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DEVELOPMENT AND IMPLEMENTATION OF AN ENGINEERING PRODUCTIVITY MEASUREMENT SYSTEM (EPMS) FOR BENCHMARKING

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DEVELOPMENT AND IMPLEMENTATION OF AN ENGINEERING PRODUCTIVITY MEASUREMENT SYSTEM (EPMS) FOR BENCHMARKING

by

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To my wife, Sunghee

my sons, Siyoon and Minjae,

and all of my family and friends,

with love and appreciation.

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DEVELOPMENT AND IMPLEMENTATION OF AN ENGINEERING PRODUCTIVITY MEASUREMENT SYSTEM (EPMS) FOR BENCHMARKING

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Reliable engineering productivity measurement is a critical element of predictable project performance and continuous improvement. Despite the fact that engineering costs have risen to levels approaching 20 percent of total project cost on some industrial projects, engineering productivity is less well understood and has received less study than construction productivity. Furthermore, engineering productivity is a critical determinant of the final cost and schedule performance of a project (Chang et al. 2001). For these reasons, metrics for assessing productivity to drive improvement are essential, especially considering trends toward offshore engineering.

Applicable industry standard engineering productivity measurements must first be established and then applied to present day work processes before significant improvement and predictability of performance can be established (CII

2001). Over the years, a number of different approaches for engineering productivity measurement have been proposed. These approaches are discussed and the development of the CII Benchmarking and Metrics approach, a direct measurement approach, is presented for this research.

This research: (1) identifies critical issues for the implementation of engineering productivity measurement; (2) develops an Engineering Productivity Measurement System (EPMS) based on real project data; and, finally (3) recommends a framework for future studies.

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Chapter 1: INTRODUCTION

1.1 PROBLEM STATEMENT

The Construction Industry Institute (CII) was founded in 1983 to carry forward the recommendations of The Business Roundtable's Construction Industry Cost Effectiveness (CICE) Project. One of the first research efforts conducted by CII addressed the productivity measurement recommendations made in the CICE A-1 Report (BRT 1982), *Measuring Productivity in Construction* (CII 1990). However, little effort to develop an engineering productivity measurement system was undertaken at that time. Some twenty years later, the industry still struggles with this issue. In 2002, the CII Benchmarking & Metrics (BM&M) program undertook the task in order to establish an engineering productivity measurement system within its ongoing benchmarking program.

Reliable engineering productivity measurement is a crucial element of predictable project performance and improvement. Despite the fact that engineering costs have risen to levels approaching 20 percent of total project cost on some industrial projects, engineering productivity is not as well understood as construction productivity and has received less study. The effective delivery of engineering during the project life cycle is a critical determinant of a project's overall cost and schedule performance (Chang et al. 2001). Productivity measurement is also key to management of the design process. Appropriate industry-standard engineering productivity measurements must be established and then applied to present day work processes before significant improvement and predictability of performance can be made (CII 2001).

Many engineering companies measure productivity using intermediate deliverables such as drawings as output. Measurement of productivity using engineering drawings has many drawbacks, however. Metrics are difficult to define objectively, and computer-based engineering tools are constantly evolving (Chang et al. 2001).

At the time this research commenced, the engineering industry had not developed an accepted method to measure engineering productivity. Little research had been done to establish a method to measure engineering productivity using empirical data with a set of common definitions across the industry.

1.2 BACKGROUND

Considering that "measurement is the first step that leads to control and eventually to improvement" (Harrington 1987), development of a reliable standard engineering productivity measurement system is a critical process in engineering performance evaluation and improvement. The industry needs a tool to drive performance improvement through internal or external benchmarking. Measurement may not directly lead to performance improvement; however, performance improvement over time can be achieved through recognizing the need for improvement and by establishing quantitative goals. As an example, measurement and tracking of safety performance by CII member companies led to improvement in safety performance. CII has tracked safety performance of member companies since 1989. The measurement and reporting of safety metrics has been instrumental in driving CII efforts to improve safety performance (CII 2005).

1.2.1 Overview of the Construction Industry Institute

CII was established at The University of Texas at Austin to address the need for construction research and to unify the fragmented industry. CII is a consortium of leading owners, engineering and construction contractors, suppliers, and academia working to improve the cost effectiveness of the capital facility project life cycle, from pre-project planning through completion and commissioning. By collaborating on important industry issues and by providing guidance on best practices developed through research, CII has evolved to be a principle industry forum for the engineer-procure-construct process (CII 2006a).

The mission of CII is to improve the safety, quality, schedule, and cost effectiveness of the capital investment process through research and implementation support for the purpose of providing a competitive advantage to its members in the global marketplace (CII 2006a).

As of July 2007, there are 109 member organizations representing 53 owners and 56 contractors involved in CII programs such as Research, Benchmarking and Metrics (BM&M), Implementation, Education, Globalization, and Breakthrough Strategy.

1.2.2 Overview of the Benchmarking and Metrics Program

The BM&M Committee was formed in 1994 as an ad hoc committee and became a standing committee of CII in 1996. The primary focus of the committee is the measurement of the capital facility project delivery process through survey of multiple performance factors and practice use implementation indices with the purpose of providing recommendations for continuous improvement. The Productivity Metrics Team began as an ad hoc group in 2000 and later transitioned into a standing team. The committee is currently composed of 22 committee members and two standing teams: 1) Analysis and Questionnaire and 2) Productivity. Other task-oriented teams such as the Annual Conference /

Marketing team and a Small Projects team forum on an as-needed basis to accomplish special initiatives like small project benchmarking.

The CII BM&M survey instrument has been developed over the years through thorough review and incorporation of many elements derived from CII research and implementation documents. It is now a well-structured survey instrument for effective measurement of project performance and best practice use. The instrument evolved from a paper-based questionnaire to a secure web-based data collection and reporting system for industry performance and practice use norms. The survey instrument is the primary tool of the CII BM&M program. Objectives of the program are listed below (CII 2002):

- Establish a common set of metric definitions.
- Establish project performance norms.
- Establish the level of use of selected "best practices."
- Quantify the value of implementing CII recommended "best practices."
- Provide participating companies tools for self-analysis.
- Facilitate the development and sharing of benchmarking knowledge within the construction industry.

- Provide a credible database that is efficient in terms of resources required for data submission, analysis, and the reporting of findings.

The CII BM&M database currently contains 1,420 projects valued at over $65 billion from four industry groups: heavy industrial, light industrial, buildings, and infrastructure. The BM&M program collects project information on cost, schedule, safety, change, rework and the use of twelve best practices (Thomas et al. 2002). Descriptive project information including project type, nature, impact factors, and project participant data are also collected. Practices that are measured include pre-project planning, alignment during pre-project planning, constructability, team building, zero accidents techniques (safety), change management, automation and integration (A/I) technology, materials management, planning for startup, quality management, international project risk assessment, and design for maintainability. As will be discussed later in greater detail, the questionnaire also surveys construction and engineering productivity for categories including concrete, structural steel, electrical, piping, instrumentation, and equipment. Construction productivity for insulation is also evaluated. In recent years, the small project questionnaire and the pharmaceutical project questionnaire have also been developed and were incorporated into the CII BM&M system. These questionnaires also adopted the productivity measures developed in this research; the BM&M large project questionnaire will be the focus of review and analysis herein, however.

1.2.3 Engineering Productivity Metrics Initiative

In 2000, a number of CII members proposed the development of a common set of definitions that could produce norms to measure construction productivity. An organized effort to measure engineering productivity on the same basis as construction productivity would soon follow. The BM&M productivity metrics team understood that common definitions would be essential for successful external benchmarking, and that a system using quantity-based metrics rather than intermediate deliverables did not exist. Following the development of construction productivity metrics in 2000 and 2001, a series of workshops were conducted in 2002 to establish consensus definitions for six engineering productivity metrics categories.

The BM&M productivity metrics team currently operates as a standing team under the CII Benchmarking and Metrics Committee. The team is staffed with members from the organizations as given in Table 1.1. During the course of the development of these metrics, several other companies participated as well. Additional discussion will be given in Chapter 4 on this development effort.

Table 1.1 Participating Organizations of Productivity Metrics Team

Participating Organizations
BE&K Inc.
Chevron Corporation
Aramco Services Company
Rohm and Haas Company
Fru-Con Construction Corporation
S&B Engineers and Constructors, Ltd.
ALSTOM Power
CII/ The Univ. of Texas at Austin

1.3 RESEARCH OBJECTIVES

The purpose of this research investigation was to develop a system for engineering productivity measurement that is suitable for benchmarking and to provide quantitative feedback to participants for improving their productivity performance. This study primarily focused on the development of a standard engineering productivity metrics system.

More specifically, the objectives of this research are:

1) To establish engineering productivity metric definitions that are acceptable to industry.
2) To develop a system for the implementation of these metrics.
3) To collect a pilot set of data for preliminary validation.
4) To identify and discuss the issues of engineering productivity measurement.
5) To recommend directions for future studies.

1.4 RESEARCH HYPOTHESIS

The following hypothesis was developed in support of the research objectives.

> Engineering work-hours and design quantities provide reliable measures of engineering productivity.

The hypothesis relates engineering work-hours to design quantities or more specifically, Issued for Construction (IFC) quantities. This relates engineering productivity to the final product as opposed to intermediate deliverables which can provide distorted measures, depending on the media used (Chang et al. 2001). The term “reliable” as used in the hypothesis should not be construed to indicate reliable in a statistical sense, but rather means that productivity metrics based on engineering work-hours and design quantities provide metrics for which industry can report and which produce distributions which are sufficiently dependable for benchmarking purposes.

1.5 RESEARCH SCOPE

This research is limited to developing and validating an engineering productivity measurement system using input from participating CII companies. Even though CII membership represents a broad range of industry types, the metrics developed in this study are best suited to large industrial process projects. Therefore, the outputs from this research are most applicable to larger heavy industrial projects. Although this research focuses on the industrial sector, much of the system and development methodology may be applied to other sectors. While there are many ways to measure productivity, this system uses design work-hours and IFC quantities as inputs to determine productivity.

Data collected for this research provide only initial validation for the developed engineering productivity metrics. In most cases, sufficient data will not be available to establish statistically significant relationships for several years. Another limitation of this research is its reliance on convenience sampling rather than true random sampling. To obtain sufficient data to support the research, CII volunteers provide data from available projects, a methodology which is typical for most CII research. Thus, the data are not a random sample and also CII members may not be truly representative of the construction industry. Caution should therefore be exercised when interpreting finding of this research. Nevertheless, these analyses provide an approach that may be used for metric validation when additional data are available.

1.6 ORGANIZATION OF DISSERTATION

Chapter 1 presents a general overview of the problem statement, background, research objectives, and research scope. Following this introductory chapter, Chapter 2 explores some of the published research regarding construction and engineering productivity measurement issues. The rationale for the direction and approach chosen for this research is explained by review of other productivity studies and their strengths and weaknesses. The research approach is discussed in Chapter 3, including a description of CII Benchmarking & Metrics Productivity workshops, evaluation of other models, and the process for development of engineering productivity metrics. Chapter 4 introduces the metrics for measuring engineering productivity developed by this research effort. In Chapter 5, analyses of an initial data set are presented to demonstrate that these engineering productivity metrics can provide meaningful information for productivity benchmarking and to validate the methodology. Chapter 6 illustrates implementation barriers for this research. Conclusions and recommendations follow in Chapter 7.

Chapter 2: RESEARCH BACKGROUND

2.1 DEFINITION OF BENCHMARKING

This section discusses the definition of benchmarking and types of benchmarking that are available. Among the various definitions of benchmarking, the CII BM&M Committee has adopted the following definition:

> "Benchmarking is a systematic process of measuring one's performance against results from recognized leaders for the purpose of determining best practices that lead to superior performance when adapted and implemented." (CII 1993; CII 2002)

The construction industry has been relatively slow to adopt competitive benchmarking as a tool for continuous improvement whereas the manufacturing industry has successfully implemented benchmarking and thereby improved its processes and the quality of its products (Lee et al. 2005). Measurement is the key to benchmarking. Comparing measured performance with world-class performance identifies the gaps, and so the improvement journey begins. Performance benchmarks can be used to measure the output of business processes. Therefore, “world class” represents the best performance outcomes anywhere in the world.

Benchmarking is considered a productivity improvement tool (Jackson et al. 1994). Since CII started the BM&M program in 1994, it has published various reports to provide industry norms and to recommend the use of best practices to improve processes and performance. CII BM&M efforts have traditionally focused on performance and process benchmarking for competitive performance comparison benchmarking (Park 2002). Likewise, the engineering productivity metrics in this research enable performance benchmarking with external competitive benchmarks. This effort establishes a common framework for engineering productivity benchmarking that can be used for internal or external benchmarking.

2.2 DEFINITION OF PRODUCTIVITY

There are many different terms employed to define productivity (Sink 1985). For example, productivity has been defined variously as the production rate, unit rate, unit cost rate, or performance factor, as well as a number of other terms.

Thomas et al. (1986) discussed the strengths and weaknesses of different productivity definitions. The most classical way of defining productivity is as a comparison of the output of the production process to the corresponding input (i.e., Productivity = Output/Input) The construction industry however, uses input/output as a measurement of productivity, e.g., work-hours (input) per linear foot of pipe installed (output). The reason for this variation appears to be that typically the construction industry places paramount importance upon costs during both estimating and project execution; therefore, if productivity is reported as work-hours/unit, the cost engineer can easily determine project costs by multiplying (input/output) productivity times the estimated quantity and the wage rate (Thomas et al. 1986). Therefore, this research defined productivity as the production rate, i.e., the input work-hours divided by the output quantity.

Productivity Definition in This Research

$$\text{Engineering Productivity} = \frac{\text{Actual Work-Hours*}}{\text{IFC Quantity Designed}}$$

* Per Design Component

Figure 2.1 Engineering Productivity Definition for This Research

As shown in Figure 2.1, this is a very basic measurement, which can be also called “Raw Productivity,” herein referred to as “Engineering Productivity.” It is measured in actual work-hours per Issued for Construction (IFC) quantity designed; that is, the number of actual work-hours required for design components on the IFC drawings. Thus, for this system, the lower the value calculated for productivity, the better the productivity performance.

2.3 PRODUCTIVITY MEASUREMENT IN SOFTWARE ENGINEERING

Since software engineering is somewhat similar to engineering in the construction industry (Chang et al. 2001), software engineering productivity measurement research was reviewed. Historically, source lines of code (SLOC) had been used as a productivity measurement tool despite many shortcomings to this approach (CII 2001). One of the drawbacks is that the expressiveness of source code varies with language level. Software can usually be coded in a higher level language with less SLOC (DACS 2005). During the 1970s, the software industry developed the Function Point Analysis approach to overcome the differences among project development environmental factors such as platform, programming language and so on (Bok and Raman 2000).

Function Points (FPs) are defined as a weighted sum of the number of program inputs, outputs, user inquiries, files and external interfaces. Productivity is measured as FP produced per person month. Standardization of these factors has taken tremendous effort from both academia and industry in the software industry (DACS 2005). Adaptation of this methodology for the construction industry does not seem to be feasible, unless the industry is willing to spend tremendous effort to standardize virtual output units regarding each component's complexity.

2.4 PRODUCTIVITY RESEARCH IN THE CONSTRUCTION INDUSTRY

Since several publications point out that productivity in construction has declined over the years, both industry and academia have initiated numerous research projects on construction productivity. Therefore, construction productivity is one of the richest research areas in construction management. In fact, the Construction Industry Cost Effectiveness (CICE) project report indicated that construction productivity had declined. The CICE study reviewed existing construction productivity measurement procedures. It then recommended that productivity measurement programs should be established (BRT 1982).

In 1990, CII developed a productivity measurement system that included a reporting system, an output and input measuring system and a performance evaluation system to measure site-level productivity (CII 1990), but this system was not implemented due to lack of industry commitment and the lack of a well-established system. Adrian and Boyer (1976) established a productivity model known as the Method Productivity Delay Model (MPDM), to measure, predict, and improve the productivity of a given construction method. Weber and Lippiatt

(1983) reviewed the methods for measuring single factor productivity and total factor productivity in construction (Park et al. 2005). These efforts however, did not address engineering productivity measurements.

Liou and Borcherding (1986) stated, “Productivity measurement is not a one-time task. Continuous measurement and comparison with other projects or companies are key to productivity improvement.” Thomas and Yiakoumis (1987) also emphasized the importance of a standardized data collection system to provide reliable analyses. This research recognizes that need and establishes a standardized data collection system for engineering productivity in order to compare performance with other projects or companies for continuous productivity measurement.

The CII benchmarking productivity measurement initiative began in 2000 with development of a common set of definitions established through input from a series of industry workshops attended by 30 companies. It produced a system for CII to collect real project data using a standardized construction productivity metrics questionnaire via the secure web-based BM&M system (Park 2002, Park et al. 2005). This effort continues to collect construction productivity data for actual projects to provide reliable information for the industry. If the data collection effort continues to be successful, it will provide tremendous benefits not only to the industry but also to academia. The construction productivity measurement research by CII BM&M provided a foundation for this research.

2.5 ENGINEERING PRODUCTIVITY MEASUREMENT IN CONSTRUCTION

A literature review was performed to identify previous engineering productivity studies relevant to this research. It revealed that there is heretofore little quantitative work reported on the topic of measurement for engineering productivity. References to productivity and/or performance of engineers are typically qualitative in nature, and usually include a recommendation for a given product. In such cases, one frequently finds references to the idea that, by making use of a particular technique under discussion, one can improve their engineers' productivity, quality, and/or performance. There are many examples of such claims, and they can be found in all branches of engineering. Several papers have reported potential performance improvements resulting from the use of particular techniques (Isbell 1993; Girczyc and Carlson 1993; Graham 1990; Sackett and Evans 1984; Winter 1992). In these studies, there is an abundance of conclusions and a lack of data.

Stull and Tucker (1986) attempted to make a quantitative evaluation of the effectiveness of the design process. Mindful of the complexity of the design effort for an entire project, they considered only the piping design process and the subsequent erection of the piping. They selected seven parameters to describe the project's design effectiveness, namely: accuracy, usability, cost of the design, constructability, performance against design schedule, economy of the design, and ease of start-up (Stull and Tucker 1986). Some of these parameters were evaluated quantitatively (e.g., accuracy = number of drawings requiring revision/total number of drawings), while others were evaluated subjectively using a 1 – 10 scale (e.g., constructability and usability) (Chang et al. 2001). However, this method lacks objectivity for the scoring of individual parameters (Glavan and Tucker 1991; Dumont et al. 1997; Walsh et al. 2004).

2.5.1 Productivity Measurement Based on Intermediate Deliverables

The majority of engineering firms today still measure productivity based upon the number of drawings completed using the earned value method. This does not provide valid productivity measurement however, because of the continual evolution of technology like Computer Aided Design (CAD) (CII 2001; Chang et al. 2001), complexity factors, and different scale issues. This system continues to be widely used despite its shortcomings (Chang et. al 2001), because project owners use this methodology to calculate progress measurement. The primary weakness is that the measure can be easily skewed simply by increasing or decreasing the number of drawings delivered for a similar project scope (Feir 2004).

Thomas et al. (1999) developed a conceptual model for measuring the productivity of design professionals during the design phase based upon intermediate deliverables for architectural work. Unlike traditional cost accounting methods that rely on careful delineation of time into numerous cost codes, this system relies on the measurement of design output. Rules of credit and conversion factors were initially developed for unique classes of projects. However, employing this methodology has been very difficult because of a lack of industry consensus on defining rules of credit and conversion factors. Another limitation of this study is that it did not address other disciplines.

2.5.2 Related CII Research

Engineering control based on quantities is analogous to the progress measurement techniques used for construction activities. Diekmann and Thrush (1986) claimed several potential benefits for adopting this system. For instance, much of the subjectivity is removed from the measurement system by adopting a quantitative measure of progress. An additional benefit is a quantity-based engineering control system that puts design and construction on an equivalent basis for assessment and control. This system provides an important basis for this research.

CII has conducted two other studies on engineering productivity measurement: Research Team (RT) 156 and Project Team (PT) 192. In the following sections, those two studies are discussed in some detail.

2.5.2.1 Research Team 156: Engineering Productivity Measurement

Since CII concluded that the current practice for engineering productivity measurement in the construction industry did not yield satisfactory results, it commissioned RT 156 in 1998 to develop engineering productivity measurements.

CII RT 156 advanced the concept of measuring engineering productivity, not by the traditional method of using design hours per direct engineering output of drawings and specifications, but by using the physical quantities to be installed in the field. The team concluded that the physical quantity was a better output measure because it:

a. was more directly tied to the design activity,
b. was less subject to manipulation,
c. was already tracked in most design environments,

d. puts construction and design on the same basis,

e. focuses attention on the final product (Chang et al. 2001; Walsh et al. 2004).

Since a number of engineering disciplines constitute major drivers of performance in several industry groups, RT 156 evaluated driver disciplines for several industry types. Table 2.1 illustrates the matrix developed by RT 156 where ten engineering disciplines and six industry types are recognized. The “x” mark denotes an engineering discipline considered a driver of performance in the associated industry type (Chang et al. 2001).

Table 2.1 Engineering Productivity Drivers by Industry (Source: CII RR 156-11)

Industry → Discipline ↓	Light Industrial		Heavy Industrial		Buildings	Infrastructure
	Process	Mech.	Process	Mech.		
Civil/Structural			×	×	×	×
Architectural					×	
Project Mgmt & Controls						
Mechanical (HVAC, Utilities, Vessels)				×		
Piping (Design & Mechanical)	×		×			
Manufacturing Process (Mechanical)		×		×		
Manufacturing Process (Chemical)	×		×			
Electrical						
Instrument/ Controls/ Automation	×	×	×	×		
Other						

The piping discipline was selected as the experimental area because it is considered to have a significant impact on an industry-wide basis (Chang et al. 2001). The team conducted a detailed evaluation of the piping design process and sought correlation between the engineering hours for piping design and physical measures of quantities. Because piping constitutes a significant portion of the costs in delivery of an industrial facility and has had relatively more study in piping engineering and design practices, it was considered to be an important discipline area for metrics development.

The team found good correlation between hours and the total length of pipe designed and the number of equipment pieces in the piping systems. Equipment piece count was seen as an indication of project complexity (CII 2001). The team developed a proposed model for piping using raw productivity and the number of pieces of equipment with data obtained from 40 projects:

Hours/ Feet of Piping = (0.44985 + 0.00134 * Number of Pieces of Equipment)

(Source: CII 156-1)

Raw productivity addresses the productivity of the actual work itself, by measuring the time required to produce designs for the physical quantities to be installed in the field. However, some projects are more complex than others, so an adjustment to account for the scope and complexity of the project was suggested. In the case where the design basis is incomplete, or the client changes the project in midstream, the design hours may reasonably be expected to increase, so the quality of the input must also be considered.

Finally, RT 156 realized that a possible (but undesirable) path to apparent productivity improvement would be to transfer design work from the design phase to the construction phase of the project. Accordingly, the quality of the engineering deliverables must also be considered (Chang et al. 2001).

Taken together, these four components provide a good understanding of engineering performance (Chang et al. 2001). Therefore, RT 156 proposed a conceptual model in which detailed design engineering productivity would consist of 1) a raw productivity (work-hours per designed quantity), which could be adjusted to account for 2) project complexity, 3) the quality of input to detailed design, and 4) the quality of the design output (CII 2001). Figure 2.2 represents a conceptual model proposed by the team. However, this model has not been fully developed.

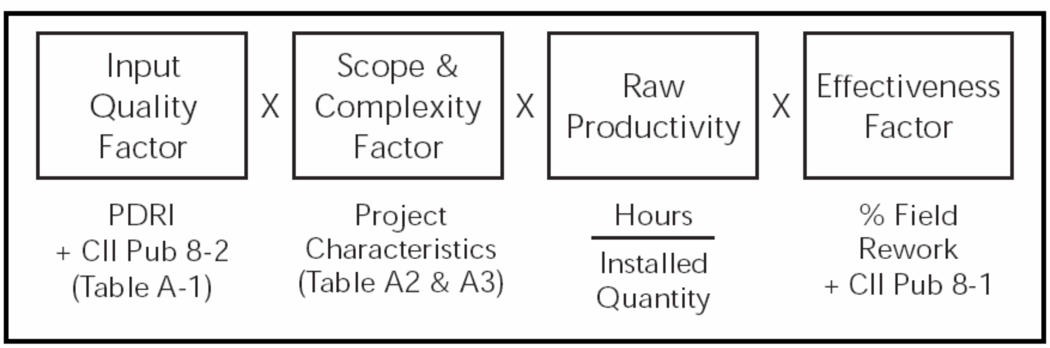

Figure 2.2 A Conceptual Model from RT 156 (Chang et al. 2001)

RT 156 suggested that the raw productivity to be used for discipline budgets and performance tracking should be adjusted by three Influence factors:

1. Input Quality Factor, which adjusts the raw productivity measures for the quality and completeness of the design basis. The project PDRI (Project Definition Rating Index) would serve well as a large part of this factor.

2. Scope and Complexity Factor, which would account for differences in industry and project characteristics.

3. Design Effectiveness Factor, which is necessary to expose the hidden transfer of cost from engineering to other parts of the project, usually at higher at overall cost. The percentage of field rework as a result of design tested against industry average would account for most of this factor (CII 2001; Chang et al. 2001).

2.5.2.2 Project Team 192: Engineering Productivity Measurement II

Project Team (PT) 192, Engineering Productivity Measurements II was launched by CII in 2002 as follow-on research to RT 156. The objective of PT 192 was to develop a standardized productivity measurement methodology.

PT 192 conducted a series of discipline workshops and developed a data collection instrument targeting selected engineering design quantities, discipline hours and possible input/output measures. The team collected 118 projects from 14 different CII member design firms. The team developed multiple regression models for each discipline to produce "basis hours" according to selected quantities identified as significant and some variables industry experts believed to be work-hour drivers. Basis hours are predicted discipline hours calculated from a multiple regression model using selected design quantities for each discipline. For instance, the regression model for the civil /structural basis hour is as follows:

Civil/structural basis hour = (0.0161 x SF of building area) + (0.492 x CY of concrete) + (6.39 x tons of steel) + (3.53 x no. of deep foundations)

(Source: CII 192-1)

A productivity index for each discipline can be calculated by dividing the actual discipline design hours by the discipline basis hours predicted by the model using actual design quantities (CII 2004; Walsh et al. 2004). Figure 2.3 represents Productivity Index for PT 192.

PT192 Productivity Index Definition

$$\text{Productivity Index} = \frac{\text{Discipline Actual Hours}}{\text{Productivity Basis Hours}}$$

(Source: CII 192-1)

Figure 2.3 PT 192 Productivity Index Definition

The team suggested two different methods to measure engineering productivity using its research findings (CII 2004).

- The "off-the-shelf" approach: This model uses "basis hours" equations developed from the PT 192 data set to measure productivity and establish baselines. The team stated that this approach can be used with minimal startup costs to monitor projects. This method requires ascertaining average performance of a group of projects in order to track changes in productivity.
- The "custom-tailored" approach: In this approach, users develop their own basis hour functions based on data collected from their own projects. A large number of variables that might be correlated with engineering work-hours of each discipline would need to be collected. The team specified that this approach may provide a more accurate system linked to company-specific projects or work processes, although it may take more effort than the off-the-shelf approach.

Figure 2.4 depicts the suggested process described for the PT 192 implementation approaches.

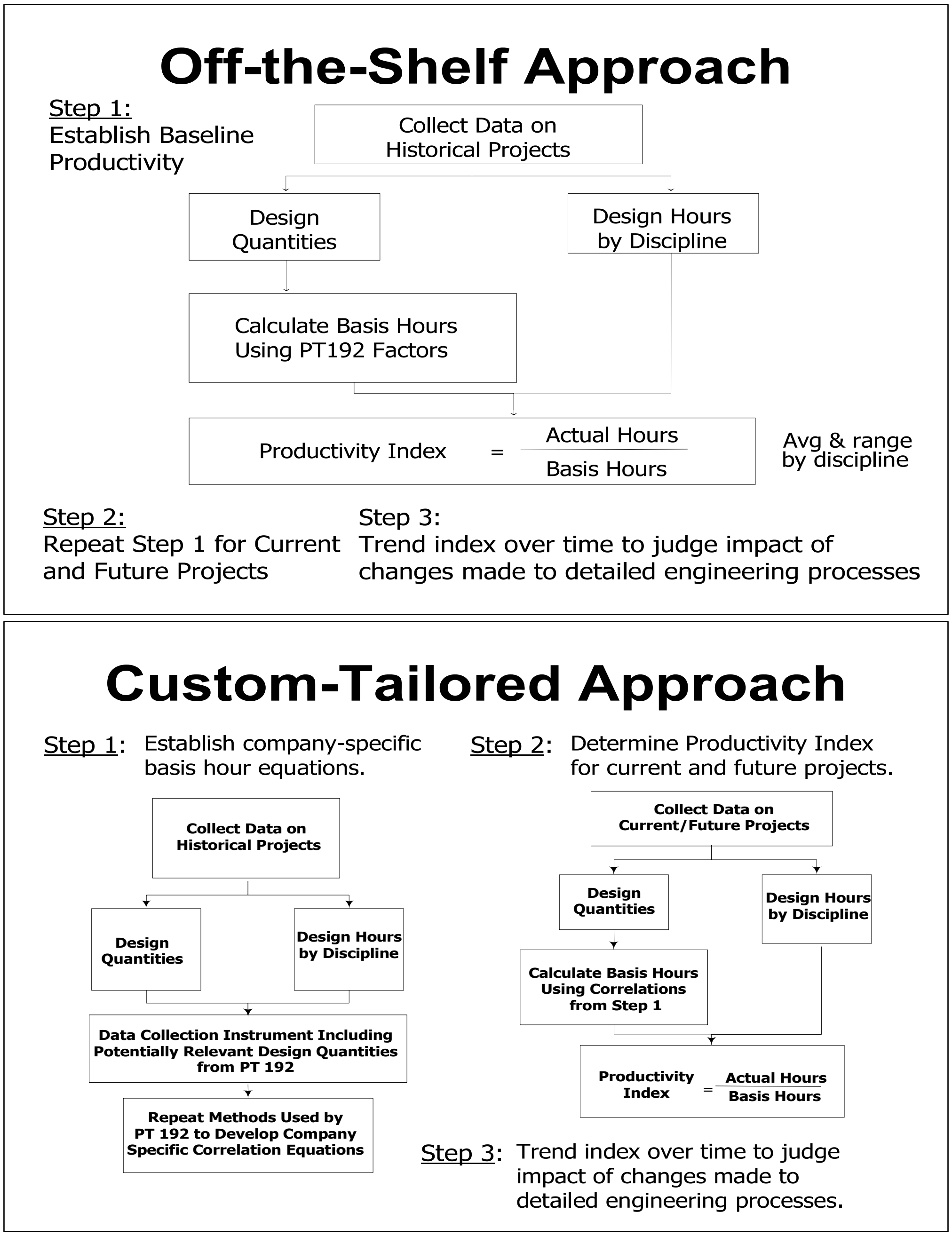

Figure 2.4 Suggested Process of PT 192 Model Implementation Approaches (Source: CII 2004)

Although the PT 192 put much effort into developing a regression model for each discipline to predict basis hours, the approach may not be suitable for individual project benchmarking. More detailed discussion for PT 192 is provided in Section 3.2 and Appendix B. A comparison between the PT 192 approach and the BM&M approach is presented in Appendix A in detail.

2.6 LITERATURE REVIEW CONCLUSION

The literature review provides background for this research by showing previous studies focused on construction productivity and engineering productivity measurement using intermediate deliverables and predictive models.

Section 2.1 introduces productivity as a benchmarking tool. Section 2.2 discusses different definitions of productivity that have been promulgated in previous research efforts. The review made clear that the industry should use a single definition of productivity in order to develop, collect, and compare engineering productivity across the industry. Section 2.3 reviews productivity measurement in software engineering using lines of code and Function Point Analysis. Section 2.4 outlines productivity research performed for construction and concludes that more research has been focused in this area than for engineering. Finally, Section 2.5 reviews various studies on engineering productivity measurement. Previous studies indicate that usage of intermediate deliverables is not an ideal methodology to measure productivity and that IFC quantity is recommended as an output measure for engineering productivity measurement. It is important to note however, that none of the previous studies developed engineering productivity metrics using direct measurement and common definitions.

Chapter 3: RESEARCH METHODOLOGY

3.1 RESEARCH METHODOLOGY OVERVIEW

This chapter describes the research methodology employed in the establishment of the Engineering Productivity Measurement System (EPMS). Figure 3.1 provides a graphical representation of the research methodology.

Initially, a literature review was performed to identify previous studies relevant to this research as documented in Chapter 2. Productivity definitions, productivity measurement in software engineering, and construction and engineering productivity measurement studies were reviewed.

While reviewing engineering productivity measurement in the construction industry, the parallel effort of PT 192, discussed in the previous chapter, was ongoing within CII. Therefore, the author reviewed its research process to evaluate the PT 192 models for applicability of use in a sustainable benchmarking program as previously discussed in Section 2.5.2.

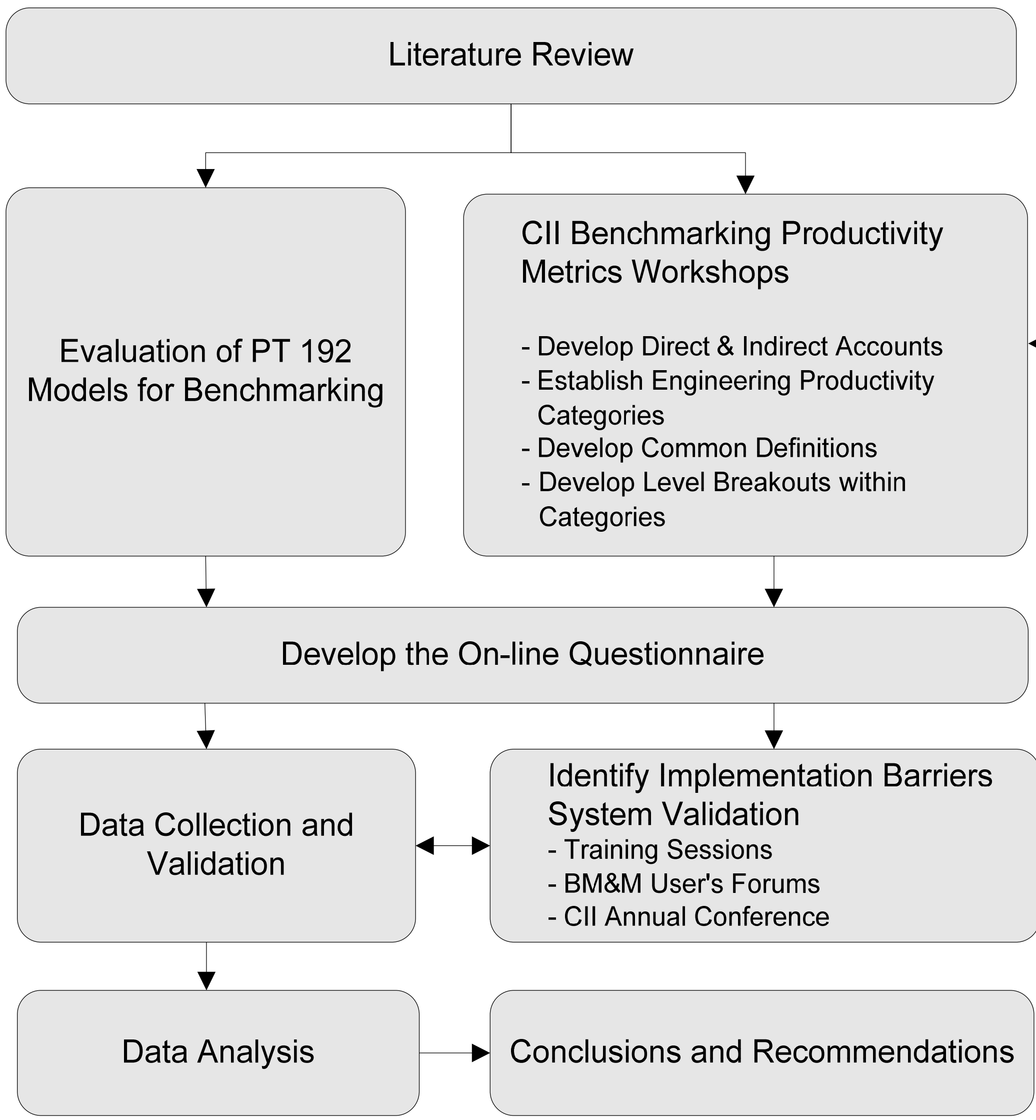

Figure 3.1 Research Methodology Diagram

3.2 EVALUATION OF THE PT 192 MODEL FOR BENCHMARKING

During this research, the Benchmarking Productivity Metrics team decided to align metric development efforts with PT 192 to maximize benefits and minimize the duplication of effort. To assist in understanding of the BM&M and PT 192 scope of work, Table 3.1 provides a high-level comparison. As shown, the engineering productivity metrics for this research consist of concrete, structural steel, electrical, piping, instrumentation, and equipment. The PT 192 engineering productivity measurement questionnaire includes civil/structural steel, electrical, piping, instrumentation, mechanical (equipment), architecture, and process disciplines (Walsh et al. 2004).

Table 3.1 Scope Comparison between BM&M and PT 192 Approaches

Major Categories / Discipline	BM&M	PT192
Concrete	√	√
Structural Steel	√	
Electrical	√	√
Piping	√	√
Instrumentation	√	√
Equipment	√	√
Architecture		√
Process		√

To examine the PT 192 statistical models for potential use within the CII benchmarking system, the author reviewed the procedures used by the research team for model development. Evaluation of PT 192 models and their applicability for benchmarking are discussed further in Appendix A.

3.3 CII Benchmarking Engineering Productivity Metrics Workshops

A series of CII Benchmarking Productivity Metrics workshops were conducted to develop engineering productivity metrics. These workshops followed a format established in previous years for defining construction productivity metrics. The definitions were based on common knowledge reflecting the practices of industry professionals and a consensus of opinion. Because each organization employs a different productivity management system with unique definitions and categories, a consensus on definitions and categories was important to induce the participation of the CII member organizations and to provide reliable measurement results.

Initial engineering productivity workshops were held in January and April of 2002 to establish engineering productivity categories which loosely follow engineering disciplines. These workshops were also used to establish the list of direct and indirect accounts and a set of common definitions. In these workshops, the following engineering productivity categories were established: 1) concrete, 2) structural steel, 3) electrical, 4) piping, 5) instrumentation, and 6) equipment. This development effort included valuable input from many industry experts. Guiding principles for these workshops were:

- The number of metrics categories must remain doable (five to eight); there was never any intent to collect 100 percent of the engineering effort.
- Data collected must be auditable and repeatable.
- The engineering definition categories should be similar to construction productivity metrics to prevent sub-optimizing one activity from the other.

After the initial development of engineering productivity metrics, pilot data collection was conducted to receive feedback from the industry. Since some issues were identified during various BM&M training sessions and Benchmarking User's Forums, a productivity metrics retreat was organized to resolve these issues. In June 2004, 27 individuals from 20 companies including some PT 192 members met in Woodville, TX. During the workshop, methodologies to measure engineering productivity from a direct measurement approach versus a predicted approach were reviewed, and the group selected the direct measurement approach. Modifications were made to the BM&M questionnaire to ease the burden of data collection. The author assisted in various planning activities and in facilitation of the workshop.

After the productivity retreat, the engineering productivity questionnaire was modified to incorporate decisions from the retreat. Shortly thereafter, the retreat outcomes were presented at various industry forums to extend the opportunity to participate in the data collection initiative to other companies. In final form, the developed version of the BM&M engineering productivity metrics survey consists of 39 elements, grouped into 26 subcategories which ultimately roll up into six major categories. Development of engineering productivity metrics are further discussed in Chapter 4.

3.4 Development of The Online Questionnaire

Soon after engineering productivity metrics categories and common definitions were developed, a paper version of the engineering productivity questionnaire was developed and reviewed by the Productivity Metrics team. Then, the questionnaire was programmed, tested, and integrated into the CII BM&M secure online data collection system. This allows collection for general project information, cost, schedule, change, rework, safety, construction productivity metrics and CII best practices data, ultimately providing a means for an assessment of a complete set of a project data. Integrating the engineering productivity data collection instrument into the CII BM&M web-based system facilitates use of an established and proven system in previous CII BM&M studies.

CII offers several different specialized versions of its questionnaire to collect project information. There are survey instruments for large and small projects and a special one for pharmaceutical projects. The engineering productivity metrics can be accessed with any version of the questionnaire, but only the CII BM&M large project questionnaire is provided as a reference in Appendix B.

3.5 IDENTIFICATION OF IMPLEMENTATION BARRIERS

The author has assisted in conducting Benchmarking Associate (BMA) training sessions and facilitated Benchmarking User's Forums and BM&M committee meetings. Through these meetings, valuable feedback from industry experts was received for the implementation of engineering productivity metrics. Many engineering firms acknowledge that they currently do not track engineering work-hours as defined in the questionnaire. Their control systems do not allow reporting of engineering work-hours per design components for historical projects. This was viewed as one of the most significant barriers to the success of this study. Further discussion on system validation and implementation issues including system validation will follow in Chapter 6.

3.6 DATA COLLECTION AND VALIDATION

This data collection effort follows the guidelines established by the CII BM&M Committee. The first stage of data collection was initiated using a pilot version of the questionnaire in September 2002. Collection continued for approximately one year. Through this early round of data collection, feedback from the industry was received and used for refinement of the instrument.

A second round of data collection was then performed to enrich the data set to allow for preliminary analysis. At the Productivity Retreat in 2004, data collection strategies were established by workshop participants and action items for the data collection effort were decided and later conducted. This effort was supported by special Productivity Benchmarking Associate (BMA) Training sessions to ensure understanding of productivity metrics and to facilitate a structured data collection procedure.

The next step for the data collection is the validation of the data to minimize or eliminate ambiguous or missing data. After the validation process is completed, the data are officially included in the CII BM&M database for analysis. Data collection and validation processes are further discussed in Chapter 5.

As discussed in Chapter 1, the process for data collection relied on convenience sampling rather than random sampling. Therefore application of findings from analyses of the data to the industry in general may be limited. Practitioners should apply caution until more data are available for further validation.

3.6.1 Data Confidentiality

Since productivity data are directly related to competitiveness, the data are considered highly confidential. The CII BM&M committee has established a strict Confidentiality Policy and a Code of Conduct defining appropriate use of the data along with the development of the construction productivity metrics system. These policies address the activities of the members of the Benchmarking & Metrics Committee and the CII staff who support the Committee's activities. Both the Confidentiality Policy and the CII Benchmarking Code of Conduct can be found at the CII Benchmarking and Metrics website at http://www.construction-institute.org.

3.7 DATA ANALYSIS

Data analysis and results should be presented in a manner that industry practitioners can understand without difficulty. Research experience suggests that the construction industry tends to be reluctant to make decisions based upon data unless the organizations understand and are confident about the process of data analysis (Huh 2004). The data analysis commenced with presenting profiles of the engineering productivity dataset. Then, Box-Whisker plots were generated to graphically present the distribution of engineering productivity metrics for various categories.

Correlation studies of design work-hours and IFC quantities were employed to examine the relationships between the two and to test the research hypothesis that engineering work-hours and design quantities provide reliable measures of engineering productivity. Theoretical background of the Box-Whisker plot and correlation analysis are reviewed in subsequent sections. The data analysis is presented in Chapter 5 in detail.

3.7.1 Box-Whisker Plot

The Box - Whisker plot, also called a box plot, portrays the range and the quartiles of the data, and outliers if present. The central portion, or the box, consists of the middle 50 percent of the data, from the first quartile (25^{th} percentile) to the third quartile (75^{th} percentile). This range is also referred to as the inter-quartile range (IQR). The median is drawn as a horizontal line in the box. The mean, according to graphical preferences, can also be plotted. Plotting both the median and the mean offers an efficient way to indicate the central tendency. The whiskers extend away from the box, indicating the range of the data that is not considered an outlier (Agresti and Finlay 1999; Albright et al. 2003). The end points of the whiskers represent the last data observation that falls within the 1.5 IQR fence. Mild Outliers are defined as those observations located between 1.5 IQR and 3.0 IQR from the box. Extreme outliers are defined as those observations located beyond 3.0 IQR from the box. A sample box plot is included in Figure 3.2.

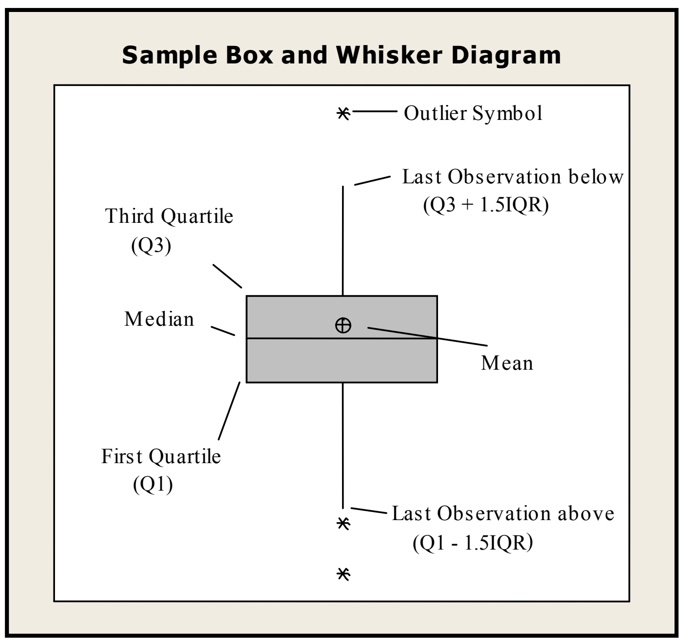

Figure 3.2 Sample Box - Whisker Plot

The box plot is an efficient way to present both the central tendency and range, which makes it extremely useful in comparing data among groups. The data presented can help users compare the median, mean, and variance between groups, draw conclusions among the differences, and contribute to decision making (Agresti and Finlay 1999; Albright et al. 2003). The Box and Whisker plots were generated by using MINITAB® to present the norms for productivity metrics and to check extreme outliers.

3.7.2 Correlation Analysis

Correlation analysis is conducted to determine if there is a significant linear relationship between engineering work-hours and IFC quantities. While regression in general is used to build and test a prediction model, correlation analysis is often applied to test the direction and strength of the linear relationship and to assess the feasibility of using regression analysis. The correlation coefficient, *r*, is calculated as follows:

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

The correlation coefficient, *r*, is a unit-less value that always falls between -1 and +1. A coefficient close to 1 indicates a strong positive linear relationship between two random variables. A key assumption underlying the analysis is that a linear relationship is appropriate. The correlation results of the analysis should be interpreted with appropriate caution as to how well the data meet this assumption (Agresti and Finlay 1999; Albright et al. 2003).

Significance of the Pearson correlation coefficient, r can be tested. If the true correlation between X and Y within the general population is ρ (rho) = 0, and if the size of the sample, N, on which an observed value of r is based on N [≥ 6], then the simplest formula for computing the appropriate t value to test significance of a correlation coefficient employs the t distribution with degree of freedom (N-2):

$$t = r\sqrt{\frac{N-2}{1-r^2}}$$

3.8 SUMMARY

Chapter 3 discussed research methodology employed in the establishment of the Engineering Productivity Measurement System (EPMS) including evaluation of the PT 192 model, the CII BM&M engineering productivity workshops, development of the online questionnaire, identification of implementation barriers, data collection and validation, and finally data analysis utilized in this research. The following chapter will discuss development of the engineering productivity metrics.

Chapter 4: DEVELOPMENT OF THE ENGINEERING PRODUCTIVITY METRICS

There have been many recommendations emphasizing the need for a standard method to measure productivity including various levels of project work activities for both construction and engineering productivity (Liou and Borcherding 1986; Thomas and Yiakoumis 1987). The CII Productivity Metrics team held workshops to develop a standard engineering productivity measurement system with input from both industry experts and academia. This chapter describes in detail the development workshops, direct and indirect accounts, levels of metrics, engineering productivity metrics, and their common definitions.

4.1 ENGINEERING PRODUCTIVITY METRICS WORKSHOPS

Development of suitable industry standard engineering productivity metrics for benchmarking was accomplished through significant effort from industry and academia. As noted, the engineering productivity development workshops followed the development of CII BM&M construction productivity metrics with the goal of tying engineering and construction productivity metrics as much as possible to improve overall work processes and not sub-optimize either one. Table 4.1 shows major categories for construction and engineering productivity metrics. Engineering productivity consists of six major categories, and construction productivity has seven, with an additional section for insulation which was not included in engineering since it is not a major design activity.

Table 4.1 Construction and Engineering Productivity Metrics Categories

Construction Productivity	Engineering Productivity
Concrete	Concrete
Structural Steel	Structural Steel
Electrical	Electrical
Piping	Piping
Instrumentation	Instrumentation
Equipment	Equipment
Insulation	

4.1.1 Engineering Productivity Metrics Development Milestones

As noted, a series of CII Benchmarking Productivity Metrics workshops was conducted to develop engineering productivity metrics. Initial engineering productivity workshops were held in January and April of 2002 to establish engineering productivity categories which loosely follow engineering disciplines. These workshops were also used to establish a list of direct and indirect accounts and a set of common definitions. The definitions were based on expert knowledge reflecting the practices of industry professionals and a consensus of opinion. After the initial development of engineering productivity metrics, a pilot data collection in September 2002 commenced to receive feedback from the industry.

Much feedback was collected through the pilot data collection effort at various BM&M training sessions and during the Benchmarking User's Forums. Most input focused on data collection issues and the different research approaches undertaken by this research (BM&M) and PT 192. A key data collection issue from the initial version of the engineering productivity metrics surveys was that they provided only detail-level metrics without the ability to enter data at the rollup-level. This hindered data collection activities, considering that a quantity–based engineering productivity was a paradigm shift for the industry, and many companies had difficulty providing engineering work-hours for detailed categories for past projects.

To resolve these issues, the Productivity Metrics Retreat was planned and announced at a CII Board of Advisors round table discussion in Baltimore in April 2004. The round table discussion was conducted to explain the need for the Retreat and to get consensus on support from CII's Board of Advisor Members. Also, a registration form for the retreat was passed out to invite companies' project control managers and engineering managers who would have the authority to change their systems if necessary. At the same time, invitation letters were mailed to the prospective participants including former workshops participants, the CII's Board of Advisors, engineering managers, and project control managers.

In June 2004, 27 individuals from 20 companies including some PT 192 members met in Woodville, TX. During the workshop, methodologies to measure engineering productivity using a direct measurement approach versus the PT 192 predicted approach were reviewed and the direct measurement approach was selected. Modifications were made to the BM&M questionnaire to ease the burden of data collection by including rollups such as total slab and total concrete. The option to enter data at the major category level and sub-category level enables more companies to more readily participate.

After the productivity retreat, the engineering productivity questionnaire was modified to incorporate decisions from the retreat. The outcomes were presented at various industry forums to extend the opportunity to participate in the data collection initiative to other companies. Table 4.2 summarizes the major activities for development of engineering productivity metrics.

Table 4.2 Development Milestones

Date	Outputs
Jan 2002	Developed first cut of engineering productivity metrics
Apr 2002	Refined engineering productivity metrics
Sep 2002	Initiated pilot data collection
Apr 02 – Jun 04	Alignment/integration with PT192 on engineering metrics
Jun 2004	Productivity retreat to achieve alignment & established data collection plan
Aug 2004	Established a specialized productivity training sessions.
Feb 2005	A special paper-version productivity questionnaire mailed out
Jun 2005	Received first significant quantities of productivity metric data

4.1.2 Productivity Metrics Workshop Participants

Several workshops were conducted to collect input from industry experts and to develop engineering productivity metrics. Productivity metrics team members and workshop participants discussed and established direct and indirect accounts, categories for the metrics, and measuring elements included in the engineering productivity questionnaire. A total of 28 member organizations, representing 11 owner companies and 17 contractor companies participated. The 44 participants consisted of members of the BM&M Committee and other CII member representatives who participated in the development workshops. Table

4.3 shows a list of the participating organizations. The author also attended several workshops as a facilitator and documented and constructed the engineering productivity metrics questionnaire based upon input from these workshops.

Table 4.3 Productivity Workshop Participant Companies

Owners (11)	**Contractors (17)**
3M	Aker Kvaerner
Aramco Services Company	ALSTOM Power Inc.
BP America, Inc.	BE&K, Inc.
Chevron Corporation	Bibb & Associates (Kiewit)
Conoco Inc.*	Black and Veatch
General Motors Corporation	CDI Engineering Solutions
GlaxoSmithKline	Flint Energy Services Ltd.
Rohm and Haas Company	Fluor Corporation
Southern Company Services	Fru-Con Construction Corporation
Texaco Inc.*	Jacobs Engineering
The Dow Chemical Company	Mustang Engineering, L.P.
	Rust Constructors Inc.*
	S&B Engineers and Constructors Ltd.
	The Shaw Group
	Washington Group International, Inc.
	Watkins Engineers & Constructors*
	Zachry Construction Corporation

*Company names are indicated as of the time of workshops

4.2 ENGINEERING PRODUCTIVITY METRICS

The engineering productivity metrics section of the BM&M questionnaire is introduced with a discussion of the direct and indirect accounts. Achieving industry consensus on the definitions of direct and indirect accounts was crucial to accomplishing research objectives since valid comparisons of data without a common basis can not be made.

The following section discusses direct and indirect accounts, levels of metrics, and the developed metrics for each major category to include definitions. Major categories are 1) concrete, 2) structural steel, 3) electrical, 4) piping, 5) instrumentation, and 6) equipment.

4.2.1 Direct and Indirect Accounts

Early in the course of the engineering productivity workshops, the importance of defining direct and indirect activities was identified. A common set of definitions for direct and indirect accounts is critical to benchmarking success since productivity metrics as defined in this research are based on direct work-hours only. Because each owner or contractor organization has different accounting systems, a common list of direct and indirect accounts were developed based on a consensus of industry experts.

Actual work-hours are computed by the summation of all the account hours listed as direct accounts in the following table. Actual work hours include rework hours where tracked in order to account for the whole effort required to produce the deliverables. Many companies do not track rework hours in engineering and thus cannot separate engineering rework effort. The list of direct and indirect accounts is presented in Table 4.4.

Table 4.4 List of Direct and Indirect Accounts

	Direct	**Indirect**
Account	Discipline Engineer	Document Control
	Designer	Reproduction Graphics
	Technician	Project Management
		Project Controls (cost/schedule/estimating)
		Project Engineer
		Secretary/clerk
		Procurement (supply management)
		Construction Support (test package support, commissioning, etc.)
		Quality Assurance
		Accounting
		Legal

In the engineering productivity metrics questionnaire, detailed instruction is provided to explain direct and indirect accounts. Direct work-hours should include all hours used to produce deliverables including site investigations, meetings, planning, constructability, RFIs (Request for Information), and rework. Work-hours for operating manuals and demolition drawings are excluded. Engineering work-hours should be reported only for the categories requested and may not equal the total engineering work-hours for the project. The team did not intend to collect 100 percent of engineering work-hours but intended only to collect the engineering work-hours for the major categories shown. It is expected that after progress has been made in productivity metrics for the categories shown, other categories such as architectural finishes and process will be added.

It is important to note that this research effort focused on industrial projects. For this reason, the following categories were excluded: architectural design, plumbing, process design, civil/site preparation, HVAC (Heating, Ventilating, and Air Conditioning), insulation and paint, and sprinkler/deluge systems. When there are direct work-hours that cannot be specifically assigned into the provided classifications, but have not been excluded within a category, these work-hours should be prorated based on known work-hours or quantities as appropriate.

Ultimately, various engineering productivity metrics and their common definitions were developed through a series of workshops and later refined from industry feedback. These were incorporated into the engineering productivity questionnaire. The definitions of the metrics and detailed discussion for various applications follow in Section 4.3.

4.2.2 Levels of Metrics

This section discusses definitions of levels of metrics. Since this research developed six major categories and a total 49 engineering productivity metrics to compare with industry norms, it was quickly realized that it would be beneficial to develop different levels of metrics to collect engineering productivity data effectively. Different levels of metrics were defined to allow flexibility in terms of data collection and to show performance at different levels: the project level, the major category level, the sub-category level, and the element level. Figure 4.1 also provides a graphical illustration of hierarchical structure for a concrete example.

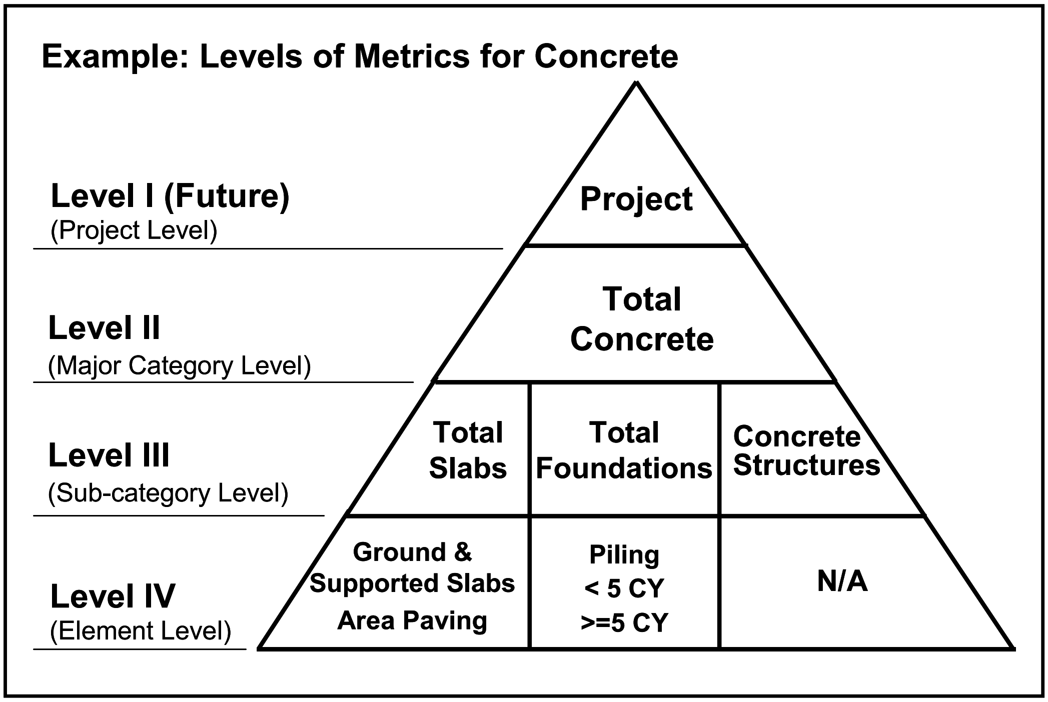

Figure 4.1 Hierarchical Structure of Metrics (Concrete Example)

Following development of Level II, III, and IV metrics, many discussions focused on developing a project-level metric. The CII BM&M Productivity Metrics team recommended a guideline for a Level I metric. The committee stressed that the Level 1 metric should be easy to understand for both industry and academia, and that it should be a meaningful metric, that is repeatable and may ultimately be used for trending. This metric would serve various analyses, be economical to collect and produce, and would be a reasonable summary of project productivity. The Level I metric for engineering productivity measures will be developed as follow-on research and is not in the scope of this dissertation.

4.2.3 Metric Categories

This section briefly explains the developed metrics for each major category from the engineering productivity development workshops. Major categories are 1) concrete, 2) structural steel, 3) electrical, 4) piping, 5) instrumentation, and 6) equipment. To assist readers' understanding, the overall framework for the developed engineering productivity metrics and their associated levels are given in Figure 4.2. It presents various levels of engineering productivity metrics with Level II (major category), Level III (sub-category), and Level IV (element) and also summarizes the metrics and categories for engineering productivity. The following sections discuss engineering productivity metrics and common definitions in great detail for each major category.

Concrete

- ▪ **Total Concrete**
  - o Total Slabs
    - Ground and Supported Slab
    - Area Paving
  - o Total Foundations
    - Piling
    - Foundation (<5 CY)
    - Foundation (>=5CY)
  - o Concrete Structures

Structural Steel

- ▪ **Total Steel**
  - o Combined Structural Steel / Pipe Racks and Utility Bridges
    - Structural Steel
    - Pipe Racks and Utility Bridges
  - o Miscellaneous Steel

Electrical

- o Total Electrical Equipment
  - Electrical Equipment 600V and Below
  - Electrical Equipment Over 600V
- o Conduit
  - Conduit (Linear Feet)
  - Conduit (Number of Runs)
- o Cable Tray
- o Wire and Cable
  - **Wire and Cable (Linear Feet)**
  - Wire and Cable (Number of Terminations)
- o Other Electric Metric
  - Lighting

Piping

- ▪ **Total Piping**
  - o Small Bore (2-1/2" and Smaller)
  - o Large Bore (3" and Lager)
  - o Engineered Hangers and Supports

Instrumentation

- o Loops
- o **Tagged Devices**
- o I/O

Equipment

- ▪ **Total Equipment**
  - o Pressure Vessels
  - o Atmospheric Tanks
  - o Heat Transfer Equipment
  - o Boiler and Fired Heaters
  - o Rotating Equipment
  - o Material Handling Equipment
  - o Power Generation Equipment
  - o Total Pulp and Paper Equipment
    - Woodyard Equipment
    - Pulp Mill Equipment
    - Bleach Plant Equipment
    - Stock Preparation Equipment
    - Wet End Equipment
    - Dryer Sections
    - Wet End Equipment including Roll Wrap/Converter Equipment
  - o Other Process Equipment
  - o Vendor-Designed Modules and Pre-Assembled Skids

Legends
- ▪ **Level II**
  - o Level III
    - Level IV

Figure 4.2 Engineering Productivity Metrics Categories

4.2.3.1 Concrete

Each of the six major engineering productivity categories provides specific instructions for the submission of data. For example, the concrete major category provides the following definition: the quantity of concrete is that concrete that is required for the specified slab, foundation, or structure provided in the final issued for construction (IFC) drawings.

Concrete is measured as total slabs, total foundations, and concrete structures such as beams and columns. Total slabs are categorized into two types: ground and supported slabs and area paving. Total foundations are further categorized as pilings (each), foundations <5 cubic yards, and foundations >= 5 cubic yards. The output measure for pilings is each instead of cubic yards to follow expert opinions. Table 4.5 provides the concrete productivity metrics, their definitions, metrics levels, and the corresponding units. It is structured to resemble the questionnaire format to assist the reader's understanding of the hierarchy of metrics and the definitions developed during the workshops. The metrics are calculated based on IFC quantity and actual work hours required for design.

Table 4.5 Concrete Productivity Metrics

Level of Metrics	Concrete	Unit
IV	Ground & Supported Slabs	Hrs/CY
	Both slabs on ground and supported slabs IFC quantity. Engineering work-hours should also include hours for design of all embedments.	
IV	Area Paving	Hrs/CY
	Paving included within the project, excluding roadways.	
III	Total Slabs	Hrs/CY
	Total slab quantity and work-hours only if data can not be separated into quantity and work-hours above.	
IV	Piling (each)	Hrs/EA
	The total number of piling designed in the IFC drawings. Engineering work-hours include all embedments.	
IV	Foundations (< 5CY) (cubic yards)	Hrs/CY
	The total CYs of foundation (<5CY); Engineering work-hours include all embedments. Exclude piling.	
IV	Foundations (>= 5CY) (cubic yards)	Hrs/CY
	The total CYs of foundation (>=5CY); Engineering work-hours include all embedments. Exclude piling.	
III	Total Foundations (CY) (Excluding piling)	Hrs/CY
	Total Foundation quantity is cubic yards of concrete only. Total foundation work-hours should exclude piling quantity and work-hours.	
III	Concrete Structures	Hrs/CY
	Concrete Structures include concrete structures, columns, beams, cooling tower basins, trenches, formed elevated slabs/structures, and retaining walls.	
II	Total Concrete	Hrs/CY
	Total concrete quantity is cubic yards only, excluding piling quantities. The total concrete work-hours include those hours for total slabs, total foundations (excluding piling), and concrete structures. The work-hours should also include work-hours for all embedments.	

Various levels within each category are provided such as total concrete, total slabs, ground & supported slabs and area paving in order to allow flexibility in data entry. The pilot version of the engineering productivity metrics questionnaire did not allow the user to submit any data at the roll-up level such as Level III and Level II. Several respondents, however, had difficulty reporting at the detailed levels provided because each engineering firm tracks its work-hours and quantities differently. The necessity for providing flexible categories to facilitate data collection was discussed and the category "totals" were incorporated as appropriate during the Productivity Metrics Retreat in June 2004.

4.2.3.2 Structural Steel

Structural steel is a crucial component in construction that supports and transfers loads in structures and buildings. For measurement, structural steel was divided into structural steel, pipe racks and utility bridges, and miscellaneous steel. Each element was defined for collecting standard productivity data and definitions of elements are provided in Table 4.6. The table also lists the various levels of metrics and their corresponding units.

These metrics are computed based on actual engineering work-hours including rework hours and IFC quantities for each metric. Structural steel quantities are measured in tons, and the unit of engineering productivity metrics is hours/ton. A combined structural steel / pipe racks and utility bridges category was added at the request of several companies at the productivity retreat whose WBS (Work Breakdown Structure) systems did not separate structural steel and pipe racks & utility bridges.

Table 4.6 Structural Steel Productivity Metrics

Level of Metrics	Structural Steel	Unit
IV	Structural Steel	Hrs/Ton
	Trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts.	
IV	Pipe Racks & Utility Bridges	Hrs/Ton
	Steel structures outside the physical boundaries of a major structure, which are used to support pipe, conduit, and/or cable tray.	
III	Combined Structural Steel / Pipe Racks & Utility Bridges	Hrs/Ton
	Combined structural steel and pipe racks & utility bridges if data cannot be separated into the quantities above.	
III	Miscellaneous Steel	Hrs/Ton
	Handrails, toeplate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, pre-mounted ladders and platforms, miscellaneous support steel including scab on supports, "T" and "H" type supports, trench covers, and Q decking.	
II	**Total Steel**	Hrs/Ton
	The total of structural steel, pipe racks & utility bridges, and miscellaneous steel from above or the total of combined structural steel, pipe racks & utility bridges (if not separated) and miscellaneous steel. Quantities for any steel not included in the breakouts above, include in the total.	

4.2.3.3 Electrical

Electrical design is the engineering required to provide electricity to facilities and also includes the design of electrical equipment. Electrical engineering can be divided into five sub-categories to measure engineering productivity. These are electrical equipment, conduit, cable trays, wire and cable, and other electrical metric. The five sub-categories are further separated into a total of eight elements as listed in Table 4.7. Table 4.7 also provides level of metrics, common definitions, and corresponding units.

Quantities for these elements are measured as the quantity of each element, as provided in the final issued for construction (IFC) drawings. Metrics can be computed based on the IFC quantity of each electrical element and actual engineering work-hours for the components defined for each element. Quantities for electrical equipment and lighting fixtures are counted as the numbers shown in the IFC drawings. Quantities of other metrics such as conduit, cable tray, and wire and cable are generally measured in linear feet. However, the number of runs for conduit design and the number of terminations for wire and cable are popular measuring units for some organizations, so the questionnaire was designed to collect multiple IFC units. Since the electrical section of the questionnaire has a number of different units for measuring engineering productivity, wire and cable (Hrs/LF) was determined to be representative as a Level II metric for the electrical section. Common definition for the electrical elements from various engineering productivity metrics workshops are also defined in Table 4.7. This table also provides the level of the metrics and the measuring units.

Table 4.7 Electrical Productivity Metrics

<table>
<tr><th>Level of Metrics</th><th colspan="2">Electrical</th><th>Unit</th></tr>
<tr><td>IV</td><td colspan="2">Electrical Equipment 600V & Below</td><td>Hrs/ EA</td></tr>
<tr><td>IV</td><td colspan="2">Electrical Equipment Over 600V</td><td>Hrs/ EA</td></tr>
<tr><td rowspan="2">III</td><td colspan="2">Total Electrical Equipment</td><td>Hrs/ EA</td></tr>
<tr><td colspan="3">Electrical equipment includes transformers, switchgear, uninterrupted power supply (UPS) systems, motor-control centers (MCC), rectifiers, motors, generators, etc. This also includes work-hours for single line, elementary diagrams and studies.</td></tr>
<tr><td>IV</td><td rowspan="2">Conduit</td><td>Linear Feet</td><td>Hrs/LF</td></tr>
<tr><td rowspan="2">IV</td><td>Number of Runs</td><td>Hrs/No. of Runs</td></tr>
<tr><td colspan="3">Power plan, cable and conduit schedule and interconnects. Exposed / aboveground and underground</td></tr>
<tr><td rowspan="2">III</td><td colspan="2">Cable Tray</td><td>Hrs/LF</td></tr>
<tr><td colspan="3">Electrical and instrument cable trays, channels, supports, covers, etc.</td></tr>
<tr><td>IV</td><td rowspan="2">Wire & Cable (w/o conduit or tray)</td><td>Linear Feet</td><td>Hrs/LF</td></tr>
<tr><td rowspan="2">IV</td><td>Number of Terminations</td><td>Hrs/No. of Terminations</td></tr>
<tr><td colspan="3">Power, control and grounding cables.</td></tr>
<tr><td rowspan="2">IV</td><td colspan="2">Other Electrical - Lighting</td><td>Hrs/EA-Fixtures</td></tr>
<tr><td colspan="3">Fixtures, conduit, wiring, panels, and control devices. Quantity to be number of fixtures.</td></tr>
</table>

4.2.3.4 Piping

Piping is an essential component in industrial projects and often considered a driver of overall productivity. Detailed instructions for piping are provided to increase respondents' understanding and to emphasize the need for rework data as provided in Table 4.8. A standard definition to measure piping quantity as a "center-to-center" length was provided to respondents to ensure data were collected in a consistent manner. Table 4.8 gives an example of instruction and a standard definition of piping measurement in the questionnaire.

Table 4.8 Piping Instructions

Piping	Instructions
Piping Instruction	Please complete the following tables indicating quantity, percent hot and cold, and engineering work-hours for the categories appropriate to your project. Piping includes underground pressure pipe. Exclude tubing. If you cannot enter all breakouts then enter totals only. Include rework in the work-hours only. If the project had no work-hours or quantities for a category, enter none.
Definition of Piping Quantity	The quantity of piping is that piping specified in the final Issued for Construction (IFC) drawings. This quantity should not be "cut lengths" but should be measured "center-to-center" through valves and fittings as with the quantity for the construction metric. Most "CADD dumps" are cut lengths. The quantity should be adjusted to be the length measured as noted above.

Engineering productivity for the piping is measured as: small bore, large bore, engineered hangers and supports, and total piping. Table 4.9 shows the list of piping metrics, level of metrics, common definitions for the metric and measuring units. Standard definitions for small bore pipe and large bore pipe are developed and provided in Table 4.9. Work-hours for P&ID (Piping and Instrumentation Diagram) are excluded from piping work-hours because P&ID tasks are performed very differently project to project.

Table 4.9 Piping Productivity Metrics

Level of Metrics	**Piping**	**Unit**
III	Small Bore (2-1/2" and Smaller) (linear feet)	Hrs/LF
	Small bore is defined as pipe with a diameter less than or equal to two and one half inches.	
III	Large Bore (3" and Larger) (linear feet)	Hrs/LF
	Large bore is defined as pipe with a diameter equal to and greater than three inches.	
III	Engineered Hangers and Supports (each) (Includes stress analysis)	Hrs/EA
	This is only for non-standard pipe supports and hangers IFC quantity and engineering work-hours including rework hours.	
N/A	Number of pipe fittings	EA
	Elbows, flanges, reducers, branch connection fittings e.g. o-lets, saddles etc., Y's, T's, caps, unions, couplings, etc.	
II	**Total Piping** **(linear feet only)**	Hrs/LF
	Total piping quantity is linear feet only. The total piping work-hours include those hours for small & large bore piping, engineered hangers and supports and fittings.	

The number of pipe fittings has long been considered a complexity factor in piping design, so the productivity metrics team also added this question to provide for future comprehensive analysis.

Total piping can be calculated in two different ways. One approach includes total piping work-hours including engineered hangers and supports and the second includes only work-hours for total linear feet of pipe designed. This accommodates organizations that cannot separate design work-hours associated with hangers and supports. The other method measures piping productivity by calculating total work-hours and total linear feet of small and large bore. This metric is ideal for capturing the most accurate productivity for total linear feet of pipe designed.

Information on the percent of hot and cold designed piping was also collected. Hot and cold piping requires special piping materials and special welding to prevent leaking (Turtor et al. 1998), therefore hot and cold piping design is expected to require more design effort. There has been no previous research on this topic however. This metrics system includes the percent of hot and cold pipe designed to identify the correlation between hot and cold piping and piping productivity in further studies. There were no standard definitions for hot and cold piping, so the group developed definitions, given in Table 4.10.

Table 4.10 Definitions for Hot and Cold Piping

Hot and Cold	Definition
Hot Piping	Piping that has a design temperature greater than 250 degrees Fahrenheit
Cold Piping	Piping that has a design temperature less than minus 20 degrees Fahrenheit.

4.2.3.5 Instrumentation

This section explains metrics for instrumentation. According to Sandler and Luckiewicz, instrumentation includes sensors, controllers, and transmitters between sensors and controllers (Sandler and Luckiewicz 1987). In this research, the instrumentation category includes: loops, tagged devices, and I/O (Input/Output). Instrumentation work-hours were collected differently from other categories because the productivity group decided that it was quite difficult to separate engineering work-hours associated with loops, tagged devices and I/O count. Therefore, instrumentation work-hours were collected as a rollup of instrument and control design work-hours except for Distributed Control System (DCS) and Programming Logic Control (PLC) configuration and programming. DCS/PLC programming and configuration hours are excluded because they are very different from project to project and are often outsourced.

Instrumentation productivity metrics, level of metrics, definitions for metrics, and units are provided in Table 4.11, which is similar to the engineering productivity questionnaire. Productivity for loops, tagged devices, and I/O is measured by total instrumentation work-hours divided by counts for each designed. The engineering productivity metric of tagged devices was determined to be a representative metric for instrumentation as a Level II metric.

Table 4.11 Instrumentation Productivity Metrics

Level of Metrics	Instrumentation	IFC Quantity	Engineering Work-Hours (including rework) (hours)	Unit
III	Loops (count)		*	Hrs/Count
	A loop is all sensors, wiring, control algorithms and actuators that are used to display or regulate a <u>single</u> process variable. A loop may be either a control loop or an indication-only loop.			
III	Tagged Devices (count)			Hrs/Count
	The number of physical instrument devices that are shown on the Piping and Instrument Diagrams that have tag numbers.			
III	I/O (count)			Hrs/Count
	This includes input/output devices. The total number of local sensing devices and the total number of local final control devices. The list includes transmitters, switches, meters, thermocouples, RTD's, analyzers, pressure gages, temperature gages, etc. Control devices include valves, alarms, horns, motor starters, variable drive motor controllers, etc.			
*Instrumentation engineering work-hours include all instrument and control design work-hours except DCS/PLC Configuration and Programming. I/O (count) includes the I/O that comes over digital communication interfaces from outside of the control system. For such interfaces, count the addressable points. For fieldbus interfaces, count only the devices.				
◘ DCS/PLC Design included				
N/A	DCS/PLC Configuration and Programming			N/A

4.2.3.6 Equipment

This section presents common definitions and engineering productivity metrics for equipment. As discussed previously, this study follows the development of CII's construction productivity metrics system, so many of the definitions and categories resemble those developed for construction productivity to allow for measurement on a similar basis. Equipment is a major part of industrial projects. Piping, instrumentation, and insulation are installed to connect, control, and insulate equipment (Park 2002). In the process industry, equipment is often somewhat simple, but the installation of equipment, piping, insulation, and instrumentation takes more time. Equipment in a paper mill however, is quite different from typical industrial projects and thus, pulp and paper equipment is separately grouped in this category.

Since a unique equipment design can have multiple tagged items in the IFC drawings and it can be reused often, the engineering equipment section collects two different equipment design quantities (i.e., individually design quantity and total design quantity). For these reasons, the productivity group decided during the workshops that the total quantity and the individually designed quantity should both be measured and developed definitions for these terms. The definitions for individually design quantity and total quantity are given in Table 4.12.

Table 4.12 Equipment Quantity Definitions

Equipment	Definition
Individually Designed Quantity	The individually designed quantity is defined as the quantity defined by unique data sheets. For instance, pump P201a/b is one unique data sheet, but is a total of two items.
Total Quantity	The total quantity of equipment is the quantity of tagged items provided in the final Issued for Construction (IFC) drawings, with vendor-designed skids being counted as a single item.

Figure 4.3 provide an example of the equipment section. The equipment section of the questionnaire collects data for individually designed quantity, total quantity, engineering work-hours, and additional measures for the capacity of the equipment. As explained, a unique equipment design can be reused if identical equipment is to be installed during the construction. Although engineering productivity metrics for equipment can be measured by individually designed quantity and in total quantity, the productivity metrics using individually designed quantity are preferable because they capture an original design quantity. Additional measures for the capacity of equipment are further discussed in Table 4.15.

Boiler & Fired Heaters	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework)(hours)	Total (BTU/Hr)
	○				
This includes packaged boilers, field erected boilers, fired heaters, waste heat boilers, stand-alone stacks, and miscellaneous other boilers and fired heaters.					

Rotating Equipment (w/drivers)	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)	Total (horsepower)
	○				
This includes compressors (centrifugal/reciprocating), blowers, screw rotary compressors, metering/in-line pumps, pumps (centrifugal/reciprocating), positive displacement pumps, agitators, mixers, blenders and other miscellaneous compressors, fans and pumps.					

Figure 4.3 Example of Equipment Section

The equipment category is further divided into ten different equipment sub-categories. These are 1) pressure vessels, 2) atmospheric tanks, 3) heat transfer equipment, 4) material handling equipment (w/drivers), 5) total pulp and paper, 6) boiler and fired heaters, 7) rotating equipment (w/drivers), 8) power generation equipment, 9) other process equipment, and 10) vendor-designed modules and pre-assembled skids. Tables 4.13 through 4.16 provide the complete list of equipment items with associated definitions, level of metrics, and measuring unit. Pulp and paper equipment is further divided into seven specific pulp and paper equipment elements as listed in Table 4.14.

Table 4.13 Equipment Productivity Metrics I

Level of Metrics	**Equipment**	**Unit**
III	Pressure Vessels	Hrs/EA
	Tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Field fabricated towers, columns, reactors and regenerators are to be included.	
III	Atmospheric Tanks	Hrs/EA
	Storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic & low temperature tanks and miscellaneous other atmospheric tanks.	
III	Heat Transfer Equipment	Hrs/EA
	Heat exchangers, fin fan coolers, evaporators, cooling towers and miscellaneous other heat transfer equipment.	
III	Material Handling Equipment (w/drivers)	Hrs/EA
	Conveyors (belt, chain, screen, rotor, etc.), cranes & hoists, scales, lifts, stackers, reclaimers, ship loaders, compactors, feeders and baggers, and miscellaneous other material handling equipment.	

Table 4.14 Equipment Productivity Metrics II

Level of Metrics	Pulp & Paper Equipment	Unit
IV	Woodyard Equipment	Hrs/EA
IV	Pulp Mill Equipment	Hrs/EA
IV	Bleach Plant Equipment	Hrs/EA
IV	Stock Preparation Equipment	Hrs/EA
IV	Wet End Equipment (through the Presses)	Hrs/EA
IV	Dryer Sections	Hrs/EA
IV	Dry End Equipment including Roll Wrap/Converter Equipment	Hrs/EA
III	Total Pulp & Paper Equipment	Hrs/EA
	All paper machines and miscellaneous other pulp & paper equipment.	

Table 4.15 also provides additional capacity measures for equipment. These additional equipment size or capacity measures were based upon a consensus of the industry experts and were prevailing units for the specific equipment items. Even though all equipment metrics are measured in hours/each, the size of equipment may influence the productivity rate, so the total capacity of the equipment is also requested to establish the relationship between equipment size and productivity. Total equipment is also provided as a summary metric and is shown in Table 4.16 since all equipment elements are measured in the same unit (i.e., hours per each).

Table 4.15 Equipment Productivity Metrics III

Level of Metrics	Equipment	Additional Measures	Unit
III	Boiler & Fired Heaters	Total (BTU/Hr)	Hrs/EA
	Packaged boilers, field erected boilers, fired heaters, waste heat boilers, stand-alone stacks, and miscellaneous other boilers and fired heaters.		
III	Rotating Equipment (w/drivers)	Total (horsepower)	Hrs/EA
	Compressors (centrifugal/reciprocating), blowers, screw rotary compressors, metering/in-line pumps, pumps (centrifugal/reciprocating), positive displacement pumps, agitators, mixers, blenders and other miscellaneous compressors, fans and pumps.		
III	Power Generation Equipment	Total (kilo-watts)	Hrs/EA
	Gas turbines, steam turbines, diesel generators, and other miscellaneous power generation equipment.		

Table 4.16 Equipment Productivity Metrics IV

Level of Metrics	Equipment	Unit
III	Other Process Equipment	Hrs/EA
	Specialty gas equipment, bulk chemical equipment, process equipment, particle extraction (bag houses, scrubbers, etc.), treatment systems (water treatment, etc.), incinerators, and flares/flare systems.	
III	Vendor-Designed Modules & Pre-Assembled Skids	Hrs/EA
	Modules (partial units) and complete skid units. Skids & modules with multiple equipments are counted still as a single entry.	
II	**Total Equipment**	Hrs/EA
	Total equipment count may include items not identified above. This is total mechanical discipline direct work-hours.	

4.2.3.7 Rework

Rework negatively impacts engineering productivity since work-hours are increased without increasing design quantities. It may be unavoidable in engineering activities, even though appropriate planning and complete scope definition may minimize design rework and its adverse impact on project performance within the detailed design phase.

Rework hours are included in actual work hours for each section because some organizations do not track rework hours and can not separate them from actual work hours. In addition, total engineering rework hours are to be recorded separately, by source, if available at the end of each major category. The sources of total rework hours tracked include design, vendor, owner, and other. Tracking of rework by source was implemented after the Productivity Metrics Retreat for future analysis. Table 4.17 shows an example of the rework table provided in each major engineering productivity category in the questionnaire.

Table 4.17 Sources of Engineering Rework-Hours

Source of Rework-Hours for Concrete	**Rework-Hours (hours)**
Design	
Vendor	
Owner	
Other: ____________	
Total	

The rework factor is a metric established to analyze rework performance in each category. Rework factors are calculated using the equation described below:

$$\text{Productivity Rework Factor}_i = \frac{\text{Total Rework Hours}_i}{\text{Total Actual Work Hours}_i}$$

where, i = category.

By applying the above equation, the rework portion of each category can be compared. Note that lower values obtained in the rework factor indicate better performance.

4.3 SUMMARY

This chapter discussed the development of engineering productivity metrics including the development workshops, direct and indirect accounts, various levels of metrics, the developed engineering productivity metrics, and corresponding definitions for six major categories. In final form, the engineering productivity metrics survey consists of six major categories, 26 sub-categories, and 49 metrics. The following chapter will discuss data analysis for engineering productivity.

Chapter 5: DATA ANALYSIS

This chapter presents the data collection effort, discusses descriptive statistics for the collected data, reviews engineering productivity metric distributions, and illustrates correlations between engineering work-hours and IFC design quantities.

Section 5.1 discusses data collection, validation, and data preparation. Section 5.2 presents descriptive information for the projects submitted to provide context and understanding for the dataset. Section 5.3 provides engineering productivity metric distributions. The current dataset is not sufficient to establish reliable engineering productivity norms, but is useful in validating the overall research methodology. By reviewing the distributions, it can be established that engineering productivity can be reasonably measured using engineering work-hours and IFC quantities, and that these metrics are collectable, analyzable, and meaningful. Section 5.4 examines correlation between engineering work-hours and IFC quantity for structural steel and piping categories, in order to validate the engineering productivity definition.

5.1 Data Collection, Validation, and Preparation

5.1.1 Data Collection Effort

Data collection within the industry was the most challenging part of this research, because this research changed the output measure from intermediate deliverables to IFC quantities. This caused data collection efforts to be substantial and critical for the participants in this research.

Data were collected from a total of 87 projects through three separate data collection efforts. These efforts, from 2002 to 2005, included: 1) regular benchmarking data collection, 2) a data collection initiative launched from the Productivity Retreat workshop, and 3) a special productivity data collection.

At the CII Benchmarking Associate (BMA) training sessions, CII annual conferences, and CPI (Construction Productivity Improvement) conferences, engineering productivity metrics and the questionnaire were introduced. The first version of the engineering productivity questionnaire only allowed data entry at the element level (Level IV) described in Section 4.1.1. Attendees were asked to enter their data through the Benchmarking Central website at www.construction-intitute.org. This belongs to the regular CII BM&M data collection.

A data collection initiative was launched as an outcome of the Productivity Retreat workshop in June 2004. After the review of the first version of the engineering productivity questionnaire, modifications in the questionnaire to add sub-category level metrics (Level III) and major category level metrics (Level II) made the data collection easier. The Productivity Retreat attendees from 20 organizations planned their additional commitments for the data collection effort.

Following the first and the second rounds of data collection efforts, the CII Productivity Metrics team agreed to broaden the participation and to enrich the engineering productivity database, ultimately establishing credible industry norms. In this round of data collection, minimal project information such as project characteristics, costs, and schedules needed to assess engineering productivity metrics was collected.

5.1.2 Data Validation

Once a Benchmarking Associate submitted a project, the validation process soon began. The main purposes of validation include correcting data errors, reducing omissions, and eliminating dubious data. To accomplish these objectives, CII Benchmarking & Metrics Committee has established an effective validation procedure. The current validation procedure is given in Figure 5.1.

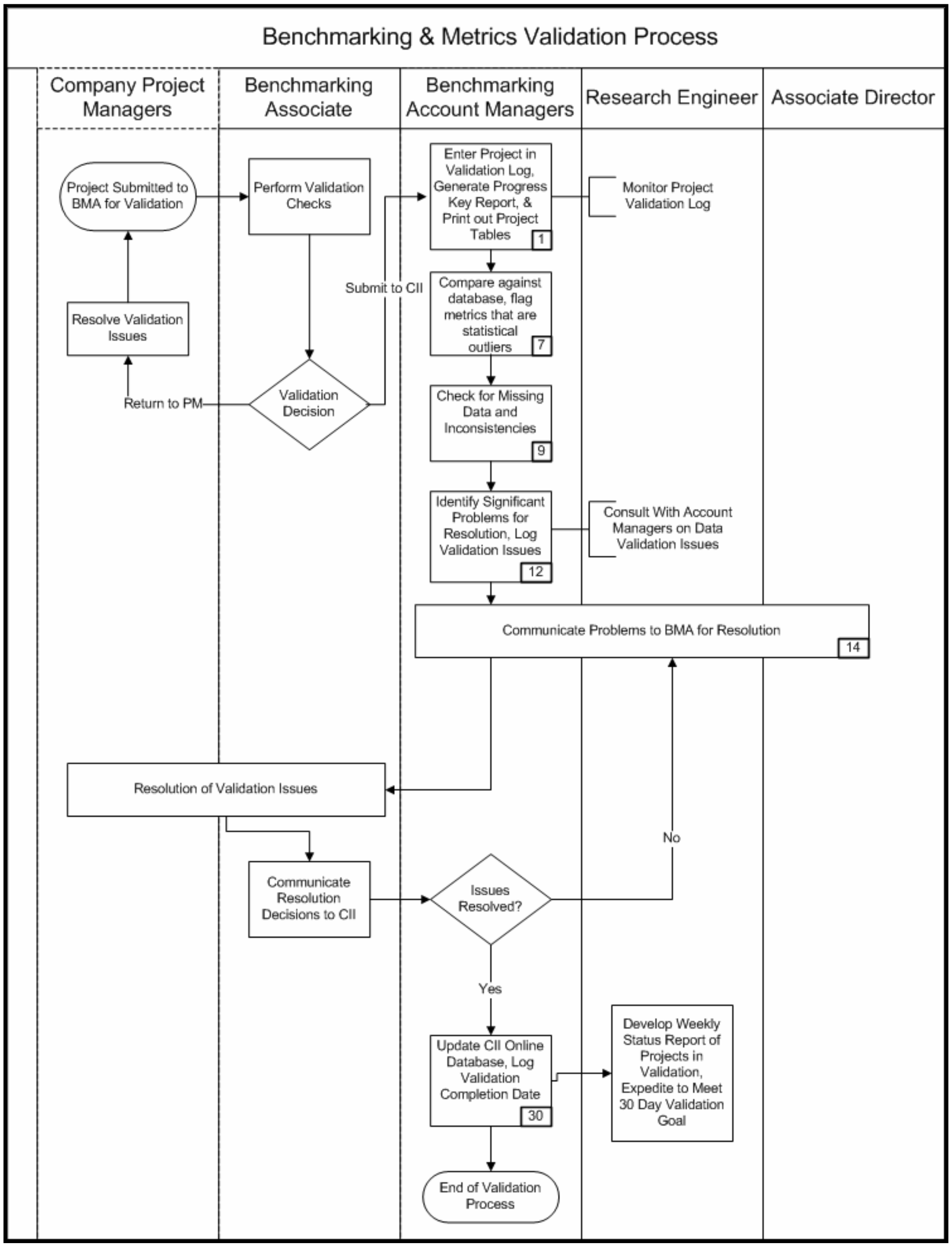

Figure 5.1 BM&M Validation Process

This process is performed among company project managers, its Benchmarking Associate (Company's trained representative for benchmarking activities), and CII BM&M staff including benchmarking account managers, a research engineer, and an associate director. This process is briefly discussed below.

1) Company project managers submitted a project to its Benchmarking Associate (BMA) for validation.
2) BMA performs an internal validation to check project data accuracy.
3) Based upon the internal validation, project data is either returned to project managers to resolve validation issues or submitted to CII.
4) Benchmarking account managers (graduate research assistants) check for missing data and inconsistencies by comparing against database and identify validation issues.
5) Benchmarking account managers communicate issues to BMA for resolution.
6) BMA resolves validation issues with project managers.
7) BMA provides resolution decisions to CII.
8) If issues were not resolved, repeat 4) to 7) otherwise go to 9)
9) Update CII online database and validation log.

5.1.3 Data Preparation

Effective data analysis is contingent upon proper data preparation. In this study, engineering productivity data were recorded into the CII BM&M online database. Data preparation is discussed below.

To conduct data analysis, the BM&M online database, including engineering productivity tables, were downloaded into Microsoft Visual FoxPro® 2003. Engineering productivity tables and general BM&M metrics tables were imported and saved as Microsoft Access® 2003 format in order to consider user friendly interface. An engineering productivity metric table including necessary project characteristics and raw data tables for six major categories were prepared using Microsoft Access® 2003. Then, the tables were saved as the Microsoft Excel format due to its compatibility among database management programs and statistical packages. After preparation of the dataset, MINITAB version 14.0 was used for the statistical analyses.

5.2 DESCRIPTIVE STATISTICS: PRODUCTIVITY DATA SET

A proper analysis of the data requires knowledge of descriptive characteristics of these projects. Eighty-seven projects were submitted with engineering productivity data. The data set consists of 70 contractor projects and 17 owner projects from 21 different organizations, as shown in Figure 5.2. The data set is comprised of 82 domestic projects and 5 international projects. As expected, most of the projects (80) submitted were from the heavy industrial sector, 4 were light industrial projects, and 3 were infrastructure projects. Figure 5.3 shows the project distribution by industry group. The total project cost represented in the data set is $2.1 billion, with an average project cost of $26.3 million. Data characterizing these projects are provided in the charts and tables which follow.

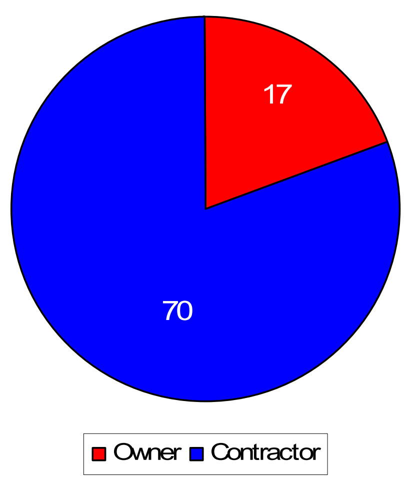

Figure 5.2 Projects Breakout

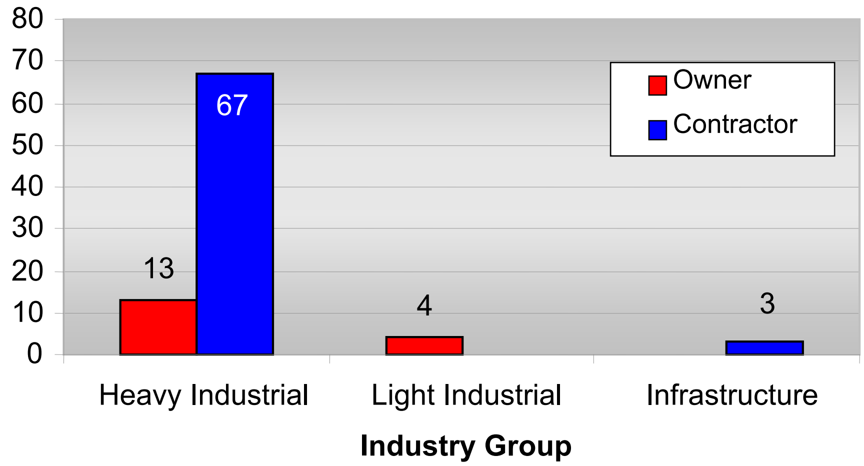

Figure 5.3 Engineering Productivity Dataset by Industry Group

The engineering productivity section is included in both the small and the large project BM&M questionnaires. Large projects were originally expected to provide the most data, but 40 projects costing less than $5 million were submitted. Figure 5.4 provides a graphical presentation of projects sorted by cost to illustrate size.

The dataset may also be categorized by project nature. The projects are comprised of 34 modernization projects, 33 addition projects, 19 grass roots projects, and one maintenance project. Figure 5.5 shows the dataset distribution by project nature.

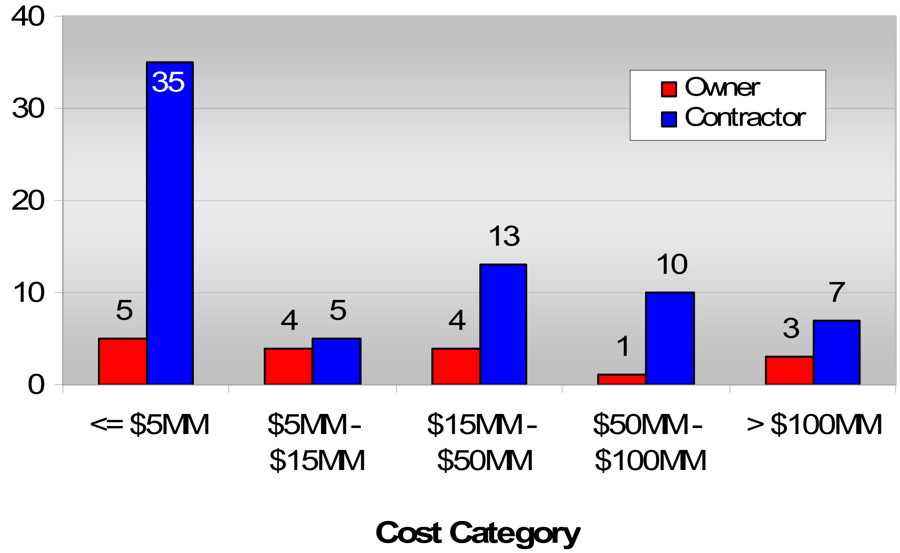

Figure 5.4 Engineering Productivity Dataset by Project Cost

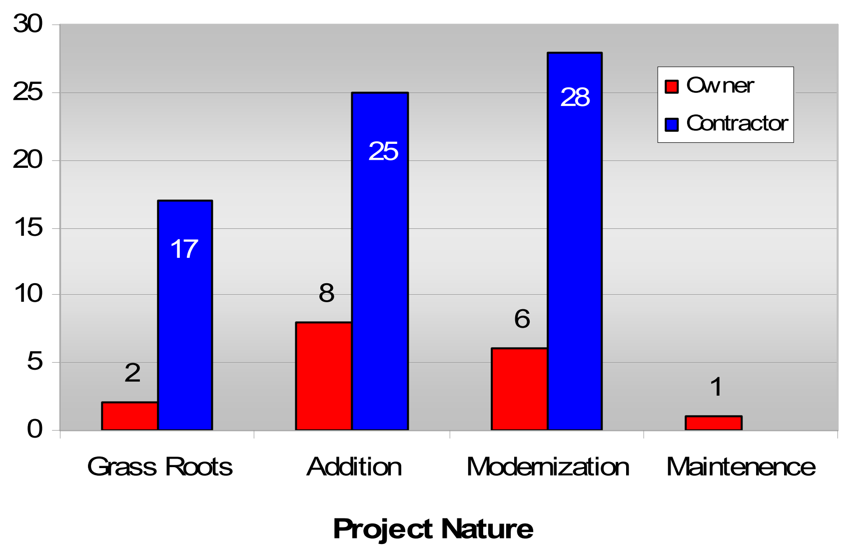

Figure 5.5 Engineering Productivity Dataset by Project Nature

The project type category provides more specific project characteristics information than the industry group category. Oil refining and chemical manufacturing projects were the two dominant project types with environmental, and pulp and paper projects following. Table 5.1 summarizes projects with engineering productivity data sorted by type.

Table 5.1 Engineering Productivity Projects by Project Type

Project Type	**Owner**	**Contractor**	**Total**
Oil Refining	0	44	44
Chemical Mfg.	8	4	12
Environmental	2	5	7
Pulp and Paper	0	7	7
Electrical (Generating)	3	1	4
Other Heavy Industrial	0	3	3
Pharmaceutical Mfg.	3	0	3
Oil Exploration/Production	0	2	2
Laboratory	1	0	1
Natural Gas Processing	0	1	1
Pipeline	0	1	1
Rail	0	1	1
Water/Wastewater	0	1	1
Total Projects	17	70	87

Although 87 projects submitted engineering productivity data, the amount of data for each metric varies widely because of the different characteristics of the projects and the different levels of data collection. Table 5.2 shows the number of projects and number of organizations which submitted data for each major category. It is important to note that number of project data submitted by each organization is not equally distributed; due to the nature of convenience sampling, some participating companies submitted more data than others. Table C.1 in Appendix C shows the amount of data by project and metric category submitted by each company. The names of the companies are suppressed for confidentiality reasons. At the project level, 53 percent of the data were submitted by 3 companies; however, the other 47 percent of the data are well distributed among the remaining 17 companies. At the category level the distributions ranged from 24 percent of the data from 1 company and 76 percent from 14 companies for structural steel to 54 percent from 3 companies and 46 percent from 15 companies for piping. Thus, 2 or 3 companies, depending on the category have a disproportional influence on the data, a situation that should be improve with continued data collection.

Table 5.2 Dataset Summary Statistics for Major Metric Categories

Data Set	Number of Projects	Number of Organizations
Concrete	40	16
Structural Steel	43	15
Electrical	39	13
Piping	70	18
Instrumentation	47	19
Equipment	52	18
Total Projects	87	20

5.3 Productivity Metrics Distributions

Data were collected from 21 different owner and contractor companies and are presented using Box-Whisker Plots in the following section. It is important to note that data presented in this section are aggregates of all groups, both owner and contractor. Although CII usually segregates owner and contractor data, data are combined here because productivity data for owners and contractors have common definitions, are not distorted by perspective issues, and more reliable analysis is possible with a larger sample size. Graphical representations of engineering productivity data are based upon engineering direct work-hours and IFC quantities for the various categories.

Of note for the distributions, engineering productivity data contain outliers for nearly all metrics. While the CII BM&M Committee has established rules for the treatment of outliers, these rules are not directly applied to the engineering productivity data. Since the productivity data sample was small and norms had not yet been established, a few outliers were removed from the sample based upon industry expert opinions for the highly improbable cases only. In many cases, when statistical outliers were believed to be valid cases by the industry experts, they were included for the data analysis.

5.3.1 Concrete

The concrete section of the survey is applicable to all industry groups because concrete work is one of the most common design activities for buildings and infrastructure projects, as well as industrial projects. The concrete section is divided into slabs, foundations, and concrete structures. Engineering productivity metrics for concrete and their definitions are provided in Table 4.5. It is important to note that statistical summaries produced from data analysis must be interpreted with caution due to the limited size of the initial data set. However, they are useful for establishing the methodology for analyzing and presenting engineering productivity data.

Figure 5.6 presents a box plot for concrete slab productivity distributions including ground and supported slabs (Level IV), area paving (Level IV), and total slabs (Level III). When comparing ground and supported slabs with area paving, area paving takes much less design work-hours per cubic yard (CY) of concrete due to less complex design than ground and supported slabs. According to an industry expert opinion (Kim 2007), engineering design for area paving tends to be very standardized and thus fewer design work-hours are required for the quantity of work to be installed. This box plot supports the argument that detailed element level (Level IV) benchmarking can provide more meaningful comparisons than higher category levels such as total slabs (Level III).

Total slabs data can be a mixture of projects that provide both area paving data and ground-supported data or either of them. It can also be a roll-up of total slab data without Level IV data entered since data can be entered at any level.

Caution should be exercised when interpreting data at the total slab level given the possibility of widely varying proportions of Level IV element slices. For an example, the n value for ground and supported slabs indicates the number of projects submitting data at that element level. An n value of 10 for area paving indicates the number of projects submitting data at Level IV. Oftentimes, the number of project submitting data for ground and supported slabs, and area paving overlap. For this reason, and the fact that data can be entered at the total slab level; the total slab n value may not be intuitive based on element level n values.

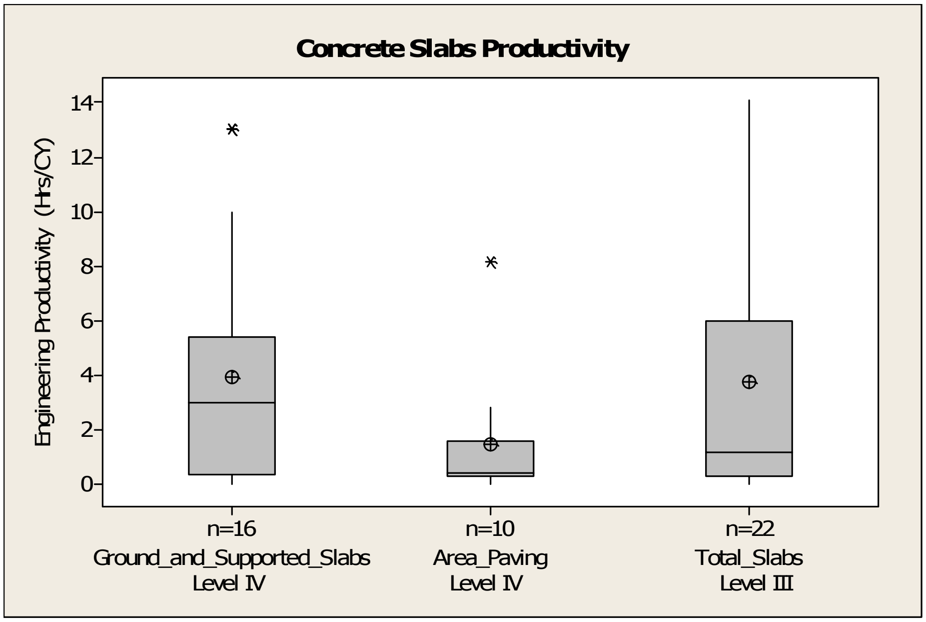

Figure 5.6 Concrete: Slabs Productivity

Figure 5.7 illustrates the engineering productivity distributions for concrete foundations. Foundation distributions are provided for foundations less than 5 CY, foundations equal to or greater than 5 CY, and total foundations. Piling foundations which are measured as Hrs/Ea could not be provided due to a small sample size and a different unit. Detailed discussion of these metrics can be found in Chapter 4. As shown in Figure 5.7, as expected, engineering productivity for larger foundations is better than that of smaller ones. It is also important to note that the variability in designing larger foundations is less than in smaller foundations. Park (2002) identified a similar tendency for productivity improvement with increasing foundation size in construction productivity. The inter-quartile range of total foundations shown as the height of the shaded box is located between those of foundations less than 5 CY and foundations equal or greater than 5 CY as expected because it is a combination of the two datasets and also because data can be directly entered at the total foundation level. Outliers for total foundations probably show impacts of higher level data entry; these outliers are likely caused by data entered at the total foundations. It is important to note that data provided at Level III will likely have less value. In this case, due to the outliers in the distribution of the total foundations, it is recommended to use the median values for comparison purposes.

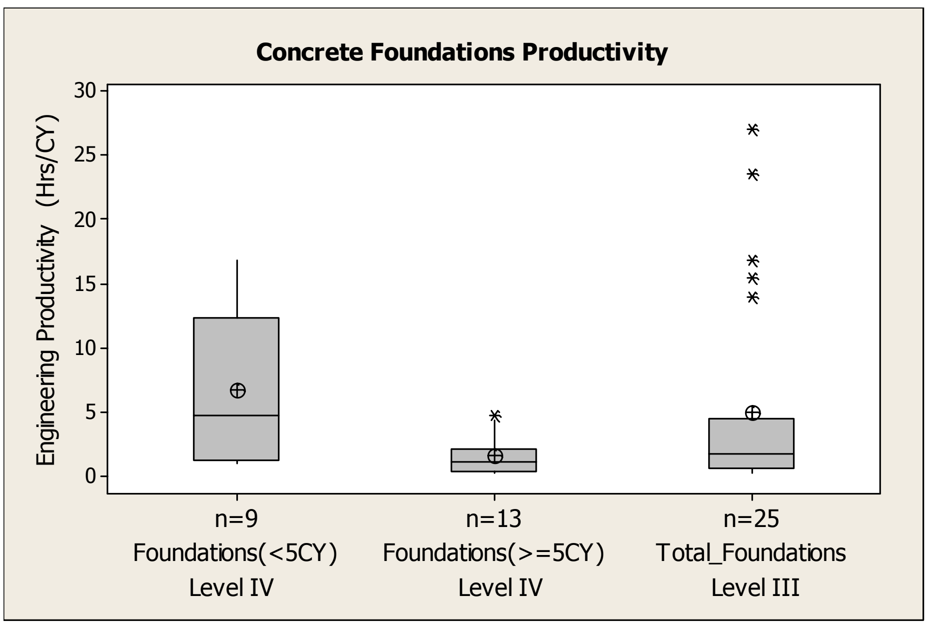

Figure 5.7 Concrete: Foundations Productivity

Figure 5.8 compares distributions for total slabs, total foundations, concrete structures, and total concrete. Similar to Figure 5.7, these distributions in Figure 5.8 should be interpreted by using the median values instead of the mean value distorted by outliers; especially when the sample size is small. Median productivity appears worse for concrete structures than for foundations and slabs. This might be related to design complexities and the result, therefore, follows general expectations. However, the differences are not likely statistically significant. Variability of engineering productivity is, however, greater for both foundations and slabs. Again, small samples may be a factor here. As discussed previously, the n value for total concrete is not a sum of n values from lower levels.

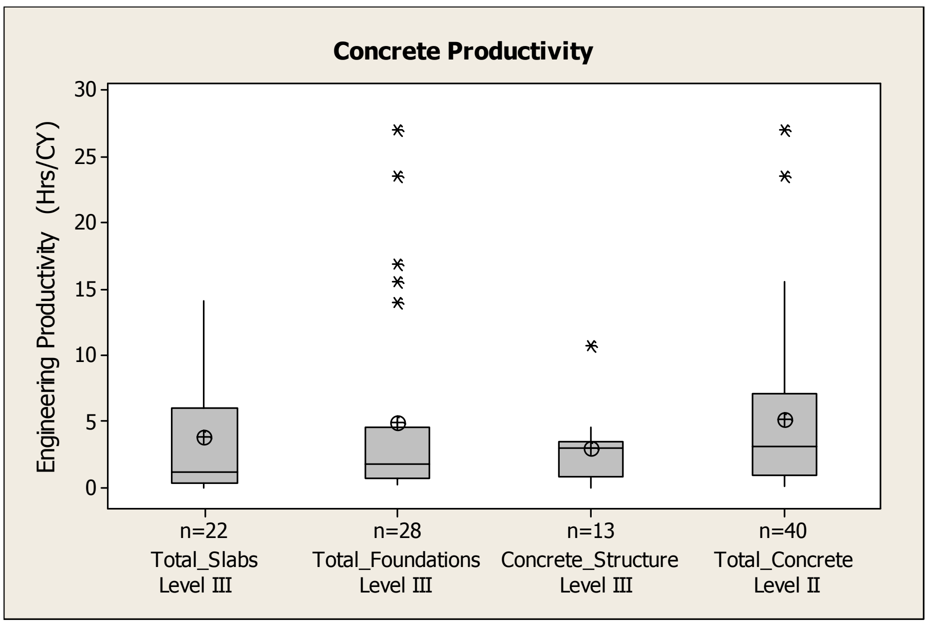

Figure 5.8 Concrete Productivity

After reviewing the distributions for concrete engineering productivity metrics, the author can conclude that meaningful measures of engineering productivity can be collected with standard definitions and the categories classification and distributions appear to be reasonable.

5.3.2 Structural Steel

Engineering productivity metrics for structural steel are defined for five different breakouts providing flexibility for data collection. As shown in Table 4.6, metrics are provided for structural steel (Level IV), pipe racks and utility bridges (Level IV), combined structural steel and pipe racks and utility bridges (Level III), miscellaneous steel (Level III), and total steel (Level II). Common definitions for the structural steel metrics are provided in Table 4.6. These metrics mirror those collected for CII BM&M construction productivity.

Figure 5.9 presents the distribution of the metrics. Miscellaneous steel tends to have the greatest variability among the five different metrics. This result can be explained because its definition includes a heterogeneous mix of all types of structural steel that are not classified as structural steel or pipe racks and utility bridges. Comparing engineering productivity for structural steel and pipe racks and utility bridges (Level IV metrics), structural steel tends to have better productivity because pipe rack and utility design practice including smaller piece design than that of structural steel. Thus, pipe racks and utility engineering takes more effort to design (Woldy 2007). It is important to note that combined structural steel, and pipe racks and utility bridges (Level III) metric was added at the productivity retreat to accommodate some companies WBS. Sample size for the total steel is different from sum of samples for detailed levels since a project, for example, can have metric values for the structural steel and the miscellaneous steel. When the data were aggregated form a lower to higher level, the aggregate of the data may result in a changed unit rate, either from additional data at the higher level or from the combination of the lower levels. For this reason, outliers appearing at lower level may appear no longer at the higher level.

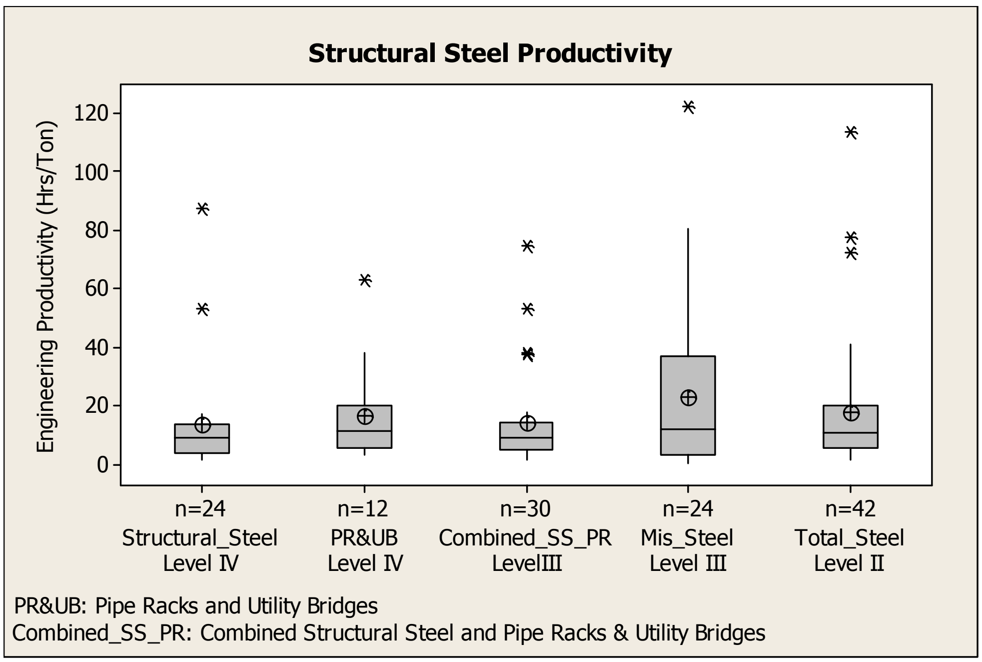

Figure 5.9 Structural Steel Productivity

According to the data analysis, structural steel productivity produces more outliers than the other major productivity metric categories. This might be that the structural steel categories include more heterogeneous design items. Outlier projects often have very small design quantities compared to average design quantities. This implies that minimum design effort such as owner requirement analysis, job site consideration is required in spite of small design quantity (Woldy 2007). In most cases, outlier data are classified as addition or modernization projects which require more design considerations and often have a relatively smaller design quantity than grass root type projects.

5.3.3 Electrical

The electrical section is not summarized at the major category level (Level II) because this section has a mixture of output units making it difficult to form an aggregate metric. The electrical category is divided into five subcategories: 1) electrical equipment, 2) conduit, 3) cable tray, 4) wire and cable, and 5) other electrical metrics. Conduit and wire & cable metrics each include two different output units. They are linear feet and number of runs for conduit and linear feet and number of terminations for wire and cable. During the productivity development workshops, the prevailing output units for these two metrics were different among participating companies, so two different output units are collected in order to accommodate participants. After review, the BM&M productivity team recently defined the wire and cable metric with linear feet as a representative metric for the electrical section.

Electrical equipment is sub-divided into 1) electrical equipment 600V and below and 2) electrical equipment over 600V. The distributions for these metrics are provided in Figure 5.10. The engineering productivity for equipment 600V and below is better than that of electrical equipment over 600V and has less variability; however, the small samples render conclusions unreliable. A total electrical equipment category was added to the questionnaire to accommodate companies whose threshold is different from 600V or those that cannot separate the data. Based upon the industry opinion (Woldy 2007), design for electrical equipment with higher voltages generally have more engineering consideration and takes more effort to maximize the reliability of the equipment. A project encompassing an outlier in Figure 5.10 has only one design quantity in electrical equipment over 600V, and 92 designed quantities are included in equipment 600V and below. However, since the metric for total electrical equipment was calculated by dividing the sum of engineering work-hours from the two categories by total design quantities (93), the outlier found in electrical equipment over 600V is no longer an outlier in the total electrical equipment category. As discussed in Section 5.3.1, the total n value is not a sum of n values form lower levels.

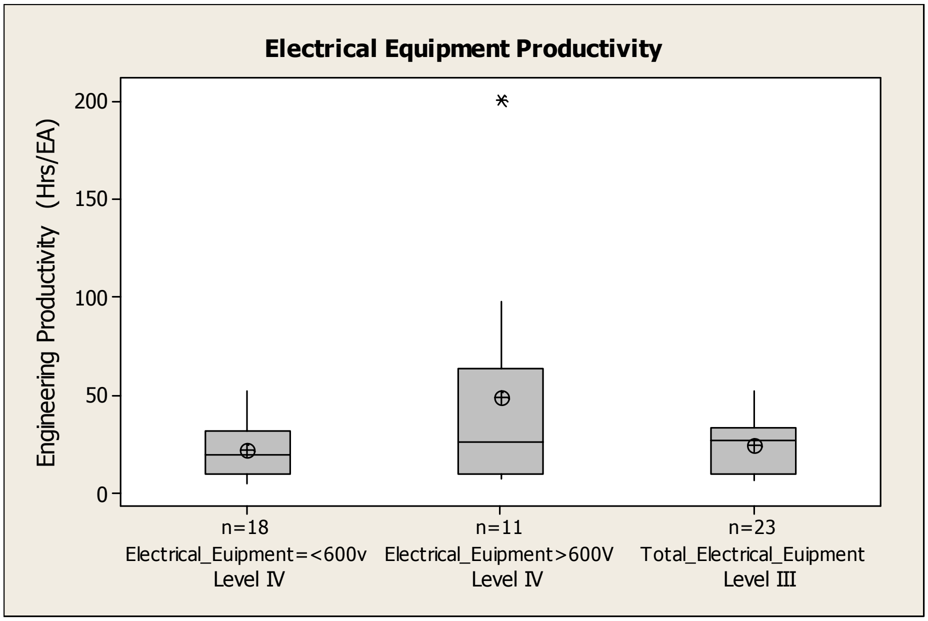

Figure 5.10 Electrical Equipment Productivity

The engineering productivity distributions for conduit are shown in Figures 5.11 and 5.12 using work-hours for linear foot and work-hours per number of runs respectively. Due to the different units, variance in two box- plots may not be directly compared. However, the reduction in variance in Figure 5.11 may also be due to the larger sample size. More data will assist with these interpretations.

Work-hours/LF may be a better measurement rather than the conduit productivity using the number of runs since number of runs can be considered as a complexity factor rather than output measure (Woldy 2007; Hoenerhoff 2007).

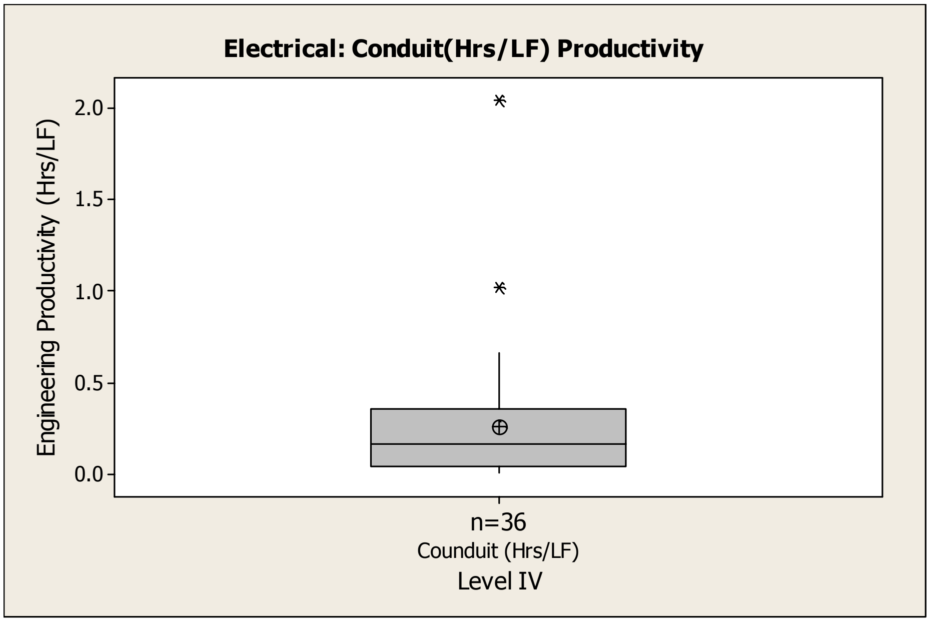

Figure 5.11 Electrical: Conduit (Hrs/LF) Productivity

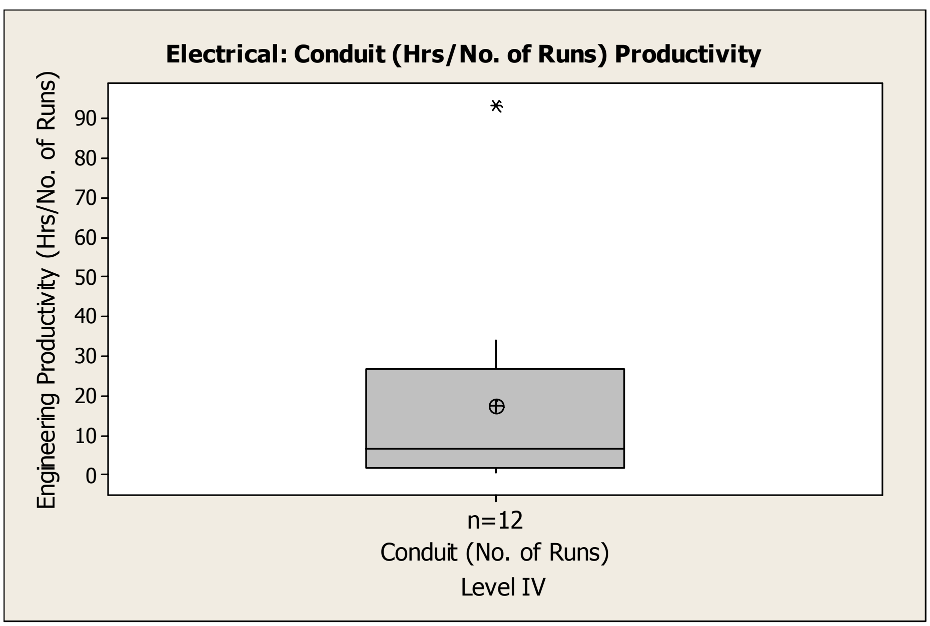

Figure 5.12 Electrical: Conduit (Hrs/No. of Runs) Productivity

Figure 5.13 illustrates the distribution for cable tray productivity. The median value of 0.514 and the mean value of 0.606 are closer than other metrics and this confirms to the central tendency of the distribution. Engineering productivity for cable trays is based on linear feet of cable tray designed.

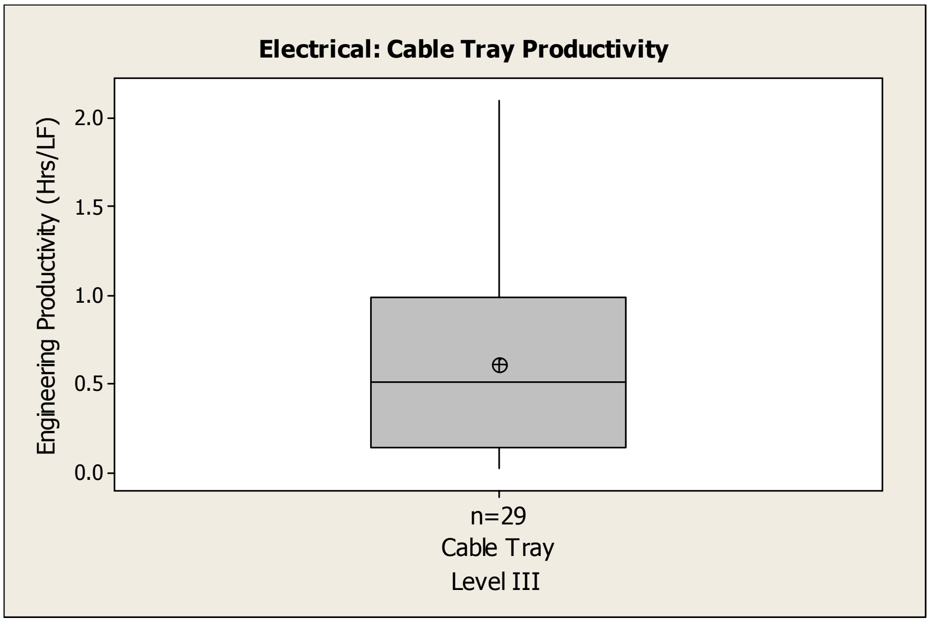

Figure 5.13 Electrical: Cable Tray Productivity

The box-plots for wire and cable are shown using Hrs/LF and Hrs/No. of Terminations in Figure 5.14 and Figure 5.15. The number of data points for the linear feet measure of wire and cable is about two times greater than the number of terminations. In other words, the linear foot is the more commonly reported measure for wire and cable. Therefore, the author recommends that usage of wire and cable with LF based on the apparent ease of reporting.

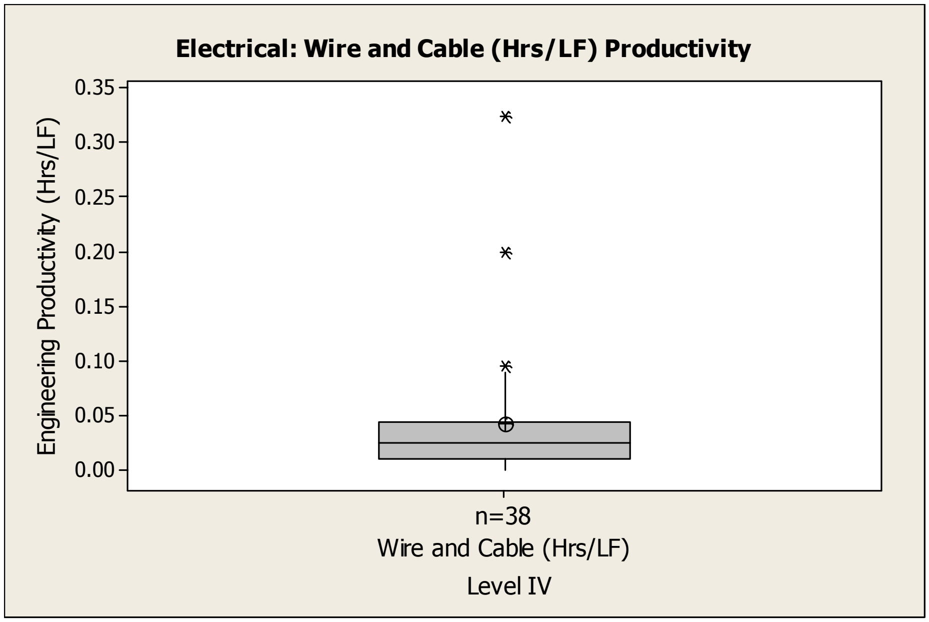

Figure 5.14 Electrical: Wire and Cable (Hrs/LF) Productivity

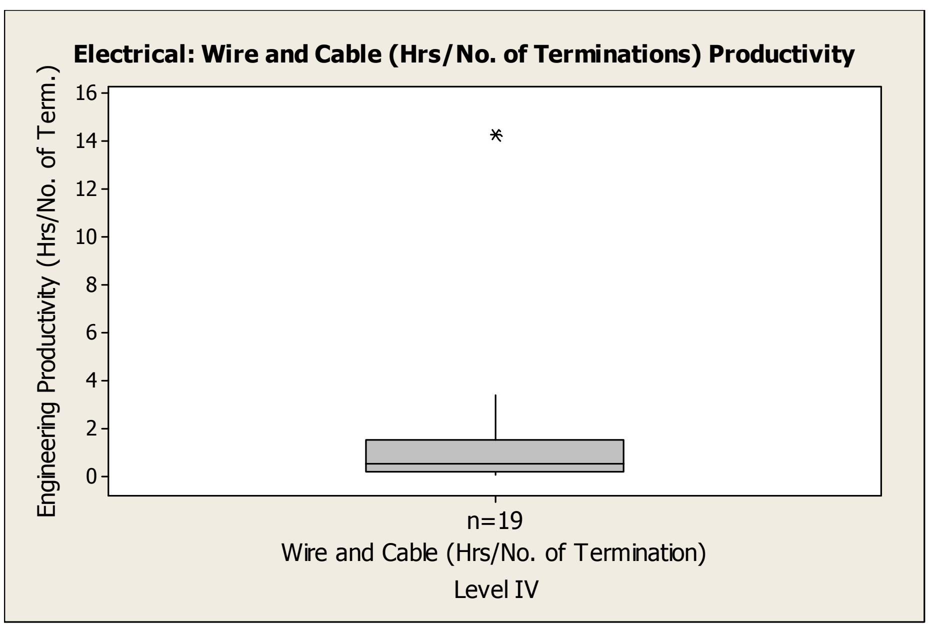

Figure 5.15 Electrical: Wire and Cable (Hrs/No. of Terminations) Productivity

Figure 5.16 shows the distribution for the lighting productivity, which is skewed similar to the other metrics. The mean of lighting productivity is skewed because of outliers, so the median value that is not affected by outliers can be more meaningful. When the sample size increases with additional data collection, better confirmation of the central tendency of the distribution is expected.

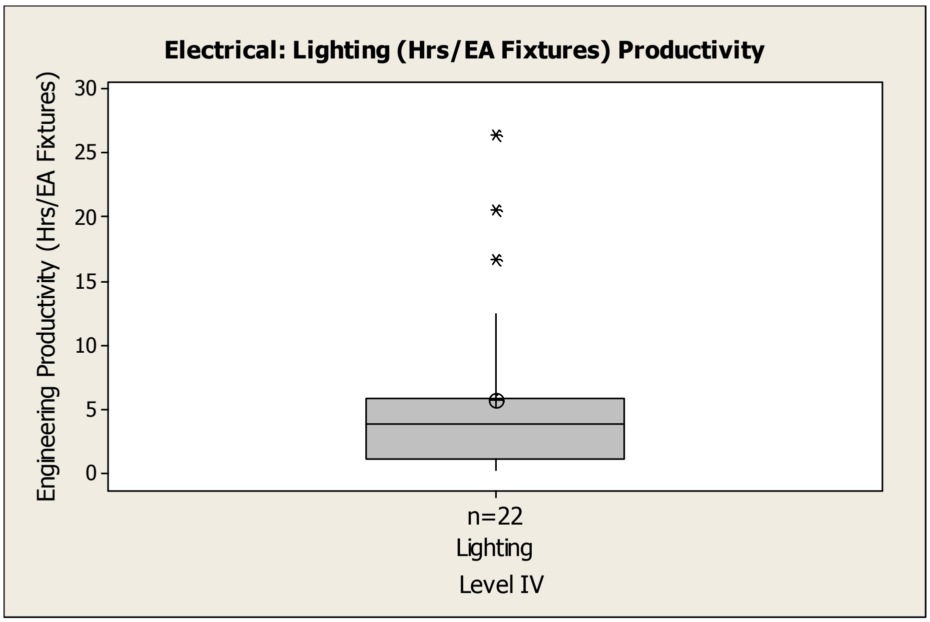

Figure 5.16 Electrical: Lighting Productivity

After reviewing electrical metrics, the author believes that the engineering productivity for electrical equipment can be measured best at Level IV rather than at the Level III, total electrical equipment level because the total electrical equipment sub-category does not differentiate equipment voltages or its design complexity. Generally, electrical equipment with higher voltage requires more complex design codes and more arrangements. The engineering productivity of conduit and wire and cable can be measured better using linear feet rather than by number of runs or number of terminations since number of runs and number of terminations are more complexity measures of the design rather than output measures (Hoenerhoff 2007; Ebert 2007).

5.3.4 Piping

Piping may be most important discipline for assessing engineering productivity for industrial projects. The piping category provides four different metrics: small bore (Level III), large bore (Level III), engineered hangers and supports (Level III), and total piping (Level II) as shown in Table 4.9.

Figure 5.17 shows the distribution of productivity in small bore pipe (Level III), large bore pipe (Level III), and total piping (Level II). This figure includes many statistical outliers, but they were included for the analysis because outliers often provide very important information. The variability caused by outliers could be explained because this analysis did not control project types or complexity of the design due to sample size. The BM&M productivity metrics team reviewed the overall distributions and concluded that these outliers may in deed be valid data. Some of them have relatively small design quantities and are designed for extreme weather conditions. The hot and cold percentage and the number of pipe fittings have been collected as complexity factors of design. Future analyses could provide relationships between piping engineering productivity and its complexity factors. As expected, an observed difference in means between large bore and small bore has been identified although it was not statistically significant. This may change with larger samples. Similar to an example given in Section 5.3.2, outliers appearing at lower levels may not appear at the higher level such as the total piping. Engineered hangers and supports are separated from the piping box-plot because of different unit and scale issues, and are shown in Figure 5.18.

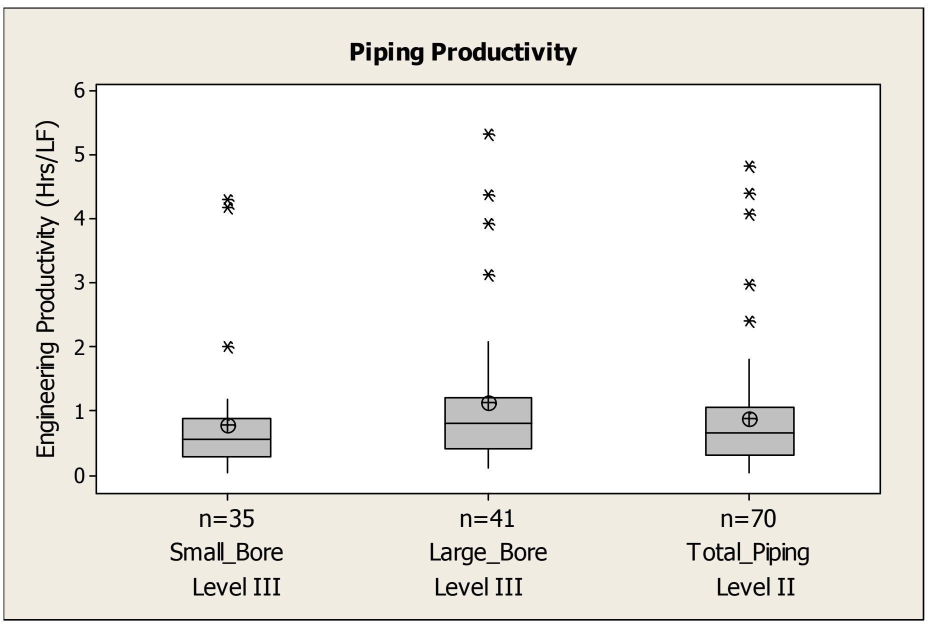

Figure 5.17 Piping Productivity

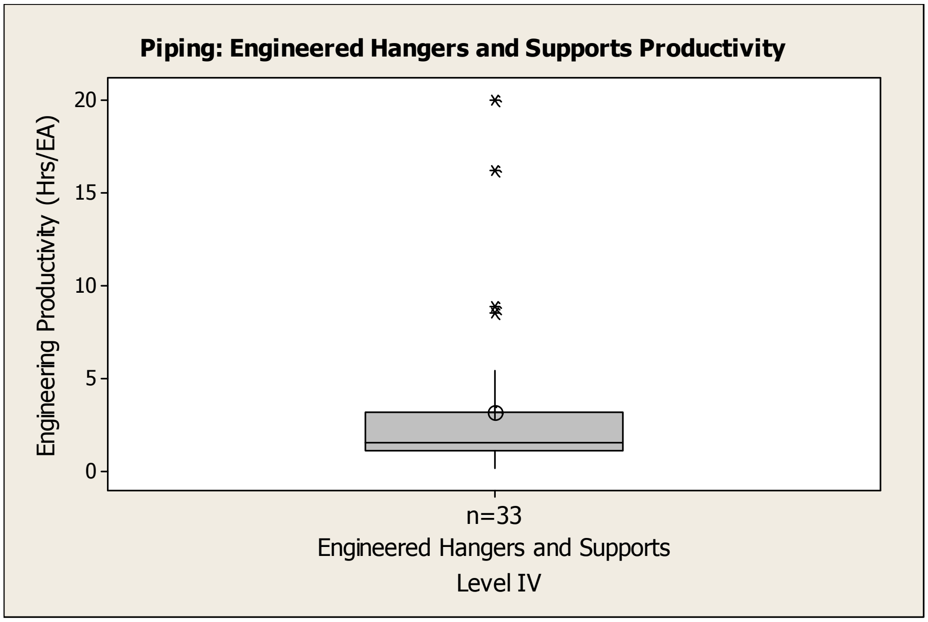

Figure 5.18 Piping: Engineered Hangers and Support Productivity

5.3.5 Instrumentation

As discussed in Section 4.3.2.5, instrumentation design work-hours can not be separated into discrete hours for loops, tagged devices, and I/O counts. Thus they are collected as the total instrumentation work-hours. For these reasons, three different instrumentation metrics were determined to provide different aspects of the instrumentation performance. The metrics and corresponding definitions for instrumentation are provided in Table 4.11.

Figure 5.19 illustrates the distributions of loop (Level III), tagged devices (Level III), and I/O (Level III) metrics for instrumentation.   As shown in Figure

5.19, engineering productivity for loops has the greatest variability among the three metrics. The IQR (Inter Quartile Range) of the loops is much wider than that of tagged devices or I/O and the least data were collected for loops. Based upon industry expert opinions (Woldy 2007; Ebert 2007), this result is caused by reasons that the definition for loop provides a less objective measure than those for tagged devices and I/O. Thus, the author recommends that the loop count should be considered a complexity factor for instrumentation rather than an output measure. The engineering productivity distributions for the tagged devices and the I/O can likely serve as a better metric than that of loops because they provide better distributions. When more data are collected, more reliable norms can be established considering project characteristics.

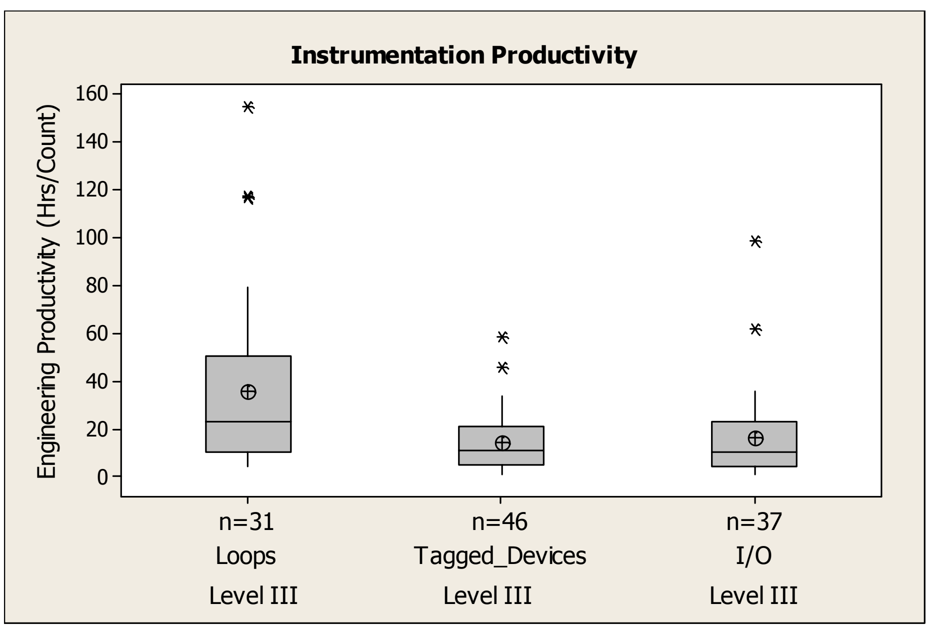

Figure 5.19 Instrumentation Productivity

5.3.6 Equipment

The equipment section provides engineering productivity metrics for a variety of equipment types. Equipment is a major component of industrial projects. Often, several pieces of equipment are tied into systems with piping, electrical, and instrumentation connections for control and processing. Equipment metrics and corresponding definitions is provided in Table 4.13 through 4.16.

As previously described in Section 4.2.3.6, equipment metrics are calculated in two different ways: 1) using individually designed quantities and 2) using total quantities. The metrics using individually designed quantities serve better to measure engineering productivity and these metrics are presented and discussed herein. It is also important to note that metrics with either less than ten projects or from less than three companies cannot be presented due to the CII Confidentiality Policy that can be found at the CII Benchmarking website (http://www.construction-institute.org/scriptcontent/code.cfm). Due to small sample sizes and the CII confidentiality Policy, the metrics for material handling equipment, pulp and paper equipment, power generation equipment, and other process equipment are excluded from the following discussion.

Figure 5.20 shows the distributions for design of pressure vessels and atmospheric tanks. The distribution of pressure vessels shows more variability than that of atmospheric tanks. Equipment metrics are calculated by the number of pieces of equipment designed rather than total equipment size or capacity.

According to an industry expert, pressure vessels generally take more engineering work-hours to design than atmospheric tanks because the complexity of the pressure vessel is greater than the atmospheric tank design. Design codes are more complex because of high temperatures and high pressures since the pressure vessels require more time to interpret design codes, more calculations, and more safety regulations (Personal Conversation with Dr. Kirk Morrow, May 30, 2006).

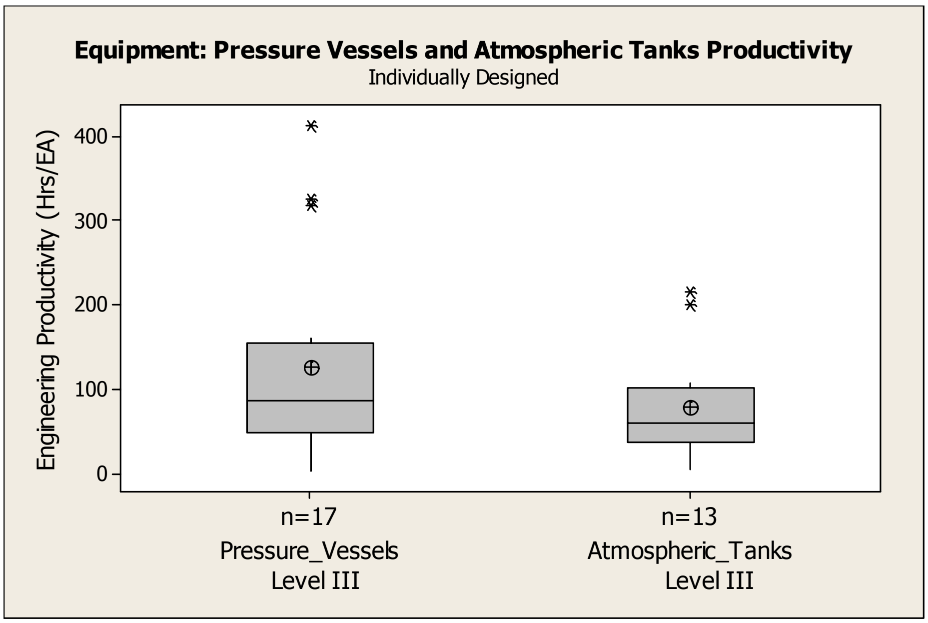

Figure 5.20 Equipment: Pressure Vessels and Atmospheric Tanks Productivity

Figure 5.21 illustrates the box-plot of heat transfer equipment with 15 project data points. The average hours for designing of heat transfer equipment takes about 83 hours each and the median value is about 67 hours each. Prior to this study, there were no industry-wide estimates of the average number of hours for the design of heat transfer equipment. However, a small sample size may affect reliability of the average. Continued data collection is necessary to increase reliability of the statistics.

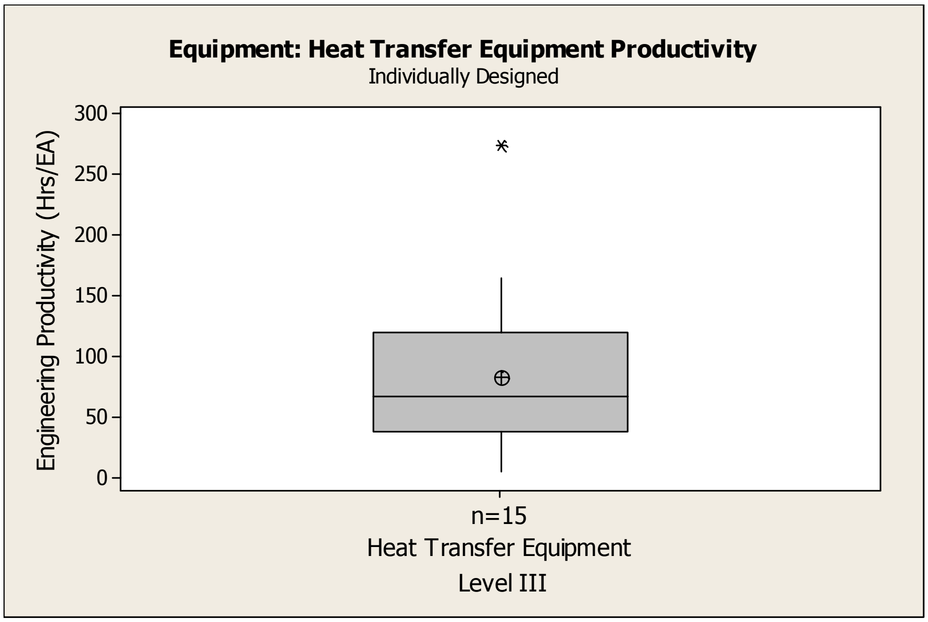

Figure 5.21 Equipment: Heat Transfer Equipment Productivity

The distributions for boiler and fired heaters, and rotating equipment design are shown in Figure 5.22. When examining the boiler and fired heater distribution, a wider range than that for any other equipment metric was observed. Considering that the boiler definition includes packaged boilers, field erected boilers, fired heaters, waste heat boilers, stand-alone stacks, and miscellaneous other boilers and fired heaters, engineering productivity is probably varied due to the many types of equipment and also the capacity differences. Additional information on BTU per hour has been collected and when more data are available; capacity could be included to provide better comparisons.

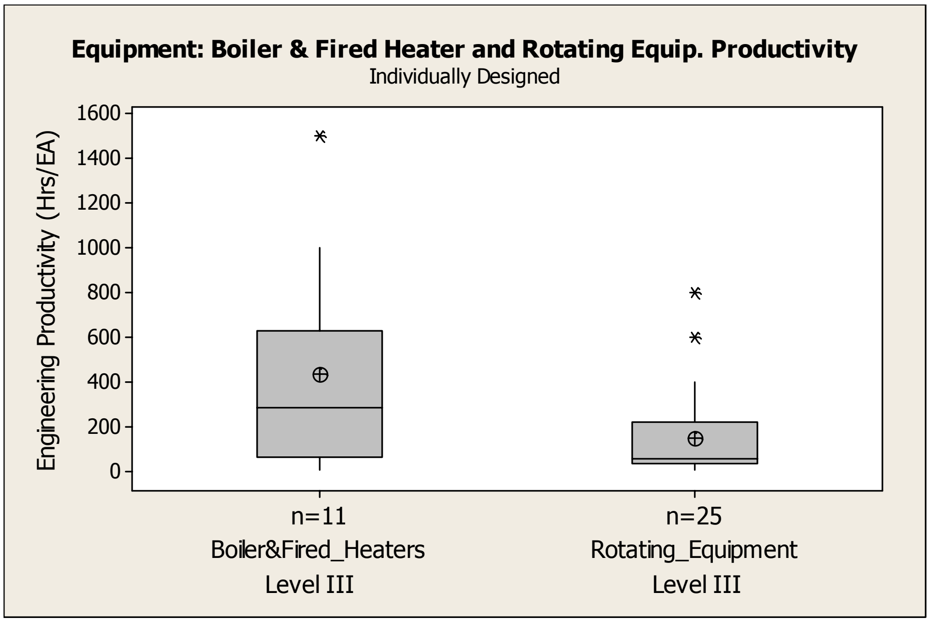

Figure 5.22 Equipment: Boiler & Fired Heaters and Rotating Equipment Productivity

Vendor designed modules and pre-assembled skids and total equipment distributions are presented in Figure 5.23. Generally speaking, the equipment section has the greatest variability among engineering metrics and this section is no different; therefore, additional analysis exploring the relationship between the average weight or the capacity of equipment and its engineering productivity should be considered.

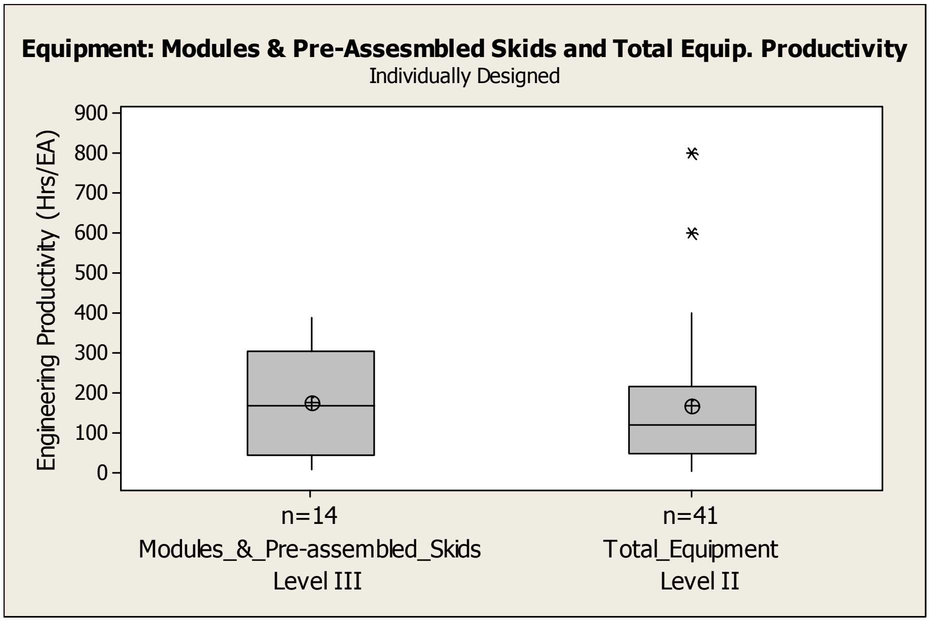

Figure 5.23 Equipment: Modules & Pre-assembled Skids and Total Equipment Productivity

5.4 RELATIONSHIPS BETWEEN IFC QUANTITIES AND ENGINEERING WORK-HOURS: CORRELATION STUDIES

This section examines correlation between actual work-hours and IFC quantities to validate the hypothesis of this research study. The hypothesis posits that reliable measures of engineering productivity can be established from design hours and design quantities. Statistically significant relationships between design hours and quantities lend strong support to the hypothesis.

The structural steel and piping sections were selected for statistical analyses because these categories have a reasonable size dataset and also provide different levels of metrics. Correlation analyses were performed and were summarized in the following sections. Scatter plots are also presented to show bivariate relationships between engineering work-hours and IFC quantities of in a graphical manner in Appendix D.

It is important to note that assumption of bivariate linear relationships between actual engineering work-hours and IFC design quantities was made in the following analyses. Non-linear relationship may be possible such as learning curve effects; however, the author did not find strong evidences of non-linear relationships for these metrics. Therefore, the analyses assume linear relationships.

5.4.1 Structural Steel

The structural steel category provides Level II, III, and IV metrics with a relatively reasonable size dataset, enabling correlation analyses between direct engineering work-hours and IFC design quantities. Different levels of metrics were discussed in Chapter 4.2.2. Correlation analyses were performed for five structural steel metrics to validate the engineering productivity metric definitions proposed by this research. Scatter plots for these five metrics are also provided in Appendix D.

Pearson correlation analyses were conducted to examine the direction and strength of the linear relationship between engineering work-hours and IFC quantities. The results are provided in Table 5.3. As shown, the relationship between direct engineering work-hours and IFC quantities generally demonstrates a reasonable correlation coefficient between 0.492 and 0.847 with statistical significance at the 0.05 significance level except for that of miscellaneous steel. As mentioned in Chapter 4, miscellaneous steel includes many different steel elements which are not classified as structural steel or pipe racks and utility bridges and thus contribute to a weaker relationship as a result of its definition. The statistical significance exceeded original expectations. Pearson correlation assumes bivariate linear relationships.

Table 5.3 Correlation Results in Structural Steel Category, Engineering Work-hours and IFC Quantities

Metrics	n	Correlation Coefficient	P-value	Level
Structural Steel	24	0.664	<0.001	IV
Pipe Racks & Utility Bridges	12	0.834	0.001	IV
Combined Structural Steel / Pipe Racks & Utility Bridges	30	0.760	<0.001	III
Miscellaneous Steel	23 (24)	0.492* (0.277)	0.017* (0.189)	III
Total Steel	42	0.847	<0.001	II

* Relationship and significance after removing a bivariate outlier

5.4.2 Piping

Piping is a critical part of industrial projects and has considerable impacts on overall project outcomes to include productivity, cost, and schedule performance. This category was also selected for correlation analysis to test the hypothesis of this research. First, scatter plots of the four piping metrics are generated to check graphical bivariate relationships between direct engineering work-hours and IFC quantities and given in Appendix D. Then, correlation analyses were performed for small bore pipe, large bore pipe, engineered hangers and supports, and total piping to validate the engineering productivity metric definitions.

Pearson correlation analyses for piping were conducted to examine the direction and strength of the linear relationship between engineering work-hours and IFC quantities. The results are summarized in Table 5.4. Statistical test results show that all of the piping category metrics have statistically significant relationships between 0.800 and 0.952 at the 0.05 significance level. Small bore piping has the best Pearson correlation among the four piping metrics. This may be explained as it has more homogenous definitions than others.

Table 5.4 Correlation Results in Piping Category, Engineering Work-hours and IFC Quantities

Metrics	n	Correlation Coefficient	P-value	Level
Small Bore	35	0.952	<0.001	III
Large Bore	41	0.874	<0.001	III
Engineered Hangers and Supports	33	0.949	<0.001	III
Total Piping	70	0.800	<0.001	II

Since statistically significant bivariate relationships for each piping category have been established between direct engineering work-hours and IFC quantities using the overall dataset, the engineering productivity metric can provide meaningful data to the industry.

5.5 Data Analysis Summary

Preliminary data analysis results gathered from initial engineering productivity data collection have been presented. As discussed in Chapter 1, the research hypothesis was established to support the research objectives and provide preliminary validation of this research. The hypothesis is presented below:

Engineering work-hours and design quantities provide reliable measures of engineering productivity.

A reasonable number of the engineering productivity data points were collected and analyzed for each metric using the box-plot to check for the reasonableness of this methodology using IFC design quantities rather than intermediate deliverables. A methodology for establishing industry norms was presented and these norms will mature with further data collection. Considering this is the first attempt to establish, collect, and analyze engineering productivity data below the disciplines level with common definitions and industry consensus categories, preliminary data analysis suggests that meaningful metrics based on work-hours and IFC quantities for benchmarking are possible. Therefore, the author can conclude that engineering work-hours and design quantities can provide reliable measures of engineering productivity.

The research hypothesis was also reviewed utilizing correlation analysis between direct engineering work-hours and IFC design quantities. Structural steel and piping data were utilized to test this hypothesis. The results were statistically significant at the 0.05 significance level except in the case of miscellaneous steel, and even miscellaneous steel was found to be significant after removing a bivariate outlier. Statistically significant bivariate relationships between direct engineering work-hours and IFC quantities were found for structural steel and piping category. This finding is very important to support the hypothesis and to establish the engineering productivity definition as a function of engineering work-hours and IFC design quantities. This proposed metric approach is preferable for the industry because the metric of work-hours per drawing is notorious for its limited efficacy and validity. The author can conclude that this research method of defining the engineering productivity using IFC quantities is valid and can provide meaningful data when utilizing the CII common definitions.

Chapter 6: SYSTEM VALIDATION AND IMPLEMENTATION ISSUES

After development of the EPMS (Engineering Productivity Measurement System) through this research, there was a need to validate and modify the developed system as necessary to ensure its acceptance and implementation by the industry. This chapter discusses system validation, implementation issues, resource requirements for effective implementation, and a proposed ten-step process for implementation.

6.1 SYSTEM VALIDATION

Through this research, EPMS, including industry consensus directs and indirects, engineering productivity metrics categories, the secure web-based data collection system, and a real-time industry report generator, has been developed. However, validation of the system is essential for industry acceptance and broad industry adaptation. Figure 6.1 illustrates the system validation process which includes 1) industry feedback through BMA training, industry forums, and conference presentations, 2) data analysis, and 3) industry acceptance and adaptation of the system. While system validation occurred in the EPMS Development stage, most of the validation occurred during Implementation.

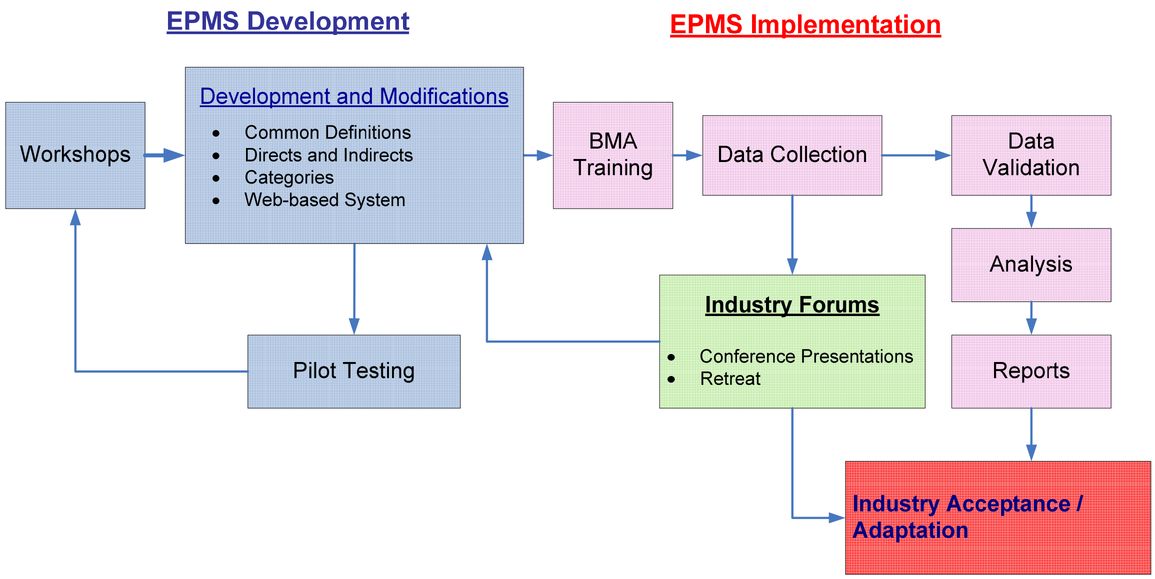

Figure 6.1 System Validation Process

6.1.1 Industry User Feedback

Valuable industry feedback has been received from many different activities. After productivity metrics workshops and development of EPMS, pilot testing was conducted to validate the definitions prior to large scale data collection. In addition, the BM&M Productivity Metrics team regularly reviewed industry feedback to improve the system. Early implementation of the system from September 2002 to 2003 provided valuable feedback to increase its usability.

As discussed previously, modification of engineering productivity metric such as Level III and Level II metrics were made in June 2004 at the Productivity Metrics Retreat for increased flexibility of data collection. This change to the system broadened industry acceptance and implementation as ease of use was enhanced.

Following refinement of the system, special productivity metrics training for Benchmarking Associates was developed and implemented for increased understanding of metric definitions and system use. These training sessions continue to enhance data quality by increasing knowledge and awareness to the functionality of the system and acceptance of its definitions.

The EPMS has been introduced to the industry at CII Annual Conferences, Construction Project Improvement conferences, Board of Advisor round table discussions, and Benchmarking User' Forums in many locations. Most of the industry participants agreed that the system provides very practical information to the industry and improves engineering productivity measurement.

6.1.2 Data Analysis

Engineering productivity metric data received from the three different data collection efforts were analyzed as a part of the validation of the EPMS system. Data analysis of these metrics affirms that the data collected for the engineering productivity metric categories were reasonable and that the metrics with common definitions provided distributions that met the expectations of industry and its professionals.

As discussed in Chapter 5, analysis of engineering productivity data, distributions confirm that engineering productivity metrics based upon IFC quantities can provide reasonable measures of performance. Correlation analyses for structural steel and piping were performed to examine relationships between actual engineering work-hours and IFC designed quantities. Statistically significant relationships were found providing strong support for system validation.

6.1.3 Industry Acceptance / Adaptation

At the Productivity Metrics Retreat in 2004, both the EPMS and PT 192 metrics were presented and analyzed. Comparison of the two approaches is discussed in Appendix A in detail. The industry preferred to implement the EPMS using actual work-hours and IFC design quantity for measuring engineering productivity despite of its relative difficulty for data collection. The industry experts acknowledged that this system would provide more objective measures for engineering productivity.

In addition data from 87 projects from 20 companies have been analyzed during this research. The CII BM&M Committee also continues data collection and refinement of the system. This ongoing implementation of EPMS is expected to broaden industry acceptance and adaptation of the system.

In a summary, the Engineering Productivity Measurement System (EPMS) developed by the author has been validated in multiple aspects, including industry feedback, data analysis, and industry acceptance of EPMS. The following section will discuss implementation barriers and possible solutions.

6.2 Barriers to the Implementation of Benchmarking Engineering Productivity

The research discussed in this dissertation developed an engineering productivity measurement system for effective measurement of engineering performance. It would not be complete however, without an assessment of the barriers to implementation of this system. A number of barriers were identified through a series of workshops, productivity metrics team meetings, BMA training sessions and discussions with project managers during data validation. Identified implementation barriers are listed below:

- Incompatible codes of accounts
- Inadequate time-sheet programs
- Cultural resistance
- Confidentiality issues
- Concerns regarding the use of the productivity data
- Dual approaches within CII

The most critical barrier may be reconciling company internal accounting systems with CII definitions. Generally, tracking codes used by accounting systems within many engineering firms are not compatible with recommendations of this study in terms of direct / indirect accounting, units of measure, and definitions. This incompatibility hinders the effective collection of engineering work-hours in the various CII categories. Therefore, the modification of internal code of accounts should be considered, but this does require significant effort from companies to be successful. One company's approach was to develop a customized query program to extract the data from their existing accounting program, thereby circumventing the need to overhaul their entire legacy system. Further, it is also recommended that a separate time sheet application should be developed to be compatible with the CII BM&M definitions and categories, in order to capture engineering work-hours. This approach may be more economical and viable for implementation.

There may also be cultural resistance against changes to methodology for measuring engineering productivity. Some engineers and project managers are not accustomed to measuring their engineering productivity based upon IFC quantities. However, company leadership should explain the value of measuring engineering productivity and why quantity – based metrics should be used. It is always difficult to change daily work processes, but resistance to change should be minimized with support from company leadership and the project control group. Indeed, a discussion of the issues in tracking intermediate deliverables-based measurement may be enough to convince some of the advantages of the objective quantities approach.

The requirement to report with standard definitions and categories means, however, that it is difficult to retrieve engineering productivity data from historical projects, because generally internal definitions did not match those promulgated by this research. Therefore, company leadership and benchmarking associates (BMA) will need to modify their codes of accounts for projects to be benchmarked so that engineering productivity data can be recorded during project execution for future projects.

Confidentiality of productivity data was another concern expressed by the industry participants since productivity data are directly related to a company's competitiveness in the construction market. All data from participating companies are considered highly confidential and the CII BM&M Committee has established a strict Confidentiality Policy and a Code of Conduct defining appropriate use of the data. These documents can be found at the CII Benchmarking and Metrics website at http://www.construction-institute.org. The code of conduct explicitly prohibits the use of data for anti-competitive practices and emphasizes that the data will only be published in the aggregate, to protect confidentiality. Companies access their own project data, but may only compare against the aggregate. The online benchmarking system allows flexibility to access project data in real time while keeping data confidential.

As discussed previously, two different approaches for the measurement of engineering productivity, (PT 192 and the BM&M approach) exist within CII. Some members were initially confused as to which approach their company should apply. In order to minimize this confusion among CII members, the two teams collaborated during their research process and then presented the similarity and differences of the approaches at CII annual conferences, CPI conferences, Benchmarking User's Forums, and BMA training sessions.

This research has formed a good approach to measure engineering productivity with standard definitions and flexibility in data collection levels; however, implementation issues discussed here should not be neglected, as they are critical to a successful implementation of engineering productivity measurement and are necessary for the long-term benefits from this effort to be realized.

6.3 Path Forward: Resource Requirements for Implementation

This section discusses resources required at the company level to sustain this research in engineering productivity metrics benchmarking. First, to build a successful implementation model, continuity of required resources is critical. The true benefits of this research will be realized through continuous benchmarking over time and further analysis of data.

The success of this effort over the long term is contingent upon bringing more engineering companies into this research and maintaining industry focus on measuring engineering productivity. Ultimately, industry-level trends for productivity similar to CII's safety trend analysis will drive improvement. However, participating companies must provide enough resources for productivity metrics data collection and follow-up before significant improvement can be realized.

6.4 A Ten-Step Process For Implementation of Engineering Productivity Benchmarking

Real benefits of engineering productivity benchmarking can only be attained by a successful implementation program for productivity benchmarking within a company or the industry. Establishing a benchmarking program within an organization is a long journey to truly succeed. The previous section discusses barriers to the implementation of benchmarking of engineering productivity. In response, a guideline for establishing a successful benchmarking program was developed, resulting in a ***ten-step process*** *for companies to implement this system.* Figure 6.2 provides a proposed ten-step process graphically.

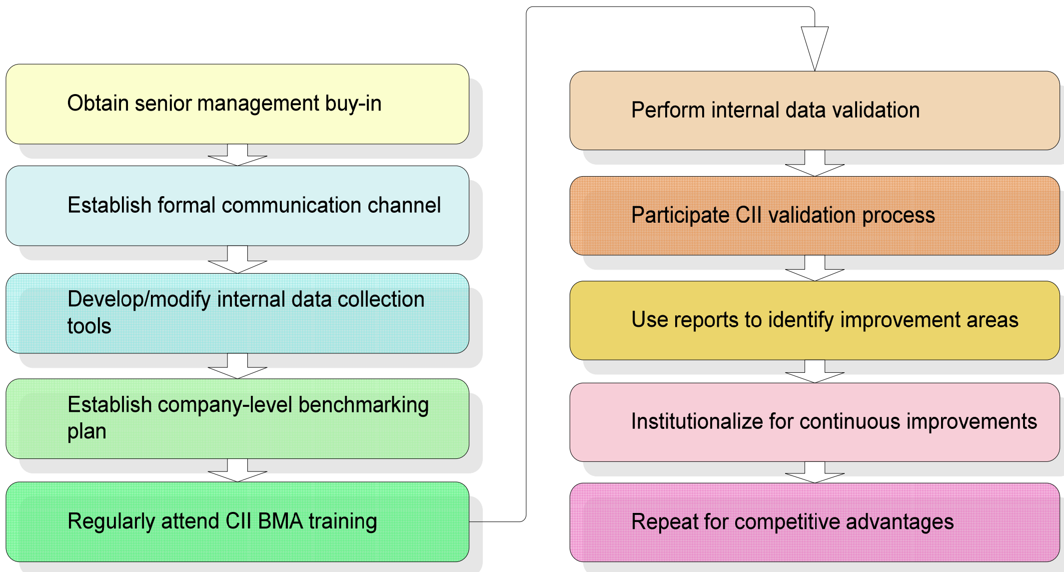

Figure 6.2 Proposed Ten-Step Implementation Process

More specifically, this proposed Ten-Step implementation process should be implemented by following guidelines.

1) Obtain buy-in from company executive management for productivity benchmarking.
2) Establish a formal communication channel among Benchmarking Associates, project managers, and engineering discipline managers.
3) Develop or modify internal data collection tools, such as time sheet programs and accounting codes to make data collection easier by matching with CII standard definitions and categories for external benchmarking.

4) Set up a company-level benchmarking plan to select representative projects to benchmark and initiate data collection at the beginning of each project.
5) Annually attend CII Productivity Metrics Benchmarking Associate training sessions to learn about the CII productivity metrics program and lessons learned from other companies.
6) Validate engineering productivity data and other necessary project information internally before submission to CII to assure data quality.
7) Cooperate with the CII account manager to clarify any issues before final acceptance of project data.
8) Use the company-confidential productivity key report to analyze performance against a similar industry data set and identify specific metrics or discipline areas to improve.
9) Utilize results from the key report and provide recommendations for company process improvement and future project planning.
10) Repeat the above procedures to improve the company's competitive edge within the industry.

6.5 SUMMARY

This Chapter has discussed the critical issues arising from the development of a standard engineering productivity measurement system along with an approach to derive real benefits from industry acceptance of the methodology. System validation for EPMS has been discussed. Barriers for implementation have been also identified and discussed. The importance of continuity of required resources from industry participants was also emphasized in order to realize true benefits from implementation. A ten-step implementation process was proposed as an example of how a company may begin its productivity benchmarking. The next chapter will review research objectives and contributions. Recommendations for future studies will also be discussed.

Chapter 7: CONCLUSIONS AND RECOMMENDATIONS

This dissertation presents and discusses the motivation, background, and methodology for the development of an Engineering Productivity Measurement System (EPMS). The research is another important step by CII in developing much needed metrics for measuring and ultimately improving engineering productivity.

This chapter completes the documentation of the research by presenting conclusions and recommendations. The research objectives are reviewed and conclusions are presented. Recommendations for future research are also identified. Finally, contributions of this research are discussed.

7.1 REVIEW OF THE RESEARCH OBJECTIVES AND CONCLUSIONS

Chapter 1 records the main objective of this study: to develop a system for engineering productivity measurement that is suitable for benchmarking and to provide quantitative feedback to participants for improving their productivity performance. More specifically, the aim of this research was:

1) To establish engineering productivity metric definitions that are acceptable to industry.
2) To develop a system for the implementation of these metrics.
3) To collect a pilot set of data for preliminary validation.
4) To identify and discuss the implementation issues of engineering productivity measurement.
5) To recommend directions for future studies.

7.1.1 Development of Engineering Productivity Metrics

The CII BM&M productivity metrics team began developing standard engineering productivity metrics in 2002 to provide a basis for industry to perform both internal and external benchmarking. A total of 44 industry experts from 28 member organizations participated in the development workshops. A metrics system of standard direct/indirect accounts, six metric categories and 49 individual metrics were developed through a series of workshops. Revisions were made by gathering feedback from the industry through pilot data collection and a Productivity Metrics Retreat. In doing so, the main objective of this research has been achieved. Detailed discussion of the metric definitions is provided in Chapter 4 and the engineering productivity questionnaire is provided as a part of the CII Benchmarking Project questionnaire in Appendix B.

7.1.2 Development of Engineering Productivity Measurement System

A web-based Engineering Productivity Measurement System (EPMS) has been developed for implementation of these metrics by the construction industry. To collect data for these metrics, an online database was designed and an online questionnaire was programmed and tested. This questionnaire was integrated into the CII BM&M system to enable collection of a wide range of project data to support analysis of the productivity metrics. The EPMS allows flexible data collection for engineering productivity by establishing different levels of metrics. The system leveraged theoretical and practical suggestions from literature review and expert opinions. Finally, an automated reporting system which generates confidential engineering productivity performance reports for each participating company was developed for feedback to participants.

Validation of EPMS was important for industry acceptance and broad adaptation. Thus, the system validation process which includes industry feedback, data analysis, and industry acceptance and adaptation of the system were discussed in Chapter 6.

7.1.3 Initial Data Analysis / Validation

The engineering productivity data reviewed by this research consisted of a total of 87 projects. Preliminary data analyses were performed for initial validation. The Box-Whisker plot was utilized to discuss metric distributions and scatter plot and Pearson correlation analyses results were provided to examine the relationship between engineering work-hours and IFC quantities. Findings from the analyses should be interpreted with caution however, since convenience sampling rather than true random sampling was employed.

Through the pilot data collection and preliminary analysis of engineering productivity metrics, the following conclusions can be made:

- A reasonable number of data points have been collected for initial validation.
- Meaningful engineering productivity norms can be established at various levels, even considering the data input constraints of industry.
- Significant relationships between engineering work-hours and IFC quantities show that quantity-based metrics are feasible for engineering productivity benchmarking.
- The CII BM&M survey defines metrics at an appropriate level of detail to permit industry to provide data and also to produce meaningful metrics.

7.1.4 Discussion of Implementation Issues for Engineering Productivity Measurement

One of the research objectives was to identify and discuss the implementation issues of engineering productivity measurement. This research proposed a benchmarking methodology using direct engineering work-hours and

IFC quantities for most engineering disciplines. Barriers and issues for implementation of this system were identified through the research process and discussed along with possible solutions in Chapter 6. Valuable lessons learned were identified from early implementation of the metrics. Resources required for implementation were also discussed. The author proposed a ten-step process for companies to implement the EPMS as a general guideline for improvement.

7.2 REVIEW OF RESEARCH HYPOTHESIS AND CONCLUSIONS

This section provides a review of the research hypothesis established in Chapter 1 and relevant discussions. The research hypothesis posited that ***Engineering work-hours and design quantities provide reliable measures of engineering productivity.***

This research established a new system to measure engineering productivity using direct actual engineering work-hours and IFC design quantities below the discipline level with common definitions and industry consensus categories. Preliminary analysis results of a total of 87 project data gathered have been presented using the Box-Whisker plot to check for the reasonableness of this methodology in Chapter 5. This analysis showed that meaningful metrics based on work-hours and IFC quantities for benchmarking are possible. Therefore, the author can conclude that engineering work-hours and design quantities can provide reliable measures of engineering productivity.

As discussed in Section 1.4, the term "reliable" as used in the hypothesis should not be construed to indicate reliable in a statistical sense, but rather means that productivity metrics based on engineering work-hours and design quantities provide metrics for which industry can report and which produce distributions which are sufficiently dependable for benchmarking purposes.

Pearson correlation analyses were preformed to examine the relationship between engineering work-hours and IFC design quantities for structural steel and piping. Statistically significant relationships between engineering work-hours and IFC design quantities were found. This finding is very critical to support the hypothesis and to establish the engineering productivity definition as a function of engineering work-hours and IFC design quantities. The author can conclude that this research method of defining the engineering productivity using IFC quantities is valid and can provide meaningful data with common definitions.

7.3 Recommendations for Future Research

This dissertation demonstrates that the BM&M engineering productivity measurement system provides an effective benchmarking tool for the construction industry to measure engineering productivity. This research mainly focuses on the development of industry-standard engineering productivity metrics and a system for their use. Since this can be considered an early study of engineering productivity measurement, many other studies may follow using this research as a basis; therefore recommendations concerning this research are provided below.

Since this research produced engineering productivity metrics for six major categories consisting of multiple levels, development of a Level I metric representing overall engineering productivity performance at the project level would be useful to future research. To be meaningful, it should be repeatable and should ultimately be represented as a trend. A Level I metric should serve various analyses, should be economical to collect and produce, and should be a reasonable summary of more detailed level II through IV metrics. Additionally, the construction industry has lacked a valid industry-level productivity trend analysis. Although there is a high level productivity trend analysis provided by the BLS (Bureau of Labor Statistics), doubt has been cast on its accuracy because of its simplistic methodology. In contrast, the BM&M system can provide various yearly trend analyses for engineering and construction productivity both at the discipline level and the industry level with the development of the Level I metric and a more extensive dataset.

Analyses of relationships among engineering productivity, project performance, and implementation of selected best practices are also very critical to understanding how engineering productivity contributes to project success. Information regarding other performance metrics and selected best practices are also collected using the engineering productivity measurement system because it is integrated into the general benchmarking survey instrument. Suggested future analysis questions are listed below:

- How does engineering productivity performance affect detailed-design phase cost growth and schedule growth?
- How does engineering productivity affect overall project cost growth and schedule growth?
- How does engineering productivity impact construction productivity?
- What is the effect of automation and integrated technologies on engineering productivity?
- How do front end planning and the use of the Project Definition Rating Index (PDRI) (CII 1996; CII 2006b) impact engineering productivity?

This research primarily focused on development of engineering productivity measures for the detailed-design phase. However, numerous factors likely affect engineering productivity and future data collection with other pertinent data would enable analyses of these factors. Some suggested analysis topics are listed below:

- What is the ratio of indirect to direct engineering hours and how does it affect engineering productivity metrics performance?
- What is the relationship between change orders during the detailed-design phase and engineering productivity?
- How do different complexity factors affect engineering productivity?

7.3.1 Engineering Productivity Factors

During this research, several workshops with industry experts were conducted to gain consensus on common definitions and engineering productivity categories. In these workshops, there were some discussions of engineering productivity drivers such as project complexity factors and use of information management systems. The scope of this research was limited to development of a quantity-based metrics system for measuring engineering productivity and therefore this research does not provide an analysis of engineering productivity drivers. Those who measure their productivity through the CII BM&M system would benefit by analyzing their results with industry norms in terms of various extant conditions to identify their strengths and shortcomings. This is a critical step for improving future performance. Further research into identification of the drivers for engineering productivity improvement is warranted.

For future research, it is useful to document potential characteristics or practices that were discussed during various industry workshops, Benchmarking Associates (BMA) training sessions, and CII Board of Advisor (BOA) round table discussions that may correlate with engineering productivity. A summary of these potential factors are listed below:

- Project complexity: Overall project complexity and/or complexity for each engineering discipline

- Automation of engineering activities and how well technologies are integrated across the various activities
- Percentage of design reuse
- Project characteristics (i.e., grass roots, modernization, and addition)
- Project size (small project vs. large project)
- Contract types (reimbursable vs. lump-sum)
- Utilization of off-shore engineering
- Completeness of project scope definition before the detailed design phase
- Use of change management practices
- Difference among industry groups (heavy industrial, light industrial, buildings, and infrastructure)

Although the CII Benchmarking & Metrics questionnaire collects data for many of these possible project characteristics or factors, the impact on engineering productivity performance is not yet well understood, and the small sample size makes it difficult to analyze comprehensively the quantitative impact on engineering productivity. The research of the various impacts on engineering productivity using a larger dataset and input from industry experts is recommended.

7.4 RESEARCH CONTRIBUTIONS

The primary contribution to the construction industry from this research is the establishment of a standard engineering productivity measurement system. This system includes a common set of definitions and a list of direct and indirect accounts. These metrics allow an organization to determine its productivity at the work package level and in many cases, the discipline level. Other contributions are:

1) Direct and indirect accounts were developed.
2) Metric definitions for six categories consisting of many of the engineering disciplines were established.
3) A web-based system for implementation of engineering productivity measurement has been developed and has been incorporated into the CII Benchmarking & Metrics system.
4) Preliminary validation of metric definitions has been performed.
5) Recommendations for future research were made.

Appendix A: Comparison of CII Benchmarking vs. PT 192 Approaches

Comparison of CII Benchmarking vs. PT 192 Approaches

Increased attention has been given in recent years to developing engineering productivity measures. As mentioned in Chapter 3.2, Project Team 192 (PT 192) was funded by CII to develop engineering productivity metrics. The team's research approach was to compare actual design hours to predicted design hours based on select quantities. This is different from the direct measurement approach taken by the CII BM&M research. The PT 192 team and the BM&M Productivity Metrics team each initiated its own research for engineering productivity measurement in 2002. Both systems utilized quantity-based metrics rather than intermediate deliverables, but they have little in common beyond this. Since these approaches are perhaps the most rigorous to date for developing engineering productivity metrics, a comparison of the two is useful.

Engineering productivity metrics for BM&M research were produced for the concrete, structural steel, electrical, piping, instrumentation, and equipment disciplines. The PT 192 engineering productivity measurement research produced indices for civil, electrical, piping, instrumentation, mechanical (equipment), architecture, and process disciplines (Walsh et al. 2004). These categories were shown in Table 3.1.

Table A.1 provides a summary of comparisons on different aspects of the PT 192 and BM&M approaches. Detailed discussion of the comparison attributes follows the table.

Table A.1 PT 192 vs. BM&M Comparison

Attributes	PT 192	BM&M
Level of Measurement	discipline	flexible levels, generally below discipline
Measurement	indirect measurement using predictive models	direct measurement
Productivity Definition	actual discipline hours/ productivity basis hours	actual work-hours/ IFC quantity
Data Collection	past projects + current projects	current and future projects
Types of Metrics	relative	absolute
Accuracy	likely less	potentially better
Consistency	likely weaker	potentially better
Ease of Implementation	relatively easy (off-the-shelf) more difficult (custom-tailored)	relatively difficult
Trend Analysis	possible at the discipline and project level	Level II through IV when data available Level I when developed
Future Utility	limited	flexible
Individual Project Benchmarking	Groups of Projects	Individual and Groups of Projects

Level of Measurement: Comparison of the levels of measurement offered by the two approaches reveals that PT 192 approach can produce its productivity index at only discipline level (Walsh et al. 2004) while the BM&M approach can measure and compare engineering productivity at various levels from Level IV (element level) to Level II (discipline or major category level). The BM&M approach can measure productivity to Level II at present, but has the potential to extend to Level I in the future. In brief, the BM&M approach provides more detailed levels of comparison of engineering productivity. Figure A.1 provides an illustration of level of measurement for the two teams.

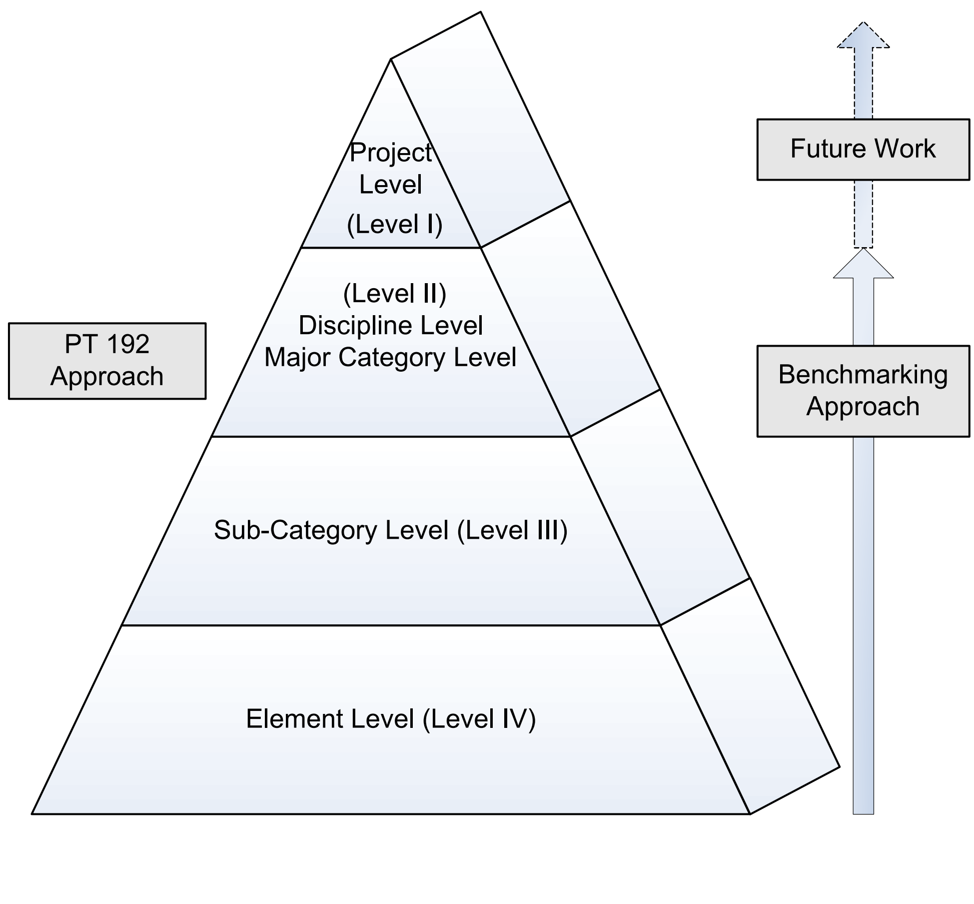

Figure A.1 Level of Measurement for the Two Teams

Measurement and Productivity Definition: Considering measurement methodologies, Figure A.2 provides a graphical illustration of the two teams' different methodologies. The PT 192 methodology can be classified as an indirect measurement system where the team collected numerous designed quantities and overall discipline engineering work-hours for use in regression models. After the development of regression models for predicting total discipline work-hours (basis-hours) for selected design quantity variables, a productivity index for each discipline was calculated as a ratio between actual discipline work-hours and the predicted work-hours from the regression model for each discipline (Walsh et al. 2004). In contrast, the Benchmarking (direct measurement) approach measures direct engineering work-hours and IFC design component quantities at the same level, which enables the direct measurement of engineering productivity. Figure A.2 illustrates the two different approaches for the civil discipline example for PT 192 and the concrete category for Benchmarking.

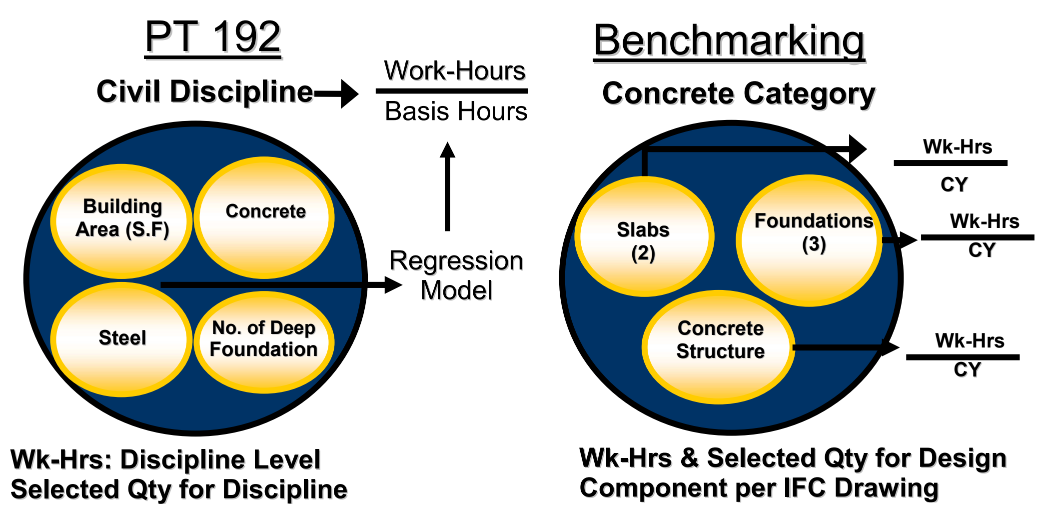

Figure A.2 PT 192 and Benchmarking Approaches

Data Collection: The PT 192 and BM&M teams approached data collection quite differently. PT 192 collected its project data mostly from past projects, primarily due to its short data collection time frame. The BM&M data collection effort instead focused on only current projects and future projects because it was difficult to collect engineering productivity data from past projects due to the unavailability of data using the standard definitions promulgated by the team.

Types of Metrics: The metrics from PT 192 can be classified as relative metrics, but the metrics for BM&M can be classified as absolute metrics. Since the PT 192 metrics are a ratio of actual discipline work-hours and predicted discipline work-hours, the calculated PI is a relative metric. BM&M engineering productivity is measured in actual engineering work-hours per IFC quantity designed, so it is not a relative metric, but an absolute one.

Accuracy: Since engineering productivity is a performance metric, it must be emphasized that it requires a certain level of accuracy. Regarding accuracy of the PT 192 metrics, many concerns are raised due to the regression models for prediction of productivity. It is of paramount importance to assess the accuracy of the predicted basis hours since they act as "the industry norms" for producing the PT 192 Productivity Indices. As described by the model development documentation, the team included non-significant variables, in some cases, and may have failed to remove highly correlated variables that cause collinearity (Kelly 2004a). These variables were not removed for conceptual reasons (Walsh et al. 2004). The inclusion of insignificant variables also contributes to the inaccuracy of the predictions of basis hours. In addition, the team may have eliminated significant negative coefficient variables from the multiple regression models for conceptual reasons, and this could lessen the ability to maximize the predictability of the basis hour forecasts (Kelly 2004a; Kelly 2004b). The PT 192 metrics therefore may not offer an appropriate level of accuracy for a productivity index, due to the relatively large standard error of the estimate (Walsh et al. 2004) from the prediction model and reasons cited above. The BM&M engineering productivity does not include any predicted values for calculating its engineering productivity and can provide more accurate comparisons against the industry norms. The possibility of measurement error for engineering productivity data collection could theoretically produce inaccuracy as in any measurement survey.

Consistency: The consistency of the PT 192 Productivity Index as a result may be weaker than that of BM&M because the PT 192 index includes a basis hour from the prediction model that includes the large standard of errors, which are ignored when calculating its PI (Productivity Index), while the BM&M approach does not include any predicted error to produce its engineering productivity. Values for its numerator and denominator are actual project data which may have measurement errors however, if participants do not report according to the standard definitions. This can be a problem, however, since it is uncertain how successful companies will be at separating directs and indirects for reporting at the design component level.

Ease of Implementation: The PT 192 "off-the-shelf" approach is relatively easier than the BM&M approach. The "off-the-shelf" approach uses "basis hours" equations developed from the PT 192 data set to measure productivity and establish baselines (CII 2004). Implementation using the PT-192 "custom-tailored" approach is likely to be more difficult than that of the BM&M approach since an organization should repeat the research process of PT 192, including the prediction model development. The only benefit for this approach is that the compared dataset can be more homogeneous than that of the "off-the-shelf" approach. The "custom-tailored" approach is that users develop their own basis hour functions based on data collected from their own projects (CII 2004).

Implementation of the BM&M approach can be relatively difficult during the early phase of engineering productivity benchmarking implementation. Companies must attend a CII BM&M productivity training session and provide their project data based upon the CII common definitions and standard categories. Once the tracking system is in place however, the application of continuous benchmarking activities for engineering productivity is manageable, and leads to quick comparisons against the BM&M database.

Trend Analysis: Trend analyses are possible for both PT 192 and BM&M approaches, but a big difference exists between the two approaches. According to PT 192 literature, trend analysis for its productivity indices is possible at the discipline level and project level (Walsh et al. 2004). The BM&M approach can produce trend analysis at various levels of metrics such as Level II, Level III, and Level IV. Assuming continuous data collection using the BM&M approach, trend analysis of engineering productivity is even possible for different project characteristics. Trend analysis for Level I metric is possible with further development of Level I metric. For these reasons, the BM&M approach can provide more flexible trend analysis of engineering productivity than heretofore available.

Future Utility: The BM&M engineering productivity can be easily converted into project costs derived from the CII industry norms. This process is shown in Figure A.3. The system can be utilized as checking for the detailed estimation and reviewing bidding packages, not for actual estimation however.

1) $\text{Engineering Productivity} = \dfrac{\text{Actual Work-Hours}}{\text{IFC Quantity Designed}} \text{ X Total IFC Quantities}$

2) $\text{Total Design Work-Hours} = \sum \left(\dfrac{\text{Actual Work-Hours}}{\text{IFC Quantity Designed}} \text{ X Total IFC Quantities} \right)$

3) Direct Design Cost = Total Design Work-Hours x Avg. Wages per Hours

4) Project Cost = Direct Design Cost + Direct Design Cost x Indirect Ratio

Figure A.3. Example for Project Cost Conversion

Benchmarking: Finally, the PT 192 approach is not applicable for individual project benchmarking, and the BM&M approach is more suitable for individual project benchmarking and even for company-level benchmarking.

As a result of the comparisons discussed in this section, the author concluded that the usage of PT 192 models to measure engineering productivity was unsuitable for individual project-level benchmarking, and the BM&M model offers a better solution.

Appendix B: CII Benchmarking & Metrics Questionnaire

Contractor Large Project Questionnaire version 8.0

Contractor Questionnaire version 8.0

Table of Contents

Contractor Questionnaire Version 8.0

1. General Information Form

Your Company Name: ___________________________________
Project ID: ____
Please provide the Name that you will use to refer to this Project: ________________
Project Location: Domestic (US States or Canadian Territories) _________________
Project Location: International (Country) ___________________________________
Contact Person: (Name of knowledgeable person) ____________________________
Contact's Phone: __________________________________
Contact's Fax: ____________________________________
Contact's E-mail Address: ___________________________
Is the owner of this project ☐ Public sector owner ☐ Private sector owner

1.1. Project Description

Principle Type of Project:

Choose a Project Type which **best** describes the project from the categories below. If the project is a mixture of two or more of those listed, select the principle type. If the project type does not appear in the list, select other under the appropriate industry group and specify the project type.

Heavy Industrial	**Light Industrial**
☐ Chemical Manufacturing	☐ Automotive Manufacturing
☐ Electrical (Generating)	☐ Consumer Products Manufacturing
☐ Environmental	☐ Foods
☐ Metals Refining/Processing	☐ Microelectronics Manufacturing
☐ Mining	☐ Office Products Manufacturing
☐ Natural Gas Processing	☐ Pharmaceutical Manufacturing
☐ Oil Exploration/Production	☐ Pharmaceutical Labs
☐ Oil Refining	☐ Clean Room (Hi-Tech)
☐ Pulp and Paper	☐ Other Light Industrial
☐ Pipeline	
☐ Gas Distribution	
☐ Other Heavy Industrial	

Buildings		Infrastructure	
☐	Communications Center	☐	Airport
☐	Dormitory/Hotel/Housing/Residential	☐	Electrical Distribution
☐	Low rise Office (≤3 floors)	☐	Flood Control
☐	High rise Office (>3 floors)	☐	Highway
☐	Hospital	☐	Marine Facilities
☐	Laboratory	☐	Navigation
☐	Maintenance Facilities	☐	Rail
☐	Parking Garage	☐	Tunneling
☐	Physical Fitness Center	☐	Water/Wastewater
☐	Restaurant/Nightclub	☐	Telecom, Wide Area Network
☐	Retail Building	☐	Other Infrastructure
☐	School		
☐	Warehouse		
☐	Prison		
☐	Movie Theatre		
☐	Courthouse		
☐	Embassy		
☐	Other Buildings		

If other, please describe: ______________________________

1.2. Project Nature

From the list below select the category that best describes the nature of this project. If your project is a combination of these natures, select the category that you would like your project to be benchmarked against. Please see the glossary for definitions.

The Project Nature was:
- ☐ Grass Roots
- ☐ Modernization
- ☐ Addition
- ☐ Other Project Nature (Please describe):

1.3. Project Drivers

a. Project Drivers

Select the primary driver influencing the execution of this project. Assume safety is a given for all projects.

The primary driver was:

- ☐ Cost
- ☐ Schedule
- ☐ Meeting Product Specifications
- ☐ Production Capacity
- ☐ Other (Please describe):
- ☐ No primary driver

b. Turnarounds/Shutdowns/Outages

Construction performance (cost, schedule and quality) during project turnarounds, shutdowns, and outages may be impacted by schedule demands of the turnaround. These turnarounds may be scheduled or unscheduled. Please complete the blocks below to indicate the percentage of construction work completed during turnaround.

1. Percent construction during **scheduled turnaround:**		%
2. Percent construction during **unscheduled turnaround:**		%
3. Percent construction during **non-turnaround:**		%

Note: the percentages should add up to 100 %

c. Percent Modularization

Choose a percentage value that best describes the level of modularization (offsite construction) used. This value should be determined as a ratio of the cost of all modules divided by total installed cost.

◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

1.4. Typical Project

Projects submitted for benchmarking should be representative of the typical project that you execute, i.e., not impacted by extraordinary factors that might influence performance or practice use metrics. If the project is not representative, it can still be submitted to be scored, however, please let us know by checking the appropriate box below.

◘ **Typical** ◘ **Not Typical**

If project is not typical, please provide reason:

____

1.5. PIP Implementation Questions for Heavy Industrial Projects

	Criteria (Heavy Industry Project only)	Strongly Disagree 0	Disagree 1	Neutral 2	Agree 3	Strongly Agree 4	NA / UNK
A	The project was executed with internal owner engineering standards and specifications.	◘	◘	◘	◘	◘	◘
B	The project was executed with contractor engineering standards and specifications.	◘	◘	◘	◘	◘	◘
C	The project was executed using industry consortia engineering practices for standards and specifications.	◘	◘	◘	◘	◘	◘
D	The project was executed using Process Industry Practices (PIP) standards and specifications.	◘	◘	◘	◘	◘	◘

1.6. Project Delivery System

Please choose the project delivery system from those listed below that most closely characterizes the delivery system used for your project. If more than one delivery system was used, select the primary system.

Delivery System		Description
	Traditional Design-Bid-Build	Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
	Design-Build (or EPC)	Overlapped sequence of design and construction phase; procurement normally begins during design; owner contracts with Design-Build (or EPC) contractor.
	CM @ Risk	Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts separately with designer and CM @ Risk (constructor). CM holds the contracts.
	Multiple Design-Build	Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts with two Design-Build (or EPC) contractors, one for process and one for facilities.
	Parallel Primes	Overlapped sequence of design and construction phases; Procurement normally begins during design. Owner contracts separately with designer and multiple prime constructors.

Did you use a Construction Manager not @Risk in conjunction with the selected delivery system?
Yes________________ No________________

1.7. Project Complexity

Choose a value that best describes the level of complexity for this project as compared to other projects from all the companies within the same industry sector. For example, if this is a heavy industrial project, how does it compare in complexity to other heavy industrial projects? Use the definitions below as general guidelines.

- **Low** - Characterized by the use of no unproven technology, small number of process steps, small facility size or process capacity, previously used facility configuration or geometry, proven construction methods, etc.
- **High**- Characterized by the use of unproven technology, an unusually large number of process steps, large facility size or process capacity, new facility configuration or geometry, new construction methods, etc.

Low			Average				High		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1.8. Project Scope

Please provide a brief description of the project scope (what is actually being designed / constructed), limit your response to 200 words.

1.9. Project Participation

Please provide information about the **functions** performed **your company**.

Indicate the **function(s)** your company performed and the **approximate percent of that function.** For each function, indicate the **principle contract type** in use at the completion of the work. Also, indicate **if the contract contained incentives**.

Project participant information will be collected over a series of several pages.

Project Functions: Identify the Function performed by each project participant. Functions include:

- Pre-Project Planning
- Design
- Procurement - Equipment
- Procurement - Bulks
- Construction Support
- Demolition/Abatement
- General/Prime Contracting
- Project Management
- Construction Management
- Startup Support

Principle Type of Contract for each company: Unit price refers to a price for in place units of work and does not refer to hourly charges for skill categories or time card mark-ups. Hourly rate payment schedules should be categorized as cost reimbursable. The contract type for your own company's contribution will be recorded as In House.

- Cost Reimbursable/Target Price
- Guaranteed Maximum Price
- In House
- Lump Sum
- Unit Price

Contract Incentives: Please indicate whether cost, schedule, safety, and quality incentives were used. Incentives may be positive (a financial incentive for attaining an objective), negative (a financial disincentive for failure to achieve an objective), or both. Indicate "none" if no incentives were used for a category.

Project Participants Screen 1 – Identification of Participants

Project C7001 contractor 7

	Pre-Project Planning	Pre-Project Planning Consulting	Design	Procurement Equipment	Procurement Bulks	Construction Support	Demolition Abatement	General Contracting	Prime Contracting	Project Management	Construction Management	Startup Support
My Company	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0

Continue

Is the Owner of this project a CII member company?

- Yes
- No

Is your company an Alliance Partner with the Owner of this project?

- Yes
- No

Project Participants Screen 2 – Input Participant Data

Company	% Function	Function	Contract Type	Incentives
My Company	100 %	Pre-Project Planning	Lump Sum	**Cost** Negative **Schedule** Positive **Safety** Positive **Quality** None
My Company	50 %	Design	Lump Sum	**Cost** Positive **Schedule** Positive **Safety** None **Quality** None
My Company	55 %	General Contracting	Unit Price	**Cost** Negative **Schedule** Positive **Safety** Positive **Quality** Positive

Continue

Go Back to Previous Screen

Project Participants Screen 3 – Final Printable Results Screen

Company	% Function	Function	Contract Type	Incentives
My Company	100 %	Pre-Project Planning	Lump Sum	**Cost :** Negative **Schedule :** Positive **Safety :** Positive **Quality :** None
My Company	50 %	Design	Lump Sum	**Cost :** Positive **Schedule :** Positive **Safety :** None **Quality :** None
My Company	55 %	General Contracting	Unit Price	**Cost :** Negative **Schedule :** Positive **Safety :** Positive **Quality :** Positive

Enter Another Project Section//Back to Project Central

1.10. Union / non-union work force

Please indicate the percentage of Union Labor employed for the following disciplines.

Discipline	Percentage Union Work Force
Concrete	______% ◘ NA ◘Unknown
Structural Steel	______% ◘ NA ◘Unknown
Electrical	______% ◘ NA ◘Unknown
Piping	______% ◘ NA ◘Unknown
Instrumentation	______% ◘ NA ◘Unknown
Equipment	______% ◘ NA ◘Unknown
Insulation	______% ◘ NA ◘Unknown

2. Performance

2.1. Budgeted and Actual Project Costs by Phase

Please indicate the Budgeted (Baseline) and Actual Project Costs by phase:

1. Only enter data for your scope of work.
2. Budget amounts should include contingency and correspond to the estimate at time of contract award. This is the original baseline budget, and should not be updated to include any changes. Change data are collected in a later section. Metrics definitions specifically address changes as appropriate.
3. Click on the project phase links below for phase definitions and typical cost elements.
4. If this project did not include a particular phase, please select N/A.
5. The total project **budget** amount should be the **planned expenses** of all phases performed by your company, including amounts for in-house salaries, overhead, travel, excluding the cost of land.
6. The total **actual** project cost should be the **actual** project costs for phases performed by your company, including amounts expended for in-house salaries, overhead, travel, excluding the cost of land.
7. **If you know total contract costs but have incomplete phase information**, you may enter as much phase information as you know and override the automatic totaling function by manually filling in the total project cost. As long as you don't click back into a phase field, your total will be accepted and recorded.
8. **Enter cost in U.S. Dollars, if currency conversion is required; use the exchange rate at the midpoint of the project.**

Project Phase	Baseline Budget (Including Contingency)	Amount of Contingency in Budget	Actual Phase Cost
Pre-Project Planning	◘ NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Detail Design	◘ NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Procurement	◘ NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Demolition/Abatement	◘ NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Construction	◘ NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Startup	◘ NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Total Project			
If you track the cost of construction management, please provide it. $______________			

Actual Total Cost of Major Equipment

The purpose of this question is to determine the extent to which the overall project cost is driven by the purchase of major equipment. Please see the Equipment Reference Table provided below. Record the total purchase cost of major equipment for this project. Exclude costs for field services, bulk construction equipment (such as valves, bus duct etc.) and off-the-shelf equipment.

$______________ ◘ N/A ◘ Unknown

Equipment Reference Table

Examples of Major Equipment	Kinds of Equipment Covered
HVAC Systems	Prefabricated air supply houses
Columns and Pressure Vessels	Towers, columns, reactors, unfired pressure vessels, bulk storage spheres, and unfired kilns; includes internals such as trays and packing.
Tanks	Atmospheric storage tanks, bins, hoppers, and silos.
Exchangers	Heat transfer equipment: tubular exchangers, condensers, evaporators, reboilers, coolers (including fin-fan coolers and coolingtowers).
Direct-fired Equipment	Fired heaters, furnaces, boilers, kilns, and dryers, including associated equipment such as super-heaters, air preheaters, burners, stacks, flues, draft fans and drivers, etc.
Pumps	All types of liquid pumps and drivers.
Vacuum Equipment	Mechanical vacuum pumps, ejectors, and other vacuum producing apparatus and integral auxiliary equipment.
Motors	600V and above
Electricity Generation and Transmission	Major electrical items (e.g., unit substations, transformers, switch gear, motor-control centers, batteries, battery chargers, turbines, diesel generators).
Materials-Handling Equipment	Conveyers, cranes, hoists, chutes, feeders, scales and other weighing devices, packaging machines, and lift trucks.
Package Units	Integrated systems bought as a package (e.g., air dryers, air compressors, refrigeration systems, ion exchange systems, etc.).
Special Processing Equipment	Agitators, crushers, pulverizers, blenders, separators, cyclones, filters, centrifuges, mixers, dryers, extruders, fermenters, reactors, pulp and paper, and other such machinery with their drivers.

2.2. Planned and Actual Project Schedule

Please indicate your company's Planned Baseline and Actual Project Schedule by phase:

1. The dates for the planned schedule should be those in effect at the estimate time of contract award. If you cannot provide an exact day for either the planned or actual, estimate to the nearest week.
2. Click on the project phase links below for a description of starting and stopping points for each phase.
3. If this project did not involve a particular phase please select N/A.
4. **If you have incomplete phase information**, please enter as much phase information as you know. You must enter overall project start and stop dates, however. They will not be calculated from phase data.

Project Phase	**Baseline Schedule**		**Actual Schedule**	
	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**
Pre-Project Planning	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Detail Design	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Procurement	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Demolition/Abatement	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Construction	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Startup	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown	◘NA ◘Unknown
Your Project Start and Stop dates	◘Unknown	◘Unknown	◘Unknown	◘Unknown

% Design Complete

What percentage of detailed design workhours was completed prior to total project budget authorization? _____ %

◘ Unknown

What percentage of detailed design workhours was completed prior to start of the construction phase? _____ %

◘ Unknown

2.3. Project Development Changes and Scope Changes

Please record the changes to your project by phase in the table provided below. For each phase indicate the total number, the net cost impact, and the net schedule impact resulting from project development changes and scope changes. Either the owner or contractor may initiate changes.

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis.

Scope Changes include changes in the base scope of work or process basis.

1. Changes should be included in the phase in which they were initiated. Click on the project phase links below for assistance in classifying the changes by project phase. **If you cannot provide the requested change information by phase** but can provide the information for the total project, please fill in the totals field manually, thereby overriding the totaling function. As long as you don't click back into a phase field, your total will be accepted and recoded.
2. Following the cost and schedule impacts, indicate whether the impact was an increase (Inc.) or decrease (Dec.). If no change orders were granted during a phase, write "0" in the "Total Number" columns.

Project Phase	Total Number of Project Development Changes	Total Number of Scope Changes	Cost Increase (+) / Decrease (-) of Project Development Changes	Cost Increase (+) / Decrease (-) of Scope Changes	Schedule Increase (+) / Decrease (-) of Project Development Changes (weeks)	Schedule Increase (+) / Decrease (-) of Scope Changes (weeks)
Design	______ ☐ Unknown	______ ☐ Unknown	$______ ☐ Unknown	$______ ☐ Unknown	______ ☐ Unknown	______ ☐ Unknown
Procurement	______ ☐ Unknown	______ ☐ Unknown	$______ ☐ Unknown	$______ ☐ Unknown	______ ☐ Unknown	______ ☐ Unknown
Demolition/ Abatement	______ ☐ Unknown	______ ☐ Unknown	$______ ☐ Unknown	$______ ☐ Unknown	______ ☐ Unknown	______ ☐ Unknown
Construction	______ ☐ Unknown	______ ☐ Unknown	$______ ☐ Unknown	$______ ☐ Unknown	______ ☐ Unknown	______ ☐ Unknown
Startup	______ ☐ Unknown	______ ☐ Unknown	$______ ☐ Unknown	$______ ☐ Unknown	______ ☐ Unknown	______ ☐ Unknown
Totals	______	______	$______	$______	______	______

2.4. Field Rework

Did you track field rework for this project?

◘Yes ◘No ◘Unknown

1. Please indicate the Direct Cost and Schedule Impact of Field Rework for each source shown below. The **direct cost of field rework** relates to all costs needed to perform the rework itself.
2. If there was no direct cost of field rework for a category, please enter "0".
3. **If you cannot provide the requested information by source**, but can provide the total for the project, please click unknown in the source fields and **enter the project total**. This will override the totaling function. As long as you don't click back into a phase field, your total will be accepted and recorded.

.

Source of Field Rework	Direct Cost of Field Rework	Schedule Impact of Field Rework (weeks)
Design	$ ________ ◘Unknown	________ ◘Unknown
Vendor	$ ________ ◘Unknown	________ ◘Unknown
Owner	$ ________ ◘Unknown	________ ◘Unknown
Contractor	$ ________ ◘Unknown	________ ◘Unknown
Other	$ ________ ◘Unknown	________ ◘Unknown
Total	$ ________	________

3. Practices

3.1. Pre Project Planning

Pre-Project Planning involves the process of developing sufficient strategic information that owners can address risk and decide to commit resources to maximize the chance for a successful project. Pre-project planning includes putting together the project team, selecting technology, selecting project site, developing project scope, and developing project alternatives. Pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, and conceptual planning.

Your Pre-Project Planning score is based on your response to the questions below (4 for owners or 6 for contractors) and to select questions from the PDRI (Project Definition Rating Index) which follows. If you use the PDRI as part of your project planning process, please respond to the following questions and then complete the PDRI (either Industrial, Building, or both) which follow. If you do not desire to use the full PDRI(s), you may obtain your Pre-Project Planning score by completing the questions below (4 for owners or 6 for contractors) and completing only the PDRI questions that are highlighted by italics. You will obtain the same Pre-Project Planning score that you would have received if you completed the full PDRI. Those completing the full PDRI(s) will also receive their score(s) on the 0 to 1000 scale used for PDRI assessments.

Contractor Question Only

Select the response below that best describes your company's participation in the pre-project planning effort.

Did your company participate in the pre-project planning effort?

- ◘ Yes, as the pre-project planner.
- ◘ Yes, as a consultant.
- ◘ No, my company did not participate in the preplanning effort. Please skip following Pre-Project Planning questions and continue with the next best practice (Team Building).

Contractor Question Only

Did your company formally assess the quality of the pre-project planning effort?

Yes ◘ No ◘

Owner and Contractor Questions

Select a number below that best describes the composition of the pre-project planning team using the scale and definitions provided.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

1. **Excellent** – Highly skilled and experienced members with authority; representation from business, project management, technical disciplines, and operations; able to respond to both business and project objectives.
2. **Poor** – Members with a poor combination of skill or experience that lack authority; insufficient representation from business, project management, technical disciplines, and operations; unable to respond to both business and project objectives.

Select a number below that best describes the technology evaluation performed for this project during Pre-Project Planning.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1. **Excellent** – Thorough and detailed identification and analysis of existing and emerging technologies for feasibility and compatibility with corporate business and operations objectives. Scale-up problems and hands-on process experience were considered.
2. **Poor** – Poor or no technology evaluation.

Select a number below that best describes the evaluation of alternate siting locations.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1. **Excellent** – Thorough and detailed assessment of relative strengths and weaknesses of alternate locations to meet owner requirements.
2. **Poor** – Poor or no evaluation of alternate siting locations.

Select a number below that best describes the risk analysis performed for project alternatives.

Poor			Average				Excellent		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
1	2	3	4	5	6	7	8	9	10

1. **Excellent** – Risks associated with the selected project alternatives were identified and analyzed. These analyses included financial/business, regulatory, project and operational risk categories in order to minimize the impacts of risks on project success.

Poor – Poor or no risk analysis performed for project alternatives.

3.1.1. Full Building PDRI

Was a Front End Loading Index used to determine the quality of Pre-Project Planning for this project? (Includes PDRI, FEL, or an in-house developed system.)
Yes ◘ No ◘

Was the Project Definition Rating Index (PDRI) utilized on this project?
Yes ◘ No ◘

If yes, please copy your original responses to the PDRI below, if not, please fill in the PDRI below using existing, available information.

Please complete the following matrix using the ***appropriate definition levels*** given below. Indicate how well defined each element was ***prior to the total project budget authorization*** by selecting the appropriate definition level.

1. Complete definition
2. Minor deficiencies
3. Some deficiencies
4. Major deficiencies
5. Incomplete or poor definition
6. Not Applicable
7. Unknown

Note: If this is an infrastructure project some of the following elements may not apply to your project. Please fill in "Not Applicable" to indicate if any element does not apply to your project. ***Italicized questions will be scored for your Pre-Project Planning Score***

A. Business Strategy	**(1) Complete <---------->Poor (5)**					
	1	2	3	4	5	NA	UNK
A1. ***Building Use***	◘	◘	◘	◘	◘	◘	◘
A2. ***Business Justification***	◘	◘	◘	◘	◘	◘	◘
A3. ***Business Plan***	◘	◘	◘	◘	◘	◘	◘
A4. ***Economic Analysis***	◘	◘	◘	◘	◘	◘	◘
A5. ***Facility Requirements***	◘	◘	◘	◘	◘	◘	◘
A6. ***Future Expansion/Alternate Consideration***	◘	◘	◘	◘	◘	◘	◘
A7. ***Site Selection Consideration***	◘	◘	◘	◘	◘	◘	◘

A8. ***Project Objectives Statement***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B. Owner Philosophies	**(1) Complete <---------->Poor (5)**						
B1. Reliability Philosophy	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B2. Maintenance Philosophy	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B3. Operating Philosophy	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B4. Design Philosophy	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C. Project Requirements	**(1) Complete <---------->Poor (5)**						
C1. Value-Analysis Process	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C2. ***Project Design Criteria***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C3. ***Evaluation of Existing Facilities***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C4. Scope of Work Overview	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C5. Project Schedule	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C6. ***Project Cost Estimate***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D. Site Information	**(1) Complete <---------->Poor (5)**						
D1. Site Layout	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D2. Site Surveys	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D3. ***Civil/Geotechnical Information***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D4. Governing Regulatory Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D5. ***Environmental Assessment***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

D6. Utility Sources with Supply Conditions	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D7. Site Life Safety Considerations	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D8. Special Water and Waste Treatment Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E. Building Programming	**(1) Complete <---------->Poor (5)**						
E1. ***Program Statement***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E2. ***Building Summary Space List***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E3. Overall Adjacency Diagrams	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E4. Stacking Diagrams	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E5. ***Growth and Phased Development***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E6. Circulation and Open Space Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E7. Functional Relationship Diagrams/Room by Room	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E8. Loading/Unloading/Storage Facilities Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E9. Transportation Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E10. ***Building Finishes***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E11. Room Data Sheets	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E12. Furnishings, Equipment, and Built-Ins	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
E13. Window Treatment	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
F. Building/Project Design Parameters	**(1) Complete <---------->Poor (5)**						
F1. Civil/Site Design	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

Item	1	2	3	4	5	NA	UNK
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	**(1) Complete <---------->Poor (5)**						
G1. ***Equipment List***	◘	◘	◘	◘	◘	◘	◘
G2. Equipment Location Drawings	◘	◘	◘	◘	◘	◘	◘
G3. Equipment Utility Requirements/TD>	◘	◘	◘	◘	◘	◘	◘
H. Procurement Strategy	**(1) Complete <---------->Poor (5)**						
H1. Identify Long-Lead/Critical Equip. and Materials	◘	◘	◘	◘	◘	◘	◘
H2. Procurement Procedures and Plans	◘	◘	◘	◘	◘	◘	◘
J. Deliverables	**(1) Complete <---------->Poor (5)**						
J1. CADD/Model Requirements	◘	◘	◘	◘	◘	◘	◘
J2. Documentation/Deliverables	◘	◘	◘	◘	◘	◘	◘
K. Project Control	**(1) Complete <---------->Poor (5)**						
K1. Project Quality Assurance and Control	◘	◘	◘	◘	◘	◘	◘
K2. Project Cost Control	◘	◘	◘	◘	◘	◘	◘

K3. Project Schedule Control	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
K4. ***Risk Management***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
K5. Safety Procedures	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
L. Project Execution Plan	**(1) Complete <---------->Poor (5)**						
L1. Project Organization	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
L2. Owner Approval Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
L3. ***Project Delivery Method***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
L4. ***Design/Construction Plan & Approach***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
L5. Substantial Completion Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

3.1.2. Full Industrial PDRI

Was a Front End Loading Index used to determine the quality of Pre-Project Planning for this project? (Includes PDRI, FEL, or an in-house developed system.)
Yes No

Was the Project Definition Rating Index (PDRI) utilized on this project?
Yes No

Please complete the following matrix using the ***appropriate definition levels*** given below. Indicate how well defined each element ***was prior to the total project budget authorization*** by selecting the appropriate definition level.

1. Complete definition
2. Minor deficiencies
3. Some deficiencies
4. Major deficiencies
5. Incomplete or poor definition
6. Not Applicable
7. Unknown

Note: If this is an infrastructure project some of the following elements may not apply to your project. Please fill in "Not Applicable" to indicate if any element does not apply to your project. ***Italicized questions will be scored for your Pre-Project Planning Score***

Industrial PDRI	**Definition Level at Authorization**						
A. Manufacturing Objectives Criteria	**(1) Complete <---------->Poor (5)**						
A1. ***Reliability Philosophy***	1	2	3	4	5	NA	UNK
A2. Maintenance Philosophy	1	2	3	4	5	NA	UNK
A3. Operating Philosophy	1	2	3	4	5	NA	UNK
B. Business Objectives	**(1) Complete <---------->Poor (5)**						
B1. ***Products***	1	2	3	4	5	NA	UNK
B2. ***Market Strategy***	1	2	3	4	5	NA	UNK
B3. ***Project Strategy***	1	2	3	4	5	NA	UNK
B4. Affordability/Feasibility	1	2	3	4	5	NA	UNK

B5. ***Capacities***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B6. Future Expansion Considerations	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B7. Expected Project Life Cycle	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
B8. Social Issues	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C. Basic Data Research & Development	**(1) Complete <----------->Poor (5)**						
C1. ***Technology***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
C2. ***Processes***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D. Project Scope	**(1) Complete <----------->Poor (5)**						
D1. ***Project Objectives Statement***	Yes	No	NA	UNK			
	◘	◘	◘	◘			
D2. ***Project Design Criteria***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D3. ***Site Characteristics Available vs. Required***	Yes	No	NA	UNK			
	◘	◘	◘	◘			
D4. Dismantling and Demolition Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D5. Lead/Discipline Scope of Work	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
D6. Project Schedule	Yes	No	NA	UNK			
	◘	◘	◘	◘			
E. Value Engineering	**(1) Complete <----------->Poor (5)**						
E1. Process Simplification	Yes	No	NA	UNK			
	◘	◘	◘	◘			
E2. Design & Material Alternatives	Yes	No	NA	UNK			
	◘	◘	◘	◘			
E3. Design for Constructability Analysis	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
F. Site Information	**(1) Complete <----------->Poor (5)**						
F1. ***Site Location***	Yes	No	NA	UNK			
	◘	◘	◘	◘			

F2. Surveys & Soil Tests	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
F3. ***Environmental Assessment***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
F4. Permit Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
F5. ***Utility Sources with Supply Conditions***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
F6. Fire Protection & Safety Considerations	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G. Process/Mechanical	**(1) Complete <---------->Poor (5)**						
G1. ***Process Flow Sheets***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G2. ***Heat & Material Balances***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G3. ***Piping & Instrumentation Diagrams***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G4. Process Safety Management	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G5. Utility Flow Diagrams	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G6. ***Specifications***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G7. Piping System Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G8. ***Plot Plan***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G9. ***Mechanical Equipment List***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G10. Line List	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G11. Tie-In List	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
G12. Piping Specialty Items List	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

G13. Instrument Index	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
H. Equipment Scope	**(1) Complete <---------->Poor (5)**						
H1. ***Equipment Status***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
H2. Equipment Location Drawings	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
H3. Equipment Utility Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
I. Civil, Structural, & Architectural	**(1) Complete <---------->Poor (5)**						
I1. Civil/Structural Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
I2. Architectural Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
J. Infrastructure	**(1) Complete <---------->Poor (5)**						
Water Treatment Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
J2. Loading/Unloading/Storage Facilities Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
J3. Transportation Requirements	Yes		No			NA	UNK
	◘		◘			◘	◘
K. Instrument & Electrical	**(1) Complete <---------->Poor (5)**						
K1. Control Philosophy	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
K2. Logic Diagrams	Yes		No			NA	UNK
	◘		◘			◘	◘
K3. Electrical Area Classifications	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
K4. Substation Requirements Power Sources Identification	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
K5. Electric Single Line Diagrams	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
K6. Instrument & Electrical Specifications	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

L. Procurement Strategy	**(1) Complete <---------->Poor (5)**						
L1. ***Identify Long Lead/Critical Equip. &***	1	2	3	4	5	NA	UNK
Materials	◘	◘	◘	◘	◘	◘	◘
L2. Procurement Procedures and Plans	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
L3. Procurement Responsibility Matrix	Yes		No			NA	UNK
	◘		◘			◘	◘
M. Deliverables	**(1) Complete <---------->Poor (5)**						
M1. CADD/Model Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
M2. Deliverables Defined	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
M3. Distribution Matrix	Yes		No			NA	UNK
	◘		◘			◘	◘
N. Project Control	**(1) Complete <---------->Poor (5)**						
N1. ***Project Control Requirements***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
N2. Project Accounting Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
N3. Risk Analysis	Yes		No			NA	UNK
	◘		◘			◘	◘
P. Project Execution Plan	**(1) Complete <---------->Poor (5)**						
P1. Owner Approval Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
P2. ***Engineering/Construction Plan & Approach***	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
P3. Shut Down/Turn-Around Requirements	Yes		No			NA	UNK
	◘		◘			◘	◘
P4. Pre-Commissioned Turnover Sequence Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
P5. Startup Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
P6. Training Requirements	1	2	3	4	5	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

3.2. Team Building

Team Building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members problem-solving skills.
Unless otherwise indicated, for each question select the single most appropriate response.

1. To what extent was a ***formal*** team building process used for this project?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent did upper management support the ***formal*** team building process (e.g. funding, training, etc.)?

Not at all		Moderately		Extensively	No formal team building used	
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. What was the level of involvement in the team building process of a facilitator who was external to this project?

None		Moderate		Extensive		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. To what extent were objectives of the team building process documented and clearly defined?

Very poorly or not at all		Moderately		Very well		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. To what extent were objectives of the team building process achieved?

Not at all		Moderately		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. To what extent were new team members integrated into team building activities?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. For each project phase, please indicate the extent that your company was involved in the team building process using a scale from 0 to 4, with 0 indicating not at all and 4 indicating extensively.

	Not at all			Extensively			
• Pre-Project Planning	0	1	2	3	4	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
• Design	0	1	2	3	4	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
• Procurement	0	1	2	3	4	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
• Construction	0	1	2	3	4	NA	UNK
	◘	◘	◘	◘	◘	◘	◘
• Startup	0	1	2	3	4	NA	UNK
	◘	◘	◘	◘	◘	◘	◘

8. Please indicate the parties involved in the team building process? (Check all that apply)

◘Owner
◘Engineer(s) & Designer(s)
◘Constructor(s)
◘ Regulator(s)
◘Major Suppliers
◘ Subcontractor(s)
◘Construction Manager
◘Other. If other, please specify:

3.3. Alignment during Pre-Project Planning

Alignment is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives.

For each question, select the single most appropriate response as it pertains to the pre-project planning phase of the project.

1. How appropriately were stakeholders (individuals and organizations who are involved in or may be affected by project activities) represented on the Project Team (e.g., operations, business management, construction, security, etc.)?

Poorly		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

2. How effective was project leadership in aligning team members to meet project objectives?

Not at all		Moderately		Yes, very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

3. How well were project objectives defined and prioritized (cost, quality, security & schedule)?

Poorly		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

4. How effective was the communication within the team?

Not at all		Moderately		Very	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

5. How effective was the communication with stakeholders?

Not at all		Moderately		Very	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

6. How effective were team meetings in achieving project objectives?

Not at all		Moderately		Very productive	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

7. To what extent was a clear reward & recognition system implemented to meet identified project objectives?

Not at all		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

8. How effectively were planning tools (e.g., aide-memoirs, analysis techniques, checklists, simulations, software programs, and work flow diagrams used to plan, develop, control and manage projects) used to promote alignment?

Not at all		Moderately		Very well	
0	1	2	3	4	NA / UNK
◘	◘	◘	◘	◘	◘

3.4. Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction and field operations of a project to achieve the overall project objectives with the best possible time and accuracy, at the most cost-effective levels.
For each question select the single most appropriate response.

1. To what extent was constructability implemented on this project?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent was constructability an element addressed in this project's formal written execution plan?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. Which of the following best describes how constructability principles were emphasized and communicated on this project? (Select only one)

◘No effort to emphasize and communicate

◘Minimum effort through informal means such as on-the-job training

◘Moderate effort as a component of ongoing management training (e.g. part of project management conference)

◘Substantial effort through structured and dedicated formal constructability training

◘Not Applicable

◘Unknown

4. On what basis was a constructability coordinator assigned to this project? (Select only one)

◘ No coordinator assigned

◘Assigned as a part-time responsibility

◘Assigned as a full-time responsibility

◘Not Applicable

◘Unknown

5. Which of the following best describes the constructability program documentation for this project? (Select only one)

- ◘None; no documentation existed.
- ◘Limited reference in any source (e.g. CII reference)
- ◘Project level constructability documents exist; may be included in other corporate documents
- ◘Project constructability manual is available, but neither widely used nor updated
- ◘Project constructability manual is available, widely used and periodically updated
- ◘Not Applicable
- ◘Unknown

6. Which of the following best describes the method(s) used to track lessons learned and saving/effects on this project due to the constructability program? (Select only one)

- ◘No tracking was used.
- ◘Ideas were conveyed via word of mouth and personal interaction; limited tracking of saving/effects
- ◘Some individual documentation existed; selected tracking of saving/ effects
- ◘System existed for capture and communication of lessons learned; extensive tracking of saving/effects
- ◘Not Applicable
- ◘Unknown

7. Please indicate the ***earliest time period*** of the first project meeting that deliberately and explicitly focused on constructability. Place a check below the ***earliest time period*** (Select only one).

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

3.5. Materials Management

Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management systems combine and integrate the takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.

Unless otherwise indicated, select the single most appropriate response for each question.

1. To what extent did this project have a ***designated*** materials management organization that was integrated across project teams?

Not at all / Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. How ***comprehensive*** was the ***written*** materials management plan for this project in addressing elements such as project goals, responsibility, cost & schedule, and transportation?

Not at all / Very Comprehensive

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. How extensively was the written materials management plan utilized throughout the life of the project?

Not at all / Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How adequate was the plan for addressing the effects of change orders on materials management?

Not at all Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. How extensively was an ***automated system*** (or integrated set of computer systems) used to identify, track, report, and facilitate control of project material throughout the life of the project?

Not at all Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. How effective was site materials management during the construction phase?

Not at all Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. How effective was the materials tracking and reporting system?

Not at all Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. How effective were purchasing plans & procedures over the life of the project?

Not at all Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

9. How effective were receipt and inspection procedures for critical materials and equipment?

Not at all Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. How adequate was the pre-qualification process for securing the appropriate suppliers of major equipment and materials?

Not at all / Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. To what extent did the materials management plan utilize quality management practices?

Not at all / Extensively

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. How well were QA/QC plans implemented with the suppliers of major equipment and materials?

Not at all / Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

13. Were there other activities that critically impacted your materials management?

No	Yes	NA	UNK
◘	◘	◘	◘

If yes, please list the activities and indicate whether the impact was positive or negative.

	Negative	Positive
______________________________	◘	◘

3.6. Project Change Management

Change Management is the process of incorporating a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes.
Unless otherwise indicated, select the single most appropriate response for each question.

1. To what extent was a ***formal*** documented change management process used to ***actively*** manage changes on this project? Please answer for each phase.

Not at all — Moderately — Extensively

- Detailed Design

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

- Construction

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

- Startup

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. How often were major changes (i.e., those that exceed a project threshold) required to go through a formal change justification procedure?

Not at all — Sometimes — Always

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. Was authorization for change required before implementation?

No — Sometimes — Always

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How timely was communication of change information to the proper disciplines and project participants?

Not at all — Moderately — Very

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. How well did the project contract identify the primary components and procedures of the project change management system?

Not at all		Moderately		Very well		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. To what extent were areas susceptible to change identified and evaluated for risk during review of the project design basis?

Not at all		Moderately		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. To what extent were changes on this project evaluated against the business drivers and success criteria for the project?

Not at all		Moderately		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. At what point were the criteria for change approval established and communicated to all project participants? Place ***a check*** below the earliest time period (Select only one).

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

9. How often were changes managed against a baseline established at authorization or contract award?

Not at all		Sometimes		Always		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. At project close-out, how extensive was the evaluation of changes and their impact on the project cost and schedule performance for future use as lessons learned?

Not at all		Moderately		Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. Did project personnel settle, authorize, and execute change orders on this project in a timely manner?

Not at all		Sometimes		Always		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. To what extent does the formal change management process establish plans for mitigating cost and schedule impacts?

Not at all		Partially		Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3.7. Zero Accident Techniques

Zero accident techniques include the site specific safety programs and implementation, auditing and incentive efforts to create a project environment and a level of training that embraces the mind set that all accidents are preventable and that zero accidents is an obtainable goal.
For each question, select the single most appropriate response.

1. To what extent has an overall project safety plan been implemented?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent was safety a priority topic at pre-construction and construction meetings?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. To what extent was pre-task planning for safety conducted by contractor foremen or other site managers?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How often were safety toolbox meetings held?

None	Monthly	Bi-weekly	Weekly	Daily	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. How often were safety audits performed by corporate safety personnel?

Annually or Less frequently	Quarterly	Monthly	Biweekly	Weekly	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. Which of the following best describes the time commitment of the site safety supervisor for this project?

No site safety supervisor	Part-time function	Full-time function	NA	UNK
◘	◘	◘	◘	◘

7. Overall how many workers per safety person were typically on site?

Over 200	151 to 200	71 to 150	21 to 70	1 to 20	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. What type of job-specific safety orientation was conducted for new contractor and subcontractor employees?

None	Informal	Formal	NA	UNK
◘	◘	◘	◘	◘

9. On average how much ongoing formal safety training did workers receive each month?

None	Less than 1 hr	1 hr but less than 4 hrs	4 hr but less than 7 hrs	Over 7 hrs	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. To what extent were safety incentives used?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. To what extent was safety performance utilized as criterion for contractor /subcontractor selection?

Not at all		Moderately		Extensively		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. How often were accidents formally investigated?

Not at all		Sometimes		Always		
0	1	2	3	4	No accidents occurred	UNK
◘	◘	◘	◘	◘	◘	◘

13. How often were near-misses formally investigated?

Not at all		Sometimes		Always		
0	1	2	3	4	None occurred	UNK
◘	◘	◘	◘	◘	◘	◘

14. How extensively was senior company management typically involved in the investigation of accidents?

Not at all		Moderately		Extensively		
0	1	2	3	4	No accidents occurred	UNK
◘	◘	◘	◘	◘	◘	◘

15. Were pre-employment substance abuse tests for contractor employees conducted?

Never	Sometimes	Usually	Always	NA	UNK
◘	◘	◘	◘	◘	◘

16. Were contractor employees randomly screened for alcohol and drugs?

Not at all	Once a year or less	Twice a year or more	Quarterly or more	Monthly or more	NA	UNK
◘	◘	◘	◘	◘	◘	◘

17. Were substance abuse tests conducted after accidents?

Never	Sometimes	Usually	Always	No accidents occurred	UNK
◘	◘	◘	◘	◘	◘

18. Were ***reasonable cause substance abuse tests*** for contractor employees conducted?

Never	Sometimes	Usually	Always	NA	UNK
◘	◘	◘	◘	◘	◘

Reasonable cause test: An employee who is reasonably suspected of using alcohol or illegal drugs in the workplace or performing official duties while under the influence of alcohol or illegal drugs will be required to undergo an alcohol and drug test.

3.8. Quality Management

Quality Management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and start-up elements of construction projects.
Unless otherwise indicated, select the single most appropriate response for each question.

1. To what extent did your company implement a formal ***corporate*** Quality Management System (QMS)?

Not at all — Fully Implemented

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. (Owner Only) Rate the degree to which the engineering/construction QMS was considered in the selection process.

Not at all — Moderate — Extensive

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. To what extent were specific quality management goals & objectives included in the prime contract?

Not at all — Entirely

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How extensively were quality management goals and objectives used to determine project reimbursement (e.g. Incentives)?

Not at all — Moderately — Extensively

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. Is the Quality Management System a budgeted item?

No	Yes	NA	UNK
◘	◘	◘	◘

6. To what degree was a formal ***project*** Quality Management System used on this project?

Not at all — Extensively

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. Please indicate the earliest time period of the project that quality management planning was initiated. Place a check below the earliest time period.

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

8. How well was the Quality Management System communicated to key project personnel?

Not at all — Very well

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

9. To what extent was the Quality Management System implemented by key project personnel?

Not at all — Very well

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

10. To what extent were the following elements or resources used to implement the Quality Management system on this project?

	Not Used			Extensively Used			
	0	1	2	3	4	NA	UNK
• External quality services	◘	◘	◘	◘	◘	◘	◘
• Internal quality manager	◘	◘	◘	◘	◘	◘	◘
• Discipline-specific quality program	◘	◘	◘	◘	◘	◘	◘
• Owner's procedures	◘	◘	◘	◘	◘	◘	◘
• Contractor's procedures	◘	◘	◘	◘	◘	◘	◘

11. Does the QA/QC manager for this project have external certification?

No	Yes	NA	UNK
◘	◘	◘	◘

12. To what extent were corrective actions implemented for root cause quality defects?

Not at all Partially Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

13. Which of the following quality management techniques were used on this project by your company? Check all that apply:

______ Statistical methods
______ Audits
______ Quality cost tracking
______ Quality circles/quality improvement teams
______ Quality goals
______ Team building / alignment
______ Customer satisfaction measurement
______ Quality assurance & quality control requirements
______ Post project review
______ Rejection rate analysis
______ Reference documented quality policies and procedures (Quality manual, etc.)
______ Lessons learned systems

14. What are the primary sources of quality problems on this project?
Check all that apply:

_____ Design Engineering
_____ Contractual
_____ Procurement/Materials Management
_____ Specifications
_____ Sub-Contracted scope of services
_____ Craft Labor
_____ Civil/Concrete
_____ Mechanical/Equipment
_____ Electrical/Instrumentation
_____ Piping
_____ Fit-up or Welding
_____ Start-up/Turnover of System
_____ Other(s)

3.9. Automation/Integration (AI) Technology

This section addresses ***the degree of automation/level of use and integration of automated systems*** for specific tasks/work functions common to most projects. Using the first matrix, please assess the degree of automation and level of use ***only***. Using the second matrix, please assess the level of integration of these automated systems among the tasks/work functions.

Referring to the use levels below, indicate how well for this project, the tasks/work functions were automated. Select the single most appropriate ***use level*** for the task/work functions listed.

USE LEVELS

- **Level 1(None/Minimal):** Little or no utilization beyond e-mail.
- **Level 2 (Some):** "Office" equivalent software, 2D CAD for detailed design.
- **Level 3 (Moderate):** Standalone electronic/automated engineering discipline (3D CAD) and project services systems.
- **Level 4 (Nearly Full):** Some automated input/output from multiple databases with automated engineering discipline design and project services systems.
- **Level 5 (Full):** Fully or nearly fully automated systems dominate execution of all work functions.

Automation of Task/Work Functions

	Use Level						
Task/Work Functions	1	2	3	4	5	NA	UNK
Business planning and analysis	◘	◘	◘	◘	◘	◘	◘
Conceptual definition & design	◘	◘	◘	◘	◘	◘	◘
Project (discipline) definition & facility design	◘	◘	◘	◘	◘	◘	◘
Supply management	◘	◘	◘	◘	◘	◘	◘
Project management							
Coordination system	◘	◘	◘	◘	◘	◘	◘
Communications system	◘	◘	◘	◘	◘	◘	◘
Cost system	◘	◘	◘	◘	◘	◘	◘
Schedule system	◘	◘	◘	◘	◘	◘	◘
Quality system	◘	◘	◘	◘	◘	◘	◘
Off-site/pre-construction	◘	◘	◘	◘	◘	◘	◘
Construction	◘	◘	◘	◘	◘	◘	◘
As-built documentation	◘	◘	◘	◘	◘	◘	◘
Facility start-up & life cycle support	◘	◘	◘	◘	◘	◘	◘

Referring to the use levels below, indicate how well for this project, the tasks/work functions were ***integrated across all other*** work functions. Select the single most appropriate ***integration level*** for the task/work functions listed.

USE LEVELS

- **Level 1(None/Minimal):** Little or no integration of electronic systems/applications.
- **Level 2 (Some):** Manual transfer of information via hardcopy of email.
- **Level 3 (Moderate):** Manual and some electronic transfer between automated systems.
- **Level 4 (Nearly Full):** Most systems are integrated with significant human intervention for tracking inputs/outputs.
- **Level 5 (Full):** All information is stored on a network system accessible to all automation systems and users. All routine communications are automated. The automated process and discipline design systems are fully integrated into 3D design, supply management, and project services systems (cost, schedule, quality, and safety).

Integration of Task/Work Functions

	Integration Level					
Task/Work Functions	1	2	3	4	5	NA	UNK
Business planning & analysis	◘	◘	◘	◘	◘	◘	◘
Conceptual definition & design	◘	◘	◘	◘	◘	◘	◘
Project (discipline) definition & facility design	◘	◘	◘	◘	◘	◘	◘
Supply management	◘	◘	◘	◘	◘	◘	◘
Project management							
Coordination system	◘	◘	◘	◘	◘	◘	◘
Communications system	◘	◘	◘	◘	◘	◘	◘
Cost system	◘	◘	◘	◘	◘	◘	◘
Schedule system	◘	◘	◘	◘	◘	◘	◘
Quality system	◘	◘	◘	◘	◘	◘	◘
Off-site/pre construction	◘	◘	◘	◘	◘	◘	◘
Construction	◘	◘	◘	◘	◘	◘	◘
As-built documentation	◘	◘	◘	◘	◘	◘	◘
Facility start-up & life cycle support	◘	◘	◘	◘	◘	◘	◘

3.10. Planning for Startup

Startup is the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Planning for Startup consists of a sequence of activities that begins during requirements definition and extends through initial operations. This section assesses the level of Startup Planning by evaluating the degree of implementation of specific activities throughout the various phases of a project.

Please select the single most appropriate response to each question below.

1. How well were startup objectives communicated?

Not at all				Very well		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

2. To what extent was a formal startup execution plan implemented?

Not at all				Very extensive		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

3. To what extent were commissioning plans developed during planning for startup?

None were developed				Developed for All systems		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. How clearly were startup team key roles & responsibilities communicated?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

5. To what extent was the startup schedule logic based on systems and sub-systems?

Not at all				Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

6. To what extent was the startup schedule logic aligned with the EPC schedule?

Not at all Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

7. To what extent were startup needs incorporated in procurement requirements?

Not at all Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

8. To what extent were suppliers for startup services pre-qualified?

Not at all Fully

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

9. Please indicate the ***earliest time period*** of the first project meeting that deliberately and explicitly focused on planning for startup. Place a check below the ***earliest time period*** (Select only one).

Pre-Project Planning			Detail Design/ Procurement			Construction			NA	UNK
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late		
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

10. How often were the startup risks assessed?

Not at all Sometimes Continuously

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

11. To what extent was formal operator/maintenance training conducted?

Not at all Extensively

0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

12. How extensive was the system turnover plan?

Not at all				Very		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

13. To what extent were startup and Process Safety Management (PSM) procedures communicated?

Not at all				Fully		
0	1	2	3	4	NA	UNK
◘	◘	◘	◘	◘	◘	◘

4. Engineering Productivity Metrics

General Instructions

CII currently has two approaches to measuring engineering productivity. Direct measures developed by the CII Benchmarking & Metrics Committee are captured in the sections below as work-hours and quantities to produce ratios of inputs to outputs. Indices developed by Project Team 192 use selected quantities and reported discipline work-hours to establish discipline level metrics from predictive equations. Both systems are in validation and benchmarking participants are encouraged to submit data where possible to produce metrics using both approaches until sufficient data are available to assess a preferred method.

Please enter data at the most detailed level possible to produce the most meaningful metrics. If you cannot input data for the breakouts, please enter totals where possible. To keep the system as simple as possible and to minimize user burden, a toggle switch is provided at the end of most sections to enable input for production of the PT 192 indices. The PT 192 additional questions are additive; therefore to produce the PT 192 indices, you must also enter as a minimum the category totals for each section. All metrics are in the validation stage; therefore the user should apply caution when interpreting results produced. The PT 192 indices should be interpreted for groups of projects only, not individual projects. For more discussion on the use of these indices, please see IR- 192-2.

Instructions for Computation of Work-Hours and Rework-Hours

Work-hours are computed by the summation of all the account hours that are listed as **Direct** in the following table. All the account hours listed as **Indirect** are to be **excluded** from the work-hours that are submitted in the productivity data for the following sections.

Direct work-hours should include all detailed design hours used to produce deliverables including site investigations, meetings, planning, constructability, RFIs, etc., and rework. Specifically exclude work-hours for operating manuals and demolition drawings. Engineering work-hours reported should only be for the categories requested and may not equal the total engineering work-hours for the project.

Exclude the following categories: architectural design, plumbing, process design, civil/site prep, HVAC, insulation and paint, sprinkler/deluge systems, etc. Within a category, direct work-hours that cannot be specifically assigned into the provided classifications, and have not been excluded, should be prorated based on known work-hours or quantities as appropriate. Please review this table completely before providing data in the following sections.

	Direct	Indirect
Account	Discipline Engineer	Document Control
	Designer	Reproduction Graphics
	Technician	Project Management
		Project Controls (cost/schedule/estimating)
		Project Engineer
		Secretary/clerk
		Procurement (supply management)
		Construction Support (test package support, commissioning, etc.)
		Quality Assurance
		Accounting
		Legal

4.1. Concrete

Instructions

Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The quantity of concrete is that concrete that is required for the specified slab, foundation, or structure provided in the final Issued for Construction (IFC) drawings.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for a detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.

2D ( )
3D ( )

Slabs	**None**	**IFC Quantity (cubic yards)**	**Engineering Work-Hours (including rework) (hours)**
Ground & Supported Slabs			
Area Paving			
Total Slabs			

Foundations	**None**	**IFC Quantity**	**Engineering Work-Hours (including rework) (hours)**
Piling (each)			
Foundations (< 5CY) (cubic yards)			
Foundations (>= 5CY) (cubic yards)			
Total Foundations (CY) (Excluding piling)			

Concrete Structures	**None**	**IFC Quantity (cubic yards)**	**Engineering Work-Hours (including rework) (hours)**
Concrete Structures			
Concrete Structures include concrete structures, columns, beams, cooling tower basins, trenches, formed elevated slabs/structures, and retaining walls.			

Total Concrete	None	IFC Quantity (cubic yards)	Engineering Work-Hours (including rework) (hours)
Total Concrete			

Rework-Hours
Please provide rework hours, if available. If you can not provide source breakout, then enter total only.

Source of Rework-Hours for Concrete	Rework-Hours (hours)
Design	
Vendor	
Owner	
Other: _______________	
Total	

PT 192 Metrics (Concrete):

Please enter total quantity of concrete(CY) excluding deep foundations: ______________

PT 192 Metrics (Civil):

Please enter the following data:

- Civil Structural total work-hours: ____________________
- Total building area(SF):_____________________________
- Number of piers and caissons (Each): _________________

4.2. Structural Steel

Instructions

Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If possible, separate data for structural steel, pipe racks & utility bridges and miscellaneous steel. If you can not separate structural steel from pipe racks & utility bridges, combine these data in the space provided below. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The quantity of steel is that quantity of steel provided in the final Issued for Construction (IFC) drawings.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.

2D ( )
3D ( )

Structural Steel	**None**	**IFC Quantity (tons)**	**Engineering Work-Hours (including rework) (hours)**
Structural Steel			
This includes trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts.			
Pipe Racks & Utility Bridges			
This includes steel structures outside the physical boundaries of a major structure, which are used to support pipe, conduit, and/or cable tray.			
Combined Structural Steel / Pipe Racks & Utility Bridges*			
* Enter combined structural steel and pipe racks & utility bridges if you cannot separate the quantities above.			
Miscellaneous Steel			
This includes handrails, toeplate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, pre-mounted ladders and platforms, miscellaneous support steel including scab on supports, "T" and "H" type supports, trench covers, and Q decking.			
Total Steel			
This is the total of structural steel, pipe racks & utility bridges, and miscellaneous steel from above or the total of combined structural steel, pipe racks & utility bridges (if not separated) and miscellaneous steel. If you have quantities for steel not included in the breakouts above, include them in the totals here.			

Rework-Hours
Please provide rework hours, if available. If you can not provide source breakout, then enter total only.

Source of Rework-Hours for Steel	Rework- Hours (hours)
Design	
Vendor	
Owner	
Other: _______________	
Total	

4.3. Electrical

Instructions

Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

- Total Direct Engineering Electrical Work-Hours for This Project _________
- Total Connected Horsepower of Motors _________
- Number of Motors _________
- Total KVA Load of Project _________

The quantity of electrical equipment, conduit, cable trays, wire, termination, and lighting fixtures are the quantity of each provided in the final Issued for Construction (IFC) drawings.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.

2D ( )
3D ( )

Electrical Equipment	None	IFC Quantity (each)	Engineering Work-Hours (including rework) (hours)
Electrical Equipment 600V & Below			
Electrical Equipment Over 600V			
Electrical equipment includes transformers, switchgear, UPS systems, MCCs, rectifiers, motors, generators, etc. This also includes work-hours for single line, elementary diagrams and studies.			
Total Electrical Equipment			

Conduit		None	IFC Quantity	Engineering Work-Hours (including rework) (hours)
Conduit	Linear Feet			
	Number of Runs			
This includes power plan, cable and conduit schedule and interconnects. Exposed / aboveground and underground				

Cable Tray	None	IFC Quantity (linear feet)	Engineering Work-Hours (including rework) (hours)
Cable Tray			
This includes electrical and instrument cable trays, channels, supports, covers, etc.			

Wire & Cable		None	IFC Quantity	Engineering Work-Hours (including rework) (hours)
Wire & Cable (w/o conduit or tray)	Linear Feet			
	Number of Terminations			
This includes power, control and grounding cables.				

Other Electrical Metric	None	IFC Quantity (each-Fixtures)	Engineering Work-Hours (including rework) (hours)
Lighting			
This includes fixtures, conduit, wiring, panels, and control devices. Quantity to be number of fixtures.			

Rework-Hours

Please provide rework hours, if available. If you can not provide source breakout, then enter total only.

Source of Rework-Hours for Electrical	Rework-Hours (hours)
Design	
Vendor	
Owner	
Other: ______________	
Total	

PT 192 Metrics (Electrical):

Please enter the Number of Generators (EA): ______________

4.4. Piping

Instructions

Please complete the following tables indicating quantity, percent hot and cold, and engineering work-hours for the categories appropriate to your project. Piping includes under ground pressure pipe. **Exclude tubing**. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The quantity of piping is that piping specified in the final Issued for Construction (IFC) drawings. This quantity should not be "cut lengths" but should be measured "center-to-center" through valves and fittings as with the quantity for the construction metric. Most "CADD dumps" are cut lengths. The quantity should be adjusted to be the length measured as noted above.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.

2D ( )
3D ( )

Piping	None	IFC Quantity	Percent Hot and Cold (%)	Engineering Work-Hours (including rework) (hours)
Small Bore (2-1/2" and Smaller) (linear feet)				
Large Bore (3" and Larger) (linear feet)				
Engineered Hangers and Supports (each) (Includes stress analysis)				
Number of pipe fittings*				
Total Piping (linear feet only)				

* Elbows, flanges, reducers, branch connection fittings e.g. o-lets, saddles etc., Y's, T's, caps, unions, couplings, etc.
** Total piping quantity is linear feet only. The total piping work-hours include those hours for small & large bore piping, engineered hangers and supports and fittings.

Rework-Hours

Please provide rework hours, if available. If you can not provide source breakout, then enter total only.

Source of Rework-Hours for Piping	Rework- Hours (hours)
Design	
Vendor	
Owner	
Other: _______________	
Total	

PT 192 Metrics (Piping):

Please enter total direct engineering piping work-hours: ________________

Please enter Total Hangers and Supports (engineered & standard): ___________________________

4.5. Instrumentation

Instructions

Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The quantity of instrumentation is that quantity provided in the final Issued for Construction (IFC) drawings.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.

2D ( )

3D ( )

Instrumentation	**None**	**IFC Quantity**	**Engineering Work-Hours (including rework) (hours)**
Loops (count)			
Tagged Devices (count)			
I/O (count)			
This includes all instrument and control design work-hours except DCS/PLC Configuration and Programming. I/O (count) includes the I/O that comes over digital communication interfaces from outside of the control system. For such interfaces, count the addressable points. For fieldbus interfaces, count only the devices.			
◘ DCS/PLC Design included			
DCS/PLC Configuration and Programming			

Rework-Hours

Please provide rework hours, if available. If you can not provide source breakout, then enter total only.

Source of Rework-Hours for Instrumentation	**Rework-Hours (hours)**
Design	
Vendor	
Owner	
Other: _______________	
Total	

PT 192 Metrics (Instrumentation):

Total direct engineering instrumentation work-hours: ___________________

4.6. Equipment

Instructions

Please complete the following tables indicating quantity and engineering work-hours for the categories appropriate to your project. If you cannot enter all data then enter totals only. Include rework in the work-hours only. If the project had no workhours or quantities for a category, enter none.

The Total Quantity of equipment is the quantity of tagged items provided in the final Issued for Construction (IFC) drawings with vendor designed skids being counted as a single item. The Individually Designed quantity is the quantity defined by unique data sheets. For example, pump P201a/b is one unique data sheet, but is a total of two items.

These hours include only mechanical discipline hours.

Refer to the section "Instructions for Computation of Work-Hours and Rework-Hours" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the work-hours.

Which design platform was used for this category in this project? Check all that apply.

2D ( )
3D ( )

Pressure Vessels	**None**	**Individually Designed (each)**	**Total Quantity (each)**	**Engineering Work-Hours (including rework) (hours)**
This includes tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Field fabricated towers, columns, reactors and regenerators are to be included.				

Atmospheric Tanks	**None**	**Individually Designed (each)**	**Total Quantity (each)**	**Engineering Work-Hours (including rework) (hours)**
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic & low temperature tanks and miscellaneous other atmospheric tanks.				

Heat Transfer Equipment	**None**	**Individually Designed (each)**	**Total Quantity (each)**	**Engineering Work-Hours (including rework) (hours)**
This includes heat exchangers, fin fan coolers, evaporators, cooling towers and miscellaneous other heat transfer equipment.				

Boiler & Fired Heaters	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)	Total (BTU/Hr)
This includes packaged boilers, field erected boilers, fired heaters, waste heat boilers, stand-alone stacks, and miscellaneous other boilers and fired heaters.					

Rotating Equipment (w/drivers)	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)	Total (horsepower)
This includes compressors (centrifugal/reciprocating), blowers, screw rotary compressors, metering/in-line pumps, pumps (centrifugal/reciprocating), positive displacement pumps, agitators, mixers, blenders and other miscellaneous compressors, fans and pumps.					

Material Handling Equipment (w/drivers)	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)
This includes conveyors (belt, chain, screen, rotor, etc.), cranes & hoists, scales, lifts, stackers, reclaimers, ship loaders, compactors, feeders and baggers, and miscellaneous other material handling equipment.				

Power Generation Equipment	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours))	Total (kilo-watts)
This includes gas turbines, steam turbines, diesel generators, and other miscellaneous power generation equipment.					

Pulp & Paper Equipment	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)
Woodyard Equipment				
Pulp Mill Equipment				
Bleach Plant Equipment				
Stock Preparation Equipment				
Wet End Equipment (through the Presses)				
Dryer Sections				
Dry End Equipment including Roll Wrap/Converter Equipment				
Total Pulp & Paper Equipment				
This includes all paper machines and miscellaneous other pulp & paper equipment.				

Other Process Equipment	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)
This includes specialty gas equipment, bulk chemical equipment, process equipment, particle extraction (bag houses, scrubbers, etc.), treatment systems (water treatment, etc.), incinerators, and flares/flare systems.				

Vendor-Designed Modules & Pre-Assembled Skids	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)
This includes modules (partial units) and complete skids units.				

Total Equipment Count*	None	Individually Designed (each)	Total Quantity (each)	Engineering Work-Hours (including rework) (hours)**
Skids & modules with multiple equipments are counted still as a single entry. * Total equipment count may include items not identified above. ** This is total mechanical discipline direct work-hours.				

Rework-Hours

Please provide rework hours, if available. If you can not provide source breakout, then enter total only.

Source of Rework-Hours for Equipment	Rework-Hours (hours)
Design	
Vendor	
Owner	
Other: ______________	
Total	

5. Construction Productivity Metrics

Instructions for Computation of Actual Work-Hours and Rework-Hours

Actual work-hours are computed by the summation of all the account hours that are listed as **Direct** in the following table. All the account hours listed as **Indirect** are to be **excluded** from the actual work-hours that are submitted in the productivity data for the following sections. Actual work-hours should **include** hours for rework. If you track actual rework-hours, please record this information at the end of each section where requested. Please review this table completely before providing data in the following sections.

	Direct	Indirect	
Account	Direct Craft Labor	Accounting	Procurement
	Foreman	Area Superintendent	Process Equipment Maintenance
	General Foreman	Assistant Project Manager	Project Controls
	Load and Haul	Bus Drivers	Project Manager
	Oilers	Clerical	QA/QC
	Operating Engineer	Craft Planners	Quantity Surveyors
	Safety Meetings	Craft Superintendent	Receive and Offload
	Scaffolding	Craft Training	Recruiting
	Truck Drivers Direct	Crane Setup/take down	Safety
		Document Control	Safety Barricades
		Drug Testing	Security
		Equipment Coordinator	Show-up Time
		Evacuation Time	Site Construction Manager
		Field Administration Staff	Site Maintenance
		Field Engineer-Project	Subcontract Administrator
		Field Staff (Hourly)	Supervision (Hourly)
		Field Staff (Salary)	Surveying Crews
		Fire Watch	Temporary Facilities
		Flag Person	Temporary Utilities
		General Superintendent	Test Welders
		Hole Watch	Tool Room
		Janitorial	Truck Drivers Indirect
		Job Clean-Up	Warehouse
		Master Mechanic	Warehousing
		Material Control	Water Hauling
		Mobilization	
		Nomex Distribution	
		Orientation Time	
		Payroll Clerks/ Timekeepers	

5.1 Concrete

Instructions

Please complete the following tables indicating installed neat quantity and work-hours (**including rework**) for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. Also, please record the total rework-hours with source information if available where requested at the end of the section.

Include work-hours for the following selected activities:
Loading material at the jobsite yard, hauling to, and unloading at the job work site; local layout, excavation and backfill, fabrication, installation, stripping and cleaning forms; field installation of reinforcing material; field installation of all embeds; all concrete pours, curing, finishing, rubbing, mud mats; and anchor bolt installation.

Do not include work hours for:
Piling, drilled piers, well points and major de-watering, concrete fireproofing, batch plants, non-permanent roads and facilities, third party testing, mass excavations, rock excavations, site survey, q-deck, sheet piles, earthwork shoring, cold pour preparation, grouting, pre-cast tees, panels, decks, vaults, manholes, etc.

Definitions

The **Installed Neat Quantity** of concrete is that concrete that is required for the specified slab, foundation, or structure provided in the project's plans and specifications and does not include any quantity of concrete that is used due to rework.
Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.

Slabs	None	Subcontracted (Yes or No)	Installed Quantity (cubic yards)	Actual Work-Hours (including rework) (hours)
On-Grade				
Elevated Slabs/On Deck				
Area Paving				
Total Slabs				

Foundations	None	Subcontracted (Yes or No)	Installed Quantity (cubic yards)	Actual Work-Hours (including rework) (hours)
< 5 cubic yards				
5 – 20 cubic yards				
21– 50 cubic yards				
> 50 cubic yards				
Total Foundations				

Concrete Structures	None	Subcontracted (Yes or No)	Installed Quantity (cubic yards)	Actual Work-Hours (including rework) (hours)
Concrete Structures				
This Includes concrete structures, columns, beams, cooling tower basins, trenches, formed elevated slabs/structures, and retaining walls.				

Total Concrete	None	Subcontracted (Yes or No)	Installed Quantity (cubic yards)	Actual Work-Hours (including rework) (hours)
Total Concrete				

Rework-Hours

Source of Rework-Hours for Concrete	Rework-Work (hours)
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

5.2 Structural Steel

Instructions

Please complete the following tables indicating installed quantity and work-hours (**including rework**) for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. Also, please record the total rework-hours with source information if available where requested at the end of the section.

This includes work-hours for the following selected activities:
Shake-out, transporting, erection, plumbing, leveling, bolting, and welding.

Do not include work-hours for:
Fabrication, demolition, and architectural work, such as roofing, siding and vents.

Definitions

The **Installed Quantity** of steel is that quantity of steel provided in the project's plans and specifications and does not include any quantity of steel that is used due to rework. Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.

Structural Steel	None	Subcontracted (Yes or No)	Installed Quantity (tons)	Actual Work-Hours (including rework) (hours)
Structural Steel				
This includes trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts.				
Pipe Racks & Utility Bridges				
This includes steel structures outside the physical boundaries of a major structure, which is used to support pipe, conduit, and/or cable tray.				
Miscellaneous Steel				
This includes handrails, toeplate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, pre-mounted ladders and platforms, miscellaneous support steel including scab on supports, "T" and "H" type supports, trench covers, and Q decking.				
Total Structural Steel				

Rework-Hours

Source of Rework-Hours for Steel	Rework-Hours (hours)
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

5.3. Electrical

Instructions

Please complete the following tables indicating installed quantity and work-hours **(including rework)** for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. Also, please record the total rework-hours with source information if available where requested at the end of the section.

<u>This includes work-hours for the following selected activities:</u>
Installation, testing, labeling, etc.

Definitions

The **Installed Quantity** of electrical equipment, devices, conduit and cable trays are the quantity of each provided in the project's plans and specifications and does not include any quantity that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.

- Total Direct Electrical Work-Hours for This Project _________
- Total Connected Horsepower of Motors _________
- Number of Motors _________
- Total KVA Load of Project _________

Electrical Equipment and Devices	**None**	**Subcontracted (Yes or No)**	**Installed Quantity (each)**	**Actual Work-Hours (including rework) (hours)**
Panels and Small Devices				
This includes all labor for the installation of lighting and power panels, dry type transformers, control stations (pushbuttons, small local panels, etc.), welding receptacles and their supports. Count includes only actual electrical devices - not supports.				
Electrical Equipment 600V & Below				
Electrical Equipment Over 600V				
Total Electrical Equipment				
This includes all labor for the installation of transformers, switchgear, UPS systems, MCCs, DCS/PLC racks and panels, etc.				

Instructions for calculation of Weighted-Average Diameter of Conduit (Hyperlink)

Conduit	None	Subcontracted (Yes or No)	Installed Quantity (lineal feet)	Actual Work-Hours (including rework) (hours)
Exposed or Aboveground Conduit				
This includes all labor for installation of conduit, hangers, supports, fittings, flexible connections, marking, grounding jumpers, seals, boxes, etc. This excludes lighting conduit.				
Underground, Duct Bank or Embedded Conduit				
This includes all labor for installation of conduit, supports, grounding jumpers, etc. Does not include excavation, backfill, concrete, manholes, etc.				
Total Conduit				

Instructions for calculation of Weighted-Average Size of Cable Tray (Hyperlink)

Cable Tray	None	Subcontracted (Yes or No)	Weighted Average Size (width in inches)	Installed Quantity (lineal feet)	Actual Work Hours (including rework) (hours)
Cable Tray					
This includes all labor for the installation of tray, channel, supports, covers, grounding jumpers, marking, etc. It does not include fire stop or cable tray for instrument wire and cable.					

Wire and Cable	None	Subcontracted (Yes or No)	Installed Quantity (lineal feet)	Actual Work-Hours (including rework) (hours)
Power and Control Cable - 600V & below				
This includes all labor for the installation, termination, labeling, and testing of 600V and below power and control cable. It does not include heat-tracing cable.				
Power Cable – 5 & 15KV				
This includes all labor for the installation, termination, labeling, and testing of medium voltage power cables.				
Total Wire and Cable				

Other Electrical	None	Sub-contracted (Yes or No)	Installed Quantity	Actual Work-Hours (including rework) (hours)
Lighting (each-Fixtures)				
This includes all labor for the installation of fixtures (including lamps and supports) and for the installation of conduit and wiring from the lighting panel to the fixtures. Includes any control equipment, switches, conduit, wiring and accessories installed on the load side of the lighting panel. Installation of lighting panels is included in Panels and Small Devices and power feeder wiring for the panel is included in Power and Control Cable - 600V.				
Grounding (lineal feet)				
This includes all the labor for the installation of cable, ground rods, connectors and all accessories for the installation of conduit and wiring from the lighting panel to the fixtures. Includes work hours for the installation of ground cables pulled into cable trays, duct banks, and installed exposed in electric or other rooms. The footage is based on the total footage of ground cable installed.				
Electrical Heat Tracing (lineal feet)				
This includes the labor for the installation of electric heat trace cable, power feeds to the cable, control accessories, end of line devices, connectors, tape or other strapping/support materials, and any other items needed to complete the heat trace system. Footage is based on the lineal footage of process and utility piping heat traced.				

Rework-Hours

Source of Rework-Hours for Electrical	Rework-Hours (hours)
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

5.4. Piping

Instructions

Please complete the following tables indicating the weighted-average diameter in inches, the installed quantity, percent shop fabricated, percent hot and cold, and work-hours (**including rework**) for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. Also, please record the total rework-hours with source information if available where requested at the end of the section.

Include work-hours for the following selected activities:
Erecting and installing large bore piping, including welding, valves, in-line specials, flushing/hydro testing, tie-ins (excluding hot taps), material handling (from the laydown yard to the field), in-line devices, specialties, equipment operators, and hangers & supports.

Do not include work-hours for:
Non-destructive evaluation (NDE), steam tracing, stress relieving, underground piping, offloading pipe as it is received, commissioning, and field fabrication of large bore.

Definitions

The **Installed Quantity** of piping is that piping specified in the project's plans and specifications and does not include any quantity of piping that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.
Instructions for calculation of Small Bore Weighted-Average Diameter (Hyperlink)

Small Bore (2-1/2" and Smaller)
- Field and Shop Fabricated and Field Run (Excludes Tubing)

Small Bore	**None**	**Sub-contracted (Yes or No)**	**Weighted-Average Diameter (inches)**	**Installed Quantity (lineal feet)**	**Actual Work-Hours (including rework) (hours)**	**Percent Shop Fabricated (%)**
Carbon Steel						
Stainless Steel						
Chrome						
Other Alloys						
Total Small Bore						

In the following sections for large bore piping the following definitions apply for hot and cold piping. **Hot piping** is that piping which has a design temperature greater than 250 degrees Fahrenheit. **Cold piping** is that piping which has a design temperature less than minus 20 degrees Fahrenheit.

Instructions for calculation of ISBL and OSBL Large Bore Weighted-Average Diameter (Hyperlink)

Inside Battery Limits (ISBL) Large Bore (3" and Larger) (Excludes Tubing)

Large Bore (ISBL)	Weighted -Average Diameter (inches)	Average Wall Thickness (schedule)	Installed Quantity (lineal feet)	Actual Work-Hours (including rework) (hours)	% Shop Fabricated (%)	% Hot and Cold (%)
Carbon Steel						
Stainless Steel						
Chrome						
Other Alloys						
Total Large Bore (ISBL)						

Outside Battery Limits (OSBL) Large Bore (3" and Larger) (Excludes Tubing)

Large Bore (OSBL)	Weighted -Average Diameter (inches)	Average Wall Thickness (schedule)	Installed Quantity (lineal feet)	Actual Work-Hours (including rework) (hours)	% Shop Fabricated (%)	% Hot and Cold (%)
Carbon Steel						
Stainless Steel						
Chrome						
Other Alloys						
Total Large Bore (OSBL)						

Rework-Hours

Source of Rework-Hours for Piping	Rework-Hours (hours)
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

5.5 Instrumentation

Instructions

Please complete the following tables indicating installed quantity and work-hours (**including rework**) for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. Also, please record the total rework-hours with source information if available where requested at the end of the section.

<u>This includes work-hours for the following selected activities:</u>
Installation, calibration, testing, check out, and otherwise field certify the devices. A device is a physical device that has a tag number. This category includes process tubing, instrument air tubing, cable trays, conduits, instrument wire and cable, junction boxes, etc.

<u>Do not include work-hours for:</u>
DCS, software, installation of in-line devices, programming and configuration.

Definitions

The **Installed Quantity** of instrumentation is that quantity provided in the project's plans and specifications and does not include any quantity of instrumentation that is used due to rework.
Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.

Instrumentation	None	Subcontracted (Yes or No)	Installed Quantity	Actual Work-Hours (including rework) (hours)
Loops (count)				
Devices (Instruments, count)				
Unit of measure: Dual – Each based on loop check quantity. Each based on field-installed devices.				
Instrumentation wire and cable (lineal feet)				

Rework-Hours

Source of Rework-Hours for Instrumentation	**Rework-Hours (hours)**
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

5.6 Equipment

Instructions

Please complete the following tables indicating installed quantity and work-hours (**including rework**) for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. If equipment is preassembled on-skids – Do not include in the equipment count. Also, please record the total rework-hours with source information if available where requested at the end of the section.

Definitions

The **Installed Quantity** of equipment is that quantity provided in the project's plans and specifications and does not include any quantity of equipment that is used due to rework. Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.

Pressure Vessels	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Weight (tons)
Pressure Vessels					
This includes tray/packed towers, columns, reactors/regenerators, and miscellaneous other pressure vessels. Work-hours should include installation of trays and packing if installed in the field. Field fabricated towers, columns, reactors and regenerators are not to be included.					

Atmospheric Tanks – Shop Fabricated	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Capacity (tons)
Atmospheric Tanks – Shop Fabricated					
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic & low temperature tanks and miscellaneous other atmospheric tanks. Include all shop built-up and field-erected tanks. Excluded are field fabricated and assembled tanks.					

Atmospheric Tanks – Field Fabricated	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Capacity (tons)
Atmospheric Tanks –Field Fabricated					
This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic and low temperature tanks, and other miscellaneous atmospheric tanks.					

Heat Transfer Equipment	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Weight (tons)
Heat Transfer Equipment					
This includes heat exchangers, fin fan coolers, evaporators, package cooling towers and miscellaneous other heat transfer equipment.					

Boiler & Fired Heaters	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total (MBTU)
Boiler & Fired Heaters					
This includes packaged boilers, field erected boilers, fired heaters, waste heat boilers, stand-alone stacks, and miscellaneous other boilers and fired heaters.					

Rotating Equipment (w/drivers)	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total (horse-power)
Rotating Equipment (w/drivers)					
This includes compressors (centrifugal/reciprocating), blowers, screw rotary compressors, metering/in-line pumps, pumps (centrifugal/reciprocating), positive displacement pumps, agitators, mixers, blenders and other miscellaneous compressors, fans and pumps.					

Material Handling Equipment (w/drivers)	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Weight (tons)
Material Handling Equipment (w/drivers)					
This includes conveyors (belt, chain, screen, rotor, etc.), cranes & hoists, scales, lifts, stackers, reclaimers, ship loaders, compactors, feeders and baggers, and miscellaneous other material handling equipment.					

Power Generation Equipment	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total (kilo-watts)
Power Generation Equipment					
This includes gas turbines, steam turbines, diesel generators, and other miscellaneous power generation equipment.					

Pulp & Paper Equipment	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Weight (tons)
Woodyard Equipment					
Pulp Mill Equipment					
Bleach Plant Equipment					
Stock Preparation Equipment					
Wet End Equipment (through the Presses)					
Dryer Sections					
Dry End Equipment including Roll Wrap/Converter Equipment					
Total Pulp & Paper Equipment					
This includes all paper machines and miscellaneous other pulp & paper equipment.					

Other Process Equipment	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Weight (tons)
Other Process Equipment					
This includes specialty gas equipment, bulk chemical equipment, process equipment, particle extraction (bag houses, scrubbers, etc.), treatment systems (water treatment, etc.), incinerators, and flares/flare systems.					

Modules & Pre-Assembled Skids	None	Sub-contracted (Yes or No)	Installed Quantity (each)	Actual Work-Hours (including rework) (hours)	Total Weight (tons)
Modules & Pre-Assembled Skids					
This includes modules (partial units) and complete skids units.					

Rework-Hours

Source of Rework-Hours for Equipment	Rework-Hours (hours)
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

5.7 Insulation

Instructions

Please complete the following tables indicating average thickness or diameter, installed quantity, and work-hours (**including rework**) for the categories appropriate to your project and indicate if the work performed for each category was subcontracted or not. If work performed for a category was both subcontracted and in-house, indicate the type that was more predominate. Also, please record the total rework-hours with source information if available where requested at the end of the section.

Definitions

The **Installed Quantity** of insulation is that quantity of insulation that is required for the equipment and piping provided in the project's plans and specifications and does not include any quantity of insulation that is used due to rework.

Refer to the section "**Instructions for Computation of Actual Work-Hours and Rework-Hours**" for an additional detailed listing of direct hours to be included and indirect hours that are to be excluded from the computation of the actual work-hours.

Equipment

This includes work-hours for the following selected activities:
Installation of insulation, jacketing overall vessels, tanks, exchangers, etc.; installation of equipment blankets for pumps, exchangers, etc.; material handling.

Insulation	None	Subcontracted (Yes or No)	Average Thickness (inches)	Installed Quantity (square feet of insulated area)	Actual Work-Hours (including rework) (hours)
Equipment					

Piping

This includes work-hours for the following selected activities:
Installation of insulation and jacketing over pipe, valves and fittings; installation of valve insulation blankets and flange insulation.

Instructions for calculation of Weighted-Average Diameter of Piping with Insulation (Hyperlink)

Insulation	None	Sub-contracted (Yes or No)	Weighted -Average Diameter (inches)	Average Thickness (inches)	Installed Quantity (equivalent linear feet)	Actual Work-Hours (including rework) (hours)
Piping						
ELF – Equivalent Linear Feet of insulation applied to piping. Multiple layers count only one time in linear footage.						

Rework-Hours

Source of Rework-Hours for Insulation	Rework-Hours (hours)
Design	
Vendor	
Owner	
Contractor	
Other	
Total	

6. CLOSEOUT

6.1. Workhours and Accident Data

On January 31st, 2002 OSHA instituted significant changes to safety record keeping and reporting requirements. Please refer to OSHA for the new rules and definitions. A good comparison of the old and new rules may be found at:

http://www.osha.gov/recordkeeping/RKside-by-side.html and

http://www.osha.gov/recordkeeping/RKmajorchanges.html

The CII Benchmarking committee has redesigned the safety performance section so that you may report incidences accurately whether you are using the old OSHA 200 or the new OSHA 300 log.

For your Direct – Hire Employees and your Subcontractor Employees:
In the spaces below, please record the **Total OSHA Number of Recordable Incident Cases.** From that number, please break down the **Number of Injuries,** the **Number of Illnesses** and the **Number of Fatalities.** Also record the **Total Number of OSHA DART Cases,** broken out by the **Number of Days Away Cases** and the **Number of Restricted/Transfer Cases.**
Next please record the number of **Near Misses,** the **Total Site Workhours,** the **Percentage of Overtime Hours,** and the **Number of Hours in Your Normal Work Week.**

1. Use the U.S. Department of Labor's OSHA definitions for recordable injuries and lost workday cases among this project's workers. If you do not track in accordance with these definitions, click Unknown in the boxes below.

2. A consolidated project OSHA 300 log is the best source for the data.

6.1.1. YOUR DIRECT-HIRE EMPLOYEES

Total OSHA Number Recordable Incident Cases (Injuries, Illnesses, Fatalities, Transfers and Restrictions)	**Please breakdown the total number of Recordable Incident Cases by:**	**Number of OSHA DART Cases (Days Away, Restricted or Transferred)**
________ Total Recordables ◘Unknown	________ Injuries ________ Illnesses ________ Fatalities ◘Unknown	________ Days Away Cases ________ Restricted Cases ________ Transfer Cases ◘Unknown

Near Misses Near Misses are common at many worksites. They do not result in injury-but they may cause property damage. If, say, an employee had been in a slightly different position or place, or the equipment or product placement had been to the left or right, serious injury and/or damages could have resulted. A lot depends on sheer luck and circumstance (Heberle, 1998). How many near misses occurred? ______________________ ◘ Unknown
Total Site Workhours _____________________ ◘ Unknown
Percentage of Overtime Hours What percentages of the workhours were "**overtime**" - above your normal work week? If the actual percentage cannot be calculated, please provide your best assessment. Answer Unknown only if you cannot make a reasonable assessment. ________________ (%) ◘ Unknown
Hours in Normal Work Week Please indicate the number of hours in your normal work week. ________________ ◘ Unknown

6.1.2. SUBCONTRACTOR EMPLOYEES

Total OSHA Number Recordable Incident Cases (Injuries, Illnesses, Fatalities, Transfers and Restrictions)	**Please breakdown the total number of Recordable Incident Cases by:**	**Number of OSHA DART Cases (Days Away, Restricted or Transferred)**
________ Total Recordables ◘ Unknown	________ Injuries ________ Illnesses ________ Fatalities ◘ Unknown	________ Days Away Cases ________ Restricted Cases _________Transfer Cases ◘Unknown

Near Misses

Near Misses are common at many worksites. They do not result in injury-but they may cause property damage. If, say, an employee had been in a slightly different position or place, or the equipment or product placement had been to the left or right, serious injury and/or damages could have resulted. A lot depends on sheer luck and circumstance (Heberle, 1998).

How many near misses occurred? ____________________

◘ Unknown

Total Site Workhours ____________________

◘ Unknown

Percentage of Overtime Hours

What percentages of the workhours were "**overtime**" - above your normal work week? If the actual percentage cannot be calculated, please provide your best assessment. Answer Unknown only if you cannot make a reasonable assessment.

_______________ (%)

◘ Unknown

Hours in Normal Work Week

Please indicate the number of hours in your normal work week.

____

◘ Unknown

6.2. Project Environment Impacts

The following section is intended to assess whether environmental factors adversely or positively affected project performance ***beyond the conditions for which you planned.***

Impacts may be assessed ranging from “highly negative”, to “highly positive”. If the factor was adequately planned for, please indicate “As Planned”. If it was not planned for, please indicate the impact, positive or negative. Negative impacts adversely affect the metrics and positive impacts favorably affect the metrics.

Weather

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Labor Skill

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Labor Availability

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Materials Availability

☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Site Conditions

☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Complexity

☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Regulatory Requirements

☐ N/A ☐ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK					☐ N/A ☐ UNK				

Project Team Experience

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Project Team Turnover

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Detailed Engineering Design Location (Use of Offshore Engineering)

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Business Market Conditions

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

Coordination with Plant Shutdown

◘ N/A ◘ UNK

Cost					Schedule					Safety					Construction Productivity					Engineering Productivity				
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘
Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos	Hi Neg	Neg	As Planned	Pos	Hi Pos
◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK					◘ N/A ◘ UNK				

6.3. Practices Wrap-up

Please evaluate the overall effectiveness for each practice you used in this project.

Pre-Project Planning

Pre-Project Planning involves the process of developing sufficient strategic information that owners can address risk and decide to commit resources to maximize the chance for a successful project. Pre-project planning includes putting together the project team, selecting technology, selecting project site, developing project scope, and developing project alternatives. Pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, and conceptual planning.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Pre-Project Planning*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Team Building

Team Building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members problem-solving skills.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Team Building*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Alignment during Pre-Project Planning

Alignment is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Alignment during Pre-Project Planning Practices*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction and field operations of a project to achieve the overall project objectives with the best possible time and accuracy, at the most cost-effective levels.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Constructability*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Materials Management

Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management systems combine and integrate the takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.

On a scale of 0 to 10, with 0 indicating no effectiveness and 10 indicating excellent effectiveness please rate ***the overall effectiveness of Materials Management*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Change Management

Change Management is the process of incorporating a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of Project Change Management*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Zero Accident Techniques

Zero accident techniques include the site specific safety programs and implementation, auditing and incentive efforts to create a project environment and a level of training that embraces the mind set that all accidents are preventable and that zero accidents is an obtainable goal.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of the Safety Program*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Quality Management

Quality Management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and start-up elements of construction projects.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess *the overall effectiveness of Quality Management* on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Automation/Integration (AI) Technology

The Automation and Integration Technology practice addresses the degree of automation/level of use and integration of automated systems for predefined tasks/work functions common to most projects.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess *the overall effectiveness of Automation/Integration Technology Practices* on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Planning for Startup

Startup is the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Planning for Startup consists of a sequence of activities that begins during requirements definition and extends through initial operations. This section assesses the level of Startup Planning by evaluating the degree of implementation of specific activities throughout the various phases of a project.

On a scale of 0 to 10, with 0 indicating not effective and 10 indicating very effective, please assess ***the overall effectiveness of the Planning for Startup process*** on this project.

0	1	2	3	4	5	6	7	8	9	10	NA	UNK
◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘	◘

Appendix C: Data Submission by Company

Table C.1A Engineering Productivity Data Submission by Company

Company	Projects	Pct	Ground Slab	Pct	Area paving	Pct	Total Slab	Pct
Company A	3	3.45%	1	6.25%		0.00%	1	4.55%
Company B	1	1.15%		0.00%		0.00%		0.00%
Company C	1	1.15%	1	6.25%		0.00%	1	4.55%
Company D	5	5.75%		0.00%		0.00%		0.00%
Company E	11	12.64%	4	25.00%	1	10.00%	5	22.73%
Company F	17	19.54%		0.00%		0.00%		0.00%
Company G	1	1.15%	1	6.25%		0.00%	1	4.55%
Company H	3	3.45%		0.00%		0.00%		0.00%
Company I	5	5.75%		0.00%		0.00%		0.00%
Company J	1	1.15%		0.00%	1	10.00%	1	4.55%
Company K	2	2.30%	1	6.25%	1	10.00%	2	9.09%
Company L	3	3.45%	2	12.50%	1	10.00%	2	9.09%
Company M	1	1.15%		0.00%	1	10.00%	1	4.55%
Company N	2	2.30%		0.00%		0.00%		0.00%
Company O	3	3.45%	2	12.50%	2	20.00%	2	9.09%
Company P	4	4.60%	3	18.75%	1	10.00%	3	13.64%
Company Q	18	20.69%		0.00%		0.00%		0.00%
Company R	4	4.60%	1	6.25%	2	20.00%	3	13.64%
Company S	1	1.15%		0.00%		0.00%		0.00%
Company T	1	1.15%		0.00%		0.00%		0.00%
Grand Total	87	100.00%	16	100.00%	10	100.00%	22	100.00%
# of companies	20		9		8		10	

Table C.1B Engineering Productivity Data Submission by Company

Company	Total Foundation	Pct	Concrete Structures		Total Concrete	Pct	Total Steel	Pct
Company A		0.00%	1	7.69%	1	2.50%	3	7.14%
Company B		0.00%		0.00%		0.00%		0.00%
Company C		0.00%		0.00%	1	2.50%		0.00%
Company D		0.00%		0.00%		0.00%	3	7.14%
Company E	3	17.65%	4	30.77%	8	20.00%	10	23.81%
Company F		0.00%		0.00%		0.00%		0.00%
Company G	1	5.88%		0.00%	1	2.50%		0.00%
Company H		0.00%		0.00%	1	2.50%	2	4.76%
Company I		0.00%		0.00%	1	2.50%	1	2.38%
Company J	1	5.88%	1	7.69%	1	2.50%	1	2.38%
Company K	2	11.76%	1	7.69%	2	5.00%	2	4.76%
Company L	2	11.76%	1	7.69%	3	7.50%	3	7.14%
Company M		0.00%	1	7.69%	1	2.50%	1	2.38%
Company N		0.00%	1	7.69%	1	2.50%	2	4.76%
Company O	2	11.76%	1	7.69%	2	5.00%	3	7.14%
Company P	2	11.76%		0.00%	3	7.50%	3	7.14%
Company Q		0.00%		0.00%	9	22.50%	3	7.14%
Company R	4	23.53%	2	15.38%	4	10.00%	4	9.52%
Company S		0.00%		0.00%		0.00%		0.00%
Company T		0.00%		0.00%	1	2.50%	1	2.38%
Grand Total	17	100.00%	13	100.00%	40	100.00%	42	100.00%
# of companies	8		8		15		14	

Table C.1C Engineering Productivity Data Submission by Company

Company	Electrical Equipment =<600V	Pct	Electrical Equipment >600V	Pct	Total Electrical Equipment	Pct
Company A	2	11.11%		0.00%	2	8.70%
Company B		0.00%		0.00%		0.00%
Company C		0.00%		0.00%		0.00%
Company D	1	5.56%		0.00%	1	4.35%
Company E	3	16.67%		0.00%	3	13.04%
Company F		0.00%		0.00%		0.00%
Company G		0.00%		0.00%		0.00%
Company H		0.00%		0.00%		0.00%
Company I		0.00%		0.00%		0.00%
Company J	1	5.56%	1	9.09%	1	4.35%
Company K	2	11.11%	2	18.18%	2	8.70%
Company L	1	5.56%	2	18.18%	2	8.70%
Company M	1	5.56%	1	9.09%	1	4.35%
Company N	1	5.56%	1	9.09%	1	4.35%
Company O	1	5.56%	1	9.09%	1	4.35%
Company P	2	11.11%		0.00%	2	8.70%
Company Q		0.00%		0.00%	3	13.04%
Company R	3	16.67%	3	27.27%	4	17.39%
Company S		0.00%		0.00%		0.00%
Company T		0.00%		0.00%		0.00%
Grand Total	18	100.00%	11	100.00%	23	100.00%
# of companies	10		7		11	

Table C.1D Engineering Productivity Data Submission by Company

Company	Conduit (LF)	Pct	Conduit (No. of Runs)	Pct	Wire and Cable (LF)	Pct	Wire and Cable (No. of Termination)	Pct
Company A	1	2.78%	1	8.33%	2	5.26%	2	10.53%
Company B		0.00%		0.00%		0.00%		0.00%
Company C		0.00%		0.00%		0.00%		0.00%
Company D		0.00%		0.00%		0.00%		0.00%
Company E	8	22.22%	2	16.67%	9	23.68%	4	21.05%
Company F	1	2.78%	1	8.33%	1	2.63%	1	5.26%
Company G		0.00%		0.00%		0.00%		0.00%
Company H		0.00%		0.00%		0.00%		0.00%
Company I		0.00%		0.00%		0.00%		0.00%
Company J	1	2.78%		0.00%	1	2.63%		0.00%
Company K	2	5.56%		0.00%	2	5.26%	1	5.26%
Company L	2	5.56%	2	16.67%	3	7.89%	3	15.79%
Company M	1	2.78%	1	8.33%	1	2.63%	1	5.26%
Company N	1	2.78%		0.00%	2	5.26%	1	5.26%
Company O	1	2.78%	1	8.33%	1	2.63%	1	5.26%
Company P	2	5.56%	2	16.67%		0.00%	1	5.26%
Company Q	12	33.33%		0.00%	12	31.58%	1	5.26%
Company R	4	11.11%	2	16.67%	4	10.53%	3	15.79%
Company S		0.00%		0.00%		0.00%		0.00%
Company T		0.00%		0.00%		0.00%		0.00%
Grand Total	36	100.00%	12	100.00%	38	100.00%	19	100.00%
# of companies	11		7		10		10	

Table C.1E Engineering Productivity Data Submission by Company

Company	Lighting	Pct	Small Bore	Pct	Large Bore	Pct	Total Piping	Pct
Company A	2	9.09%	2	5.56%	3	7.32%	3	4.35%
Company B		0.00%		0.00%		0.00%		0.00%
Company C		0.00%	1	2.78%	1	2.44%	1	1.45%
Company D		0.00%	4	11.11%	4	9.76%	4	5.80%
Company E	6	27.27%	4	11.11%	4	9.76%	11	15.94%
Company F		0.00%	12	33.33%	16	39.02%	16	23.19%
Company G		0.00%		0.00%		0.00%		0.00%
Company H		0.00%		0.00%		0.00%	2	2.90%
Company I		0.00%		0.00%		0.00%	3	4.35%
Company J	1	4.55%	1	2.78%	1	2.44%	1	1.45%
Company K	2	9.09%	1	2.78%	1	2.44%	2	2.90%
Company L	3	13.64%	2	5.56%	2	4.88%	3	4.35%
Company M	1	4.55%	1	2.78%	1	2.44%	1	1.45%
Company N	2	9.09%	2	5.56%	2	4.88%	2	2.90%
Company O	1	4.55%	2	5.56%	2	4.88%	3	4.35%
Company P	1	4.55%	2	5.56%	2	4.88%	2	2.90%
Company Q		0.00%		0.00%		0.00%	10	14.49%
Company R	3	13.64%	2	5.56%	2	4.88%	4	5.80%
Company S		0.00%		0.00%		0.00%	1	1.45%
Company T		0.00%		0.00%		0.00%	1	1.45%
Grand Total	22	100.00%	36	100.00%	41	100.00%	70	100.00%
# of companies	9		13		13		17	

Table C.1F Engineering Productivity Data Submission by Company

Company	Loops	Pct	Tagged Devices	Pct	I/O	Pct
Company A	1	3.23%	2	4.35%	1	2.70%
Company B		0.00%	1	2.17%	1	2.70%
Company C	1	3.23%	1	2.17%	1	2.70%
Company D		0.00%	4	8.70%	5	13.51%
Company E	7	22.58%	9	19.57%	5	13.51%
Company F		0.00%		0.00%		0.00%
Company G	1	3.23%	1	2.17%	1	2.70%
Company H		0.00%	1	2.17%		0.00%
Company I		0.00%	1	2.17%		0.00%
Company J	1	3.23%	1	2.17%	1	2.70%
Company K	2	6.45%	2	4.35%	1	2.70%
Company L	3	9.68%	3	6.52%	3	8.11%
Company M	1	3.23%	1	2.17%	1	2.70%
Company N		0.00%	2	4.35%	1	2.70%
Company O	2	6.45%	3	6.52%	3	8.11%
Company P	2	6.45%	2	4.35%	2	5.41%
Company Q	6	19.35%	8	17.39%	6	16.22%
Company R	2	6.45%	3	6.52%	4	10.81%
Company S	1	3.23%	1	2.17%	1	2.70%
Company T	1	3.23%	1	2.17%		0.00%
Grand Total	31	100.00%	47	100.00%	37	100.00%
# of companies	13		18		15	

Table C.1G Engineering Productivity Data Submission by Company

Company	Total Equipment (Individually Designed)	Pct	Total Equipment (Total Quantity)	Pct
Company A	1	2.44%	1	1.89%
Company B		0.00%	1	1.89%
Company C	1	2.44%	1	1.89%
Company D		0.00%		0.00%
Company E	6	14.63%	6	11.32%
Company F	12	29.27%	12	22.64%
Company G		0.00%		0.00%
Company H		0.00%	1	1.89%
Company I		0.00%	4	7.55%
Company J	1	2.44%	1	1.89%
Company K	2	4.88%	2	3.77%
Company L	3	7.32%	3	5.66%
Company M	1	2.44%	1	1.89%
Company N	2	4.88%	2	3.77%
Company O	2	4.88%	2	3.77%
Company P	3	7.32%	3	5.66%
Company Q	6	14.63%	9	16.98%
Company R		0.00%	2	3.77%
Company S	1	2.44%	1	1.89%
Company T		0.00%	1	1.89%
Grand Total	41	100.00%	53	100.00%
# of companies	12		17	

Appendix D: Scatter Plots between Eng. Work-Hours and IFC Quantities

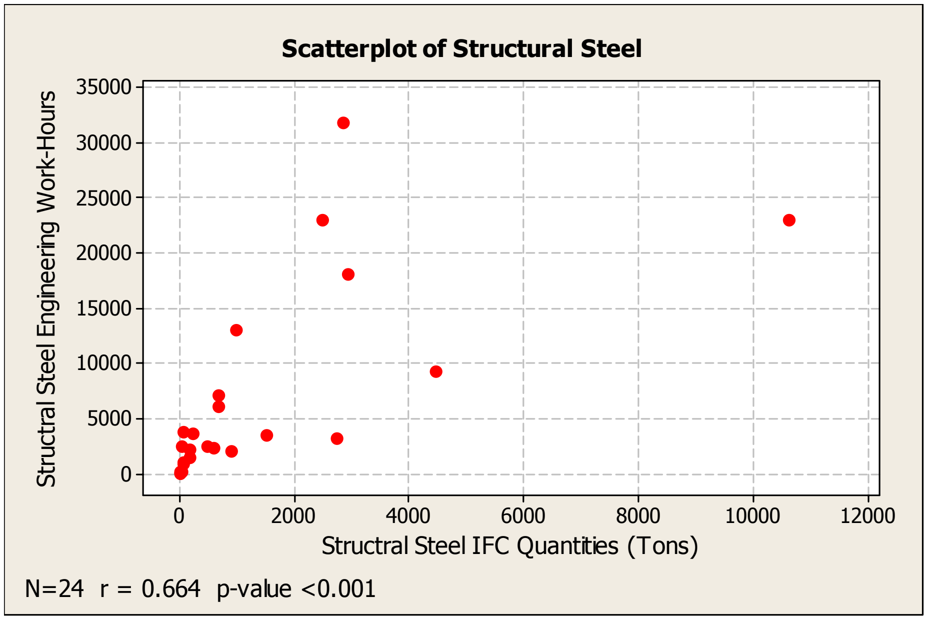

Figure D.1 Scatter Plot of Structural Steel Eng. Wk-Hrs vs. IFC Quantities

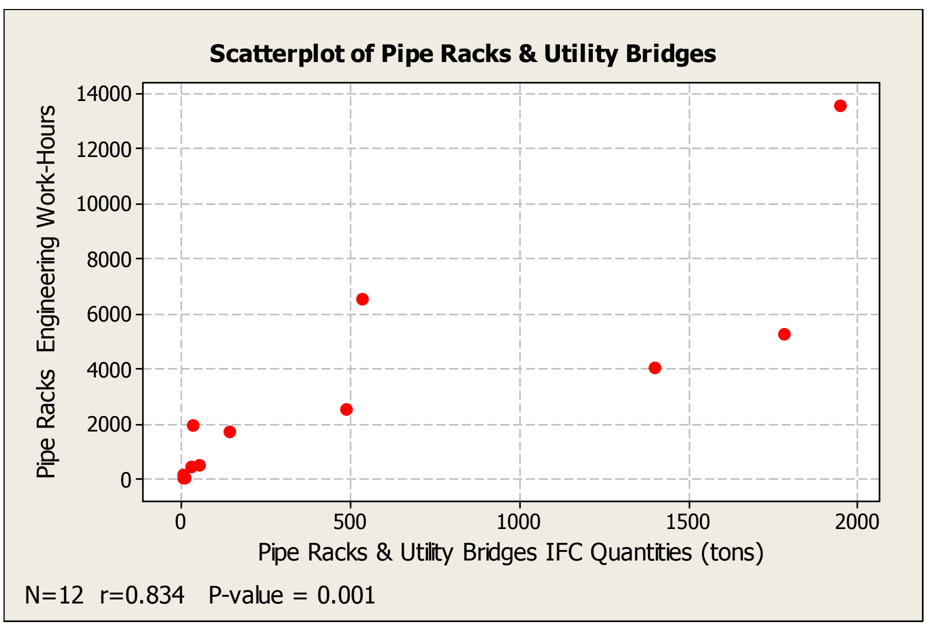

Figure D.2 Scatter Plot of Pipe Racks & Utility Bridges Eng. Wk-Hrs vs. IFC Quantities

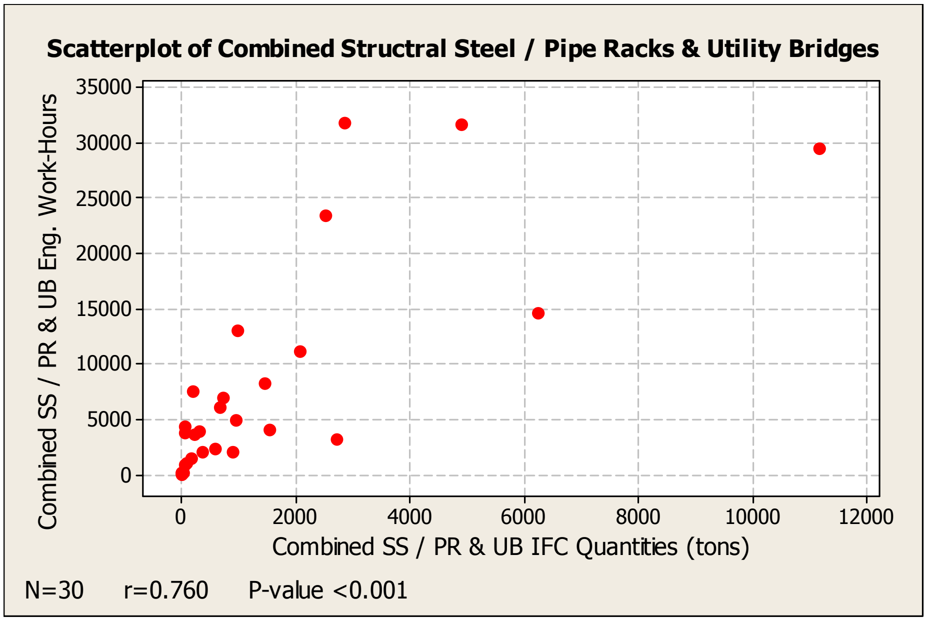

Figure D.3 Scatter Plot of Combined Structural Steel / Pipe Racks & Utility Bridges Eng. Wk-Hrs vs. IFC Quantities

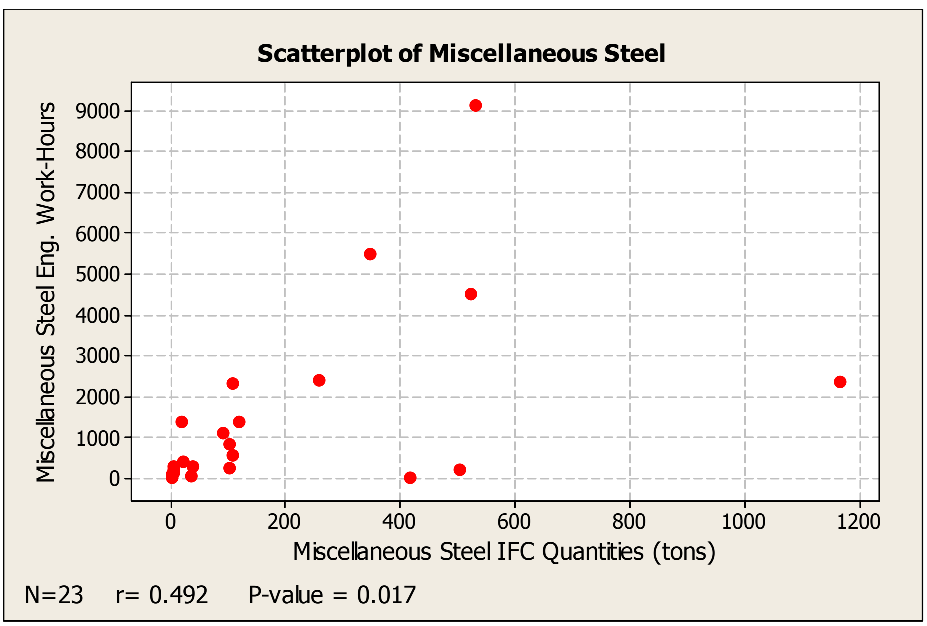

Figure D.4 Scatter Plot of Miscellaneous Steel Eng. Wk-Hrs vs. IFC Quantities

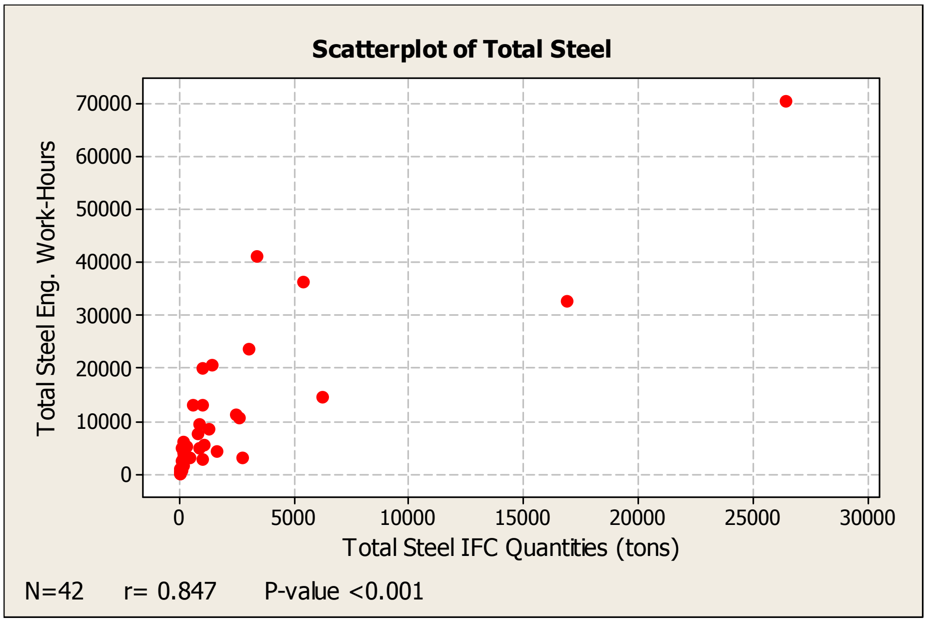

Figure D.5 Scatter Plot of Total Steel Eng. Wk-Hrs vs. IFC Quantities

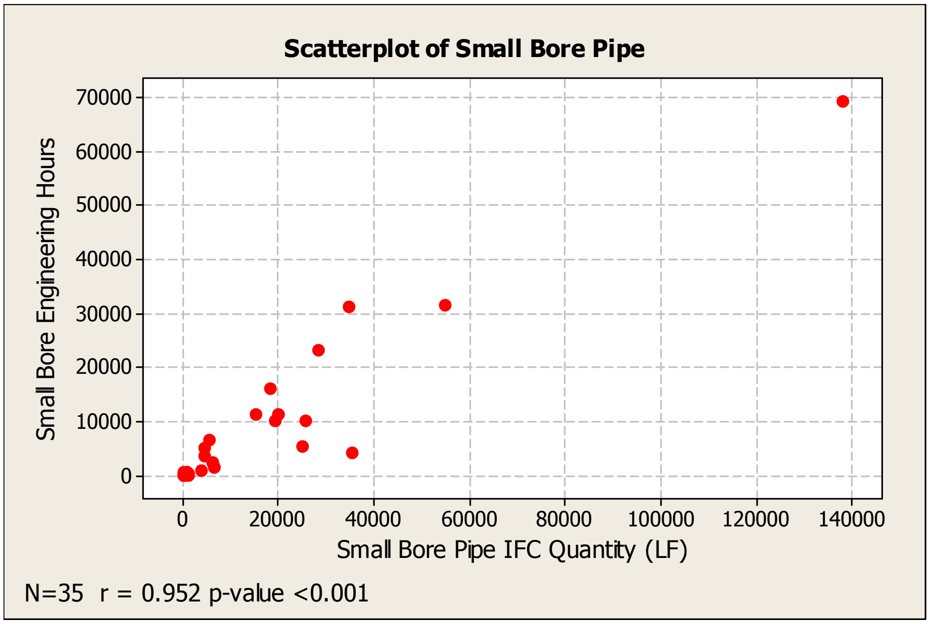

Figure D.6 Scatter Plot of Small Bore Pipe Eng. Wk-Hrs vs. IFC Quantities

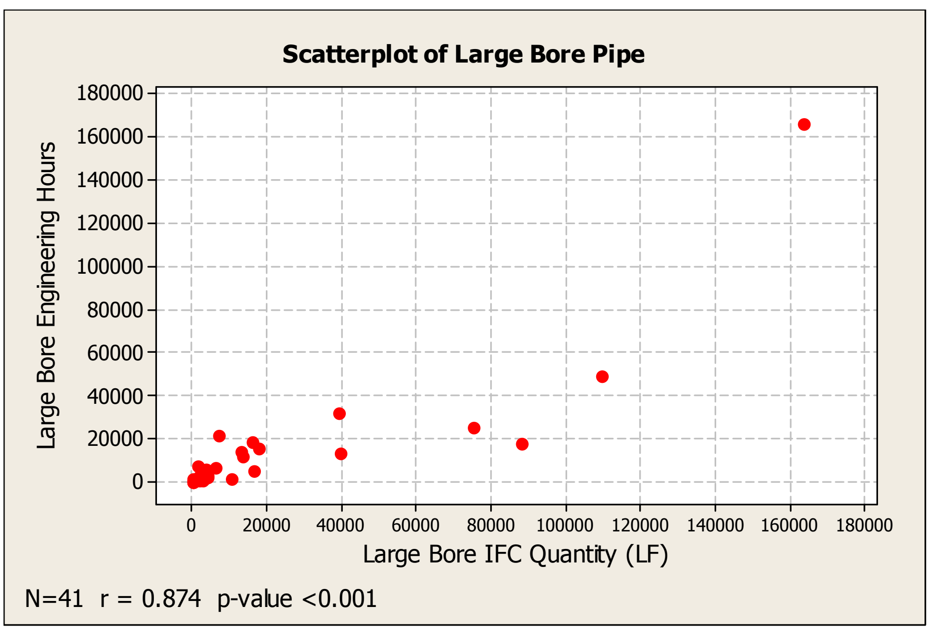

Figure D.7 Scatter Plot of Large Bore Pipe Eng. Wk-Hrs vs. IFC Quantities

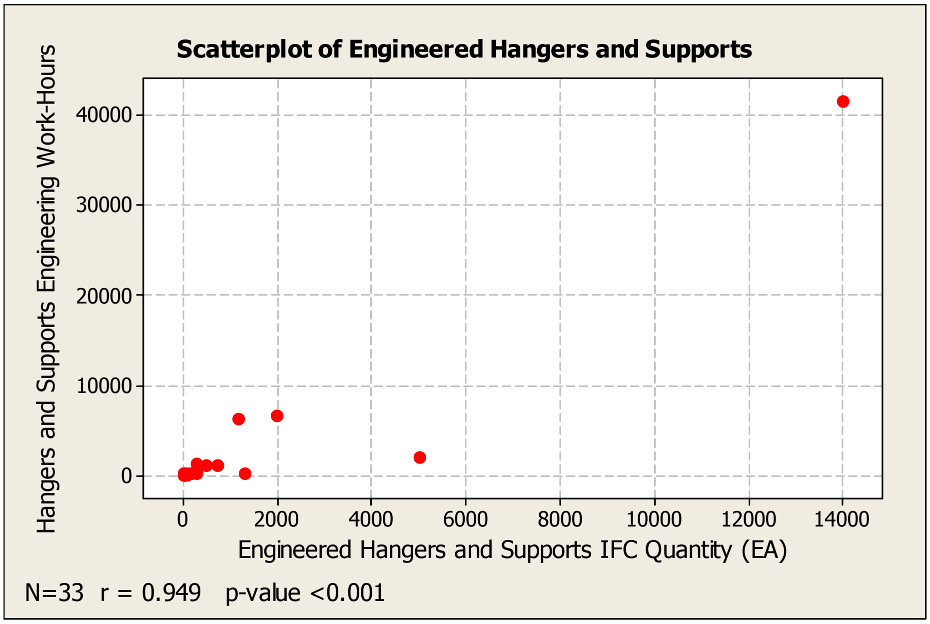

Figure D.8 Scatter Plot of Engineered Hangers and Supports Eng. Wk-Hrs vs. IFC Quantities

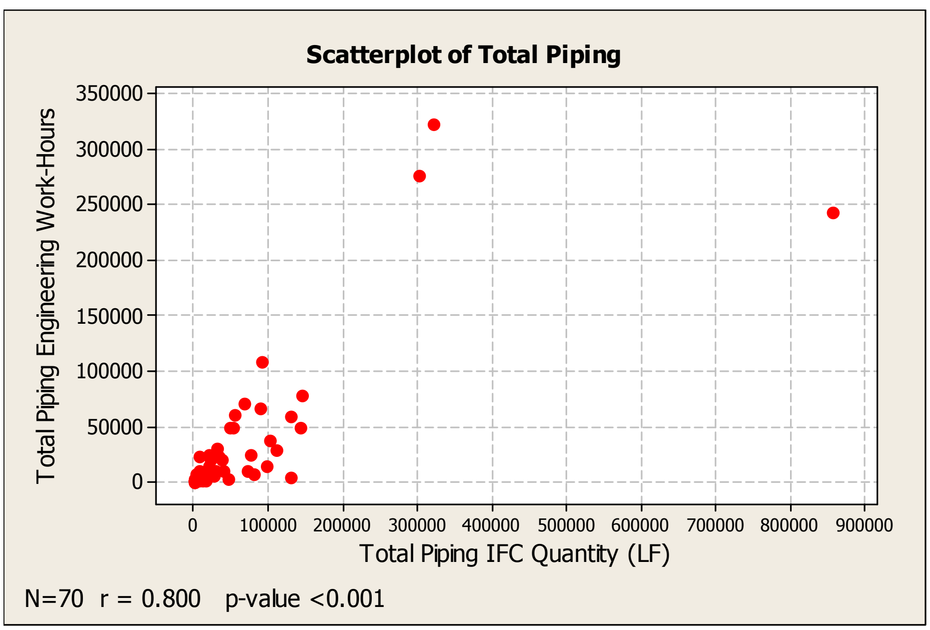

Figure D.9 Scatter Plot of Total Piping Eng. Wk-Hrs vs. IFC Quantities

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Inho Kim was born in Inchon, Korea on September 3, 1972. He is a son of Bock-Nam Kim and Ok-Yeon Lee. After graduating from Seo-Inchon high school, Inchon, Korea, in 1991, he entered Inha University, Korea. From January 1993 to July 1994, he fulfilled his military obligation. During his senior year in college, he studied at the Georgia Institute of Technology and attended the Language program in Atlanta. He earned the degree of Bachelor of Science in Civil Engineering in February 1998. After graduation, he received a honor scholarship to the Graduate School of Inha University where he majored in Construction Management and received his Master of Science in Civil Engineering with honors in August 1999. He joined the Korean Institute of Construction Technology as a researcher in January, 2000 and gained valuable research experience. In 2001, he enrolled in the Ph. D. degree program in Civil Engineering (Construction Engineering and Project Management) at the University of Texas at Austin. Since June 2001, he has worked with Benchmarking & Metrics Committee at Construction Industry Institute.

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