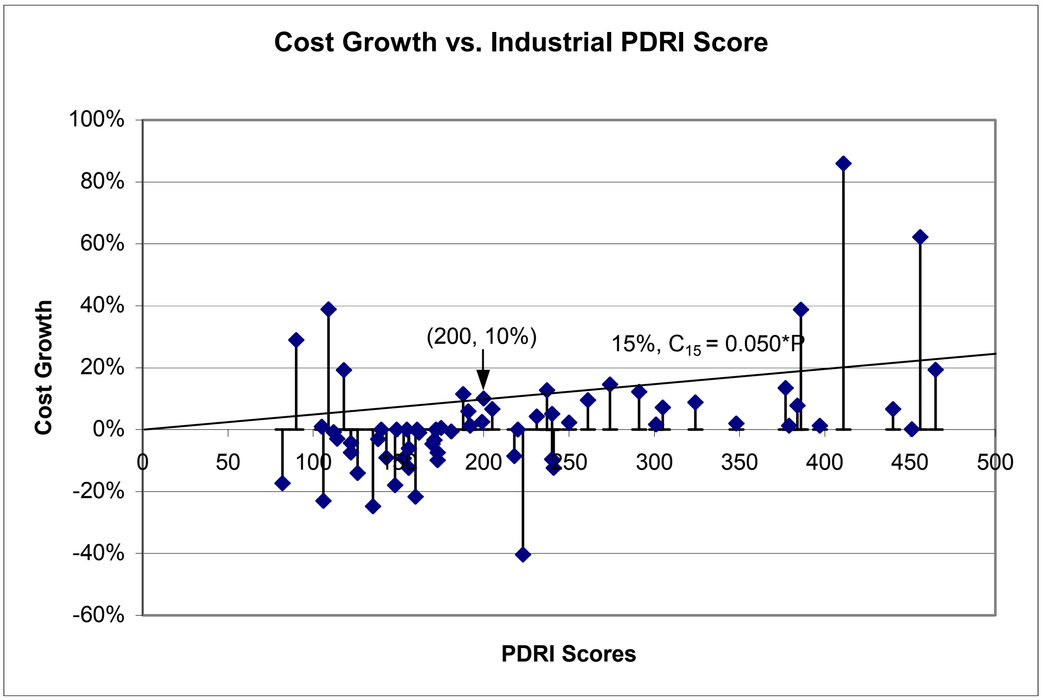


Figure 8.17. Cost Growth Accuracy Range Estimate for Industrial Projects

From Figure 8.17, there are nine line tops above the drawn line and that translates to approximately 15 percent (9/62) of total projects. Based on historical data, if a project had a PDRI score of 200 and a cost contingency of 10%, there is an 85 percent chance that the project will come in under authorized budget.

Similarly, a scatter plot of PDRI scores and project schedule growth was created for industrial projects and presented in Figure 8.18. The slopes obtained for these 10%, 50% and 90% lines were 0.10, 0.00, and -0.12 respectively. Like the results from cost performance analysis, a project with 0% schedule contingency would have a 50 percent chance that the final project schedule will be at or under authorized project duration regardless its PDRI score. A project with a PDRI score of 237 and a 33 percent schedule contingency (float) would finish before the authorized schedule date 90 percent of the time according to historical data.

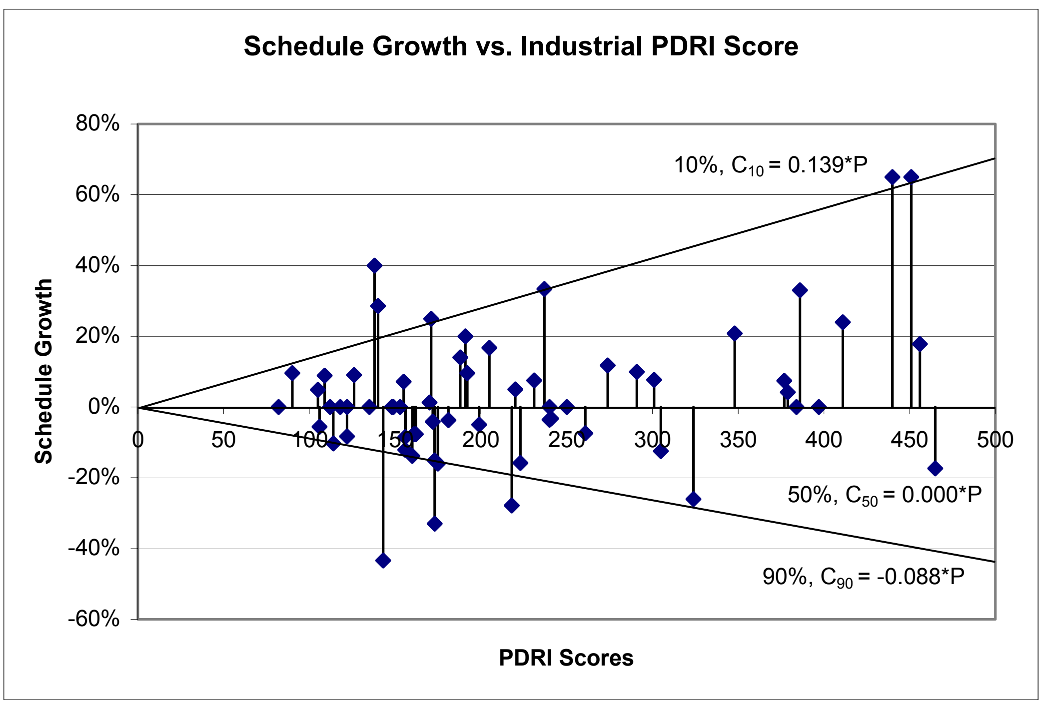


Figure 8.18. Scatter Plot: Schedule Growth vs. Industrial PDRI Score

A project with a PDRI score of 200 and an estimated schedule contingency of 10% was plotted in the scatter plot. A line that passes the origin and this point was drawn as shown in Figure 8.19.

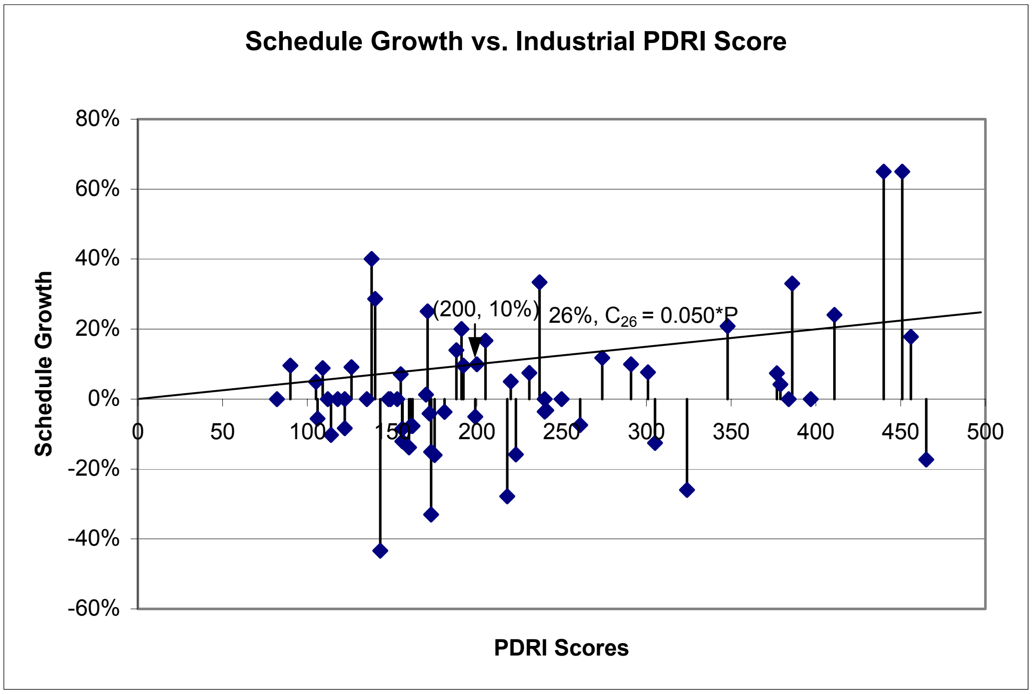


Figure 8.19. Schedule Growth Accuracy Range Estimate for Industrial Projects

From Figure 8.19, there are 16 line tops above the drawn line and that translates to approximately 26 percent (16/62) of total projects. Based on historical data, if a project had a PDRI score of 200 and a schedule contingency of 10%, there is a 74 percent chance that the project will come in at or under the authorized schedule.

**Building Project Contingency Estimate Using Hackney's Method**

A scatter plot of PDRI scores and project cost growth was created for building projects and presented in Figure 8.20. Three lines were drawn through the project data in the scatter plot: 10%, 50% and 90% line. The 10% line was drawn such that 10 percent of the line tops above and 90 percent of the line tops below. Half line tops are above the 50% line and the other half line tops are below the line. The 90% line has 90 percent of line tops above it and 10 percent of line tops below it. The slopes obtained for these lines were 0.112, 0.023, and -0.005 for the 10%, 50%, and 90% lines respectively.

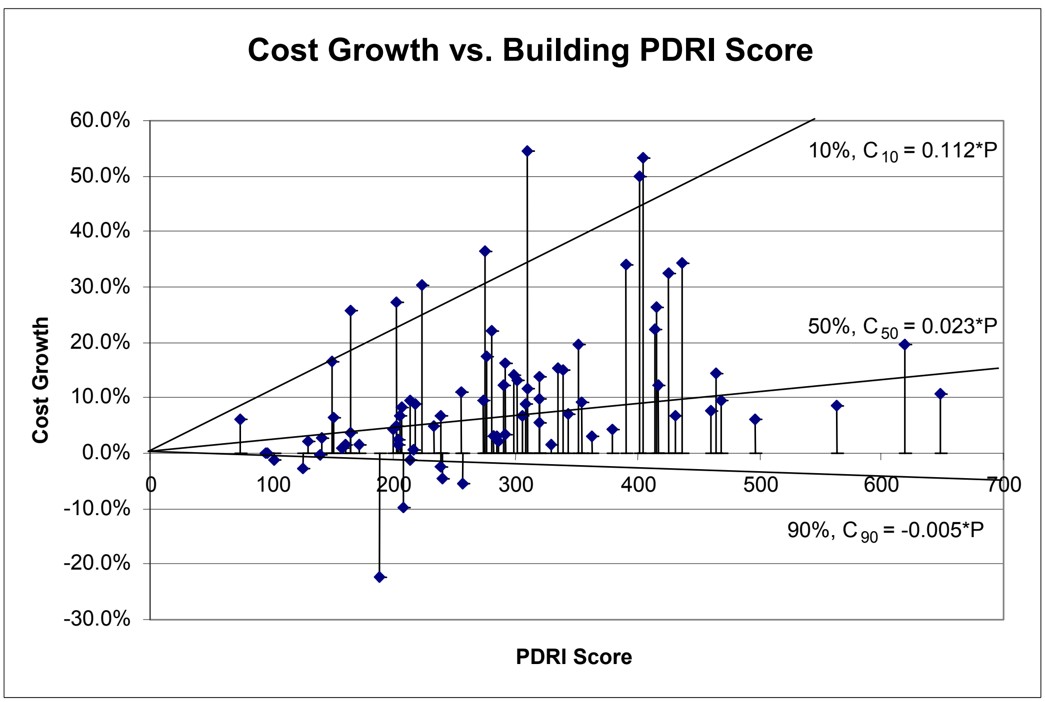


Figure 8.20. Scatter Plot: Cost Growth vs. Building PDRI Score

From Figure 8.20, a project with a PDRI score of 150 and a 17 percent cost contingency would come in under authorized budget approximately 90 percent of the time according to historical data. That is, if a project had a percentage contingency of approximately one-ninth of its PDRI score, there is merely a 10 percent chance that the project would come in over budget. Without any contingency, the building projects had a 50 percent chance that the final cost will be below authorized budget regardless of their PDRI scores. Unlike industrial projects, a certain amount of contingency should be assigned to a building project to attain a 50 percent chance of meeting the budget. The amount of contingency assigned differs from project to project and is positively related to the project's PDRI score. To be exact, the percentage amount of contingency equals 0.023 times the PDRI score.

A building project with a PDRI score of 200 and an estimated cost contingency of 10% was plotted in the scatter plot. A line that passes the origin and this point was drawn as shown in Figure 8.21.

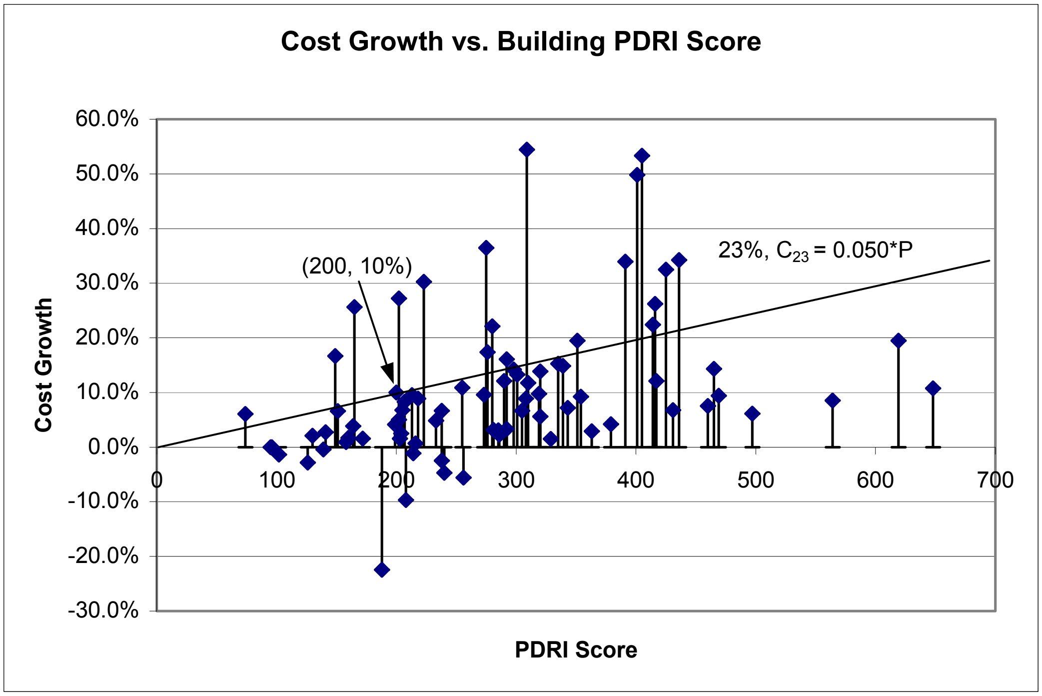


Figure 8.21. Cost Growth Accuracy Range Estimate for Building Projects

From Figure 8.21, there are 18 line tops above the drawn line and that translates to approximately 23 percent (18/78) of total projects. Based on historical data, if a project had a PDRI score of 200 and a cost contingency of 10%, there is a 77 percent chance that the project will come in under the estimated budget.

Similarly, a scatter plot of PDRI scores and project schedule growth was created for building projects and presented in Figure 8.22. The slopes obtained for these 10%, 50% and 90% lines were 0.171, 0.032, and -0.018 respectively. A project with a PDRI score of 150 and a 27 percent schedule contingency (float) would finish before the authorized schedule date 90 percent of the time according to historical data.

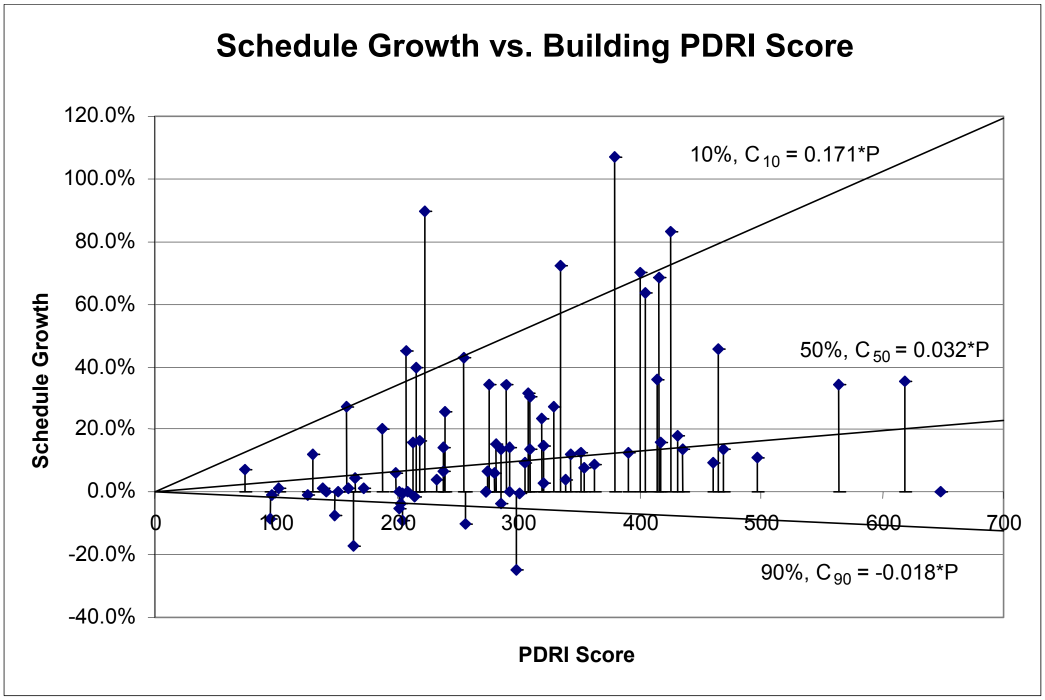


Figure 8.22. Scatter Plot: Schedule Growth vs. Building PDRI Score

A building project with a PDRI score of 200 and an estimated schedule contingency of 10% was plotted in the scatter plot. A line that passes the origin and this point was drawn as shown in Figure 8.23.

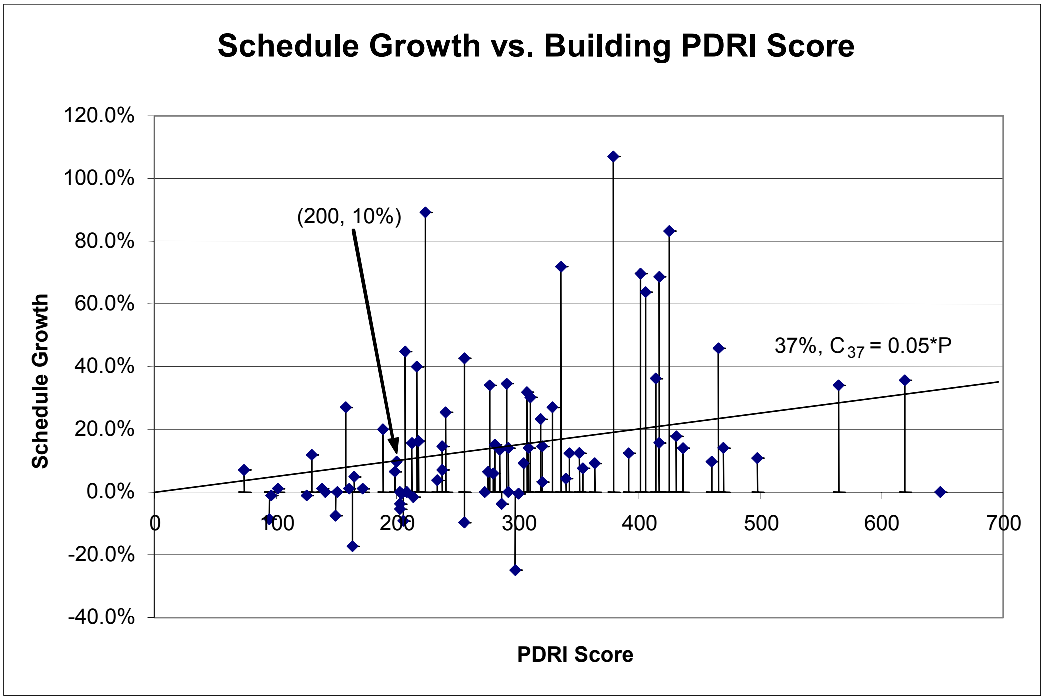


Figure 8.23. Schedule Growth Accuracy Range Estimate for Building Projects

From Figure 8.23, there are 29 line tops above the drawn line and that translates to approximately 37 percent (29/78) of total projects. Based on historical data, if a project had a PDRI score of 200 and a schedule contingency of 10%, there is a 63 percent chance that the project will finish before the authorized schedule date.

## 8.2. Risk Quantification Using PDRI

As discussed in previous sections, three approaches were explored to model the sample data. The three analysis tactics were least square linear regression, boxplots quartile analysis, and Hackney's accuracy range estimate. The following sections outline the application of these models to quantify potential risk impacts using PDRI scores. For demonstration purposes, one example for each of the three approaches will be given to illustrate the application.

### 8.2.1. Linear Regression Model

Least squares linear regression was used to describe the cost performance data and PDRI scores for industrial projects. A scatter plot with industrial PDRI scores and cost growth was plotted along with best fit line and 95 percent mean confidence level lines. As revealed in Figure 8.24, with a given PDRI score, the expected mean cost growth can be obtained.

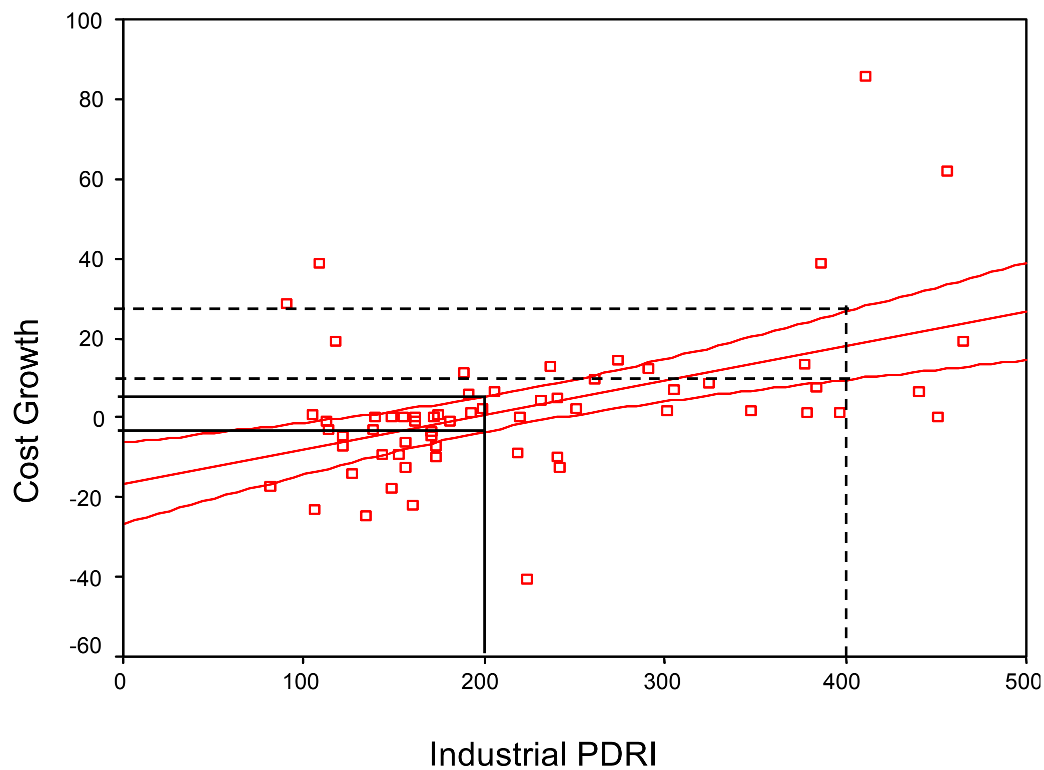


Figure 8.24. Best Fit Line and 95 Percent Confidence Line for Industrial Projects

The upper and lower bonds of the 95% confidence level for expected cost growth can be calculated using the following equations (Neter et al. 1996):

$$\hat{Y}_h \pm t(1-0.05/2; n-2)\, s\{\hat{Y}_h\}$$

where:

$\hat{Y}_h = b_0 + b_1 X_h$

$b_0 = Y_i$ axis intercept

$b_1$ = bivariate regression coefficient

$X_h$ = level of X wish to estimate

$t(1-0.05/2; n-2)$ : $t$ value for 95% confidence, n samples

$$s^2\{\hat{Y}_h\} = \text{MSE}\left[\frac{1}{n} + \frac{(X_h - \overline{X})^2}{\sum (X_i - \overline{X})^2}\right]$$

Using above equation, the 95 percent confidence interval for expected cost growth for PDRI scores of 200 and 400 are given in Table 8.12

Table 8.12. Ninety-five Percent Confidence Level Summary

| PDRI Score | $\hat{Y}_h$ | $t$ (.975, 60) | $s\{\hat{Y}_h\}$ | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| 200 | 1.5% | 2.0 | 2.5% | -3.4% | 6.5% |
| 400 | 19.5% | 2.0 | 4.8% | 9.8% | 29.2% |

From Table 8.12, there is a 95 percent chance that the expected mean cost growth for a industrial project with a PDRI score of 200 will be within the range of -3.4% to 6.5%. The range becomes much worse (9.8% ~ 29.2%) when the project has a PDRI score of 400. That is, the risks of project overrunning the authorized budget increase significantly with the increase of the PDRI score. By implementing the least square linear regression method, the project team is able to determine the expected mean cost growth based on historical data. The same approach can be applied to estimate schedule growth.

### 8.2.2. Boxplot Quartile Analysis Model

In Section 8.1.2, boxplots were created to present a visual display of summary information about the distribution of project performance. The sample projects were grouped by their PDRI scores and a total of four quartile-groups were formed. Figure 8.11 is reproduced to represent the cost growth distribution of the industrial projects for the four quartile-groups (Figure 8.25). Table 8.8 was recreated to represent the summary information for the boxplot (Table 8.13).

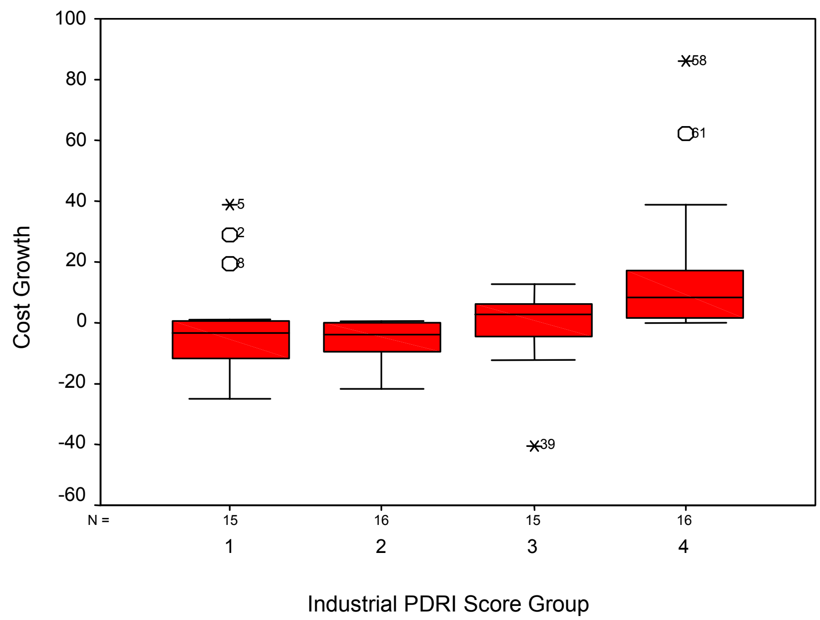


Figure 8.25. Industrial Cost Growth by PDRI Groups

Table 8.13. Summary Statistics for Industrial Cost Growth

| Cost Growth | PDRI Scores | Mean | Median | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| 1st Quartile (N=15) | 82-143 | -1.3% | -3.1% | -11.5% | 0.5% |
| 2nd Quartile (N=16) | 148-181 | -5.9% | -4.0% | -9.4% | 0.0% |
| 3rd Quartile (N=15) | 188-261 | -0.6% | 2.5% | -4.3% | 6.3% |
| 4th Quartile (N=16) | 274-465 | 17.7% | 8.3% | 1.9% | 15.8% |

From Table 8.13, similarities can be found in the descriptive statistics for the first three quartile-groups. Further statistical analysis (*t*-test) results showed that the mean difference for these three quartile-groups was not statistically significant. In turn, the first three quartile-groups in Table 8.13 were combined into a new group and the summary statistics for the updated group is presented in Table 8.14.

Table 8.14. Summary Statistics for Combined Group

| Cost Growth | PDRI Scores | Mean | Median | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| 1st – 3rd Quartile (N=46) | 82-261 | -2.7% | -0.9% | -9.2% | 2.1% |
| 4th Quartile (N=16) | 274-465 | 17.7% | 8.3% | 1.9% | 15.8% |

To be consistent, two industrial projects were used to estimate the possible cost growth of these projects. One project had a PDRI score of 200 and the other had a PDRI score of 400. From Figure 8.25 and Table 8.14, the first project with a 200 PDRI score was in the combined quartile-group and the project with a 400 PDRI score was in the fourth quartile-group. The mean cost growth for these two groups are -2.7 percent and 17.7 percent for the combined and fourth quartile-groups respectively. From historical data, there is a fifty percent chance that the cost growth for the 200 PDRI score project will fall within the range of -9.2 percent and 2.1 percent. The cost growth range for the 400 PDRI score project is between 1.9 percent and 15.8 percent. The cost growth estimates using boxplots and quartile analysis are summarized in Table 8.15.

Table 8.15. Boxplot Cost Growth Estimate Summary

| PDRI Score | Mean Cost Growth | Lower 25% | Upper 75% |
|---|---|---|---|
| 200 | -0.6% | -9.2% | 2.1% |
| 400 | 17.7% | 1.9% | 15.8% |

### 8.2.3. Hackney's Accuracy Range Estimate Model

To estimate possible cost growth for the 200 and 400 PDRI score projects, a scatter plot of PDRI scores and project cost growth was created for industrial projects. Figure 8.16 was reproduced along with the 10% and 90% lines (Figure 8.26).

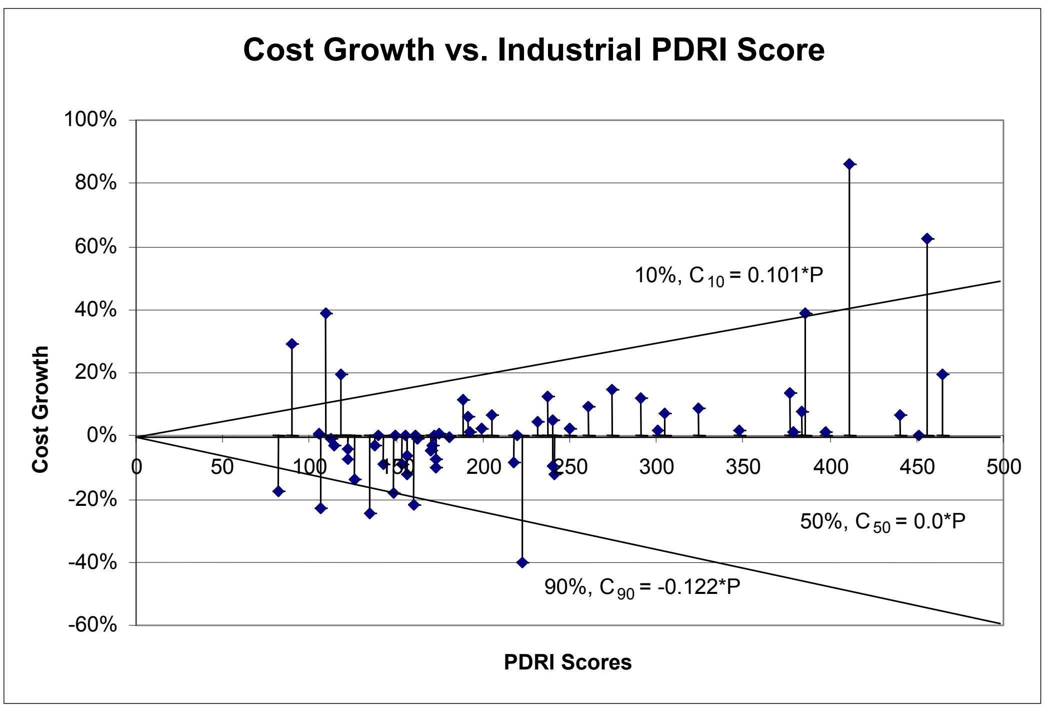


Figure 8.26. Scatter Plot: Schedule Growth vs. Industrial PDRI Score

As revealed in Figure 8.26, an industrial project has a 50/50 percent chance that the final cost will be within the authorized budget regardless of its PDRI score. Furthermore, an industrial project with a PDRI score of 200 has a 90 percent chance that the final cost will be below the authorized if 20.2 percent (200 x 0.101) contingency were added to the estimate. For a project with a PDRI score of 400, the 90 percent contingency increases to 40.4 percent (400 x 0.101).

The application of Hackney's method offers another advantage, which is the ability to estimate the probability of cost/schedule growth given PDRI scores and contingencies. As illustrated in Figure 8.17 of Section 8.1.3, an industrial project with a PDRI score of 200 and a 10 percent cost contingency would have an 85 percent chance to bring the final cost under authorized budget. Figure 8.17 was reproduced in Figure 8.27 with an added line for a project with 400 PDRI score and 10 percent contingency.

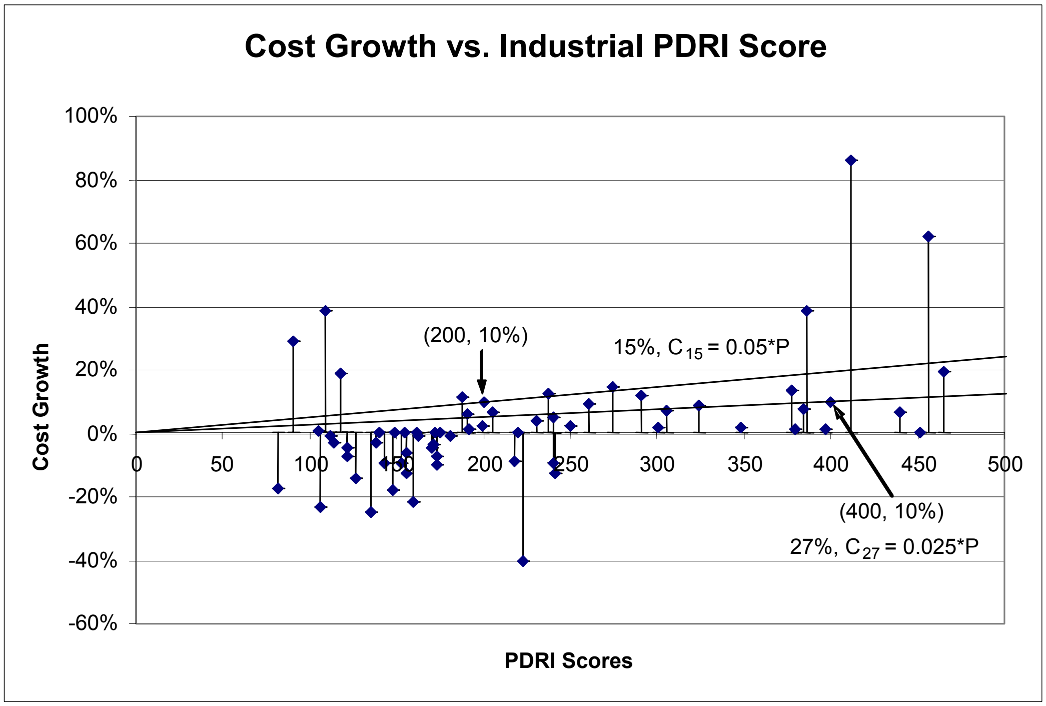


Figure 8.27. Cost Growth Accuracy Range Estimate for Industrial Projects

Results from Figure 8.27 shows that an industrial project with a PDRI score of 400 and a cost contingency of 10 percent only has a 73 percent chance that the final cost will be below the authorized budget. Whereas a 200 PDRI score project with the same contingency has an 85 percent chance of achieving the budget.

As illustrated in the previous three sections, the three proposed models can be applied to estimate the project performance given PDRI scores based on historical data. The three methods can be applied in different situations and should be chosen according to specific requirements. The results obtained from the three methods are fairly consistent and it is recommended that all three methods be employed. Table 8.16 demonstrates the estimation of industrial project cost performance for PDRI scores of 200 and 400 for the three models. Table 8.17 shows the summary estimation using similar approach for building projects.

Table 8.16. Performance Estimate Using the Three Models, Industrial Projects

| **Linear Regression Model** | | |
|---|---|---|
| PDRI Score | Expected Mean | 95% Confidence Level |
| 200 | 1.5% | -3.4% ~ 6.5% |
| 400 | 19.5% | 9.8% ~ 29.2% |
| **Boxplot Quartile Analysis Model** | | |
| PDRI Score | Mean | 50% Chance Range |
| 200 | -0.6% | -4.3% ~ 6.3% |
| 400 | 17.7% | 1.9% ~ 15.8% |
| **Hackney's Accuracy Range Estimate Model** | | |
| PDRI Score | Estimate Contingency | Probability of Overrun |
| 200 | 10% | 15% |
| 400 | 10% | 27% |

Table 8.17. Performance Estimate Using the Three Models, Building Projects

| **Linear Regression Model** | | |
|---|---|---|
| PDRI Score | Expected Mean | 95% Confidence Level |
| 200 | 6.4% | 3.4% ~ 9.5% |
| 400 | 14.4% | 8.8% ~ 20.2% |
| **Boxplot Quartile Analysis Model** | | |
| PDRI Score | Mean | 50% Chance Range |
| 200 | 4.1% | 0.0% ~ 5.5% |
| 400 | 19.2% | 8.3% ~ 27.8% |
| **Hackney's Accuracy Range Estimate Model** | | |
| PDRI Score | Estimate Contingency | Probability of Overrun |
| 200 | 10% | 23% |
| 400 | 10% | 48% |

Chapter 7 illustrated risk identification through PDRI evaluation and statistics shows that higher PDRI scores are positively related to poor project performance. After identifying project risks using the PDRI, implementation of risk quantification can be done by applying any of the three proposed methods. These models provide the project team with different perspectives during the risk quantification process. After risk quantification, the next logical step in the risk management process is risk control, which will be illustrated in the next section.

### 8.3. RISK CONTROL THROUGH PDRI

As previously discussed in the Literature Review, risk control includes risk avoidance, risk reduction, risk sharing, risk transfer, insurance, risk acceptance by establishment of contingency accounts, risk acceptance without any contingency and risk containment (CII 1989). After the project team has accomplished the PDRI evaluation, they might find that there is too much risk involved in the project and decide not to go forth with the project to completely avoid the potential risk. If the project is an international project, the owner might consider forming a joint venture with a local company to share the potential project risk. Some of the risks identified after the PDRI evaluation might be transferred to other project participants (architect, construction management, or contractors) through contracting strategy. In addition, the client can purchase insurance to cover the potential loss resulted from the project uncertainties. A common practice for the owner's organization is to set up a certain amount of budget in addition to the project cost estimate, often referred to as "contingency", to cover the unexpected cost. In some situations, the organization might decide to take the risk without any risk management measures. Among these risk control measures, risk reduction is determined most applicable for the purpose of this study, which is to apply PDRI in the risk management process. Risk reduction is a two-fold risk control technique and it decreases risk exposures by reducing the probability and financial consequences caused by risk exposures.

The PDRI can be used to reduce the risk during the risk management process. The most effective way of risk control using the PDRI is to lower PDRI score (resolve scope deficiencies) and thus reduce the probability of cost/schedule increase caused by poorly defined scopes. For illustration purpose, Table 8.12 is reproduced in Table 8.18 to summarize the cost growth estimates for projects with different scores using linear regression method. Of course, once the PDRI score is reduced, the project estimate must be reassessed.

Table 8.18. Ninety-five Percent Confidence Level Summary

| PDRI Score | $\hat{Y}_h$ | $t$ (.975, 60) | $s\{\hat{Y}_h\}$ | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| 200 | 1.5% | 2.0 | 2.5% | -3.4% | 6.5% |
| 400 | 19.5% | 2.0 | 4.8% | 9.8% | 29.2% |

From Table 8.18, it is evident that the expected mean cost growth is much lower for a 200 PDRI score project than a 400 PDRI score project. If the PDRI score for a project can be lowered from 400 to 200 by addressing poorly-defined scope elements, the expected mean cost growth for that particular project can be reduced from 19.5 percent to 1.5 percent (18 percent difference). That is, the financial consequences caused by incomplete scope can be significantly reduced by lowering the PDRI score. In addition, projects with a lower PDRI score have a smaller range of expected mean cost growth (9.9 percent) than projects with higher PDRI scores (range of 19.4 percent) when the estimates are set to 95 percent confidence levels. Therefore, lowering the PDRI score is an effective measure to reduce the financial consequences caused by risk exposures related to estimates.

Hackney's accuracy range estimate model can be used to illustrate the use of PDRI to reduce the probability of risk exposures. The results in Figure 8.27 show that two projects with the same cost contingency amount have different probability of achieving their budgets. An industrial project with a PDRI score of 200 and cost contingency of 10 percent has an 85 percent chance of achieving its authorized budget (estimate and 10 percent contingency). However, there is only a 73 percent chance that the final cost of a project with the same contingency but higher PDRI score (400) will be below the authorized budget. Hackney's model shows that lowering the PDRI score by improving the poorly-defined scope, the probability of overrunning the budget is lowered as well. That is, PDRI is an effective tool to reduce the probability of risk exposures around cost estimates.

From the previous two illustrations, lowering the PDRI score is an effective risk control measure in terms of reducing the probability and financial consequences of risk exposures. However, it should be noted that other risk control techniques (i.e. risk avoidance, risk sharing, and insurance) should be combined with risk reduction technique to minimize project risks. These techniques are beyond the scope of this research and therefore, readers should refer to other references for the application of these techniques in construction projects. However, if risk issues of identified during PDRI assessments, they can perhaps be mitigated using these methods.

### 8.4. RISK MANAGEMENT USING PDRI

Based on the Construction Risk Management System (CRMS) model developed by Al-Bahar (1988), a systematic risk management system incorporating the PDRI was proposed by the author. The format of pre-project planning process flow diagram (CII 1995) was adopted for the development of this systematic risk management system. The proposed risk management process, risk identification, risk quantification and risk control, is summarized in Figure 8.28.

From the literature review, a series of activities were identified for each of the risk management processes: risk identification, risk quantification, and risk control. In addition, a fourth process, risk control, was added to the proposed risk management system in order to make the process a continuous effort. The logical sequence to carry out these activities is presented in Figure 8.28. This proposed systematic risk management process can begin from as early as the conceptual stage of a project and continue until the beginning of detailed design to achieve the project goals set by the project team.

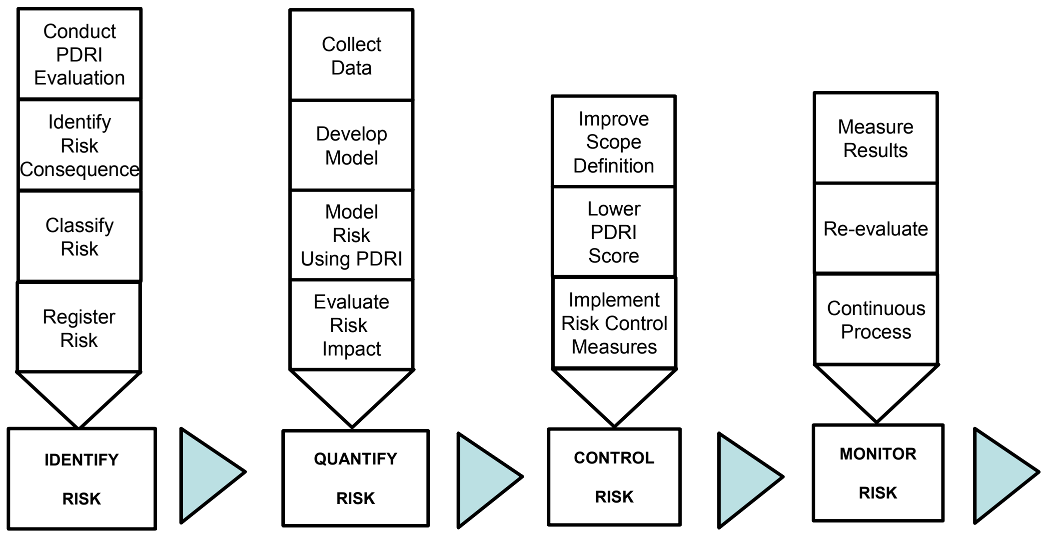


Figure 8.28. Systematic Risk Management Process Using PDRI

The first series of activities in risk management process deals with risk identification. The four major functions are: conducting PDRI evaluation, identifying risk consequence, classifying risk, and registering risk. During the pre-project planning process, the PDRI evaluation is carried out by the project team, which consists of major stakeholders of the project. The PDRI score sheets serve as a comprehensive potential project risk checklist. Poorly-defined scope elements are identified and total PDRI score is determined. These poorly-defined scope elements are treated as potential risk factors to the project. The project team then attempts to identify a set of credible risk event or consequence scenarios. The relative value of the PDRI element scores gives some indication of risk impact. Risk classification deals with classifying risk by its nature or potential impact and assigning the ownership of the risk. These risks are grouped and documented in the risk register along with their financial consequence, nature, and ownership.

The second series of activities in the risk management process deals with risk quantification. There are four major functions: collecting data, developing model, modeling risk using PDRI, and evaluating risk impact. In order to assess the potential risk impact caused by these risk exposures, historical project information within the company is first collected. The information collected should at least include basic project information, project performance, and PDRI scores. Linear regression models are developed to describe the collected data. As discussed in earlier sections, alternative analysis models include linear regression model, boxplot quartile model and Hackney's accuracy range estimate model. The models are used to estimate potential risk impact based on the results provided by the PDRI evaluation. With the given PDRI scores and basic project information, expected cost/schedule performance can be estimated. Thus, potential risk impacts caused by these risk exposures are determined. For instance, projects with a higher PDRI score (i.e., above 400) should possibly set aside more contingency than projects with a lower PDRI score (i.e., 200 or below) to cover the potential cost predictability problems caused by incomplete scope.

The third series of activities in the risk management process deals with risk control. There are three major functions in this process: improving scope definition, lowering PDRI score, and implementing risk control measures. After potential risk impacts are estimated for the risk register, a list of action items to improve the scope definitions are developed for risk reduction. Figure 8.29

illustrates an example of a partial risk register and action items identified after a PDRI evaluation. These are the results of an evaluation of an approximately $10 million electrical/mechanical upgrade of a courthouse facilitated by the author's supervisor. The relative risk score shown in Figure 8.29 was obtained from the results of PDRI evaluation. The project team evaluated each scope element in the PDRI and the relative weight for the definition level was recorded as the relative risk score in the risk register. The actions were subsequently assigned to project team members. Higher priorities are given to those action items that aim at risks with higher financial impacts. Once the poorly-defined elements are improved, the PDRI score will be lowered and the risk of poor performance is consequently reduced. Overall, the improved project scope benefits the project from the aspects that unknowns are resolved and estimate is improved.

The fourth series of activities in the risk management process deals with monitoring risk. PDRI evaluation can be applied during different stages of the project and the obtained PDRI scores can be used as a measure to monitor risk. Project definition should be improved as projects move into the next phase(s) and the PDRI score is lowered as project unknowns are resolved. That is, the project team has an objective measure with which to monitor project risk by keeping records of the PDRI score in different project phases. Finally, the risk management process should be a continuous efforts until the project is completed.

| Project Name, Date<br>(Items sorted in order of PDRI elements) | | | | | |
|---|---|---|---|---|---|
| **Item #** | **PDRI Elements** | **Relative Risk Score** | **Item Description** | **Date Complete** | **Responsible** |
| 1 | A2 | 1 | Share project prospectus with entire team | | |
| 2 | A6 and E5 | 19 | Finish future use plan for the site, which is already in progress, include technology and mechanical future uses; Complete the phase development plan | | |
| 3 | A8 | 8 | Develop project objective statement | | |
| 4 | B3 | 1 | Share five year operational plan with entire team | | |
| 5 | C2 | 13 | Define and document codes and standards to use for the project | | |
| 6 | C5 | 6 | Verify project phasing in the integrated schedule to take into account in-place tenant requirements of the project | | |
| 7 | C6 | 8 | Verify specialty consultant and testing requirements and revise budget | | |
| 8 | D1 | 4 | Verify adult requirements, structural layout and safety | | |
| 9 | D2 | 14 | Provide site survey to design team | | |
| 10 | E1 | 12 | Develop a program statement for the project | | |

Figure 8.29. Example Risk Register and Action Items, November 2001

These risk control techniques, risk avoidance, risk prevention, risk retention, risk reduction, risk transfer and insurance should be applied accordingly to ensure a successful project. It should be noted that risk control can take two forms. The first was identified in the previous two sections. Another method is contingency set aside to take care of unknown risks.

An objective way of measuring the results from risk control measures is to conduct a second PDRI evaluation. The PDRI score provides an objective measure of scope completeness and can be used to compare with each other to obtain metrics for improvement. In addition to PDRI evaluations, the results from other risk control measures should be tracked as well. All this information should be well documented to monitor the progress of risk management effort. This proposed systematic risk management process starts at the pre-project planning stage of the project life cycle and should be continued through the project to achieve the project goals.

### 8.5. LIMITATIONS AND SUMMARY

As presented in Section 4.7, there are some potential limitations of this study. Two major limitations include non-random sample selection and nature of retrospective case studies. In addition, the investigation of sample data revealed the non-normality of dependent variables (cost/schedule growth) at every level of the independent variable (PDRI score). This non-normality violated the assumptions of linear regression and thus caution must be taken when interpreting the results from the linear regression model. However, even when data violate these assumptions, the method may still be quite robust and will seldom be wrong when making conclusions about statistically significant or insignificant results (Knoke and Bohrnstedt 1994). Stevens (1996) recommended a nominal number of 15 data points per predictor for multivariable analysis when one or more assumptions underlying regression analysis are violated. For this study, there is only one predictor (PDRI score) and there are at least 62 (or 78) data points for the model. Therefore, conclusions are made that the non-normality violation does not deteriorate the ability to generalize results from the sample of interest.

This chapter outlined the development and application of three data analysis models used in this research. Based on the historical data, the models were developed using least squares linear regression method, boxplot quartile analysis method, and Hackney's accuracy range estimate method. The application of the models involved quantifying risk impact using PDRI score. Examples illustrating the application were given for each model. After the quantification of risk impact, risk reduction measures incorporating PDRI evaluation was discussed and other risk control technique were explored. Finally, a systematic risk management system prototype using the PDRI was introduced and discussed. A process flow chart was developed for this risk management process as well. The risk management process is a continuous cycle and should start at the pre-project planning stage and end with project completion to insure the successful delivery of capital facility projects.

# Chapter 9 Conclusions and Recommendations

This chapter completes this research study by presenting research conclusions and recommendations. The research objectives are first reviewed and specific conclusions relating to whether or not the research data support the hypotheses are then discussed. Recommendations are made based on research results and potential areas for future study are identified. The contributions of this research are discussed at the end.

## 9.1. REVIEW OF RESEARCH OBJECTIVES

As identified in Chapter 1, this research effort had four primary objectives which were:

1. To further validate the PDRI through testing by measuring the level of project scope definition and comparing to the degree of actual project success using a more robust sample
2. To identify the specific impact of PDRI elements using statistical analysis methods
3. To develop a systematic project risk management approach based on the PDRI
4. To establish a baseline methodology and database for follow up research

The following four sections present a detailed discussion of these four objectives.

### 9.1.1. Further Validation of the PDRI

The PDRI for industrial projects was validated as an effective scope definition tool using a sample of 40 industrial projects representing approximately \$3.3 billion (USD) in authorized cost (Dumont et al. 1997). The PDRI for building projects was validated through a sample of 33 building projects representing approximately \$0.9 billion (USD) in total construction cost. This research effort continued the data collection and PDRI validation using an expanded data set. As a result, a total of 62 industrial projects and 78 building projects were obtained for the analysis of this research.

The previous validation method was adopted for this research. In order to determine the effectiveness of the PDRI in predicting project success, linear regression analyses were conducted for both industrial and building projects. The project success was measured by success index, which was calculated using both cost performance and schedule performance. With the PDRI score as independent variable and project success index as dependent variable, bivariate linear regression analyses were conducted. The results of the regression analysis using PDRI scores and project success measured by the success index demonstrated a significant correlation between the two variables for both industrial and building projects. The results were consistent with previous PDRI research results that the PDRI is an effective scope definition tool and subsequently meet the first objective discussed in Chapter 1.

### 9.1.2. Identifying Project Risk and Potential Risk Impact

The second research objective was to identify project risk factors and their potential impact of project performance based on data collected. Statistical methods such as effect size analysis, linear regression analyses, and boxplot quartile analyses were conducted. Actual project scope definition levels were analyzed to determine if there were scope elements that distinguish between successful and less-than-successful projects. Projects were first grouped by their cost/schedule performance into successful and less-than-successful projects. Then actual scope definition level averages between the two groups were calculated and compared. Significant differences between the mean definition levels of the two groups were determined using *t*-tests. If the mean definition levels between the two performance groups were different, the magnitude of difference was measured by effect size analysis. The results showed that projects with better performance did better in defining certain scope elements than others. Moreover, elements A3: Operating Philosophy, G4: Process Safety Management (PSM), G5: Utility Flow Diagrams, and G7: Piping System Requirements were found to be performance indicators in both cost and schedule performance for industrial projects. The analysis results also indicated that no element impacting both cost and schedule were found for building projects. Only cost performance indicators were identified from this building sample.

In order to estimate the potential risk impacts caused by risk exposures as a result of incomplete scope definition, three unique techniques were explored to model the sample data: least squares linear regression method, boxplot quartile analysis method, and Hackney's accuracy range estimate method. The results given in Chapter 8 showed that these models can be applied effectively to summarize and present the data and can be used to estimate cost/schedule performance based on given PDRI scores. These findings meet the second stated objective of this dissertation research.

### 9.1.3. Systematic Project Risk Management Approach Development

Risk management process consists of three major tasks: risk identification, risk quantification and risk control. It is shown in this research that the PDRI can be effectively used in all of the three risk management processes. The next logical step is to document these findings and establish a systematic risk management approach based on these findings. By applying the CRMS model developed by Al-Bahar (1988) and adopting the format of pre-project planning process flow diagram (CII 1995), a systematic risk management process using PDRI was developed and presented in Figure 8.28.

There are four major sub-processes in the proposed risk management model: risk identification, risk quantification, risk control, and risk monitoring. Each process consists of a series of activities that are deemed important in that process. The PDRI is used in all four stages of the proposed risk management model and the process may be used one or several times for each project. The development of this unique systematic risk management system using PDRI meets the third objective of this research.

### 9.1.4. Establish Baseline Methodology

The last research objective was to establish a baseline methodology and database for follow-up research. The methodology established included PDRI benchmarking, data analysis in the form of regression modeling, boxplot quartile analysis modeling and Hackney's accuracy range estimate modeling, and statistical test for effect size. This methodology is unique in pre-project planning research and provides a basis for early project risk analysis and management for the construction industry.

Two databases were developed for follow-up research: industrial project database and building project database. These two datasets both had data stored in database software package Access™ and in SPSS™. All data are ready for any follow-up research or benchmarking studies deemed relevant.

## 9.2. RESEARCH HYPOTHESES

In Chapter 3 of this dissertation, two research hypotheses were established and discussed. The hypotheses were developed based on the results of literature review, problem statement, findings of previous PDRI and pre-project planning research. The hypotheses are set up to extend the usage of the PDRI from a pre-project planning scope definition tool to a risk management tool in the early stage of a project. These two hypotheses are discussed in detail.

*H1: A PDRI score indicates the current level of scope definition and corresponds to project performance. That is, PDRI scores correlate to measures of project success.*

In order to test this hypothesis and to find any existing correlation among the two variables (PDRI score and project success), a mechanism for measuring the project success was developed. By adopting success measures from previous PDRI research, two variables were identified for measuring success versus the PDRI score:

- **Budget Achievement:** Adherence to the estimated budget for detailed design and construction.
- **Schedule Achievement:** Adherence to the estimated detailed design and construction schedule for substantial completion

The equation derived to produce a baseline measure of success was:

| | |
|---|---|
| **Project Success Index =** | 0.50 (Budget Achievement Value) +<br>0.50 (Schedule Achievement Value) |

The results of the least squares linear regression analysis using the PDRI scores and project success measured by the success index demonstrated a significant correlation and supported the first research hypothesis. The results showed that as the PDRI score decreases, the probability of project success increases. These results support the first research hypothesis.

In addition, the regression results shown in Chapter 8 indicate positive relationships between PDRI scores and project performance (cost and schedule). It was statistically shown that as project PDRI score decreases (for both industrial and building projects in this sample), the project cost/schedule growth decreases. This result also supports the first research hypothesis.

In Chapter 6, project unit cost and PDRI score are analyzed for the 42 institutional organization projects. By comparing the actual unit cost and budgeted cost for the projects with their PDRI scores, it is shown that project with lower PDRI score (better pre-project planning) cost less to construct. Taking the real cost saving as a measure of project success, the unit cost analysis results support the first research hypothesis by showing the real cost savings for projects with better pre-project planning in the institutional organization sample.

However, some of the potential limitations of this analysis are acknowledged. The primary limitation relates to generalizing the sample characteristics to a larger population. In this study, sample project selection was based on organizations volunteering projects and not on a random selection process, organizations may have selected projects with a bias toward success, which may have influenced the results. In the mean time, the sample projects provided by the institutional organization provided a homogeneous sample and were deemed better to generalize the sample characteristics to a larger population within the organization.

*H2: The PDRI is a reliable indicator of potential project risk factors and PDRI scores can be used to quantify risk impact on project outcomes based on collected data from actual projects.*

The research results also support this second research hypothesis. Sample projects were categorized into two groups based on their project performance. The mean definition levels were compared between these two performance groups. First, the significance of mean definition level difference was tested and determined using *t*-tests. Then the magnitude of mean definition level difference was determined for these identified scope elements. The magnitude of difference was measured by effect size.

The scope elements with significant mean definition level difference were identified as indicators of poor performance. The scope definition levels can be related to project performance (cost/schedule growth). Tables 7.12 and 7.13 are recreated in Tables 9.1 and 9.2 to demonstrate the cost/schedule performance indicators identified by this research investigation.

Table 9.1. Cost Performance Indicators

| **Cost Performance Indicators** | |
|---|---|
| Industrial Projects<br>Element | Building Projects<br>Element |
| A1. Reliability Philosophy<br>A2. Maintenance Philosophy<br>A3. Operating Philosophy<br>B6. Future Expansion Considerations<br>B7. Expected Project Life Cycle<br>B8. Social Issues<br>D2. Project Design Criteria<br>D4. Dismantling and Demolition Requirements<br>F2. Surveys and Soil Tests<br>G4. Process Safety Management (PSM)<br>G5. Utility Flow Diagrams<br>G7. Piping System Requirements<br>G10. Line List<br>G11. Tie-In List<br>G12. Piping Specialty Items List<br>H2. Equipment Location Drawings<br>J2. Location/Uploading/Storage Facilities Requirements<br>P4. Pre-Commission Turnover Sequence Requirements | A8. Project Objectives Statement<br>B2. Maintenance Philosophy<br>B4. Design Philosophy<br>E1. Program Statement<br>E2. Building Summary Space List<br>E11. Room Data Sheets<br>E13. Window Treatment<br>F2. Architectural Design<br>F4. Mechanical Design<br>F5. Electric Design<br>F7. Constructability Analysis<br>H1. Identify Long-Lead/Critical Equipment and Materials<br>H2. Procurement Procedures and Plans<br>J2. Documentation/Deliverables<br>L3. Project Delivery Method |

Table 9.2. Schedule Performance Indicators

| Schedule Performance Indicators | |
|---|---|
| Industrial Projects<br>Element | Building Projects<br>Element |
| A3. Operating Philosophy<br>G4. Process Safety Management (PSM)<br>G5. Utility Flow Diagrams<br>G7. Piping System Requirements<br>G13. Instrument Index<br>K1. Control Philosophy<br>K6. Instrument & Electrical Specifications | N/A |

The PDRI scores were also used to estimate the potential risk impacts based on historical data. Three different models were established to summarize and describe the sample data. These models were then applied to estimate cost/schedule performance versus estimated given a PDRI score. The results showed that not only the probability of the risk but also the magnitude of the financial consequences caused by the risk exposures can be estimated. These results support this second research hypothesis.

## 9.3. CONCLUSIONS

A number of different methods to collect and analyze the data were utilized in the dissertation research. Historical project performance and PDRI data were collected from of 140 sample projects from two industry sectors representing approximately $5 billion (USD) in total construction cost. The large amount of data was analyzed using various statistical techniques as well as qualitative analysis techniques. In addition, a systematic risk management approach using the PDRI along with a risk management process flow diagram were presented and discussed in detail. Three fundamental conclusions were reached:

- The completeness of project scope definition during pre-project planning of capital facilities has a significant and positive direct effect on overall project success.
- There are specific scope elements identified in the PDRI that the project team should address that can have a significant and positive effect on project success.
- The PDRI is an effective tool for scope definition and can be applied in risk management process during the pre-project planning.

### 9.4. CONTRIBUTIONS

This research investigation was exploratory in nature and contributes to the body of knowledge by extending the knowledge of project risk management in pre-project planning. Previous research identified the PDRI as an effective tool for measuring project scope development and predicting project performance. This investigation extended that research by focusing on the application of the PDRI in different phases of risk management processes. Major contributions of this research include:

1. This study demonstrated that completeness of scope development has a significant and positive effect on project success. No previous research investigation using the PDRI had as many sample projects as this study. The homogeneous sample from the institutional organization offered a unique sample within one single organization. The research contributes

to the current body of knowledge by providing in-depth analysis and empirical evidence that scope development during pre-project planning is important and has a positive effect on project outcomes, including improvement of cost and schedule predictability as well and real value-based cost savings.

2. The statistical analysis used to summarize the scope definition levels of the sample projects is a way to measure the level of scope development practice in the industrial and building sectors. No comparable research was found during the literature review. This study contributes to the current body of knowledge by showing details of industry scope development practice for this sample.
3. The study contributes to the current body of knowledge by identifying scope elements that have significant effect on achieving project success. The project team can use this information to help focus their limited resources on the issues with larger impacts on project outcomes. The results provide specific guidance to project teams wishing to address scope definition during pre-project planning.
4. The systematic risk management approach using the PDRI developed in this research provides a prototype road map for risk management process during pre-project planning. It successfully combines the usage of the PDRI and project risk management process.

## 9.5. RECOMMENDATION FOR FUTURE RESEARCH

Through the course of this research effort, several areas have been identified as potential areas for future study. The first is in the area of improving the data collection process. One major limitation of this research is due to the nature of retrospective case studies. If after-the-fact information is collected, the quality of this information heavily relies on human recollection. As such, a certain degree of error is expected. Using "real time" information collected from an ongoing project should significantly enhance the reliability of the data thereby increasing the accuracy of any conclusions that can be drawn from the analysis. Organizations such as CII or individual organization wishing to improve their pre-project planning process can greatly benefit from using this approach in their benchmarking effort.

Further analysis in various areas can benefit from an improved survey instrument and increased sample size. More detailed information concerning the sample projects should be captured with an improved survey instrument so that correlations between the PDRI score and other variables (i.e. project size, type of project, contracting method) can be found to further increase the reliability of the PDRI in predicting project performance, including estimate predictability and real cost savings. An initial effort was performed for the institutional organization projects. However, the effort should be continued with an increased sample size and more detailed analysis.

This investigation utilized three different analysis methods to model the sample data. The results obtained are satisfactory for an initial exploratory study. Alternative modeling approaches to better describe the data at hand are recommended. As an experimental effort, modeling techniques such as Artificial Neural Network and Second Moment Bayesian Method were explored and initial efforts showed promising results and may warrant further analysis.

# Appendix A Logic Flow Diagram for Industrial PDRI

**Narrative of the Logic Flow Diagram for Industrial Projects**

The PDRI Logic Flow Diagram (LFD) is provided to illustrate the interrelationship between various categories and elements of the PDRI. Note that the LFD is not "CPM-type" logic in that certain elements are completed prior to the point when the next elements can start. Many times elements can be pursued concurrently. As information is gained down stream, elements already defined have to be revisited. Also, there may be many ways to organize the work differently than the flow shown. This LFD is provided as a guideline for planners to use in pursuing the planning process. Your organization may want to standardize a front-end planning process. The logic presented in these diagrams could provide the basis for that development.

Note that Section and Category Logic Flow Diagram for the Industrial PDRI are shown in Figures A.1 and A.2 respectively. Element Logic Flow Diagram cannot fit on the size of this paper and can be found in the PDRI Virtual User Group website (www.cii-pdri.org).

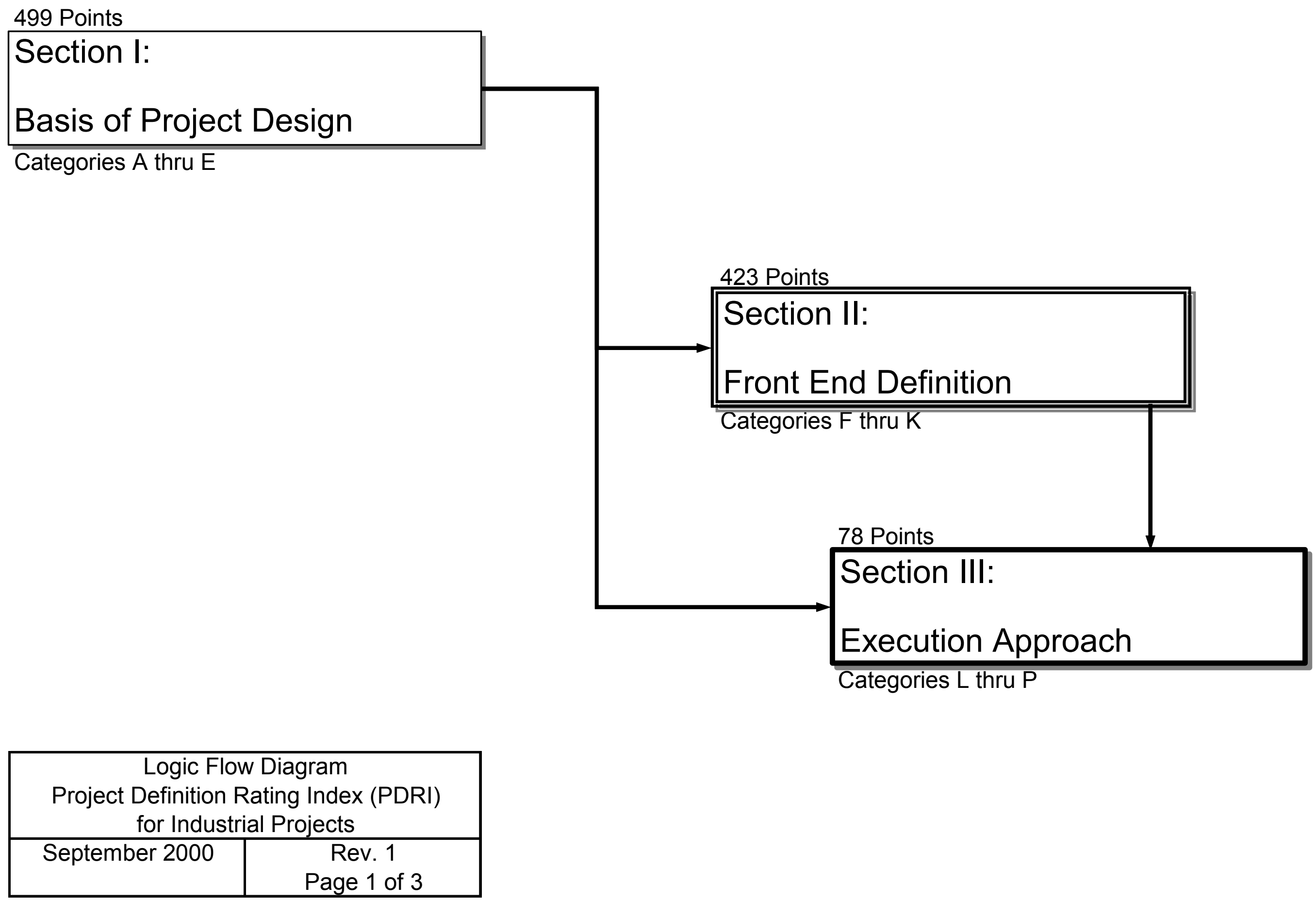


**Figure A.1. Section Logic Flow Diagram**

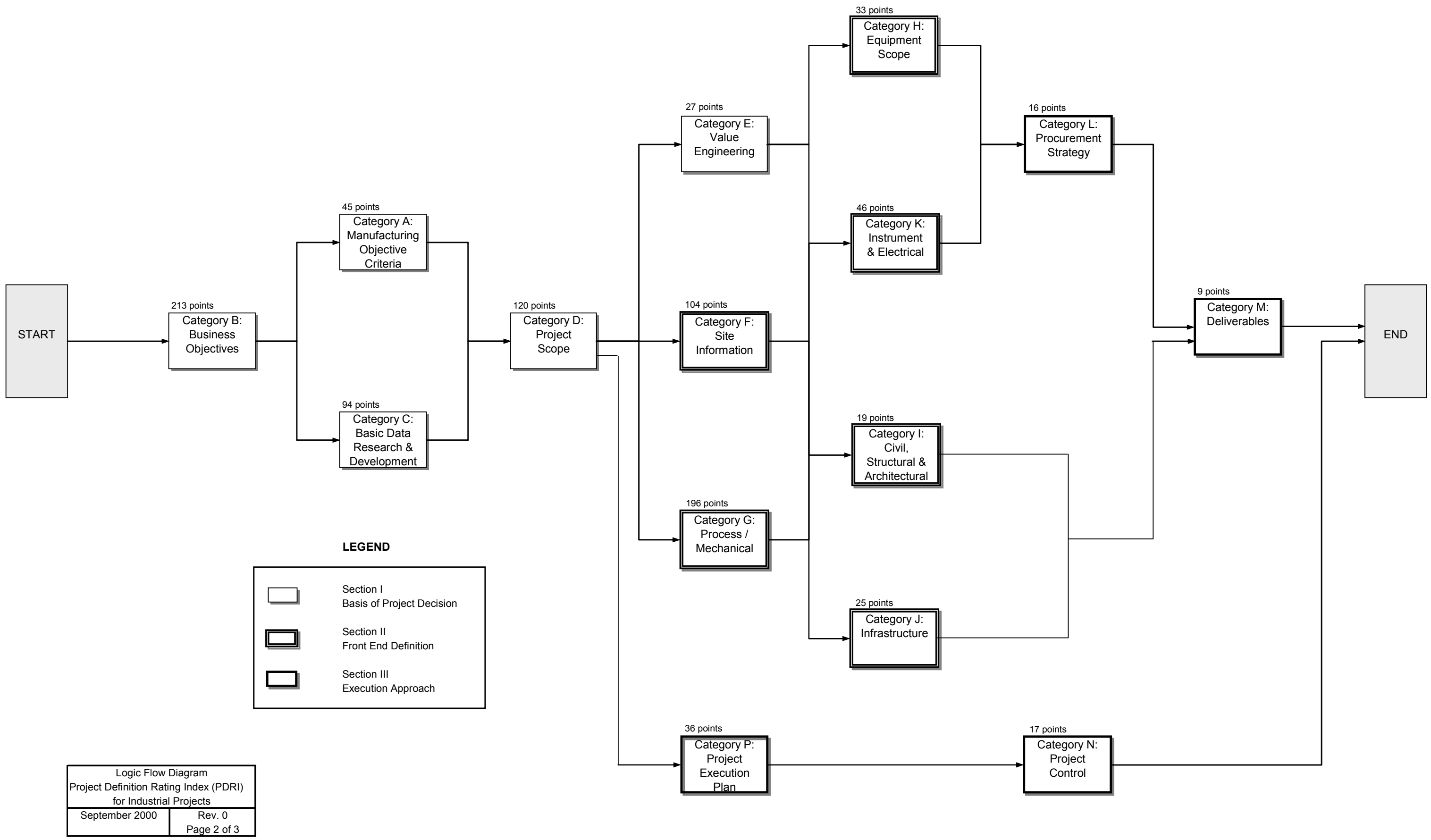


**Figure A.2. Category Logic Flow Diagram**

## Appendix B Institutional Organization Risk And Readiness Survey Questionnaires (Project Manager and User)

# BUILDING PROJECT

## Risk & Readiness Assessment

## (RRA) User Feedback Questionnaire

**Risk & Readiness Research Team**

Building Construction Department
The University of Texas at Austin
Consultant

An (RRA) Project into the development of scope definition tool for temple projects

Date:

Name:

Address:

Dear ______,

The Building Construction Department with the assistance of the University of Texas at Austin and an outside consultant is evaluating the project scope definition process. A research team has developed a project scope evaluation called the Risk & Readiness Assessment (RRA), and is now validating this tool with data from recently completed building projects. The enclosed questionnaire is designed to help in this effort by measuring the quality of project score definition during the pre-project planning phase.

The research team will be presenting the results of this study to the Managing Director of the Building Construction Department. The RRA may be approved for use on building construction projects in the future to assist with pre-project planning.

Enclosed are survey forms that will provide the research team information for the identified projects. Please be candid in your responses.

The survey package includes a brief introduction of RRA (blue) and the RRA User Feedback Questionnaire (white). Please complete the Questionnaire and return it in the pre-addressed, stamped envelope provided. The rest of the material is for your information and does not have to be returned. If you have any questions, please feel free to contact me at (123) 456-7890 or by e-mail at abc@def.ghi Questions about the survey or the research process please feel free to contact the consultant at (123) 456-7890 or by e-mail at jkl@mno.pqr.

We would appreciate the return of the surveys by December 18, 2000.

Your participation in this effort is greatly appreciated.

Sincerely,

Director

Home Office Technical Support Services

Encl. (2)
RRA Introduction
RRA User Feedback Questionnaire

## Project Risk and Readiness Assessment

### Introduction

Review of recently completed building projects shows that these projects suffer from poor or incomplete project scope definition. The Building Construction Department needs a user-friendly tool to assist in defining project scope, assessing risk and readiness, and maximizing the chance of project success. A research team from Building Construction Department, an outside consultant and the University of Texas at Austin has developed a tool called the "Risk & Readiness Assessment" (RRA) to serve this purpose. It is an adaptation of the Project Definition Rating Index (PDRI) into building projects. The PDRI, developed by the Construction Industry Institute (CII) is both user friendly and effective for qualifying project scope definition.

By introducing RRA, the research team expects significant reduction in the number and cost of change orders, greater ability to maintain project schedules, reduction of risk during construction, improved communication, and achievement of customer satisfaction, thus ensuring the success of temple projects.

### RRA Forms

RRA for building projects has already been developed and your assistance will help to prove its effectiveness. To fill out the questionnaire, follow these steps:

Step 1: Read the question.

Step 2: Collect all data that you need too properly evaluate and select the rating for each question.

Step 3: Select the rating that most closely matches the results of the question. This may require obtaining input form other individuals involved with this process.

Step 4: For each answer, circle the score (1-5) that corresponds to your results.

Step 5: Please make written comments as necessary.

**SURVEY QUESTIONNAIRE**
**BUILDING PROJECT**
**RISK & READINESS ASSESSMENT**
**(RRA)**

**Customer Satisfaction:**

Project ID Number : ______________________________________________

1. How closely did the completed temple conform to the written program? (*circle only one*)

   1 2 3 4 5

   very different ----------------------------------------------> closely matches

   If the facility is very different from the program, please list the reasons for the changes:

   ____________________________________________________________

   ____________________________________________________________

   ____________________________________________________________

2. How closely did the completed temple conform to the scope as defined in the work order? : (*circle only one*)

   1 2 3 4 5

   very different ----------------------------------------------> closely matches

   If the facility is very different from the program, please list the reasons for the changes:

   ____________________________________________________________

   ____________________________________________________________

   ____________________________________________________________

3. Have there been any alterations or retrofits already completed or anticipated during the first year of operation?

   ____________________________________________________________

   ____________________________________________________________

   Approximate Costs: ___________________________________________

4. How involved were you in the following process?

**Program Definition**

1 2 3 4 5
Little Involvement ----------------------------------------------------> Very Involved

**Scope**

1 2 3 4 5
Little Involvement ----------------------------------------------------> Very Involved

**Construction**

1 2 3 4 5
Little Involvement ----------------------------------------------------> Very Involved

5. Reflecting on the overall project, rate how smoothly the project has proceeded from design to turnover:

1 2 3 4 5
Very troubled --------------------------------------------------------> Very Smooth

6. From your perspective, what could have been done differently to make the process smoother?

__________________________________________________

__________________________________________________

__________________________________________________

__________________________________________________

__________________________________________________

__________________________________________________

# BUILDING PROJECT

## Risk & Readiness Assessment

## (RRA) Project Manager Questionnaire

**Risk & Readiness Research Team**

Building Construction Department
The University of Texas at Austin
Consultant

An (RRA) Project into the development of scope definition tool for temple projects

Date
Name:
Address:

Dear:

The Building Construction Department with the assistance of the University of Texas at Austin and an outside consultant is evaluating the project scope definition process. A research team has developed a project scope evaluation called the Risk & Readiness Assessment (RRA), and is now validating this tool with data from recently completed building projects. The enclosed questionnaire is designed to help in this effort by measuring the quality of project score definition during the pre-project planning phase.

The research team will be presenting the results of this study to the Managing Director of the Building Construction Department. The RRA may be approved for use on building construction projects in the future to assist with pre-project planning.

Enclosed are survey forms that will provide the research team information for the identified projects. Please be candid in your responses.

The survey package includes a brief introduction of RRA (blue) and the RRA Questionnaire (which includes the Project Score Sheet) (white), and RRA Element Description (yellow). Please complete the Questionnaire (white) and return it in the pre-addressed, stamped envelope provided. The rest of the material is for your information and does not have to be returned. If you have any questions, please feel free to contact me at (123) 456-7890 or by e-mail at abc@def.ghi Questions about the survey or the research process please feel free to contact the consultant at (123) 456-7890 or by e-mail at jkl@mno.pqr.

We would appreciate the return of the surveys by December 18, 2000.

Your participation in this effort is greatly appreciated.

Sincerely,

Director
Home Office Technical Support Services

Encl. (3)
RRA Introduction – Blue
RRA Questionnaire – White
RRA Element Descriptions – Yellow

## Project Risk and Readiness Assessment

### Introduction

Review of recently completed building projects shows that these projects suffer from poor or incomplete project scope definition. The Building Construction Department needs a user-friendly tool to assist in defining project scope, assessing risk and readiness, and maximizing the chance of project success. A research team from Building Construction Department, an outside consultant and the University of Texas at Austin has developed a tool called the "Risk & Readiness Assessment" (RRA) to serve this purpose. It is an adaptation of the Project Definition Rating Index (PDRI) into building projects. PDRI, developed by Construction Industry Institute (CII) is both user friendly and effective for qualifying project scope definition.

By introducing RRA, the research team expects significant reduction in the number and cost of change orders, greater ability to maintain project schedules, reduction of risk during construction, improved communication, and achievement of customer satisfaction, thus ensuring the success of temple projects.

### RRA Forms

RRA for building projects has already been developed and your assistance will help to prove its effectiveness. The RRA Survey Questionnaire consists of three main sections divided into 11 categories that are further divided into individual elements. Sections, categories, and elements on the Score Sheet parallel those in the Survey Questionnaire:

Steps remaining in this research effort include:

1. **Benchmarking building projects**
2. **Analyzing the data**
3. **Disseminating results and conclusions**
4. **Refining RRA documents for application to individual projects.**

**PROJECT MANAGER SURVEY QUESTIONNAIRE**
**BUILDING PROJECT**
**RISK & READINESS ASSESSMENT**
**(RRA)**

## PROJECT BACKGROUND INFORMATION

1.0. Date:

1.1 Project ID Number:

1.2. Home Office Contact:

1. Name:
2. Tel. No.:
3. E-mail:

1.3 Consultant Contact:

1. Name:
2. Tel. No.: Fax No.:
3. E-mail:

1.4 Completion Date and Return:

1. December 18, 2000
2. Return in pre-addressed envelope

2.0 <u>General Project Information</u>:

1. Project ID Number: ______________________________________

2. What is the size of the Building (e.g., number of occupants, volume/capacity, net or gross square footage, number of floors, etc.)

___________________________________________________________

___________________________________________________________

___________________________________________________________

___________________________________________________________

3. From your perspective, what was the level of the project complexity?

[ ] High [ ] Average [ ] Low

4. Was there anything unique about this project? *(please check all that apply)*

[ ] New Standard Plan utilized
[ ] First of a kind changes to Standard Plans
[ ] Largest (scale)
[ ] Other (e.g., special development requirements, equipment, location, execution, etc.)
*Please describe:* __________________________________
[ ] Not applicable

5. What was the execution contracting approach that you used on your project?

[ ] Design-Build
[ ] Design-Bid-Build
[ ] Other (*please specify*) ______________________________

2.1. <u>Schedule Information</u>:

1. Please provide the following **schedule** information:

| Item | Planned (mm/dd/yy) | Actual (mm/dd/yy) |
|---|---|---|
| Project Announcement | | |
| Start Date of Construction | | |
| Date of Substantial Completion | | |

2. If there were any schedule extensions or reductions during development of

construction documents and construction, please indicate the reason(s) in the appropriate box(es) below by supplying the duration(s) of the change(s) (in months) and whether it was an extension (Ext) or reduction (Red). *(please check all that apply)*

| Type | Mos. | Ext | Red | Type | Mos. | Ext | Red |
|---|---|---|---|---|---|---|---|
| Home Office Request | ____ | [ ] | [ ] | Standard Plan | ____ | [ ] | [ ] |
| Field Architect | ____ | [ ] | [ ] | Local Code | ____ | [ ] | [ ] |
| Unforeseen | ____ | [ ] | [ ] | Building Department | ____ | [ ] | [ ] |
| General Authority | ____ | [ ] | [ ] | | | | |
| Other (*please specify*) | ____ | [ ] | [ ] | | | | |

Do you have any additional comments?
________________________________________________________________
________________________________________________________________
________________________________________________________________

2.2. Cost Information:

1. Please provide the following **cost** information: (*If the person filling out this section does not have the information, please state "Don't know", if it was 0, state as 0.*)

| Item | Estimated Costs at Start of Construction Document Development | Actual Costs After Construction Complete |
|---|---|---|
| Construction Costs | | |
| Other | | |
| Total Project Cost | | |

2.3. Change Information:

1. What were the total number of change orders issued (including during both construction document development and construction)? _______________

2. What were the total dollar amounts of all change orders? $ ______________

3. What was the net duration change in the completion date resulting from change orders? _____________ (Calendar Days)

4. Did the changes increase or decrease the length of the original project duration?
   [ ] Increased [ ] Decreased

5. Were there any individual changes after project authorization that exceeded 1% of the project budget?

   [ ] No
   [ ] Yes - If "Yes," what were the total cumulative effects and the direction of these changes on:
   a. Cost: $ _________________ [ ] Increase or [ ] Decrease
   b. Schedule: ______ months. [ ] Increase or [ ] Decrease
   c. How many changes comprised 1% of the original contract amount or greater? _________________
   d. What were the reasons for the changes? *(Please check all that apply.)*

   [ ] Home Office Request
   [ ] Field Architect
   [ ] Unforeseen
   [ ] General Authority
   [ ] Other *(please specify)* ______________________________
   [ ] Standard Plan
   [ ] Local Code
   [ ] Building Department

Do you have any additional comments regarding any causes or effects of change orders?

2.5. Operating Information:

Was the facility scope reduced/increased in any significant manner?

_____ Functionality
_____ Size
_____ Materials of Construction
_____ Equipment
_____ Other (*please specify*) ________________________________

If yes, please describe ______________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

2. Reflecting on the overall project, rate how successful you feel the project has been using a scale of 1 to 5, with 1 being very unsuccessful to 5 being very successful: (*circle only one*)

**Cost**

1 2 3 4 5

very unsuccessful -----------------------------------------------------> very successful

**Quality**

1 2 3 4 5

very unsuccessful -----------------------------------------------------> very successful

**Time**

1 2 3 4 5

very unsuccessful -----------------------------------------------------> very successful

Do you have any additional comments regarding customer satisfaction?

____________________________________________________________

____________________________________________________________

____________________________________________________________

3.0. Project Rating Information:

Next, please complete the Project Rating Information form located on the next few pages. Detailed instructions for completing this form are explained below.

## INSTRUCTIONS FOR RATING A PROJECT

The RRA is intended to evaluate the completeness of the scope definition for a project when it is submitted for authorization (prior to detailed design and construction). When rating a project, evaluate whether the local project architect was supplied all the scope definition needed to define the project, and perform the rating as though you were reviewing the contract documents just prior to bid time.

The (RRA) consists of three main sections, each of, which is broken down into a series of categories which, in turn, are further broken down into elements. Evaluating and rating the individual elements performs scoring. Elements should be rated numerically from 0 to 5 based on its level of definition at the point in time prior to beginning detailed design and construction. Think of this as a "zero defects" type of evaluation. Elements that were as well defined as possible should receive a perfect rating of "one." Elements that were completely undefined should receive a rating of "five." All other elements should receive a "two," "three," or "four" depending on their levels of definition. Those elements deemed not applicable for the project under consideration should receive a "zero." The ratings are defined as follows:

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

*To rate an element, first read its definition in the Description section of the 64 RRA Elements document (yellow). Some elements contain a list of items to be considered when evaluating their levels of definition. These lists may be used as checklists. Note that some of these items may not be applicable for your project. Next, refer to the Project Rating Information form and locate the element.* ***Please choose only one definition level*** *(0, 1, 2, 3, 4, or 5) for that element based on your perception of how well it was defined when the project was authorized. Once you have chosen the appropriate definition level for the element* ***please check (√) the corresponding box.*** *Do this for each of the 64 elements in the RRA. Be sure to rate each element.*

## PROJECT RATING INFORMATION

| SECTION I - BASIS OF PROJECT DECISION | | | | | | |
|---|---|---|---|---|---|---|
| | **Definition Level** | | | | | |
| CATEGORY<br>Element | **0** | **1** | **2** | **3** | **4** | **5** |
| A. BUSINESS STRATEGY | | | | | | |
| A1. Building Use | | | | | | |
| A2. Business Justification | | | | | | |
| A3. Business Plan | | | | | | |
| A4. Economic Analysis | | | | | | |
| A5. Facility Requirements | | | | | | |
| A6. Future Expansion/Alteration Considerations | | | | | | |
| A7. Site Selection Considerations | | | | | | |
| A8. Project Objectives Statement | | | | | | |
| B. OWNER PHILOSOPHIES | | | | | | |
| B1. Reliability Philosophy | | | | | | |
| B2. Maintenance Philosophy | | | | | | |
| B3. Operating Philosophy | | | | | | |
| B4. Design Philosophy | | | | | | |
| C. PROJECT REQUIREMENTS | | | | | | |
| C1. Value-Analysis Process | | | | | | |
| C2. Project Design Criteria | | | | | | |
| C3. Evaluation of Existing Facilities | | | | | | |
| C4. Scope of Work Overview | | | | | | |
| C5. Project Schedule | | | | | | |
| C6. Project Cost Estimate | | | | | | |

*Please check (√) only one box for each element. Please do not leave any elements blank.*

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

| SECTION II - BASIS OF DESIGN | | | | | | |
|---|---|---|---|---|---|---|
| | Definition Level | | | | | |
| CATEGORY<br>Element | **0** | **1** | **2** | **3** | **4** | **5** |
| D. SITE INFORMATION | | | | | | |
| D1. Site Layout | | | | | | |
| D2. Site Surveys | | | | | | |
| D3. Civil/Geotechnical Information | | | | | | |
| D4. Governing Regulatory Requirements | | | | | | |
| D5. Environmental Assessment | | | | | | |
| D6. Utility Sources with Supply Conditions | | | | | | |
| D7. Site Life Safety Considerations | | | | | | |
| D8. Special Water and Waste Treatment Requirements | | | | | | |
| E. BUILDING PROGRAMMING | | | | | | |
| E1. Program Statement | | | | | | |
| E2. Building Summary Space List | | | | | | |
| E3. Overall Adjacency Diagrams | | | | | | |
| E4. Stacking Diagrams | | | | | | |
| E5. Growth & Phased Development | | | | | | |
| E6. Circulation and Open Space Requirements | | | | | | |
| E7. Functional Relationship Diagrams/Room by Room | | | | | | |
| E8. Loading/Unloading/Storage Facilities Requirements | | | | | | |
| E9. Transportation Requirements | | | | | | |
| E10. Building Finishes | | | | | | |
| E11. Room Data Sheets | | | | | | |
| E12. Furnishings, Equipment, & Built-Ins | | | | | | |
| E13. Window Treatment | | | | | | |
| F. BUILDING/PROJECT DESIGN PARAMETERS | | | | | | |
| F1. Civil/Site Design | | | | | | |
| F2. Architectural Design | | | | | | |
| F3. Structural Design | | | | | | |
| F4. Mechanical Design | | | | | | |
| F5. Electrical Design | | | | | | |
| F6. Building Life Safety Requirements | | | | | | |
| F7. Constructability Analysis | | | | | | |
| F8. Technological Sophistication | | | | | | |
| G. EQUIPMENT | | | | | | |
| G1. Equipment List | | | | | | |
| G2. Equipment Location Drawings | | | | | | |
| G3. Equipment Utility Requirements | | | | | | |

*Please check (√) only one box for each element. Please do not leave any elements blank.*

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

| SECTION III - EXECUTION APPROACH | | | | | | |
|---|---|---|---|---|---|---|
| | **Definition Level** | | | | | |
| CATEGORY<br>Element | **0** | **1** | **2** | **3** | **4** | **5** |
| H. PROCUREMENT STRATEGY | | | | | | |
| H1. Identify Long Lead/Critical Equip. & Materials | | | | | | |
| H2. Procurement Procedures and Plans | | | | | | |
| J. DELIVERABLES | | | | | | |
| J1. CADD/Model Requirements | | | | | | |
| J2. Documentation/Deliverables | | | | | | |
| K. PROJECT CONTROL | | | | | | |
| K1. Project Quality Assurance and Control | | | | | | |
| K2. Project Cost Control | | | | | | |
| K3. Project Schedule Control | | | | | | |
| K4. Risk Management | | | | | | |
| K5. Safety Procedures | | | | | | |
| L. PROJECT EXECUTION PLAN | | | | | | |
| L1. Project Organization | | | | | | |
| L2. Owner Approval Requirements | | | | | | |
| L3. Project Delivery Method | | | | | | |
| L4. Design/Construction Plan & Approach | | | | | | |
| L5. Substantial Completion Requirements | | | | | | |

*Please check (√) only one box for each element. Please do not leave any elements blank.*

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

4.0. General Information:

1. How long did it take you (or your team) to fill out both the Project Background Information and the Project Rating Information forms? Please specify in total work-hours (for example, a team of three working for four hours equals 12 total work-hours).

   Project Background Information: __________________ total work-hours
   Project Rating Information: __________________ total work-hours

2. Please have every individual involved with completing any portion of either the Project Background Information or the Project Rating Information forms complete the following information.

   Name: ____________________________________________

   Local Area: ____________________________________________

   Position: ____________________________________________

   Department/Division: ____________________________________

   Address (if different than address on page 1 of this questionnaire):

   ____________________________________________

   ____________________________________________

   ____________________________________________

   Phone: _________________________ Fax: ______________________

   E-mail: ____________________________________________

   Which section(s) of the Project Background Information and the Project Rating Information forms did you fill out? *(for example, Project Rating categories A-E and Project Background sections 2.1-2.2)*

   ____________________________________________

   ____________________________________________

   ____________________________________________

*Thank you very much for your participation in this survey!*

Please return this form to:

Consultant
P.O. Box 123

**RRA PROJECT BACKGROUND AND RATING INFORMATION**

# Appendix C PDRI for Industrial Projects Score Sheets

## INDUSTRIAL PROJECT SCORE SHEET

| SECTION I - BASIS OF PROJECT DECISION | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Definition Level** | | | | | | **Score** |
| CATEGORY<br>Element | **0** | **1** | **2** | **3** | **4** | **5** | |
| A. MANUFACTURING OBJECTIVES CRITERIA (Maximum Score = 45) | | | | | | | |
| A1. Reliability Philosophy | 0 | 1 | 5 | 9 | 14 | 20 | |
| A2. Maintenance Philosophy | 0 | 1 | 3 | 5 | 7 | 9 | |
| A3. Operating Philosophy | 0 | 1 | 4 | 7 | 12 | 16 | |
| **CATEGORY A TOTAL** | | | | | | | |
| B. BUSINESS OBJECTIVES (Maximum Score = 213) | | | | | | | |
| B1. Products | 0 | 1 | 11 | 22 | 33 | 56 | |
| B2. Market Strategy | 0 | 2 | 5 | 10 | 16 | 26 | |
| B3. Project Strategy | 0 | 1 | 5 | 9 | 14 | 23 | |
| B4. Affordability/Feasibility | 0 | 1 | 3 | 6 | 9 | 16 | |
| B5. Capacities | 0 | 2 | 11 | 21 | 33 | 55 | |
| B6. Future Expansion Considerations | 0 | 2 | 3 | 6 | 10 | 17 | |
| B7. Expected Project Life Cycle | 0 | 1 | 2 | 3 | 5 | 8 | |
| B8. Social Issues | 0 | 1 | 2 | 5 | 7 | 12 | |
| **CATEGORY B TOTAL** | | | | | | | |
| C. BASIC DATA RESEARCH & DEVELOPMENT (Maximum Score = 94) | | | | | | | |
| C1. Technology | 0 | 2 | 10 | 21 | 39 | 54 | |
| C2. Processes | 0 | 2 | 8 | 17 | 28 | 40 | |
| **CATEGORY C TOTAL** | | | | | | | |
| D. PROJECT SCOPE (Maximum Score = 120) | | | | | | | |
| D1. Project Objectives Statement | 0 | 2 | | | | 25 | |
| D2. Project Design Criteria | 0 | 3 | 6 | 11 | 16 | 22 | |
| D3. Site Characteristics Available vs. Req'd | 0 | 2 | | | | 29 | |
| D4. Dismantling and Demolition Req'mts | 0 | 2 | 5 | 8 | 12 | 15 | |
| D5. Lead/Discipline Scope of Work | 0 | 1 | 4 | 7 | 10 | 13 | |
| D6. Project Schedule | 0 | 2 | | | | 16 | |
| **CATEGORY D TOTAL** | | | | | | | |
| E. VALUE ENGINEERING (Maximum Score = 27) | | | | | | | |
| E1. Process Simplification | 0 | 0 | | | | 8 | |
| E2. Design & Material Alts. Considered/Rejected | 0 | 0 | | | | 7 | |
| E3. Design For Constructability Analysis | 0 | 0 | 3 | 5 | 8 | 12 | |
| **CATEGORY E TOTAL** | | | | | | | |
| **Section I Maximum Score = 499 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 |

**SECTION II - FRONT END DEFINITION**

| CATEGORY<br>Element | Definition Level | | | | | | Score |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| **F. SITE INFORMATION (Maximum Score = 104)** | | | | | | | |
| F1. Site Location | 0 | 2 | | | | 32 | |
| F2. Surveys & Soil Tests | 0 | 1 | 4 | 7 | 10 | 13 | |
| F3. Environmental Assessment | 0 | 2 | 5 | 10 | 15 | 21 | |
| F4. Permit Requirements | 0 | 1 | 3 | 5 | 9 | 12 | |
| F5. Utility Sources with Supply Conditions | 0 | 1 | 4 | 8 | 12 | 18 | |
| F6. Fire Protection & Safety Considerations | 0 | 1 | 2 | 4 | 5 | 8 | |
| **CATEGORY F TOTAL** | | | | | | | |
| **G. PROCESS / MECHANICAL (Maximum Score = 196)** | | | | | | | |
| G1. Process Flow Sheets | 0 | 2 | 8 | 17 | 26 | 36 | |
| G2. Heat & Material Balances | 0 | 1 | 5 | 10 | 17 | 23 | |
| G3. Piping & Instrumentation Diagrams (P&ID's) | 0 | 2 | 8 | 15 | 23 | 31 | |
| G4. Process Safety Management (PSM) | 0 | 1 | 2 | 4 | 6 | 8 | |
| G5. Utility Flow Diagrams | 0 | 1 | 3 | 6 | 9 | 12 | |
| G6. Specifications | 0 | 1 | 4 | 8 | 12 | 17 | |
| G7. Piping System Requirements | 0 | 1 | 2 | 4 | 6 | 8 | |
| G8. Plot Plan | 0 | 1 | 4 | 8 | 13 | 17 | |
| G9. Mechanical Equipment List | 0 | 1 | 4 | 9 | 13 | 18 | |
| G10. Line List | 0 | 1 | 2 | 4 | 6 | 8 | |
| G11. Tie-in List | 0 | 1 | 2 | 3 | 4 | 6 | |
| G12. Piping Specialty Items List | 0 | 1 | 1 | 2 | 3 | 4 | |
| G13. Instrument Index | 0 | 1 | 2 | 4 | 5 | 8 | |
| **CATEGORY G TOTAL** | | | | | | | |
| **H. EQUIPMENT SCOPE (Maximum Score = 33)** | | | | | | | |
| H1. Equipment Status | 0 | 1 | 4 | 8 | 12 | 16 | |
| H2. Equipment Location Drawings | 0 | 1 | 2 | 5 | 7 | 10 | |
| H3. Equipment Utility Requirements | 0 | 1 | 2 | 3 | 5 | 7 | |
| **CATEGORY H TOTAL** | | | | | | | |
| **I. CIVIL, STRUCTURAL, & ARCHITECTURAL (Maximum Score = 19)** | | | | | | | |
| I1. Civil/Structural Requirements | 0 | 1 | 3 | 6 | 9 | 12 | |
| I2. Architectural Requirements | 0 | 1 | 2 | 4 | 5 | 7 | |
| **CATEGORY I TOTAL** | | | | | | | |
| **J. INFRASTRUCTURE (Maximum Score = 25)** | | | | | | | |
| J1. Water Treatment Requirements | 0 | 1 | 3 | 5 | 7 | 10 | |
| J2. Loading/Unloading/Storage Facilities Req'mts | 0 | 1 | 3 | 5 | 7 | 10 | |
| J3. Transportation Requirements | 0 | 1 | | | | 5 | |
| **CATEGORY J TOTAL** | | | | | | | |

**Definition Levels**

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

**SECTION II - FRONT END DEFINITION (continued...)**

| CATEGORY<br>Element | Definition Level | | | | | | Score |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| **K. INSTRUMENT & ELECTRICAL (Maximum Score = 46)** | | | | | | | |
| K1. Control Philosophy | 0 | 1 | 3 | 5 | 7 | 10 | |
| K2. Logic Diagrams | 0 | 1 | | | | 4 | |
| K3. Electrical Area Classifications | 0 | 0 | 2 | 4 | 7 | 9 | |
| K4. Substation Req'mts Power Sources Ident. | 0 | 1 | 3 | 5 | 7 | 9 | |
| K5. Electric Single Line Diagrams | 0 | 1 | 2 | 4 | 6 | 8 | |
| K6. Instrument & Electrical Specifications | 0 | 1 | 2 | 3 | 5 | 6 | |
| **CATEGORY K TOTAL** | | | | | | | |

| | |
|---|---|
| **Section II Maximum Score = 423 SECTION II TOTAL** | |

## SECTION III - EXECUTION APPROACH

| CATEGORY<br>Element | Definition Level | | | | | | Score |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| **L. PROCUREMENT STRATEGY (Maximum Score = 16)** | | | | | | | |
| L1. Identify Long Lead/Critical Equip. & Mat'ls | 0 | 1 | 2 | 4 | 6 | 8 | |
| L2. Procurement Procedures and Plans | 0 | 0 | 1 | 2 | 4 | 5 | |
| L3. Procurement Responsibility Matrix | 0 | 0 | | | | 3 | |
| **CATEGORY L TOTAL** | | | | | | | |
| **M. DELIVERABLES (Maximum Score = 9)** | | | | | | | |
| M1. CADD/Model Requirements | 0 | 0 | 1 | 1 | 2 | 4 | |
| M2. Deliverables Defined | 0 | 0 | 1 | 2 | 3 | 4 | |
| M3. Distribution Matrix | 0 | 0 | | | | 1 | |
| **CATEGORY M TOTAL** | | | | | | | |
| **N. PROJECT CONTROL (Maximum Score = 17)** | | | | | | | |
| N1. Project Control Requirements | 0 | 0 | 2 | 4 | 6 | 8 | |
| N2. Project Accounting Requirements | 0 | 0 | 1 | 2 | 2 | 4 | |
| N3. Risk Analysis | 0 | 1 | | | | 5 | |
| **CATEGORY N 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 (continued...) | | | | | | | |
|---|---|---|---|---|---|---|---|
| CATEGORY<br>Element | Definition Level | | | | | | Score |
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| P. PROJECT EXECUTION PLAN (Maximum Score = 36) | | | | | | | |
| P1. Owner Approval Requirements | 0 | 0 | 2 | 3 | 5 | 6 | |
| P2. Engineering/Construction Plan & Approach | 0 | 1 | 3 | 5 | 8 | 11 | |
| P3. Shut Down/Turn-Around Requirements | 0 | 1 | | | | 7 | |
| P4. Pre-Commiss. Turnover Sequence Req'mts | 0 | 1 | 1 | 2 | 4 | 5 | |
| P5. Startup Requirements | 0 | 0 | 1 | 2 | 3 | 4 | |
| P6. Training Requirements | 0 | 0 | 1 | 1 | 2 | 3 | |
| | | | | | | **CATEGORY PTOTAL** | |
| **Section III Maximum Score = 78** | | **SECTION III TOTAL** | | | | | |

**Definition Levels**

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

**PDRI TOTAL SCORE**

**(Maximum Score = 1000)**

# Appendix D Project Performance and Success Index

**Industrial Project Performance, Achievement, and PDRI Score**

| Project ID | Cost Performance | Schedule Performance | Budget Achievement | Schedule Achievement | Success Index | PDRI Score |
|---|---|---|---|---|---|---|
| C199 | -40.4% | -15.8% | 5 | 5 | 5 | 223 |
| C200 | 19.3% | -17.3% | 1 | 5 | 3 | 465 |
| C320 | 1.3% | 9.6% | 3 | 2 | 2.5 | 192 |
| C323 | -3.1% | 40.0% | 4 | 1 | 2.5 | 138 |
| C325 | -0.6% | -3.7% | 4 | 4 | 4 | 181 |
| C330 | 38.8% | 8.9% | 1 | 2 | 1.5 | 109 |
| C338 | 5.1% | -3.6% | 2 | 4 | 3 | 240 |
| C4711 | 0.0% | -4.1% | 3 | 4 | 3.5 | 172 |
| C4721 | -4.6% | 1.3% | 4 | 3 | 3.5 | 170 |
| O133 | 0.5% | -16.0% | 3 | 5 | 4 | 175 |
| O314 | 7.1% | -12.5% | 2 | 5 | 3.5 | 305 |
| O316 | -0.8% | 0.0% | 4 | 3 | 3.5 | 112 |
| O317 | -9.6% | 0.0% | 5 | 3 | 4 | 240 |
| O318 | 4.2% | 7.5% | 2 | 2 | 2 | 231 |
| O319 | -3.0% | -10.3% | 4 | 5 | 4.5 | 114 |
| O324 | 28.9% | 9.6% | 1 | 2 | 1.5 | 90 |
| O339 | -12.4% | -8.5% | 5 | 4 | 4.5 | 156 |
| O439 | -24.8% | 0.0% | 5 | 3 | 4 | 135 |
| O4703 | -12.4% | -3.2% | 5 | 4 | 4.5 | 241 |
| O4704 | -9.9% | -15.1% | 5 | 5 | 5 | 173 |
| O4705 | -6.1% | -12.1% | 4 | 5 | 4.5 | 156 |
| P-01 | 6.6% | 65.0% | 2 | 1 | 1.5 | 440 |
| P-02 | -17.4% | 0.0% | 5 | 3 | 4 | 82 |
| P-04 | -21.7% | -13.8% | 5 | 5 | 5 | 160 |
| P-05 | -7.4% | -33.0% | 4 | 5 | 4.5 | 173 |
| P-06 | 0.0% | 28.6% | 3 | 1 | 2 | 140 |
| P-09 | 9.5% | -7.4% | 2 | 4 | 3 | 261 |
| P-11 | 0.0% | 0.0% | 3 | 3 | 3 | 149 |
| P-12 | 7.8% | 0.0% | 2 | 3 | 2.5 | 384 |
| P-16 | 5.9% | 20.0% | 2 | 1 | 1.5 | 191 |
| P-18 | -3.4% | 25.0% | 4 | 1 | 2.5 | 171 |
| P-19 | 8.8% | -26.0% | 2 | 5 | 3.5 | 324 |
| P-20 | -9.2% | 0.0% | 4 | 3 | 3.5 | 153 |
| P-21 | -1.0% | -7.7% | 4 | 4 | 4 | 162 |
| P-22 | 12.2% | 10.0% | 1 | 2 | 1.5 | 291 |
| P-23 | 1.7% | 7.7% | 2 | 2 | 2 | 301 |
| P-24 | 2.3% | 0.0% | 2 | 3 | 2.5 | 250 |
| P-25 | -9.1% | -43.3% | 4 | 5 | 4.5 | 143 |
| P-26 | -8.6% | -27.8% | 4 | 5 | 4.5 | 218 |

**Industrial Project Performance, Achievement, and PDRI Score (Cont'd)**

| Project ID | Cost Performance | Schedule Performance | Budget Achievement | Schedule Achievement | Success Index | PDRI Score |
|---|---|---|---|---|---|---|
| P-28 | 6.6% | 16.7% | 2 | 1 | 1.5 | 205 |
| PL-01 | 1.3% | 0.0% | 3 | 3 | 3 | 397 |
| PL-02 | 12.7% | 33.3% | 1 | 1 | 1 | 237 |
| PL-03 | 11.5% | 14.0% | 1 | 2 | 1.5 | 188 |
| PL-04 | -14.0% | 9.1% | 5 | 2 | 3.5 | 126 |
| PL-05 | -4.4% | -8.3% | 4 | 4 | 4 | 122 |
| PL-06 | 0.9% | 4.9% | 3 | 2 | 2.5 | 105 |
| PL-07 | 0.0% | 5.0% | 3 | 2 | 2.5 | 220 |
| PL-08 | 13.4% | 7.4% | 1 | 2 | 1.5 | 377 |
| PL-09 | 0.1% | 65.0% | 3 | 1 | 2 | 451 |
| PL-10 | 86.0% | 24.0% | 1 | 1 | 1 | 411 |
| PL-11 | -18.0% | 0.0% | 5 | 3 | 4 | 148 |
| PL-12 | 62.2% | 17.9% | 1 | 1 | 1 | 456 |
| PL-13 | -23.0% | -5.6% | 5 | 4 | 4.5 | 106 |
| PL-14 | 1.3% | 4.2% | 3 | 3 | 3 | 379 |
| PL-15 | 2.5% | -5.0% | 2 | 4 | 3 | 199 |
| PL-16 | 38.8% | 33.0% | 1 | 1 | 1 | 386 |
| PL-17 | -7.4% | 0.0% | 4 | 3 | 3.5 | 122 |
| PL-18 | 0.0% | 7.1% | 3 | 2 | 2.5 | 155 |
| PL-19 | 0.0% | -7.7% | 3 | 4 | 3.5 | 161 |
| PL-20 | 14.6% | 11.8% | 1 | 2 | 1.5 | 274 |
| PL-21 | 2.0% | 20.8% | 2 | 1 | 1.5 | 348 |
| PL-23 | 19.2% | 0.0% | 1 | 3 | 2 | 118 |

**Building Project Performance, Achievement, and PDRI Score**

| Project ID | Cost Performance | Schedule Performance | Budget Achievement | Schedule Achievement | Success Index | PDRI Score |
|---|---|---|---|---|---|---|
| CQ01 | -1.3% | 1.0% | 5 | 4 | 4.5 | 102 |
| CQ02 | -0.5% | 1.1% | 5 | 4 | 4.5 | 139 |
| CQ03 | 16.7% | -7.4% | 2 | 5 | 3.5 | 149 |
| CQ04 | 10.7% | 0.0% | 2 | 5 | 3.5 | 648 |
| CQ05 | 5.0% | 0.0% | 4 | 5 | 4.5 | 202 |
| CQ06 | -22.4% | 20.0% | 5 | 2 | 3.5 | 188 |
| CQ07 | 6.6% | 0.0% | 3 | 5 | 4 | 151 |
| CQ08 | 6.0% | 6.9% | 3 | 3 | 3 | 74 |
| CQ09 | 1.7% | 1.3% | 4 | 4 | 4 | 160 |
| CQ10 | 6.8% | -9.0% | 3 | 5 | 4 | 205 |
| CQ11 | 6.6% | 6.9% | 3 | 3 | 3 | 238 |
| CQ12 | 25.7% | 4.6% | 1 | 4 | 2.5 | 165 |
| LT-01 | 2.9% | 9.0% | 4 | 3 | 3.5 | 363 |
| LT-02 | -1.1% | -1.5% | 5 | 5 | 5 | 214 |
| LT-04 | 4.2% | 6.3% | 4 | 4 | 4 | 199 |
| ST-01 | 8.9% | 31.8% | 3 | 2 | 2.5 | 308 |
| ST-02 | 16.1% | 14.1% | 2 | 2 | 2 | 292 |
| ST-03 | 5.6% | 14.7% | 4 | 2 | 3 | 320 |
| ST-04 | 1.5% | 27.1% | 5 | 2 | 3.5 | 329 |
| ST-05 | 3.3% | 0.0% | 4 | 5 | 4.5 | 292 |
| ST-06 | 54.4% | 13.9% | 1 | 3 | 2 | 309 |
| ST-07 | 19.5% | 35.5% | 1 | 1 | 1 | 619 |
| ST-08 | 13.3% | -0.4% | 2 | 5 | 3.5 | 301 |
| ST-09 | 22.4% | 36.0% | 1 | 1 | 1 | 414 |
| ST-10 | 14.9% | 4.2% | 2 | 4 | 3 | 339 |
| ST-11 | 2.3% | -3.7% | 4 | 5 | 4.5 | 286 |
| ST-12 | 6.1% | 10.9% | 3 | 3 | 3 | 497 |
| ST-13 | 19.5% | 12.4% | 1 | 3 | 2 | 351 |
| ST-14 | 4.2% | 106.8% | 4 | 1 | 2.5 | 379 |
| ST-15 | 17.4% | 34.3% | 1 | 1 | 1 | 276 |
| ST-16 | 8.5% | 34.3% | 3 | 1 | 2 | 564 |
| ST-17 | 9.2% | 7.7% | 3 | 3 | 3 | 354 |
| ST-18 | 6.6% | 9.2% | 3 | 3 | 3 | 305 |
| ST-19 | 9.4% | 13.9% | 3 | 3 | 3 | 469 |
| ST-20 | 9.7% | 23.3% | 2 | 2 | 2 | 319 |
| ST-21 | 12.1% | 15.8% | 2 | 2 | 2 | 417 |
| ST-22 | 32.5% | 83.1% | 1 | 1 | 1 | 425 |
| ST-23 | 7.2% | 12.2% | 3 | 3 | 3 | 343 |
| ST-24 | 11.8% | 30.2% | 2 | 2 | 2 | 310 |
| ST-25 | 14.3% | 45.8% | 2 | 1 | 1.5 | 465 |

**Building Project Performance, Achievement, and PDRI Score (Cont'd)**

| Project ID | Cost Performance | Schedule Performance | Budget Achievement | Schedule Achievement | Success Index | PDRI Score |
|---|---|---|---|---|---|---|
| ST-26 | 33.9% | 12.5% | 1 | 3 | 2 | 391 |
| ST-27 | 10.9% | 42.7% | 2 | 1 | 1.5 | 255 |
| ST-28 | 8.3% | 45.1% | 3 | 1 | 2 | 207 |
| ST-29 | 13.9% | 3.1% | 2 | 4 | 3 | 320 |
| ST-30 | 9.6% | 0.0% | 2 | 5 | 3.5 | 273 |
| ST-31 | 6.7% | 18.0% | 3 | 2 | 2.5 | 431 |
| ST-32 | 22.1% | 6.0% | 1 | 4 | 2.5 | 280 |
| ST-33 | 15.3% | 72.0% | 2 | 1 | 1.5 | 335 |
| ST-34 | 14.2% | -24.8% | 2 | 5 | 3.5 | 298 |
| ST-35 | 3.1% | 15.2% | 4 | 2 | 3 | 281 |
| ST-36 | 49.8% | 69.9% | 1 | 1 | 1 | 401 |
| ST-37 | 34.2% | 13.8% | 1 | 3 | 2 | 436 |
| ST-38 | 53.3% | 63.7% | 1 | 1 | 1 | 405 |
| ST-39 | 26.2% | 68.5% | 1 | 1 | 1 | 416 |
| ST-40 | 12.1% | 34.4% | 2 | 1 | 1.5 | 290 |
| VQ01 | -5.6% | -9.9% | 5 | 5 | 5 | 256 |
| VQ02 | 0.0% | -0.9% | 5 | 5 | 5 | 96 |
| VQ03 | 3.8% | -17.2% | 4 | 5 | 4.5 | 164 |
| VQ04 | 1.5% | -3.6% | 5 | 5 | 5 | 203 |
| VQ05 | 3.1% | 13.6% | 4 | 3 | 3.5 | 285 |
| VQ06 | 7.5% | 9.5% | 3 | 3 | 3 | 460 |
| VQ07 | 2.7% | 0.0% | 4 | 5 | 4.5 | 141 |
| VQ08 | 2.1% | 12.0% | 4 | 3 | 3.5 | 130 |
| VQ09 | -9.7% | 0.3% | 5 | 4 | 4.5 | 208 |
| VQ10 | 27.2% | -5.2% | 1 | 5 | 3 | 202 |
| VQ11 | 2.5% | -0.3% | 4 | 5 | 4.5 | 204 |
| VQ12 | -2.9% | -1.1% | 5 | 5 | 5 | 126 |
| VQ13 | -4.7% | 25.7% | 5 | 2 | 3.5 | 240 |
| VQ14 | 30.3% | 89.4% | 1 | 1 | 1 | 223 |
| VQ15 | 1.6% | 1.3% | 5 | 4 | 4.5 | 172 |
| VQ16 | 0.0% | -8.8% | 5 | 5 | 5 | 95 |
| VQ17 | -2.5% | 14.5% | 5 | 2 | 3.5 | 238 |
| VQ18 | 4.9% | 4.0% | 4 | 4 | 4 | 233 |
| VQ19 | 8.9% | 16.4% | 3 | 2 | 2.5 | 218 |
| VQ20 | 0.9% | 27.0% | 5 | 2 | 3.5 | 158 |
| VQ21 | 0.7% | 40.0% | 5 | 1 | 3 | 216 |
| WIP-01 | 36.5% | 6.6% | 1 | 3 | 2 | 275 |
| WIP-02 | 9.5% | 15.7% | 3 | 2 | 2.5 | 213 |

# Appendix E PDRI Element Definition Level Descriptive Statistics

**Industrial Project Definition Level Characteristics**

| Scope Element | Avg. | Std. Dev. | Number of Projects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level 0 | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
| A1 | 2.1 | 1.1 | 2 | 16 | 18 | 11 | 6 | 1 |
| A2 | 2.2 | 1.1 | 1 | 15 | 20 | 10 | 7 | 1 |
| A3 | 2.1 | 1.1 | 2 | 15 | 19 | 12 | 4 | 2 |
| B1 | 1.2 | 0.8 | 8 | 32 | 9 | 4 | 1 | 0 |
| B2 | 1.4 | 1.0 | 13 | 21 | 11 | 7 | 1 | 1 |
| B3 | 1.7 | 1.1 | 7 | 22 | 13 | 7 | 4 | 1 |
| B4 | 1.6 | 1.0 | 12 | 13 | 16 | 9 | 4 | 0 |
| B5 | 1.3 | 0.7 | 6 | 31 | 12 | 4 | 1 | 0 |
| B6 | 1.7 | 1.1 | 11 | 15 | 13 | 10 | 4 | 1 |
| B7 | 2.0 | 1.4 | 9 | 16 | 10 | 6 | 9 | 4 |
| B8 | 1.9 | 1.3 | 11 | 15 | 11 | 7 | 7 | 3 |
| C1 | 1.5 | 0.8 | 3 | 30 | 12 | 8 | 1 | 0 |
| C2 | 1.6 | 0.8 | 3 | 27 | 15 | 8 | 1 | 0 |
| D1 | 1.9 | 1.7 | 0 | 42 | 0 | 0 | 0 | 12 |
| D2 | 2.0 | 0.9 | 0 | 17 | 24 | 10 | 2 | 1 |
| D3 | 1.4 | 1.3 | 1 | 47 | 0 | 0 | 0 | 6 |
| D4 | 2.0 | 1.2 | 8 | 12 | 18 | 7 | 7 | 2 |
| D5 | 2.3 | 1.1 | 0 | 14 | 18 | 15 | 4 | 3 |
| D6 | 1.4 | 1.3 | 2 | 46 | 0 | 0 | 0 | 6 |
| E1 | 1.9 | 1.7 | 0 | 42 | 0 | 0 | 0 | 12 |
| E2 | 1.8 | 1.6 | 0 | 43 | 0 | 0 | 0 | 11 |
| E3 | 2.6 | 1.2 | 0 | 13 | 10 | 20 | 7 | 4 |
| F1 | 0.9 | 0.0 | 4 | 50 | 0 | 0 | 0 | 0 |
| F2 | 1.6 | 0.9 | 6 | 20 | 16 | 11 | 1 | 0 |
| F3 | 1.5 | 0.8 | 7 | 23 | 18 | 4 | 2 | 0 |
| F4 | 1.7 | 1.1 | 6 | 20 | 20 | 3 | 3 | 2 |
| F5 | 2.0 | 0.9 | 0 | 15 | 29 | 7 | 2 | 1 |
| F6 | 2.0 | 1.1 | 0 | 21 | 21 | 6 | 4 | 2 |
| G1 | 1.6 | 0.7 | 2 | 25 | 22 | 4 | 1 | 0 |
| G10 | 2.5 | 0.9 | 5 | 11 | 9 | 17 | 4 | 8 |
| G11 | 2.5 | 1.1 | 7 | 10 | 10 | 12 | 8 | 7 |
| G12 | 2.5 | 1.2 | 6 | 19 | 0 | 10 | 9 | 10 |
| G13 | 2.9 | 1.2 | 0 | 8 | 17 | 10 | 8 | 11 |
| G2 | 1.6 | 0.9 | 6 | 23 | 17 | 5 | 3 | 0 |
| G3 | 2.5 | 1.3 | 0 | 9 | 21 | 14 | 6 | 4 |
| G4 | 2.1 | 0.9 | 5 | 16 | 14 | 12 | 4 | 3 |
| G5 | 2.3 | 0.8 | 3 | 11 | 17 | 13 | 8 | 2 |
| G6 | 2.1 | 1.3 | 0 | 14 | 24 | 13 | 2 | 1 |
| G7 | 2.4 | 1.4 | 3 | 13 | 16 | 9 | 8 | 5 |

**Industrial Project Definition Level Characteristics (Cont'd)**

| Scope Element | Avg. | Std. Dev. | Number of Projects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level 0 | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
| G8 | 1.6 | 1.6 | 3 | 27 | 14 | 7 | 3 | 0 |
| G9 | 1.9 | 1.4 | 0 | 18 | 24 | 10 | 2 | 0 |
| H1 | 2.3 | 1.1 | 3 | 12 | 14 | 17 | 7 | 1 |
| H2 | 2.3 | 1.0 | 1 | 13 | 17 | 17 | 5 | 1 |
| H3 | 2.2 | 1.1 | 2 | 14 | 19 | 12 | 5 | 2 |
| I1 | 2.5 | 1.1 | 3 | 7 | 21 | 11 | 8 | 4 |
| I2 | 2.0 | 1.1 | 10 | 9 | 18 | 8 | 7 | 2 |
| J1 | 1.4 | 0.9 | 16 | 14 | 14 | 7 | 3 | 0 |
| J2 | 1.9 | 1.1 | 9 | 12 | 19 | 8 | 4 | 2 |
| J3 | 1.4 | 1.6 | 12 | 34 | 0 | 0 | 0 | 8 |
| K1 | 2.1 | 0.9 | 0 | 14 | 24 | 13 | 2 | 1 |
| K2 | 2.9 | 2.0 | 3 | 24 | 0 | 0 | 0 | 27 |
| K3 | 1.9 | 1.2 | 0 | 28 | 13 | 6 | 4 | 3 |
| K4 | 1.8 | 1.1 | 1 | 28 | 15 | 4 | 5 | 1 |
| K5 | 2.0 | 1.3 | 2 | 20 | 19 | 5 | 3 | 5 |
| K6 | 2.6 | 1.2 | 1 | 10 | 15 | 17 | 6 | 5 |
| L1 | 1.6 | 0.9 | 0 | 35 | 12 | 3 | 4 | 0 |
| L2 | 2.1 | 1.1 | 0 | 18 | 21 | 9 | 4 | 2 |
| L3 | 2.3 | 1.9 | 0 | 36 | 0 | 0 | 0 | 18 |
| M1 | 1.8 | 1.1 | 0 | 27 | 20 | 0 | 4 | 3 |
| M2 | 2.1 | 1.0 | 0 | 17 | 18 | 15 | 3 | 1 |
| M3 | 2.0 | 1.8 | 0 | 40 | 0 | 0 | 0 | 14 |
| N1 | 2.1 | 1.1 | 0 | 20 | 18 | 10 | 4 | 2 |
| N2 | 2.0 | 0.9 | 0 | 16 | 22 | 15 | 0 | 1 |
| N3 | 2.4 | 2.0 | 5 | 29 | 0 | 0 | 0 | 20 |
| P1 | 2.1 | 1.1 | 0 | 18 | 20 | 11 | 3 | 2 |
| P2 | 2.2 | 1.1 | 2 | 15 | 18 | 12 | 4 | 3 |
| P3 | 1.6 | 1.7 | 9 | 34 | 0 | 0 | 0 | 11 |
| P4 | 2.6 | 1.6 | 2 | 22 | 0 | 13 | 6 | 11 |
| P5 | 2.8 | 1.5 | 0 | 14 | 10 | 11 | 9 | 10 |
| P6 | 2.6 | 1.5 | 0 | 13 | 24 | 0 | 7 | 10 |

**Building Project Definition Level Characteristics**

| Scope Element | Avg. | Std. Dev. | Number of Projects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level 0 | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
| A1 | 1.3 | 0.8 | 1 | 63 | 7 | 2 | 5 | 0 |
| A2 | 1.2 | 0.6 | 2 | 59 | 13 | 4 | 0 | 0 |
| A3 | 1.4 | 0.9 | 5 | 49 | 12 | 9 | 3 | 0 |
| A4 | 1.3 | 0.8 | 20 | 28 | 18 | 11 | 1 | 0 |
| A5 | 1.7 | 1.1 | 1 | 42 | 25 | 4 | 1 | 5 |
| A6 | 1.2 | 1.0 | 33 | 16 | 15 | 11 | 3 | 0 |
| A7 | 1.6 | 1.0 | 3 | 47 | 18 | 2 | 8 | 0 |
| A8 | 2.9 | 1.5 | 3 | 20 | 12 | 9 | 17 | 17 |
| B1 | 1.7 | 1.0 | 1 | 43 | 24 | 4 | 3 | 3 |
| B2 | 2.2 | 1.2 | 2 | 24 | 26 | 12 | 9 | 5 |
| B3 | 2.2 | 1.1 | 1 | 24 | 28 | 17 | 3 | 5 |
| B4 | 1.9 | 0.9 | 0 | 31 | 33 | 10 | 2 | 2 |
| C1 | 2.6 | 1.4 | 4 | 12 | 32 | 5 | 13 | 12 |
| C2 | 2.0 | 1.1 | 0 | 30 | 29 | 9 | 7 | 3 |
| C3 | 1.0 | 0.9 | 30 | 30 | 11 | 5 | 1 | 1 |
| C4 | 3.0 | 1.4 | 0 | 14 | 19 | 11 | 23 | 11 |
| C5 | 2.7 | 1.3 | 0 | 19 | 22 | 10 | 21 | 6 |
| C6 | 2.8 | 1.3 | 0 | 17 | 18 | 18 | 17 | 8 |
| D1 | 1.7 | 1.1 | 6 | 37 | 21 | 7 | 4 | 3 |
| D2 | 1.3 | 0.8 | 6 | 50 | 18 | 2 | 0 | 2 |
| D3 | 1.5 | 1.1 | 8 | 44 | 18 | 2 | 2 | 4 |
| D4 | 1.4 | 0.9 | 5 | 48 | 17 | 4 | 3 | 1 |
| D5 | 1.3 | 0.9 | 11 | 43 | 14 | 8 | 1 | 1 |
| D6 | 1.9 | 1.1 | 3 | 31 | 23 | 14 | 4 | 3 |
| D7 | 1.5 | 1.0 | 5 | 43 | 23 | 2 | 2 | 3 |
| D8 | 1.4 | 1.1 | 17 | 29 | 21 | 4 | 5 | 2 |
| E1 | 3.3 | 1.6 | 4 | 14 | 12 | 5 | 13 | 30 |
| E10 | 1.9 | 1.1 | 2 | 36 | 20 | 8 | 8 | 4 |
| E11 | 2.2 | 1.0 | 8 | 20 | 19 | 12 | 17 | 2 |
| E12 | 2.2 | 1.0 | 3 | 28 | 20 | 14 | 4 | 9 |
| E13 | 2.4 | 1.2 | 0 | 30 | 12 | 16 | 16 | 4 |
| E2 | 2.0 | 1.1 | 5 | 26 | 21 | 17 | 7 | 2 |
| E3 | 1.3 | 0.9 | 18 | 31 | 17 | 9 | 2 | 1 |
| E4 | 1.2 | 0.9 | 30 | 19 | 19 | 7 | 2 | 1 |
| E5 | 1.0 | 1.0 | 39 | 15 | 13 | 5 | 5 | 1 |
| E6 | 1.6 | 1.2 | 5 | 48 | 11 | 7 | 4 | 3 |
| E7 | 1.5 | 1.2 | 9 | 37 | 23 | 6 | 1 | 2 |
| E8 | 1.2 | 1.3 | 20 | 33 | 20 | 2 | 2 | 1 |
| E9 | 1.0 | 1.3 | 30 | 28 | 12 | 5 | 2 | 1 |

**Building Project Definition Level Characteristics (Cont'd)**

| Scope Element | Avg. | Std. Dev. | Number of Projects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level 0 | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
| F1 | 2.1 | 1.3 | 8 | 19 | 30 | 5 | 8 | 8 |
| F2 | 2.3 | 1.2 | 1 | 22 | 27 | 13 | 11 | 4 |
| F3 | 1.9 | 1.3 | 2 | 38 | 19 | 8 | 5 | 6 |
| F4 | 2.6 | 1.3 | 0 | 16 | 28 | 18 | 5 | 11 |
| F5 | 2.4 | 1.3 | 1 | 21 | 29 | 14 | 2 | 11 |
| F6 | 1.7 | 1.0 | 2 | 40 | 28 | 3 | 1 | 4 |
| F7 | 2.5 | 1.3 | 7 | 12 | 26 | 14 | 8 | 11 |
| F8 | 1.9 | 1.0 | 2 | 27 | 35 | 7 | 4 | 3 |
| G1 | 2.3 | 1.0 | 2 | 17 | 26 | 24 | 6 | 3 |
| G2 | 2.2 | 1.0 | 2 | 15 | 41 | 10 | 6 | 4 |
| G3 | 2.2 | 1.1 | 2 | 20 | 27 | 20 | 4 | 5 |
| H1 | 2.2 | 1.3 | 3 | 26 | 25 | 11 | 5 | 8 |
| H2 | 2.1 | 1.2 | 5 | 24 | 25 | 11 | 7 | 6 |
| J1 | 1.7 | 0.9 | 0 | 40 | 27 | 7 | 3 | 1 |
| J2 | 2.1 | 1.4 | 3 | 32 | 25 | 2 | 5 | 11 |
| K1 | 1.7 | 0.9 | 0 | 37 | 28 | 11 | 0 | 2 |
| K2 | 2.3 | 1.3 | 0 | 31 | 16 | 14 | 13 | 4 |
| K3 | 2.1 | 1.1 | 1 | 32 | 17 | 16 | 11 | 1 |
| K4 | 2.0 | 1.2 | 2 | 34 | 18 | 13 | 9 | 2 |
| K5 | 1.5 | 0.9 | 1 | 52 | 15 | 8 | 0 | 2 |
| L1 | 1.6 | 1.0 | 2 | 48 | 17 | 6 | 2 | 3 |
| L2 | 1.6 | 1.0 | 1 | 49 | 16 | 6 | 4 | 2 |
| L3 | 2.2 | 1.2 | 1 | 26 | 28 | 11 | 5 | 7 |
| L4 | 2.1 | 1.2 | 1 | 32 | 17 | 16 | 8 | 4 |
| L5 | 1.8 | 1.1 | 1 | 37 | 24 | 7 | 7 | 2 |

# Appendix F Project Cost and Completion Time

**Industrial Project Cost and Completion Time**

| Project ID | Project Cost (Millions) | Completion Time (Year) |
|---|---|---|
| C199 | $41.6 | 1997 |
| C200 | $56.0 | 1997 |
| C320 | $1.1 | 1998 |
| C323 | $2.7 | 1998 |
| C325 | $1.3 | 1998 |
| C330 | $13.2 | 1998 |
| C338 | $3.7 | 1998 |
| C4711 | $16.5 | 1999 |
| C4721 | $40.3 | 1999 |
| O133 | $52.9 | 1997 |
| O314 | $6.6 | 1998 |
| O316 | $77.7 | 1998 |
| O317 | $5.9 | 1998 |
| O318 | $14.0 | 1998 |
| O319 | $3.3 | 1998 |
| O324 | $4.9 | 1998 |
| O339 | $14.1 | 1998 |
| O439 | $22.1 | 1998 |
| O4703 | $12.5 | 1999 |
| O4704 | $38.2 | 1999 |
| O4705 | $26.3 | 1999 |
| P-01 | $92.2 | 1995 |
| P-02 | $434.4 | 1995 |
| P-04 | $125.0 | 1995 |
| P-05 | $635.0 | 1994 |
| P-06 | $18.6 | 1995 |
| P-09 | $21.0 | 1995 |
| P-11 | $83.0 | 1996 |
| P-12 | $120.0 | 1996 |
| P-16 | $68.0 | 1996 |
| P-18 | $75.0 | 1994 |
| P-19 | $22.3 | 1995 |
| P-20 | $24.5 | 1995 |
| P-21 | N/A | 1994 |
| P-22 | $20.8 | 1996 |
| P-23 | $96.3 | 1996 |
| P-24 | $13.0 | 1995 |
| P-25 | $23.1 | 1994 |
| P-26 | $8.4 | 1995 |

**Industrial Project Cost and Completion Time (Cont'd)**

| Project ID | Project Cost (Millions) | Completion Time (Year) |
|---|---|---|
| P-28 | $8.0 | 1994 |
| PL-01 | $113.4 | 1994 |
| PL-02 | $3.4 | 1995 |
| PL-03 | $22.2 | 1992 |
| PL-04 | $86.0 | 1994 |
| PL-05 | $8.5 | 1993 |
| PL-06 | $65.3 | 1993 |
| PL-07 | $20.4 | 1994 |
| PL-08 | $110.0 | 1994 |
| PL-09 | $80.3 | 1995 |
| PL-10 | $565.8 | 1993 |
| PL-11 | $0.9 | 1993 |
| PL-12 | $9.7 | 1990 |
| PL-13 | $0.0 | 1992 |
| PL-14 | $152.0 | 1995 |
| PL-15 | $41.0 | 1994 |
| PL-16 | $13.9 | 1993 |
| PL-17 | $3.9 | 1994 |
| PL-18 | $2.8 | 1994 |
| PL-19 | $100.0 | 1993 |
| PL-20 | $9.4 | 1995 |
| PL-21 | $15.3 | 1995 |
| PL-23 | $7.2 | 1994 |

**Building Project Cost and Completion Time**

| Project ID | Project Cost (Millions) | Completion Time (Year) |
|---|---|---|
| CQ01 | $22.4 | 1996 |
| CQ02 | $22.3 | 1997 |
| CQ03 | $3.2 | 1997 |
| CQ04 | $13.4 | 1998 |
| CQ05 | $9.2 | 1996 |
| CQ06 | $10.8 | 1998 |
| CQ07 | $25.7 | 1996 |
| CQ08 | $6.2 | 1996 |
| CQ09 | $13.2 | 1997 |
| CQ10 | $18.7 | 1997 |
| CQ11 | $24.7 | 1997 |
| CQ12 | $21.9 | 1997 |
| LT-01 | $30.2 | 2000 |
| LT-02 | $14.6 | 2000 |
| LT-04 | $18.5 | 2000 |
| ST-01 | $5.4 | 2000 |
| ST-02 | $3.9 | 1998 |
| ST-03 | $5.6 | 2000 |
| ST-04 | $3.8 | 2000 |
| ST-05 | $5.4 | 1999 |
| ST-06 | $7.1 | 2000 |
| ST-07 | $4.6 | 2000 |
| ST-08 | $4.8 | 1999 |
| ST-09 | $5.7 | 1999 |
| ST-10 | $5.4 | 1999 |
| ST-11 | $4.7 | 1999 |
| ST-12 | $4.5 | 2000 |
| ST-13 | $7.4 | 2000 |
| ST-14 | $4.0 | 2001 |
| ST-15 | $4.6 | 1999 |
| ST-16 | $3.9 | 2000 |
| ST-17 | $7.3 | 1999 |
| ST-18 | $4.8 | 2000 |
| ST-19 | $4.1 | 2000 |
| ST-20 | $5.4 | 2000 |
| ST-21 | $4.2 | 2000 |
| ST-22 | $5.1 | 2000 |
| ST-23 | $2.3 | 1998 |
| ST-24 | $5.1 | 2000 |

**Building Project Cost and Completion Time (Cont'd)**

| Project ID | Project Cost (Millions) | Completion Time (Year) |
|---|---|---|
| ST-25 | $4.2 | 2000 |
| ST-26 | $4.8 | 2000 |
| ST-27 | $4.9 | 2000 |
| ST-28 | $4.4 | 2000 |
| ST-29 | $5.5 | 1999 |
| ST-30 | $5.1 | 1999 |
| ST-31 | $5.4 | 2000 |
| ST-32 | $5.5 | 1999 |
| ST-33 | $3.7 | 2000 |
| ST-34 | $3.2 | 1999 |
| ST-35 | $5.5 | 2000 |
| ST-36 | $5.7 | 2000 |
| ST-37 | $5.0 | 2000 |
| ST-38 | $5.8 | 2000 |
| ST-39 | $5.0 | 2000 |
| ST-40 | $4.2 | 2000 |
| VQ01 | $9.4 | 1997 |
| VQ02 | $32.0 | 1998 |
| VQ03 | $33.9 | 1997 |
| VQ04 | $46.6 | 1999 |
| VQ05 | $125.0 | 1997 |
| VQ06 | $200.0 | 1997 |
| VQ07 | $9.8 | 1997 |
| VQ08 | $7.8 | 1998 |
| VQ09 | $0.7 | 1998 |
| VQ10 | $1.1 | 1998 |
| VQ11 | $42.6 | 1998 |
| VQ12 | $20.4 | 1997 |
| VQ13 | $7.9 | 1997 |
| VQ14 | $17.5 | 1998 |
| VQ15 | $4.1 | 1997 |
| VQ16 | $1.6 | 1997 |
| VQ17 | $124.4 | 1997 |
| VQ18 | $1.8 | 1999 |
| VQ19 | $1.6 | 1998 |
| VQ20 | $1.5 | 1998 |
| VQ21 | $3.6 | 1997 |
| WIP-01 | $5.3 | 2001 |
| WIP-02 | $6.5 | 2001 |

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