An Internal Benchmarking and Metrics (BM&M) Model for Industrial Construction Enterprise to Understand the Impact of Practices Implementation Level on Construction Productivity

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Construction productivity improvement is a key concern for construction companies and the industry. Productivity in construction is a complex issue because: (1) it is influenced by multiple factors interactively; and (2) it is measured in different forms and at different levels of detail for different purposes. This objective of this research is to develop an internal Benchmarking and Metrics (BM&M) model for industrial construction enterprises to help them understand and implement mechanisms for continuously improving construction productivity. Processes are developed in the model for:

1. Measuring and reporting craft labour productivity performance in a consistent form for the purposes of internal benchmarking and comparison with a selected third-party benchmark,
2. Examining productivity influencing factors in two categories with respect to construction environment factors and construction practices implementation,
3. Establishing a productivity performance evaluation model to understand the mechanisms by which the environment factors and construction practices impact construction productivity, and
4. Conducting strategic gaps analysis of construction practices implementation within a company aimed at achieving "best in class" and continuous improvement.

System functions in the model are validated through functional demonstration by applying statistical analysis on data collected by the designed benchmarking process and metrics from an industrial construction company. It is concluded that the model developed can be effectively used to understand the impact of practices implementation levels on construction productivity.

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Chapter 1: Introduction

The construction industry contributes a substantial portion of any nation's economic output. Construction productivity improvement is one of the key focus areas of the present construction industry in the world. In spite of the construction industry's value to the national economies of the United States (US) and Canada, a decline in construction productivity has been reported by many reporters and researchers (Arditi and Mochtar 2000; Haas et al. 1999). Given the current construction boom in many nations including Canada, industry stakeholders are desperate to meet demand and minimize escalating costs through improved productivity.

Productivity is a complex issue in construction because of the interaction of labour, capital, materials, information, environmental conditions, technology and equipment, and other intangibles such as entrepreneurship. Further, productivity is difficult to measure because of the heterogeneity of the industry's products and its input. Generally, productivity is stated as a constant, in-place value divided by inputs such as work hours. Some argue that productivity can be increased by working harder, faster, or longer. In the real world, productivity cannot be achieved only with speed and harder work without adopting better work practices. True productivity gains come from identifying and implementing the most efficient work processes to satisfy specifications and the client's demands. Therefore, it is very important to establish a continuous improvement mechanism that can drive consistent construction productivity measurement and can facilitate developing and applying best practices in terms of management and craft processes to increase the economic output of construction activities.

Benchmarking is the process of comparing one's business processes and performance metrics to industry bests or best practices from other industries. In the process of benchmarking, management identifies the best performance and the best practices in their industry and compares these targets to their own performance and processes. In this way, they learn how well the target projects and firms perform and, more importantly, the business processes that explain why these firms are successful. Benchmarking systems can supply a general mechanism for construction productivity continuous improvement. The leading industrial contractors have expressed a pressing need for an internal BM&M model that can be used to direct implementation at the enterprise level. Specifically, they wish to know how to measure degree of implementation of their corporate practices at the project level and to understand the influence this has on project performance. They do not know how to do this now, and there is no academic or scientific literature on the subject with respect to the construction industry. The problem is complex. It includes subsidiary needs such as gap analysis and ways to consistently measure performance factors such as productivity when account codes and their use differ between projects within a company. A systems solution is required. Thus the objectives of this research follow:

1.1 Objectives of the Research

There is a lack of information on how to effectively implement a BM&M system within a construction company to improve performance, especially that of productivity. Most BM&M systems in construction have been implemented as collaborative exercises in scientific inquiries. The objectives of this research are:

1. To develop an internal benchmarking and metrics (BM&M) model for industrial construction enterprises to understand the impact of practice implementation level on construction productivity.
2. To examine with projects data a suite of specific productivity performance improvement methods focused on: (a) increasing labour productivity, and (b) increasing direct work rates.

The methodology to achieve these objectives is described in more detail in a subsequent section. First, the scope of this research is defined.

1.2 Scope of the Research

Productivity is a complex issue in construction because of the many factors involved and how they interact. In the chapter 2 – “background review of construction productivity”, all the factors are categorized in six groups: Natural Resources, Labour, Capital Goods, Technology, Entrepreneurship (management), and Environment. This research will focus on construction productivity in terms of labour input (measured as Work Hours). Factors with respect to technology, entrepreneurship (management), and environment are widely considered to significantly affect the utilization efficiency of labour input.

Technology here refers to the innovation of construction technology, which usually takes effect on labour productivity in step improvements over period of decades. This research will not investigate effectiveness of specific technology innovations themselves. However, the management of the utilization of advanced technology will be considered as a best practice which is categorized in “Entrepreneurship”.

Entrepreneurship refers to most of the intangible resources including enterprise reputation, values, enterprise operation strategies, management, services, information, knowledge management, communications, process controls, etc. The best practices in this part are the principle elements in this research.

Environment refers to the information and data that affect the efficiency of construction activity with respect to weather, location, site conditions, congestion, complexity of craft process, etc. As the performance of productivity is under the integrated influence of construction practices and environmental factors, environmental factors should be evaluated to isolate the investigation of effectiveness of construction practices.

In general, there are four types of construction: residential, building, infrastructure, and industrial. Each type of construction project requires a unique team to plan, design, construct and maintain the project. This research is funded by a NSERC-CRD project, and the collaborative partner company is a general construction contractor in engineering, procurement, construction and maintenance in the heavy industrial sector, including nuclear power, fossil power, oil and gas, petrochemical, wastewater treatment plants, structural steel, and automotive plants. Projects performance and productivity data and construction management practices information are collected from this company, which represents typical characteristics of industrial construction. The dominant craft trades in industrial construction mainly consist of five categories: structural steel installation, piping, electrical installation, mechanical equipment installation, and concrete work. The labour productivity performance of these craft trades are investigated and measured in this research.

As stated above, a Benchmarking & Metrics system provides a general mechanism for improving construction productivity. Over the last two decades, Benchmarking & Metrics has proven in the field of general business management to be a practical method for attaining or exceeding performance goals by learning from best practices and understanding the process by which they are achieved. This research will primarily develop an internal Benchmarking & Metrics system model for a construction enterprise to improve productivity performance and related practices of projects.

Construction practices in this research are defined as a set of those regarded as standard in terms of methods, management procedures, craft processes, technologies, and rules used in a particular field or profession. Practices adopted in a company can be principally classified in three levels: business practices for a construction firm, construction practices for project management, and craft processes and technologies. This research will emphasize reviewing construction practices at the project management level, because it is widely known that they are implemented inconsistently from one project to another, and because their level of implementation on any one project expected and significantly influence its construction craft labour productivity performance. Average level of practices implementation for a firm as a whole is thus expected to impact on its performance as well.

1.3 Methodologies

1.3.1 Research organization and data sources

As an NSERC-CRD project, collaborative partners formed a research team whose mandate is to participate in all aspects of the research proposed here. The author, as one of the university members of the team, carried out the majority of the research tasks. The industry members of the team provided conceptual input, critical feedback, data access, and general guidance. Data and critical information access includes:

- Productivity data access from the partner company's project account system.
- Related documents of the partner company's defined management process.
- Practices surveys, expertise questionnaires, crew interviews, and critical feedback were collected from multiple departments from different management levels including workers, foremen, project coordinators, project managers, division managers, and presidents of division of the company.
- Direct work rate and construction activity analysis were obtained from field observations by the authors, university team members and co-op students.
- Regular research team meetings are held every one to two months.

At the same time, this research is complementary and builds on the CII (Construction Industry Institute) research – construction craft productivity improvement research program. However, the research presented here in this thesis is oriented toward enterprise level implementation and modeling. Significant raw data collected from this research will feed into the CII database and help with CII research using industry data sets. The research in this thesis also obtains data on productivity performance and best practices with respect to industry competitor benchmarking analysis.

1.3.2 Overall research process

Many tasks are required to develop and validate a model for implementation of internal corporate benchmarking and metrics (BM&M) programs for support of continuous productivity improvement processes in industrial construction firms. The research process included the steps of: (1) identifying the research questions and needs, (2) determining the scope and what to benchmark, (3) development of research methodology, (4) model development and data collection, (5) validation, and (6) reporting. These steps are demonstrated in a research methodology flow chart (Figure 1), and the key processes are explained in detail as follows:

1. Identifying the research questions and needs: Literature review and interviews with the experts in the collaborating partner company as well as attendees at CII BM&M workshop early in the research were done to identify the main problems that needed to be solved in this research. For example: what is the difference between an enterprise internal BM&M program and an industry BM&M program; how can a BM&M program be integrated with other management processes of a company; how to consistently measure labour productivity in a company; and how to do gaps analysis of construction practices implementation.
2. Determining the scope and what to benchmark. An internal BM&M program differs from the programs run by government agencies, industry associations, and consultants. It should support such programs, but it is primarily intended to work within a specific internal corporate context and to support internal continuous improvement. Therefore, the following required research tasks were performed.
    a. Develop methods to map internal estimating and project controls databases to standard construction productivity metrics;

b. Map a basic set of project performance metrics as well that include cost, schedule, quality, safety and participant satisfaction elements.

c. Identify internal corporate practices related to construction project management in terms of industry standard practice definitions such as “pre-project planning,” “partnering,” “material management,” etc., and define the procedures for how this can be repeated in other cohort corporations.

d. Develop methods to map construction environmental condition metrics and their data sources.

3. Data collection tools development focuses on the metrics defined in the preceding tasks and involves the following sub-tasks:

   a. Develop specifications for consistently measuring and reporting labour productivity for each project with its unique characteristics in a construction company.

   b. Develop processes for sustained internal benchmarking and metrics activities, and suggest methods for their integration into corporate enterprise strategies, management programs and project level processes.

   c. Suggest ways to deploy the practices developed in a standard fashion on individual construction projects, since construction projects typically enjoy significant autonomy.

4. Collect and analyze the data. Validate the developed methods and processes by populating the benchmarking and metrics database with a number of projects’ data, and conducting initial analyses of the relationships between the practices identified for those projects and their productivity performance.

5. Increasing labour productivity is a key element of improving productivity performance overall. The primary approach will focus on the underlying premise that implementing a set of best construction practices will improve labour productivity. To study the validity of this premise, several sub-tasks are required:

a. Select a tool to survey the practices implementation level on a number of projects for which productivity data is also collected as part of the preceding tasks.

b. Conduct a gap analysis to identify which of its practices are not being implemented up to industry standards or consistently within the partner organization, and generalize the procedures in this analysis so that they can be applied to similar organizations.

c. Suggest ways to ensure that best practices are implemented to the optimal extent in the partner organization. This will require a plan for staged implementation over a period of time and integration with the internal benchmarking and metrics system to ensure that improvements resulting from the practices are being measured. These procedure must also be generalized for broader subsequent application to other organizations.

6. Capturing what was learned from the preceding tasks, and incorporating that knowledge into a process model for implementing a corporate BM&M program will help support subsequent action by the partner's leadership team. This will be in addition to the documentation and training tasks described later.

7. Validation includes validation of the model functionality and model performance. Chapter 5 introduces a validation plan in detail.

8. Report on the knowledge discovered by accomplishing the preceding tasks in the form of prototype corporate procedures and specifications, industry workshops, conference papers, journal articles, and a thesis.

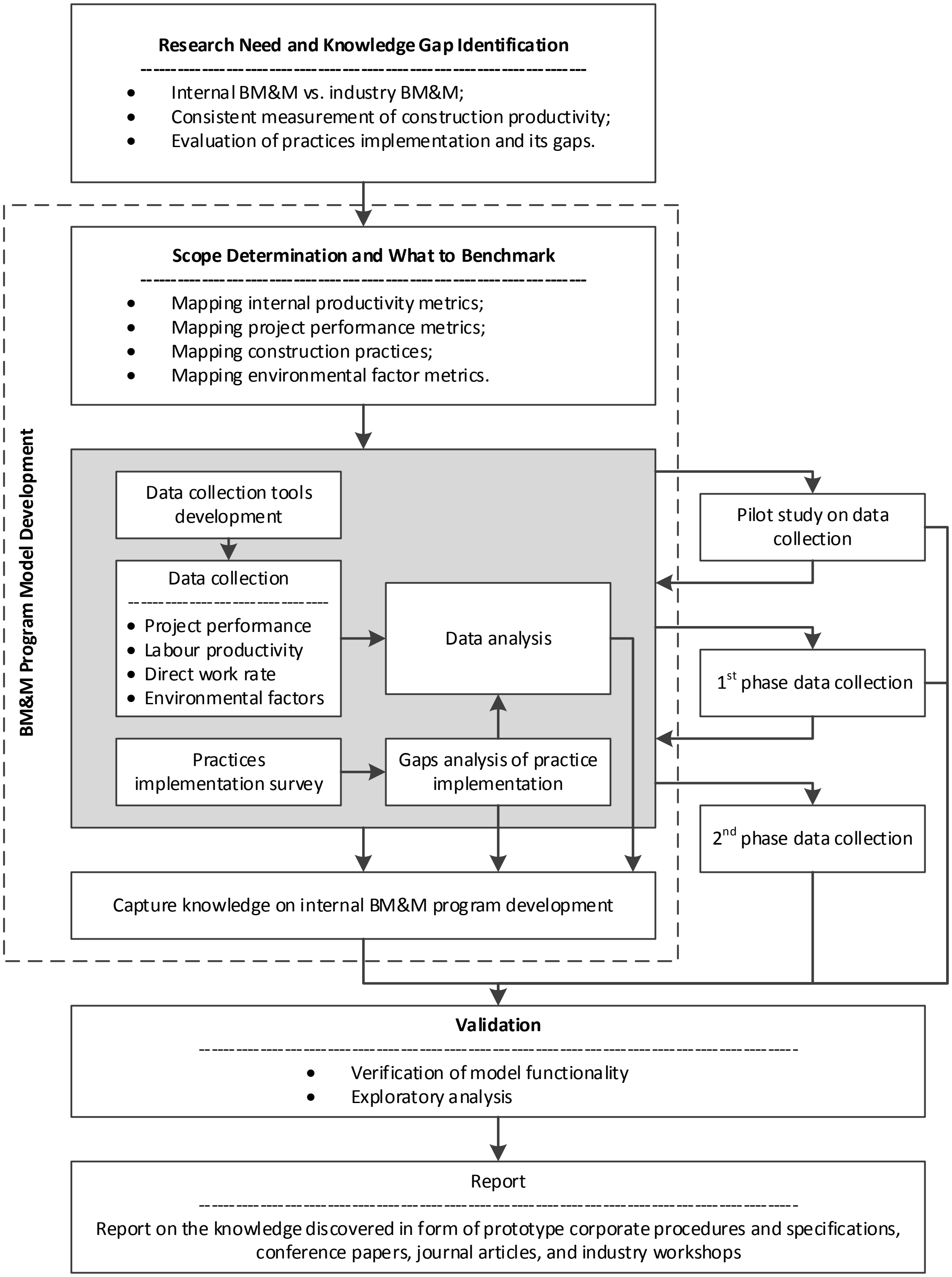

Figure 1 Research Methodology Flow Chart

1.3.3 Validation details

In order to verify the potential contribution of this research, the model validation plan is based on verification of model functionality and some exploratory analysis of the data collected. Verification of model functionality is the primary task in the model validation plan.

1. Verification of model functionality includes
   - Determine whether the designed processes and procedures in the model conform to generalized criteria in project management.
   - Determine whether the functionality of the model conforms to the initial design purpose.
   - Verify the integration of the internal BM&M program with other existing management processes of a company (the partner enterprise).
2. Exploratory analysis

Since this research resulted in data acquired from 12 projects that can be linked with data from a collaborative CII project that may contribute more projects, some statistical analysis will also be conducted to explore for significant differences and relationships as described in the full proposal. However this is not the core contribution of this thesis, as longitudinal data will not be available.

This research proposal consists of five chapters. After Chapter 1— the overall introduction of this research, Chapter 2 reviews the background information for the research including definition of construction productivity, measurement of construction productivity, factors influencing productivity, productivity related practices in construction, and Benchmarking & Metrics systems (BM&M). Chapter 3 introduces an overall program model for continuous productivity improvement by applying a BM&M system. In Chapter 4, model implementation is introduced in terms of each functional process with respect to the processes construction/integration, relevant means, and the data analysis reporting. Some key area analysis will be carried out to verify the model functionalities. Chapter 5 presents the conclusions and recommendations from this research.

Chapter 2: Background Review

Productivity is a measure of the efficiency of production. Productivity is a ratio of what is produced to what is required to produce it. Usually this ratio is in the form of an average, expressing the total output divided by the total input. Productivity is a measure of output from a production process, per unit of input. Sometimes, some researchers also present productivity as input per unit of output.

2.1 History of Productivity

Productivity is a popular topic in economics and management science, in which it is reasoned that productivity is the source of all economic value (Drucker 1998). In the early part of the 20th century, productivity was initially defined as the correlation between outputs and resources that are utilized to produce the production (Kendrick 1984). In the middle of the 20th century, economists proposed a new argument that technological innovation is the main driver and source of economic growth, instead of the traditional opinion that capital accumulation is the critical factor driving economic growth (Solow 1956). Many following research efforts on productivity also revealed the importance of technological innovation. This generalized technological innovation concept contains extensive content including advanced technology, management improvement, resources allocation improvement, and economies of scale.

Research on productivity in a production industry first appeared in the manufacturing industry. Many research efforts were conducted to explore the influential factors that could facilitate increase of productivity, and further to assess and benchmark the improvement potential in manufacturing systems (Almström and Kinnander 2011). In the construction industry, the construction process, thought of as one of the production process, is also recognized and modeled as an input-output process (Sanvido 1988; Thomas et al. 1990). Continuously improving productivity is also considered as one aspect essential to the competitiveness of a construction company. However, some characteristics of the construction industry meant that there is a great challenge to measure construction productivity and assess the improvement potential. A construction project usually consists of many different activities and processes with various work contents. Complexity of the construction process is also demonstrated as diversity of inputs and outputs (which will be explicated in a later section about the nature of construction projects). Productivity performance is always influenced by complex factors, such as weather, the unique design of each facility being constructed, site conditions, management, technology, and so on. Thus, construction performance will inevitably vary from day to day, crew to crew, site to site, and project to project due to the inherent nature of the construction industry. It is very difficult to estimate the production function of a construction activity with the many variables representing the aforementioned inputs and factors. Some of those variables are defined in the next section.

2.2 Definitions of Productivity

2.2.1 Total productivity (TP)

Productivity refers to the correlation between outputs of production or service system and all inputs that are invested to create the outputs (Prokopenko 1987). It is usually presented as the function:

$$\text{Total Productivity} = \frac{\text{Total outputs}}{\text{Total inputs}}$$

This definition actually refers to the Total Productivity, which considers all the elements applied in the production. Hereafter, in this thesis, Total Productivity (TP) is understood to specify the ratio between total outputs and total inputs. In the construction industry, the ratio of invested inputs per unit outputs is also commonly used, which is the reciprocal of the above equation. For the construction project, outputs include many engineered products such as buildings, bridges, dams, power stations, roads, railways, and equipment in plants. Depending on the craft class, they are also sorted as concrete, structure steel, earth work, piping, electrical, insulation, mechanical equipment and so on, which can be broken down into deeper levels by their pertinent grades. Inputs include labour, capital, material, equipment, and energy. Information, knowledge, management and related practices, as the factors that affect performance of productivity, are also included in inputs from a generalized perspective.

2.2.2 Single factor productivity (SFP)

Multiple Factor Productivity selects the elements that are easy to be quantified to measure the inputs, but multiple elements each with various forms of measure are still difficult to convert to commensurate measure units and their associated weights. Single Factor Productivity (SFP) is preferred by researchers to simplify the productivity measurement. Single factor herein could be labor, material, equipment, or capital. For example:

$$\text{Labor Productivity} = \frac{\text{Total output}}{\text{Labour cost}}$$

$$\text{Capital Prodcuctivity} = \frac{\text{Total output}}{\text{Capital invested}}$$

Along with the process of industrialization, labour productivity is not the only essential elements that dominates the evaluation of productivity. Production elements like equipment, information, and capital contribute more and more to productivity improvement as an economy becomes more advanced. The interaction among these various production elements make the relationships among these elements strong and complex. Nevertheless, labour productivity is always considered as one of the most direct and measurable indexes to demonstrate production efficiency, especially from one construction project to another (Freeman 2008).

2.2.3 Total factor productivity (TFP)

Differing from Total Productivity (TP), Total Factor Productivity is an index which accounts for effects in total output not caused by traditionally measured inputs. Traditional measured inputs usually refer to the tangible production elements such as labor, capital, equipment, and material (Craig 1973). A typical equation for TFP is shown as (Wikipedia 2011):

$$\mathrm{TFP} = \alpha\frac{\mathrm{Y}}{\mathrm{L}} + \beta\frac{Y}{K}$$

Y: represents the outputs (yields) of the activity

L: Labour input

K: Capital input

α, β are the capital input share of contribution for K and L respectively

By taking the derivative by time for the above equation, the following equation is found:

$$\frac{\mathrm{dTFP}}{\mathrm{dt}} = \dot{Y} - (\alpha\dot{L} + \beta\dot{K})$$

The value of TFP is calculated by using measured values of some tangible production element inputs including labour and capital. However, the underlying meaning of the expression of TFP is that the growth rate of TFP (dominated by Labour and Capital) represents the improvement of those intangible inputs that are excluded from the measurement of this TFP. In other words, considering an extreme condition, if all inputs are accounted for in the TFP calculation, then the TFP may reflect omitted inputs. For example, one project with an unusually good construction site layout plan will tend to have higher output, because a bad site layout plan hinders construction activity output. If a variable like the site layout plan is not considered as an input to a TFP calculation, then TFP could be an index reflecting the performance of the site layout plan.

For construction processes, inputs can be considered to contain six general categories: natural resources (Humphrey et al. 1975), labour, capital goods, technology, entrepreneurship and environment (Table 1).

Table 1 Summary of Construction Inputs

Natural resources	Refers to non-renewable resources such as land, forest, minerals, fossil fuels
Labour	Refers to human resources (mental and physical) Measured by 1. Persons employed (the most available) 2. Hours worked (the most accurate) 3. Labour costs (synthesized measure)
Capital goods	Refers to production generating resources including infrastructure, facilities, material, equipment, cash, and so on.
Technology	Refers to the innovation of construction technology
Entrepreneurship	Refers mostly to intangible resources including enterprise reputation, enterprise operation strategies, management, services, information, knowledge, communications, process control, etc.
Environment	Refers to the information and data that affect the efficiency of construction activity with respect to weather, location, site condition, congestion, complexity of craft process, etc.

Natural resources are normally considered at the level of national economic, but the remaining four categories of inputs are counted in enterprise operations. Generally, tangible inputs are relatively easier to measure than intangible inputs. Elements from categories of entrepreneurship and environment are usually considered as intangible, and are not easy to quantify or measure. However, much past research has revealed that most of the potential (Arditi 1985; Cottrell 2006; Goodrum and Haas 2004; Goodrum et al. 2011) that could be realized for increase construction productivity when no radical technological innovation is available is involved in the category of "Entrepreneurship". In fact, Goodrum has observed differences in productivity that exceed 50% between groups of projects that implement best practices extensively and very little.

Total Factor Productivity provides a line of thinking by which measuring tangible inputs of production such as labour hours can help reflect the performance of intangible inputs such as management practices. In another words, one available approach to measure and improve the performance of management and technology is to develop an appropriate TFP index for benchmarking.

In summary, the evolution of productivity definitions demonstrates that researchers were always exploring the right way to measure productivity, to measure influence factors of productivity, and to evaluate the effective management and technology practices to improve productivity. This has been a particular challenge in construction, because the production function varies for each project.

Among all these productivity definitions, labour productivity is considered to have greatest availability and operability in measurement and control in construction. The following section on "productivity measurement" will focus on construction labour productivity measurement.

2.3 Productivity Measurement

Productivity is defined as a ratio that relates measurements of output to measurements of input as discussed in previous section. This definition of productivity is used most often by economists. In the construction industry, productivity is defined in the narrower (and far more useful) context of work site labour hours divided by work-in-place (or the inverse, work-in-place divided by labour hours). This is the definition used throughout the remainder of this thesis.

Before delving into productivity measurement, it is useful to highlight some characteristics of construction regarding productivity measurement, which helps with understanding the measurement level, method, and labour productivity metrics.

1. Variety of construction outputs: Due to the measurement of construction, production is presented in many types, dimensions, and specification grades. It is hard to find a unified measurement that applies to all construction production. Even in one project, there still are many types of measurement to quantify the production, which are difficult to normalize. For example, piping construction includes treating with various type of material such as carbon steel, stainless steel, chrome, and plastic. Diameter size of pipes also varies from about ½ inch small to over 40 inches large with intervals from ¼ inch to ½ inch. Piping construction also includes pipe fitting, pipe spools, and in-line devices installation. If the piping construction is broken down to the lowest level with pieces, there is almost no complete same component. So, it is very important to determine the aggregation those piping components, so that piping components can be rolled up at certain level to measure the productivity. In addition, the quantities of piping measurement also vary from project to project. Some projects measure pipes in footage, but some projects measure them in diameter inch, which makes more complicate situation for keeping consistent measurement of piping.

2. Multiple participants: Construction projects usually involve many participants including owners, contractors, suppliers, consultant engineers, architects, subcontractors, and even investors, which all could impact the performance of productivity. Meanwhile, multiple participants increase the challenge of completeness of productivity data collection.
3. Variety of construction inputs: As noted in Table 1, inputs for a construction project contain many types of elements, which need different measurement methods and measurement units. It is hard to normalize measurements for all types of input.

This section will review how the outputs are classified for measurement. As well, labour productivity will be isolated from many types of inputs as a Single Factor Productivity index. As mentioned before, labour input can be quantified by three measurements: employed persons, work-hours, and labour costs. They are all available from the regular project control process. Three types of measurements are applied for different management purposes depending on management level. Work-hours is the most direct measure to illustrate the coefficient of labour resource utilization, since this measure eliminates the impact of labour market price and crew composition on the productivity measurement. In the construction industry, experts usually use the fraction of work-hours over unit physical output to represent labour productivity:

$$\text{Labour Productivity} = \frac{\text{Work} - \text{hours}}{\text{unit physical output}}$$

Apart from the fact that labour productivity is the most direct measurable index to illustrate construction productivity, labour productivity is also a fundamental piece of information for estimating and scheduling a construction project. An increase in labour productivity is broadly accepted to reflect an improvement of overall performance of management and technology utilization in a company. These are the reasons that many researchers study construction labour productivity. Following subsections will present: (1) a labour productivity breakdown based on physical output classifications; (2) measurement of work-hours input; (3) calculation of labour productivity; (4) a labour productivity index; and (5) work time study.

2.3.1 Labour productivity categories and breakdown

As aforementioned, the production of a construction project contains many types, dimensions, and specification grades. The outputs of construction are measured by various measurement units. And the construction activities that output different production have different labour efficiency, namely productivity. Outputs of construction are classified by production's nature with respect to types, dimensions, and specification grades (MasterFormat® 1978). Labour productivity for those construction activities are categorized based on production classification. The construction Industry Institute (CII) summarized a three levels breakdown to organize these labour productivity metrics (Park et al. 2005) (detail is shown in 1.1Appendix A). This took several calendar years, dozens of participants, and significant resources to achieve, as there is no broadly accepted standard of such a breakdown in the industry. Typically, each company has a slightly different or radically different breakdown, and divisions of companies can have breakdowns that vary substantially. The first CII level is following construction craft groups including concrete, structural steel, electrical, piping, equipment, and insulation. At the second level in each group, productivity metrics are sorted by types of work. And at the third level, it is divided by dimensions and specification grades.

Cost accounting breakdowns will also vary from company to company and between divisions, and there is no industry standard. As well they may be applied arbitrarily and incorrectly by project managers. For example, Dr. Goodrum studied code of accounts from six leading multi-discipline and industrial construction companies, and together with two prototypes of a master code of account from RS-Means and Richardson's (CII 2013a). Following tables display the breakdown of code of accounts for piping in those organizations, which illustrates the challenge of effective and consistent productivity measurements in construction industry. The next section explores this issue in detail.

Table 2 Number of Code of Accounts for Piping (CII 2013a)

	Companies						Means	Richard-son's
	A	**B**	**C**	**D**	**E**	**F**		
# of Piping Codes	64	31	94	40	132	363	197	1108
# of Different Materials	4	4	Not specified	7	8	13	5	18
# of Different Size Intervals	3	4	2	Not specified	6	12	16	22

Table 3 Piping Breakdown Summary (CII 2013a)

Piping	Company A	Company B	Company C	Company D	Company E	Company F
Sizes	2.5" and under	< 2.5"	Small bore < 2 ½ inch diameter allowance	Not specified	Schedule 120	<= 12"
					Schedule 160	14" to 22"
					2" & Down	24" to 30"
	3" to 10"	2.5" to 4.0"	Large bore > 2 ½ inch diameter allowance		Schedule 10	32" to 60"
	12" and over	6.0"-8.0"			Schedule 40	> 60"
		10.0"-14.0"			Schedule 80	14" to 30"
						>30"
						½" to 1-1/2"
						2" to 2-1/2"
						3" to 5"
						6" to 8"
						>= 10"
						*sizing depends on material
Materials	Carbon Steel	Carbon Steel	Not specified	Carbon Steel	Carbon Steel	Carbon Steel
				Stainless Steel	Stainless Steel	Stainless Steel
	Alloy Steel	Stainless Steel/Alloy			Chrome	Cast Iron
				Alloy Steel	Cast Iron	Cement Lined
				Chrome Alloys	PVC	Concrete
				Cast/Ductile Iron	HPDE	Ductile Iron
	Special Material	Non-Ferrous			Copper	HDPE
				Bronze/Brass Copper		Plastic/Fiber
	Chrome	All Materials			FRP	Vitrified Clay
				Non-Metallics (GRE, CPVC, Plastics, etc.)		Titanium
						PTFE
						Jacketed Pipe
						Non Metallic
Installation Location	Aboveground	If not specified, above ground	Aboveground	Not specified	Not specified	Aboveground
	Underground	Underground	Underground			Underground

2.3.2 Measurement of work-hours

For measurement of work-hours, the problems needed to be solved are: (1) what is the practical way to track the work-hours on site; (2) which types of work-hours match to which classes of outputs.

Based on review previous research and interviews with experts in the area of construction site management, it was found that one approach is tracking actual work-days to date for working on a specific work package (Chong and Chou 2006; Enshassi et al. 2007). Along with the information of numbers of pertinent workforce assigned to this work package each day, the work-hours for finishing this work package can be derived. If the output of this work package is matching the designed labour productivity metric, calculation of productivity can be done. Therefore, the critical process for matching the work-hours data with the right outputs is aligning the work package to be tracked with the productivity metric early at the phase of planning the project.

Since even a small work package may involve multiple types of workforce, another issue for measuring work-hours is that the types of workforce with respect to each work package being taken into account for productivity calculations should be uniform from project to project. The CII BM&M system developed an account list (Table 4) to standardize direct and indirect work-hours for productivity benchmarking (Park et al. 2005).

The CII BM&M system also suggested a set of lists of activities for a certain construction activity that provides a baseline to compute work hours for concrete work. For example the list of activities for concrete is shown in Table 5. These lists together with the list of direct and indirect accounts standardized the measurement of work-hours for productivity calculation for the CII BM&M program. However, a practical problem worth nothing is that hours may be charged to an account that has a positive balance rather than the account that is allocated. This can confuse tracking.

Table 4 List of Direct and Indirect Accounts

	Direct	Indirect	
Account	Direct Craft Labour	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/Travel 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	

Table 5 List of Activities for Concrete

Inclusion	Exclusion
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 placement, curing, finishing, rubbing, mud mats; and anchor bolt installation.	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, precast tees, panels, decks, vaults, manholes, etc.

2.3.3 Calculation of labour productivity

The simplest approach for calculating labour productivity is to use the cumulative value for work-hours (inputs) and installed quantity (outputs), which is used in the CII BM&M program.

$$\text{Labour Productivity} = \frac{\text{Direct Work}-\text{Hours}}{\text{Installed Quantity}}$$ (Park et al. 2005)

This factor doesn't show the variation in the performance of productivity in various phases from the average. It does not incorporate knowledge about how best performance can be achieved and how stable a productivity performance can be implemented.

Typically, productivity performance is uneven over the life of the project because resource shortages are common, and field installation is inconsistent during much of the work period (Lin and Huang 2010). Also, productivity at the beginning phase and the close-up phase is usually lower than the average productivity (Thomas et al. 1990; Zink 1990). Some researchers suggest not to take into account the production at beginning and close-up periods of the project (around 10% of period off project duration) (Zink 1981). As a good practice, one can calculate daily or weekly labour productivity along the project implementation, and take the average of these productivity numbers to represent the project labour productivity.

Another important and popular index of labour productivity is Baseline Productivity (BP) for labour. BP can be calculated by various methods such as the measured mile analysis (Ibbs and Liu 2005; Zink 1986), Thomas's BP method (Thomas, Završki, et al. 1999), the control chart method (Gulezian and Samelian 2003), the K-Means clustering method (Ibbs and Liu 2005), and the Data Envelop Analysis (DEA) method (Lin and Huang 2010).

The "Measured mile" analysis for labour productivity is a popular technique in the construction industry, which compares the cumulative actual work-hours with the earned work-hours, resulting in an index such as the Productivity Factor (PF). (Gulezian and Samelian 2003) argued that the cumulative work-hours measured mile masks variations of daily productivity and are not able to reveal causal relationships with corresponding managerial problems on site.

Some researchers defined BP as the best performance of productivity that could be achieved in a project (Thomas and Sanvido 2000; Thomas, Riley, et al. 1999; Thomas, Završki, et al. 1999). Thomas's BP method takes into account 10% of the total workdays with the highest daily labour productivity or output as the baseline subset. The BP is the median of the daily productivity values in the baseline subset. However, since project managers often "bank work" from day to day or week to week, BP can be a flowed approach. Some researchers consider BP as a normal level reflecting a contractor's normal performance of productivity (Gulezian and Samelian 2003). They developed a productivity control chart with a center line and control limits. The center line value is the arithmetic mean of the daily labour productivity; and the control limits are plotted as 3 standard deviations of the labour productivity population from the center line (noted as center line ± 3 standard deviation). The K-means clustering method improved the procedure and determination of size and choice of the baseline subset, which were predefined as 10% of the total workdays in Thomas's BP method.

Apart from the preceding calculation methods based on statistical analysis, (Lin and Huang 2010) introduced a new method – Data Envelop Analysis (DEA) to derive BP which is defined herein as the best performance of productivity in a project. DEA is a nonparametric method in operations research and economics for the estimation of production frontiers. The advantage of it is to measure the relative efficiency of a process with multiple inputs and multiple outputs. The proposed DEA method is capable of calculating relative higher level productivity metrics which may involve multiple outputs in terms of various dimensions and specification grades. For example, a piping work package (e.g. power gas control system) might contain carbon steel pipes with diameter range as 2 – 6 inches, several schedules, and joint as B-weld or Socket weld. Pipe-fitters' work-hours for implementing this piping work package are tracked at this work package level. While, the outputs (installed pipes) could be measured at a lower level than the work package level by diameter, schedule, and weld type, by using the DEA method, engineers are in theory able to calculate relatively accurate baseline productivity which synthesizes complete information of the outputs. Taking advantage of the multiple inputs and outputs capability, the DEA method could be improved to calculate total factor productivity (TFP). Unfortunately, the DEA method has a fatal weakness in that all the daily productivity data points on the frontier are considered with the same weight (because of the nonparametric principle). Thus, extreme data points such as measurement errors could cause significant problems.

In summary, labour productivity can be calculated in term of cumulative productivity, average of daily or weekly productivity, and baseline productivity.

2.3.4 Labour productivity index

In order to benchmark and evaluate the performance of productivity, some appropriate indices should be considered.

1. The labour productivity value itself can be used as a metric. As reviewed in the last section, labour productivity can be measured with accumulative productivity, average of daily productivity, or baseline productivity.
2. The Disruption Index (DI) is a measure of number of work days with the daily productivity disruption within a single project. It is defined as the following form (Moselhi et al. 1991; Thomas and Napolitan 1995; Thomas, Riley, et al. 1999):

$$\text{Disruption Index} = \frac{\text{Number of Abnormal (Disrupted) Work Days}}{\text{Total Number of Work Days}}$$

   Abnormal (disrupted) work days are identified as that the labour productivity for those days is less than specified baseline productivity.

3. Performance Ratio (PR), also titled Performance Factor (PF) or Productivity Factor (PF): The performance ratio is the actual cumulative productivity divided by the expected productivity (also called as budget productivity or estimated productivity). Thus, the following definition was adopted (Fisher, Miertschin, Pollock Jr., et al. 1995; Zink 1990) :

$$\text{Performance Ratio (PR)} = \frac{\text{Cumulative productivity}}{\text{Expected productivity}}$$

$$\text{Productivity Factor (PF)} = \frac{\text{Cumulative Work} - \text{hours}}{\text{Earned Work} - \text{hours}}$$

4. Project Management index (PMI): PMI is a dimensionless parameter that reflects the contribution of project management to the cumulative labour performance on the project.

The lower the PMI, the better was the project management's influence on overall performance (Thomas, Završki, et al. 1999).

$$\text{Project Management Index (PMI)} = \frac{\text{Cumulative Productivity} - \text{Expected Baseline Productivity}}{\text{Expected Baseline Productivity}}$$

2.3.5 Work time study

One way to improve productivity is to reduce the non-productive time spent by workers each day and to increase the direct productive work time by the same total hours. Potential improvements range from 10-30% according to a past research (Gouett et al. 2011). Work time study is a common method to directly measure and analyze non-productive time of site workforces, which extends the measurement of productivity deep to the craft process activity level.

The Industrial Engineering Terminology Standard defines time study as "a work measurement technique consisting of careful time measurement of the task with a time measuring instrument, adjusted for any observed variance from normal effort or pace and to allow adequate time for such items as foreign elements, unavoidable or machine delays, rest to overcome fatigue, and personal needs" (I.I.E. and ANSI 1982). Frederick Winslow Taylor was the pioneer to use time study methods in standard settings and optimizing work planning. At its most basic level time study involved breaking down each job into component parts, timing each part and rearranging the parts into the most efficient method of working (Payne et al. 2006).

In the construction industry, work time study was evolved to some methods such as Work Sampling, Five Minutes Rating, Group Timing Technique (GTT), and Activity Analysis.

Work Sampling

Work sampling is defined as "a productivity measurement technique used for the quantitative analysis, in terms of time, of the activities of men or equipment" (Thomas and Holland 1980). In this method a number of observations are made over a period of that activity. The percent of observations recorded for a particular activity over total observations represents a measure of the percentage of time spend on that activity. This method is based on the statistical theory of sampling, i.e. adequate random samples of observations spread over a period of time can construct an accurate picture of the actual situation of system (Aft 2000; JENKINS and ORTH 2004). The first and also important step of work sampling is defining the activity categories, which is oriented by the process control elements constituting a part of the work cycle. The categories included in the most general work sampling study are direct work, preparatory work, tools and equipment, material handling, waiting, traveling, and personal time.

Five Minutes Rating

The five minute rating technique is an older workface assessment method that is rarely used now. The method measures the effectiveness of a crew and indicates problem areas, and intends to create awareness of delays in a job. The method rates a crew’s performance as either effective or non-effective over a defined interval. The observation of an effective crew is based on determining that the amount of time spent working by the crew is greater than 50%. Compared with the snap observation of Work Sampling, the Five Minutes Rating needs to take a continuous observation for each interval, which is time consuming and costly. In addition with absence of detecting cause of delay, this method was applied less and less.

Group Timing Technique (GTT)

Group Timing Technique is a fixed short-interval work sampling procedure, which is employed for work measurement and cost reduction analysis. This technique can often substitute for traditional stopwatch time study, providing equal or better measurement of productivity reference data from manufactories of material or construction equipment.

Activity Analysis

Activity Analysis has been proposed as a project time frame continuous improvement process for increasing the amount of time that craft workers spend in direct work (Figure 3). This measured time is referred to as tool time, wrench time, or direct work time. Activity Analysis includes the step of work sampling, but it differs substantially from traditional work sampling in terms of the following major elements:

- Typically, observations are broken down into seven or more categories, which include direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal. All are also broken down by each craft on a jobsite. (see Figure 2)

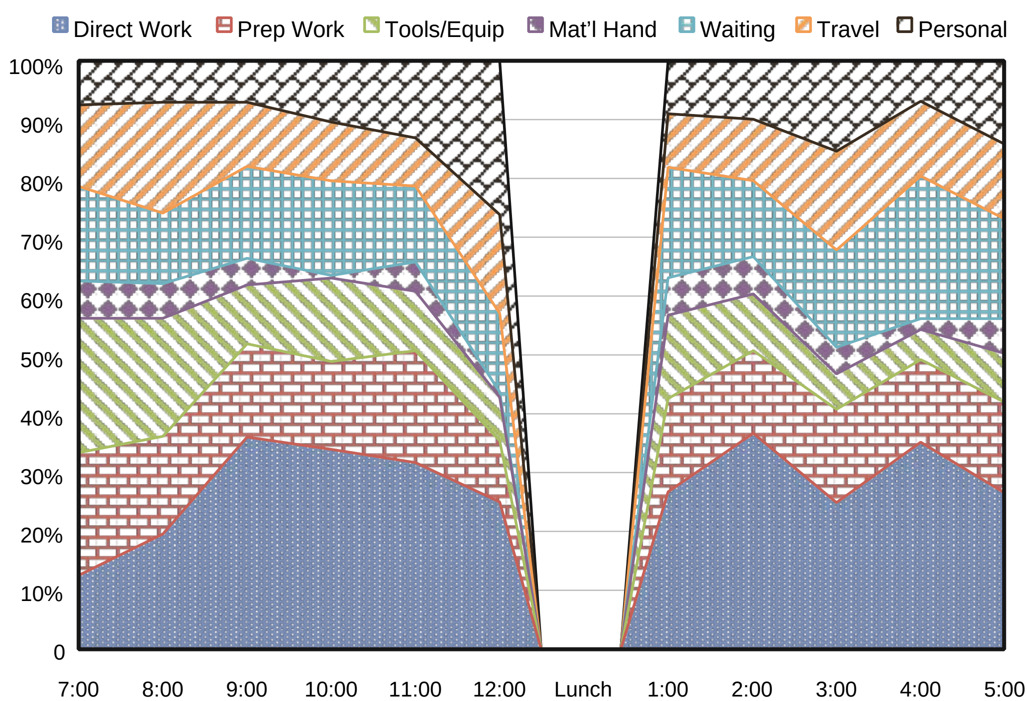

Figure 2 Example Hourly Activity Percentages (Gouett 2010)

- Reliance on a continuous process of improvement through observation, identifying areas for improvement, implementation, and reassessment is central to implementation.

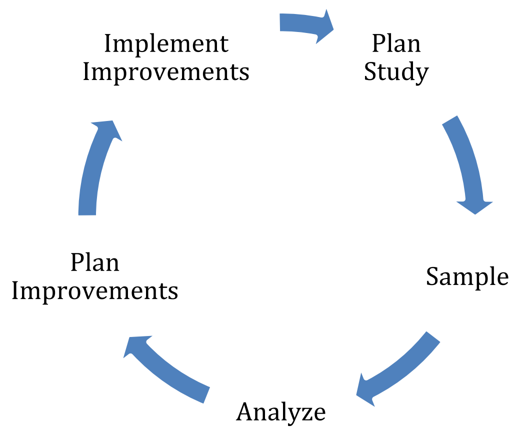

Figure 3 Activity Analysis as a Continuous Improvement Process (Gouett 2010)

Along with the growth of digital technology and information technology, many automated techniques were applied in work time study. Many digital devices were used to speed up the observation on site and depress the influence from the observer on site crews. Some research used a computer aided videotaping technique to study the work time in a concrete work cycle (Gong and Caldas 2009, 2010). They developed an intelligent video computing method to interpret videos of cyclic construction operations automatically into productivity information.

2.4 Factors impacting productivity

Because of the complexity of construction activity, there are many factors affecting construction productivity. Many articles looked at some specific factors that may highly influence construction labour productivity, and intended to measure the impact in order to improve the pertinent work process. Some researchers looked at automation and integration of information systems on construction projects (Zhai et al. 2009). They created a model to evaluate the effect that IT systems have on construction performance factors such as productivity. Further statistical analysis results showed that construction labour productivity was positively related to the use of automation and integration. Some researchers looked at worker's field behaviour by applying field theory (Maloney 1983), and concluded that four major labour factors influence productivity:

(1) The intensity of the individual worker's effort; (2) the duration of that effort; (3) the effectiveness with which the worker's effort is combined with technology and other resources; and (4) the overall efficiency with which these inputs are translated into usable outputs of acceptable quality. This argument supported applying work time study for labour productivity research. Also, this argument provided an understanding that the work site condition with respect to health and safety for workers is a very important factor that influences labour productivity. In this article, the authors also encouraged standardization of design to allow for repetitive operations (e.g., standardizing column sizes to simplify forming operations) and thus to promote an increase in productivity, which draws out design factors as a big part of the factors that influence construction labour productivity. The idea of a "level of worker effort" is significantly out of fashion, with the conventional wisdom being that all productivity is facilitated by management for a willing work force. This does not mean that (Maloney 1983) was wrong. Some more recent articles studied construction productivity by analyzing particular construction activity processes (Salem et al. 2003; Tavakoli 1985), analyzing influence of construction technologies (Goodrum and Haas 2004), investigating human resources and management issue (Liberda et al. 2003), etc.

Thoroughly summarizing the factors that affect construction labour productivity is not a simple task. Some articles made great contributions on systematically summarizing those factors. For example, based on studying masonry work, the major factors were summarized in the following categories (Thomas 1991):

- Type, Scope, Layout, and Complexity
- Time Frame
- Construction Methods
- Weather
- Skill of the Work Force

- Work Practices
- Length of Workday

In the report of U.S. construction labor productivity trends (1970–1998) (Haas et al. 1999; Teicholz et al. 2001), authors reviewed groups of factors that exercise influence over construction productivity from a macro standpoint, which includes factors related to Project Uniqueness, Technology, Management, Labour Organization, Real Wage Trends, and Construction Training.

Thomas later created a factor model for construction productivity, which draw a relative thorough summarization of factors influencing construction labour productivity. Factors are sorted in four categories: environmental factors, site factors, management factors, and design factors. Each category contains a set of factors (see Table 6)

Table 6 Factor Model of Construction Productivity

Environmental factors	• Weather • Absenteeism
Site factors	• Congestion • Access a Layout
Management factors	• Management Control • Manning Level • Crew Size & Structure • Methods • Work Schedule
Design factors	• Constructability • Quality of Documents • Specification Requirements • Quality Control Requirements

2.5 Productivity Improvement Mechanism

Based on the definition of construction labour productivity, improvement of labour productivity is producing more outputs with fewer labour hours. The book "Managing Performance in Construction" introduced several mechanisms for implementing such productivity improvement through a set of changes that can take place in construction (Bernold and AbouRizk 2010).

Change 1 = improved productivity leads to less labour hours for the same output (volume of outputs in construction is primarily determined early in design)

Change 2 = substitution of some labour hours with equipment hours

Change 3 = substitution of stick-building on the site with prefabricated elements requires less labour hours

Change 2 and 3 are primarily dominated by technology innovation with respect to capital resources equipment and material, which usually leads a step change in the productivity improvement over the whole construction industry. Evaluating the effectiveness of technology innovation is not the primary purpose of this research. In this research, it is believed that facilitating management of construction practices (as defined earlier, including methods, management procedures, craft processes, technologies, and rules used in a particular field or profession) is an effective way in day-to-day management to achieve better productivity performance in terms of Change 1.

2.6 Practices for Improving Productivity

The practices here are considered as sets of work processes that could contain work instruction, process flow (description and chart), procedure and policy, well defined responsibilities, related techniques and tools, pertinent baselines and measures, and relevant templates and examples. So far in preceding sections, a myriad of factors that influence construction labour productivity have been reviewed, and a mainly mechanistic view of productivity improvement has been taken. The purpose is to associate those factors with the pertinent construction practices. Based on an understanding of the influential factors, construction practices could be adjusted to enhance positive factors and restrain negative factors.

Several institutes have summarized series of “best practices” in the construction industry that are tried and tested combinations of processes, tools and implicit knowledge collected from experience and lessons learned. They have been repeated and improved to produce consistent outcomes. In many cases, however clear empirical and statistical validation of those practices is absent. Generally, the best practices can be organized in three levels.

1. Research institutes such as PMI (Project Management Institute), CII (Construction Industry Institute), and IPA (Independent Project Analysis Institute) all have summarized sets of best or value improving practices for project management. These best practices generally cover most of the management processes along a project lifecycle, which include Front End Planning, Alignment, Constructability, Materials Management, Supply Chain Management, Planning for Startup, Team Building, Partnering, Quality Management, Lessons Learned, Benchmarking and Metrics, Change Management, Disputes Prevention & Resolution, and Zero Accidents Techniques. More conventional practices such as CPM scheduling and cost and quality control are included in the PMI BOK (Book and Knowledge) (PMI 2013).
2. To promote some important specific management goals such as safety and productivity, some institute composed particular tools for those purposes. For instance, CII developed a “Best Productivity Practices Implementation Index (BPPII)” (CII 2013b); and the Cooperative Research Centre (CRC) for Construction Innovation composed a “Guide to Best Practice for Safer Construction”.

3. For construction craft sectors, some best practices are summarized to improve productivity, quality and safety. For instance, the Ontario General Contractor Association (OGCA) composed a "Best Practices Guidelines for Concrete Construction" (OGCA and RMCAO 2005).

Actually, most practices in these preceding three levels are related to improving construction productivity, as project cost and schedule performance often flow from productivity performance. The relationship between practices and productivity has been established based on a multi-million dollar research effort over several years directed by the CII which has over 130 corporate members. The CII Research Team 252 (RT 252) has conducted statistical analysis on the data from CII BM&M database. The analysis result (demonstrated in Figure 4) has claimed that adopting CII "best practices" has a positive effect on project productivity (CII RT-252 2013). My research is on the basis of this knowledge, but reproving this effect significance is outside scope of this thesis.

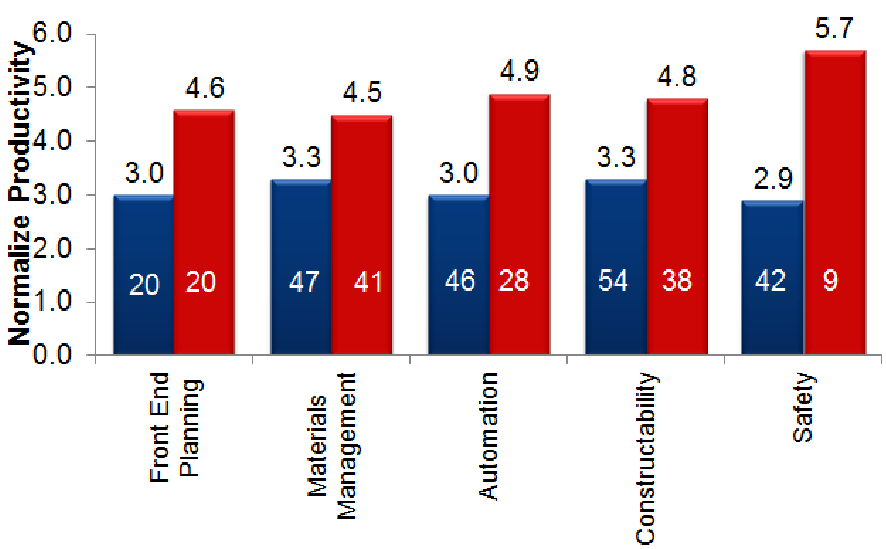

Figure 4 Positive Effect of CII Best Practices (CII RT-252 2013)

Good construction project management practices can also reduce rework, and they can improve job-site safety and project quality (NRC 2009). More recent research has begun to explore the impact of practices, both CII's and others, on productivity as well. The CII Research Team 252 (RT 252) has recently developed a Best Productivity Practices Implementation Index (BPPII) for the industrial sector of the construction industry (CII 2009). The Industrial Sector BPPII is based on the knowledge and experience of the members of the CII 252 research team cultivated through an extensive series of workshops, and it is based on research which has validated construction practices that are each individually proven to relate to improved craft worker productivity. Each practices has been organized into sections that include similar practices. Each section has been organized into a category that envelopes each of the sections and practices within each section. The Industrial BPPII has been organized into 6 categories, which include Materials Management, Equipment Logistics, Craft Information Systems, Human Resource Management, Construction Methods, and Environmental Safety and Health. Each section in each category is analyzed using an audit form with which quantitative measurements of practice implementation are made. The audit form includes several practices that are considered essential to properly planning and executing the section description. The relationship between the BPPII score and construction productivity was validated by CII's research (RT-252), by examining the difference significance in terms of project productivity performance factor between two groups of projects – project groups with high and low BPPII scores (see Figure 5) (CII 2013b). Dozens of projects were required for statistically confident validation, and this research contributed some of those projects. The BPPII tool is presented in Appendix B with the Introduction, Part A – Project Information, Part B – Project BPPII Assessment Sheet, and Elements Description (elements in category I – materials management is attached as a sample)

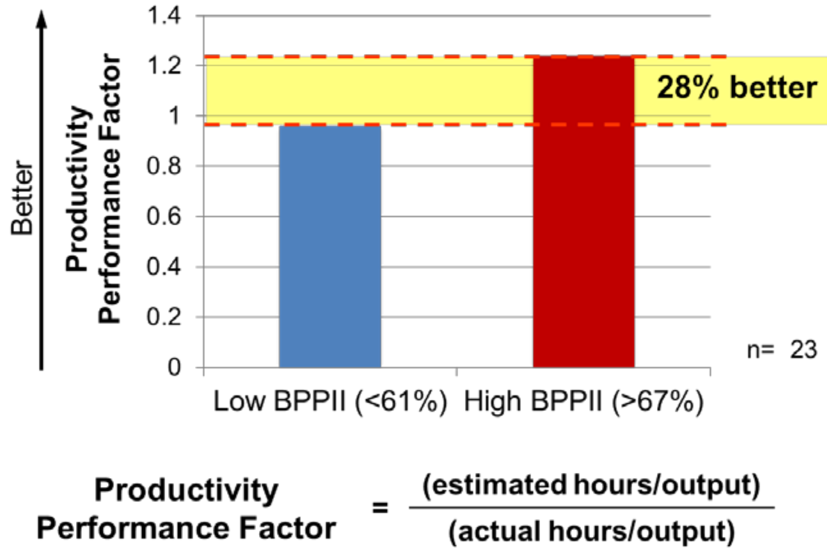

Figure 5 Higher Industrial BPPII Scores Led to Better Productivity (CII 2013b)

2.7 Previous Research on Construction Productivity Modeling

As aforementioned, previous researchers thoroughly investigated some factors that influence construction productivity performance. Many researchers continue to quantitatively analyze correlations between construction productivity performance and factors. In summary, there are two main purposes in these research efforts:

1. Establishing construction productivity modeling for measuring and predicting productivity, which is essentially the basis of project estimating and scheduling.
2. Promoting cognition and understanding of productivity-influencing factors, and exploring effective ways for improving productivity performance in terms of strategies, solutions, and practices.

The literature review shows that most of the previous research encompasses the first purpose. In addition to the inconsistent productivity measurement issue that has been reviewed in section 2.3, another difficulty of estimating productivity is coming from the complexity of influences from numerous productivity factors.

Many studies have been conducted to examine the productivity factors impacting on various construction activities, such as concrete construction (Sonmez and Rowings 1998), masonry construction (Sanders and Thomas 1991), pile construction (Zayed and Halpin 2005), mechanical construction (Chang et al. 2007), and foundation construction (Chong and Chou 2006). Those factors that directly represent the qualities of resources and site conditions were considered in these studies. For example they were mostly considering worker experience, equipment condition, weather, traffic condition, work zone congestion, and dimensions of specific construction trades. The correlation between factors and the resulting productivity is very difficult to quantify. The published standard productivity data such as RS Means only serve as a broad reference for estimators. Current industry estimating practice still relies on individuals' judgments based on the uniqueness, complexity, and uncertainty involved in construction projects. Therefore, a number of modeling techniques were introduced to research the correlation between influential factors and productivity for estimating purpose, which includes statistical and regression models (S. D. Smith 1999; Zayed and Halpin 2005; Thomas and Sakarcan 1994), fuzzy expert systems (Fayek and Oduba 2005), ANN (Dissanayake et al. 2005; Ezeldin and Sharara 2006; Lu et al. 2000; Song and AbouRizk 2008), time series (Hwang and Liu 2005, 2010; Kumar et al. 2001), and related simulation. From these research efforts, estimating work could reduce its dependence upon personal judgment which is limited by the level of knowledge and experience of a particular estimator, and may not produce consistent and reliable project plans.

Productivity performance is not only impacted by the factors that represent physical work condition, but it is also dominated by the factors with respect to implementation of construction management activities. Literature review in section 2.5 shows that several research institutes thoroughly investigated management practices that positively affect productivity performance, and summarized sets of best practice that can be regarded as guidelines to facilitate management implementation. Furthermore, it is expected that there should be a systematic mechanism for construction enterprises to support internal regular reviewing and monitoring of their management practices implementation, in order to deploy gaps analysis for their management practices and introduce effective improvement paths for their management. These are the requirements for the second main purpose of construction productivity modeling research. Not many researchers have contributed to this second purpose so far, because there are a number of challenges that are difficult to solve.

Regarding evaluation of productivity performance, the most popular way is using the estimates as a basis for judging productivity performance. Methods were well summarized, such as method of "estimated versus actual productivity" which reports the comparison of the percentage of man-hours expended against the percentage of work completed. "Measured mile" reports productivity performance using the actual man-hours against the concept of earned man-hours (Alfeld 1988). Those methods evaluate the success of productivity performance just for an individual project itself. However, only by measuring absolute values of construction labour productivity can we benchmark productivity performance from project to project.

However, consistent measurement of construction labour productivity performance is a big challenge. Productivity measures labor input per unit of work output. Three reasons lead to inconsistent measurement: (a) Measurement of input: Although it is well known that the labour input is measured in terms of labor hours, these labour hours may consist of multiple labour types and construction activities (in terms of craft process). In this sense, the measurement scope of labour hours taken into account of certain craft productivity may not be consistently defined from project to project. (b) Measurement of output may apply multiple units from different perspectives. For example, the output for structural steel may be measured by weight, length, or a number count of pieces; the output for piping may be measured by length of installed pipe, or welded diameter inches of installed pipe. (c) Field measurement for productivity performance is oriented by the organization of construction assignments. Various work breakdown structures (WBS) may increase the difficulty of consistent measurement of productivity performance.

Field measured productivity data represents productivity performance in a project, which is a composite result influenced by both physical environmental factors and construction practices implementation. How to evaluate the influence of construction practices implementation separately from the influence of physical environmental factors is an essential problem that needs to be solved.

Quantifying construction management practices is a challenge. Corresponding to measuring productivity performance, construction practices implementation level also needs to be measured, in order to identify the best practice and evaluate the deployment of practices on projects. Measuring construction practices implementation level is the fundamental basis of practices gaps analysis, for which numbers of problems need to be studied: for example, select or create appropriate diagnostics or survey tools, customize and deploy the survey tools, as little extra work as possible to get data, etc.

Regarding gaps analysis for practices implementation, an enterprise needs a systematic mechanism to support continuous internal improvement over time. Benchmarking and Metrics systems are considered potentially very useful for managing construction practices and supporting continuous improvement. BM&M was introduced to the construction industry not long ago, and normally only drives general key performance indices benchmarking at the level of project performance, such as cost performance, schedule performance, safety performance, change management, etc. This research intends to introduce BM&M to construction productivity management, especially to supporting gaps analysis of practices implementation, which requires creative research on mechanism models, practical processes, and related indices. The next section will review the background knowledge of Benchmarking and Metrics and comment on its current status of application in construction enterprises.

2.8 Systems (Benchmarking and Metrics)

Benchmarking originated in the manufacturing industry as a way of systematically and continuously measuring the firm's business and management processes and comparing them with those of leaders in the field as a means of identifying areas for potential improvement. Comparison may be with similar internal units in the same organization or with completely external competitors operating in the industry. The primary objective is to achieve best practices: principally by introducing a perceived improvement and subsequently measuring its effectiveness against changes in key indicators such as: quality of end product or service, productivity, cost performance, safety, delivery time, and sustainability criteria. The approach typically embraces the following procedure (Harris et al. 2006):

- Establishment of the functions to be benchmarked, e.g. team-building, constructability, accident rate control, pre-project planning, variations management, information technology management, equipment maintenance management, supplies and subcontractor procurement, quality management, disputes resolution, environmental impacts, etc.
- Identification of competitor or body for the benchmarking task
- Collection and gathering of data
- Analysis of the information and comparison with competitor
- Implementation of recommendations for improvement
- Monitoring the key indicators and adjustment of the modifications as necessary

The construction industry has followed the lead of manufacturing in adopting the BM&M program. Current benchmarking standards in construction are focused on general performance indices such as actual versus budgeted costs, actual versus estimated schedule, scope changes, actual versus estimated overall project construction labour (hours or cost), field rework, field defect, and safety incidents. Sets of effective influence-factors were also investigated for understanding general relationships in terms of practices impact on performance. Existing BM&M programs are normally operated by some institutes (such as CII, HBR, IPA, and PMI), as a third party, which collect and provide benchmarking information for its members in the construction industry. This is actually "blind" competitive benchmarking (Fisher, Miertschin, and Pollock Jr. 1995), because only synthesized information is presented to members, as the raw information is kept confidential. By comparing with those benchmarks, a company can set the goal of performance and drive overall strategic planning and adoption of practices at best. However, such an internal Benchmarking program model has not been found from previous literatures or commercial applications. Therefore, there is a lack of following mechanisms, policy & procedures, tools, and indices to form a specific improvement roadmap. Such a roadmap would include:

- Internal gap analysis (what practices are missing or are inconsistently deployed on projects and would have a high payoff)
- diagnostics tools (quantifying management practice implementation)
- a smart way of evolving current practices
- justification for consistent practice application across all projects
- a way of comparing internal performance with industry benchmarks
- a way of measuring own internal improvement over time
- a way of determining which practices work best for their own company
- focus on no extra work to get data

- consistent productivity performance measurement across the projects and project types (need to be consistent, need to be mapped to the selected third party benchmarking standard)
- index of consistency of deployment
- index of extent of deployment of corporate practices on each project

What are stated above are the foci of this research. In this research, a benchmarking system model provides a continuous improvement mechanism to facilitate construction best practice implementation. The system will record the information of productivity performance, practice implementation level and the data of related construction environmental factors. Analyzing that information against the selected benchmarks, gaps of practice implementation and improvement roadmap are also addressed.

Chapter 3: BM&M Model for Productivity Continuous Improvement

Success for a construction firm depends not only on a high quality product but also on a constant increase in productivity to stay competitive. Thus, construction firms constantly review their methods, procedures, technologies and related environmental factors in order to find ways to produce more outputs with fewer resources. Labour productivity has especially significant influence on a construction firm's competitiveness. This chapter presents a benchmarking model which introduces a set of systematic functions for reviewing project management practices, construction environmental factors, and craft labour productivity performance. Based on the reviews, the model also introduces functions for guiding practices improvement planning. In summary, this chapter introduces a BM&M program model to improve productivity performance within a company, and the functions of model including: (1) establishing leadership commitment, (2) determining metrics, (3) data collection, (4) productivity evaluation, (5) analysis of practices implementation, (6) practices improvement plan, and (7) corporate level model implementation. The model is summarized at the end of this chapter.

3.1 Synthesis of Construction Productivity Improvement Strategies

Construction productivity improvement strategies are practiced at three levels through optimizing activities in a construction project (see Figure 6). Productivity improvement exhibits in several classes of changes corresponding to the measures at each management level (crew, project, and corporate), which are shown in the middle column in Figure 6. At each management level, construction productivity performance is measured with a different perspective.

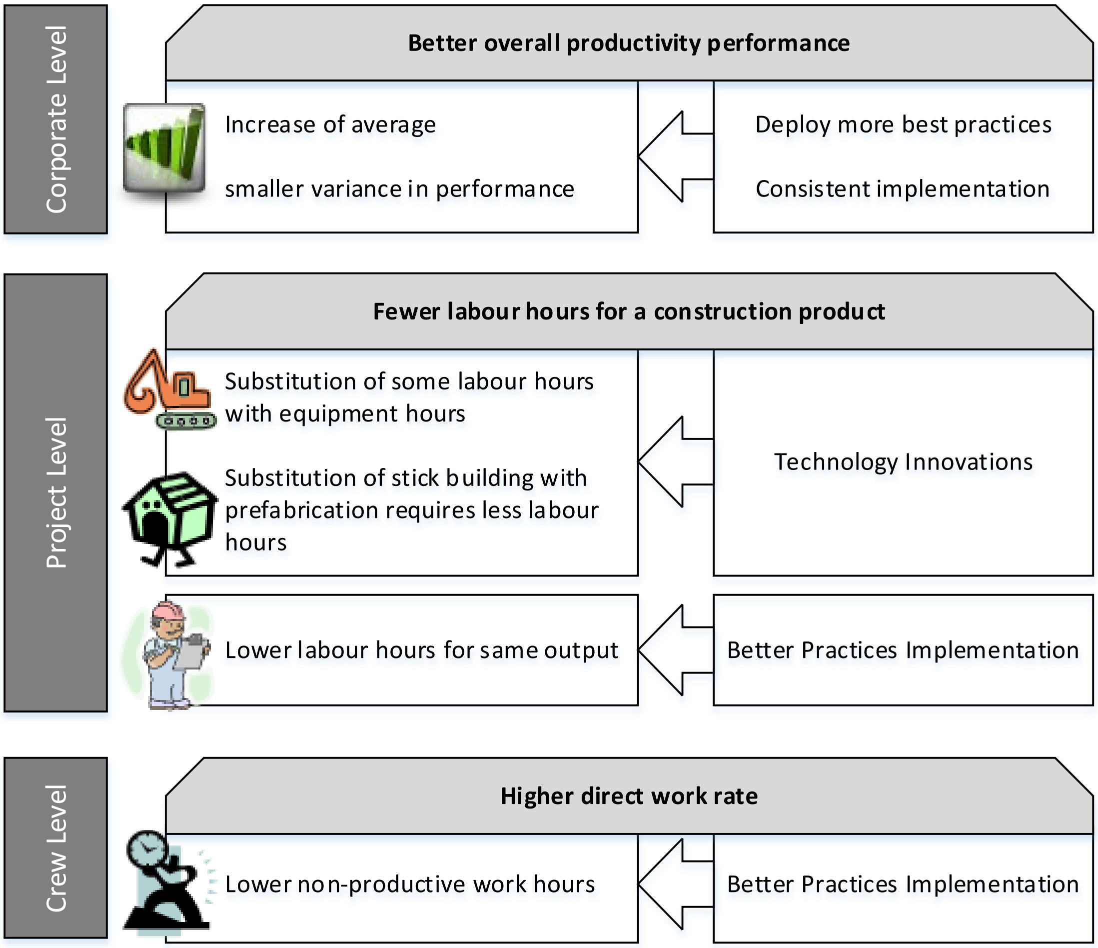

Figure 6 Construction Labour Productivity Improvement Strategies

1. At the project level, productivity is widely understood as the ratio of labour hours input over unit product output. According to a labour productivity definition, the changes that lead to fewer labour hours per unit of production is the mechanistic view of construction labour productivity improvement.
2. At the corporate level, the corporate executives care about the overall productivity level in their corporation, which drives the adjustment of the baseline productivity for a construction enterprise. The improvement of overall productivity performance is like a common quality improvement issue, which is understood as an increase in average

productivity and a decrease of productivity variance in the population of the corporate projects.

3. At the crew level, productivity improvement focuses on a higher direct work rate by reducing the non-productive work time portion in the total work time. Direct work rate is defined as the ratio of the direct work hours over the total work time (refer to section 2.3.5), which extends the measurement of productivity deep to the crew level.

Corresponding to the behaviors of productivity improvement at the three management levels, actions for driving such improvement are also classified in several classes based on the management functions (shown in right column in Figure 6). Labour productivity improvement is driven by: (1) technology innovations, and (2) better practices. “Substituting some labour hours with equipment hours” and “substituting stick building with prefabrication” both require technology innovations, which usually drives a step change all over the construction industry. Facilitating better practices usually takes effect in routine management to drive productivity improvement. The enterprise level internal BM&M program presented in this thesis is designed for benchmarking project management practices implementation, rather than evaluating a specific technology innovation. The following paragraphs delve further into: (a) the mechanism of how management practices affects productivity improvement; and (b) interpretation of “better practices implementation” and how it behaves at different levels.

3.1.1 Mechanisms for construction practices impacting labour productivity

The mechanistic view of construction practices impacting labour productivity is derived in the model presented in this thesis from activity analysis of construction sites. Labour hours spent in the field are normally classified into three categories – “direct work hours”, “supportive work hours” and “non-productive work hours”, based on their effectiveness toward producing outputs (Table 7).

Table 7 Summary of Construction Work Time Study

<table>
<tr><th>On site work hours classification</th><th>Practices require</th></tr>
<tr><td>Direct work hours</td><td>Direct work is the act of either exerting physical effort to perform an activity that directly produces outputs or of physically assisting in these activities. The efficiency of direct labour hours is dominated by:
1. Labour proficiency
2. Effective tools
3. Experience
4. Action intensity
5. Comfortable, safe, healthy work environment</td></tr>
<tr><td>Supportive work hours</td><td>This work is necessary for supporting the direct work. categories include:
• Receiving assignments
• Explaining and planning the work
• Safety talks
• Tools and equipment handling
• Materials handling
Supporting work time can be reduced by applying better practices. It ensures that:
1. The right construction resources are distributed at the right location, at the right time, and with the right quantity;
2. Quality of construction resources is appropriately maintained;
3. Instructions and communications are delivered in a timely and precise manner;
4. Work space for labour is available, safe and healthy.</td></tr>
</table>

On site work hours classification	Practices require
Non-productive work hours	Non-productive labour hours include: • Waiting or idle time • Unscheduled personal time • Rework labour hours Mitigating non-productive labour hours requires: 1. Optimal scheduling 2. Timing resources allocation 3. Precise work instruction 4. Qualified craft labour with respect to knowledge and skill

Ideally, construction management intends to eliminate non-productive time, reduce supporting work time, and further maintain direct work time in a rational high proportion of the whole work time. Table 7 summarizes the natures of these three classes of construction work time, and includes the management strategy for each of them. In summary, construction practices management should facilitate the following strategies for improving construction productivity.

1. Establish effective resources management: Resources here refer to physical elements that are put into construction production including three types: (1) materials, (2) equipment and tools, and (3) work space. Construction practices implementation should ensure that the right construction resources item is distributed in an efficient way to the right location, at the right time, and with the right quantity; and quality of construction resources is appropriately maintained.
2. Work instruction and communication management: Apply appropriate practices with respect to providing necessary information about how the work should be done, which includes short interval planning, work-face planning, work packaging, and constructability review.

3. Construction method management: this involves choosing the construction methods that are determined during planning of the project that need to be used to create the highest productivity, such as scheduling of work, start-up planning, new product investigation, and site layout planning.
4. Enhance repetitive construction operations: Standardization of design and engineering allows for repetitive operations that promote an increase in productivity. Examples of practices in this area include standardizing designed products, craft processes, and work packaging.
5. Promote human resources: This strategy requires the best practices to leverage the human resources on a project including training and development, human behavior management, project organization, and employment strategies.
6. Develop a safe and healthy work environment: There are some practices that must be followed to ensure the health and safety of all persons who will be on the jobsite during the construction of the project and in the surrounding community.

3.1.2 Behaviors of better practices implementation

Figure 6 shows that implementing better practices in routine management is the important way to improve construction productivity. Practices improvement behaves in different ways at three management levels.

At the corporate level, the better practices implementation unfolds in following ways:

- Practices related to productivity management are well defined in the management manuals (such as ISO 9000 process definitions and project execution planning requirements) to be practiced in project execution, with respect to procedures, responsibilities, information flow, and methods (techniques and tools). These manuals are typically the guides driving the overall practices implementation level in a company.

- Overall practices implementation level of the corporation is tracked, which is measured by the average practices implementation level in the population of the typical projects being taken into evaluation. It is expected that the overall corporate practices implementation level could compete with the average level of the industry and approach the best-in-class.
- Practices are implemented in a consistent way in the typical projects corporate wide.

At the project level, project management usually implements practices according to the specific conditions of project execution, typically following the corporate guideline of practices implementation, but still having adequate autonomy to adjust relevant procedures and methods in order to work better for the specific project. Project management is also encouraged to plan and implement advanced methods (techniques and tools), which are beneficial for improving overall practices implementation.

At the crew level, the construction practices are more likely to be reflected in the specific management content such as craft techniques and tools, optimized schedule and shifts, optimized site layout, etc., rather than implementing efficient and effective management procedures. Activity Analysis is the extension of work sampling technique into a continuous improvement process. One part of Activity Analysis is the workface assessment of direct work rate, which is a typical index reflecting construction productivity performance. Moreover, Activity Analysis characterizes the proportion of time that craft workers devote to specific work activities. Thus, it addresses the probable problems of construction practice planning and implementation taking place in the field. To solve these problems, better crew practices suitable for the specific conditions are introduced in cooperation with the workforce.

3.1.3 BM&M to manage practices

On the basis of reviewing construction productivity improvement strategies, it is clear that better practices implementation in routine management of construction projects facilitates improvement of construction productivity. It is generally accepted that a benchmarking program can provide timely alerts for underperformance, and it can help to identify good practices. It can help to promote a culture of continuous learning among leaders and throughout the company, and it can help identify innovations that improve performance. The Benchmarking and Metrics process is critical to improving project performance.

Based on the analysis of various behaviors of better practices implementation and evaluation of productivity performance with respect to different management levels, it is necessary to systematically benchmark productivity performance and the relevant practices taking place in the field. A set of metrics of productivity performance and practices implementation with respect to different management levels need to be introduced accordingly. On top of the data collection in terms of the selected metrics, one can examine the effectiveness of the practices implementation level, analyze the practices implementation gaps with respect to the best-in-class, and further address the best way to improve construction management practices in a specific company.

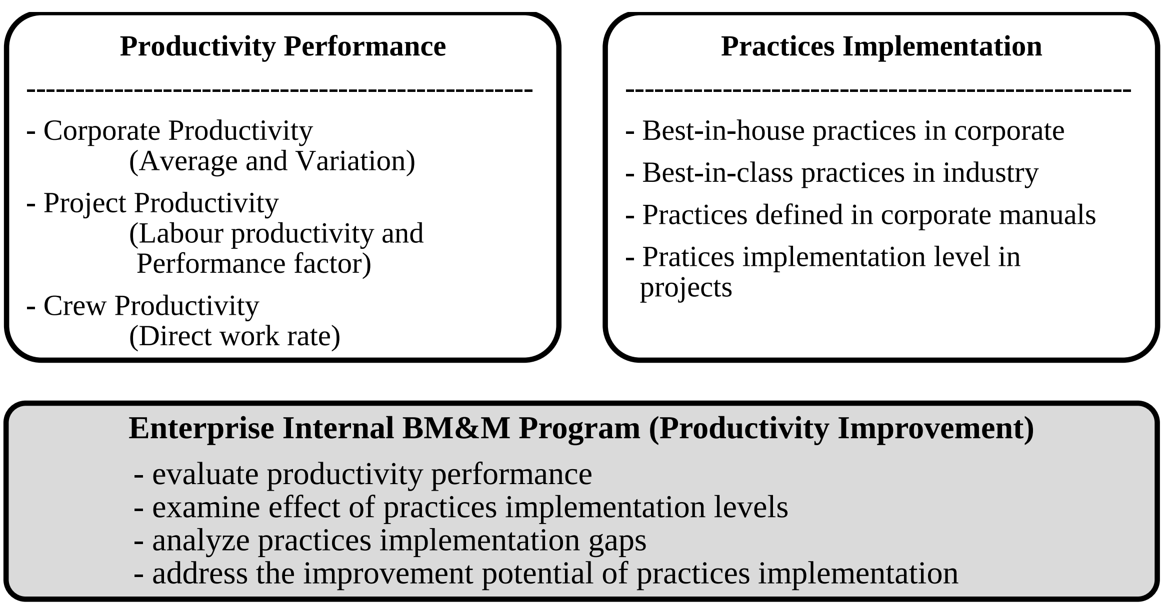

Figure 7 General Strategy of BM&M Program Supporting Productivity Improvement

The enterprise internal BM&M program model proposed in this research is focusing on improving construction productivity, by systematically reviewing relevant practices in a company's construction projects. Figure 7 demonstrates the primary subjects that need to be benchmarked and assessed, including numbers of elements regarding productivity performance and practices implementation.

3.2 BM&M Program Model Support of Continuous Improvement

The proposed BM&M program model for continuous improvement in construction productivity explained above is summarized in Figure 8. The BM&M system consists of five functional processes: Determination, Recording, Evaluation, Analysis, and Recommendation.

1. First process "Determination" means determining a set of metrics that best represents project performance level, productivity performance level, and productivity practices implementation level. This step determines the work scope of the BM&M program.
2. "Recording" includes introducing a series of efficient data collection processes and integrating them into existing project information management systems. Relevant procedures, accountability, data sources, and data collection tools must be addressed.
3. "Productivity Evaluation" is the process to evaluate the project productivity performance deviation from the target, from the best-in-class, and from the industry average. Thereby, one can examine the effect of the practices set and the effect of practices implementation improvement. The basis of these evaluations is the data collected following the selected metrics.
4. In the process of "Gaps Analysis", a systematic method is developed to detect the practices implementation gaps, including the gaps between: corporate guideline vs. industry best practices, projects practices implementation level vs. corporate guideline, and corporate average level vs. industry average level. The purpose of the gaps analysis is to identify the practices implementation improvement potentials.

5. In the process of "Planning Improvement", on the basis of gaps analysis, the most suitable ways for a specific corporation to improve their practices implementation are identified, which includes identifying most effective practices combinations, considering cost-efficiency, improvement roadmaps, automation and integration scheme, etc.

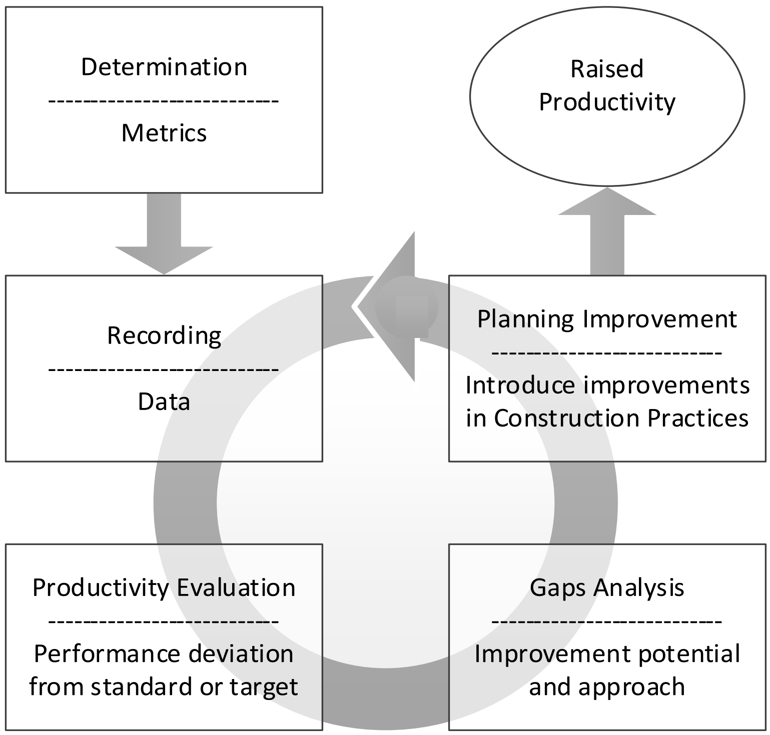

Figure 8 Continuous Improvement Framework of BM&M Program Model

Regarding production process improvement in an industrial construction corporation, there are numbers of sections being paid attention to. Productivity improvement is the main purpose of the proposed BM&M program model, which is also one of the drivers of enterprise's core competitiveness. By determining metrics related to productivity improvement in the first process step "Determination", the framework of benchmarking is established. The remaining four processes form a typical continuous improvement loop. By running this functional processes loop, the management of construction enterprise can continuously monitor the implementation level of construction practices in a corporation and further identify the improvement potential of the practices in the corporate projects management. After making appropriate adjustment on project management practices, this program is able to re-assess the implementation level of upgraded practices and then identify the new gaps of practices implementation for a corporation. Meanwhile, corporate productivity performance is also continuously benchmarked against the industry level, and against corporate productivity in each former stage, which allows examination of the productivity improvement within a corporation when an adequate longitudinal project dataset is acquired. This continuous monitoring and analysis forms the basis for implementing continuous improvement of productivity with in an enterprise. Following sections will present details of those five processes displayed in Figure 8.

3.3 Determining What to Benchmark

An internal BM&M program will differ from the programs run by government agencies, industry associations, and consultants. It is primarily intended to work within a specific internal corporate context and to support internal continuous improvement, but it should also support utilizing external collaborative BM&M data. In addition to focusing on construction productivity improvement, the principles of choosing appropriate metrics are established as follows:

3.3.1 Metrics determination principles

1. Compliance with existing systems
    - Attempt not to add too much work to existing management work flows.
    - Regarding data collection, avoid introducing new field tracking requirements to the existing project control data system.
    - Avoid conflict with existing project performance evaluation indices.
2. Flexibility to match certain external collaborative BM&M databases
    - Determine external collaborative BM&M database (CII BM&M database is chosen for this research)
    - Minimize translation required to match to CII metrics

- Only pick key elements (indices, factors, or practice elements) that reflect the nature of industrial construction, which could mitigate the work load for running the BM&M program

3. Tightly focus construction productivity improvement
    - Project performance metrics at the top level should be evaluated for examining the effect of productivity improvement on a project's overall performance.
    - Productivity performance will be evaluated for craft trades and even broken down to lower levels in some circumstances or for leading indicators.
    - Look at typical craft trades in industrial construction. For example, piping constitutes 50% of the value of a typical industrial construction project so those trades associated with piping will drive overall productivity performance.

3.3.2 Metrics determination method

Mapping is the basic method to determine metrics for a specific BM&M program, which includes: (1) reviewing full list of pertinent content about a BM&M program in construction; (2) screening content by applying the determination principles discussed earlier; (3) screening content by comparing the aggregation approaches defined in different metrics systems; (4) addressing the sources of required data and the data delivery path in the corporation; (5) creating corresponding relations between the elements based on their definitions in internal and external benchmarking programs.

For this thesis, initially, all the relevant metrics were reviewed, including review of all the practices related to improving project performance and productivity, review of all the project performance metrics, review of productivity metrics at multiple breakout levels, and addressing the possible data collection sources. Many pilot studies were also done to examine the feasibility and validity to assess those metrics with respect to data collection approach and the correlation to construction productivity. Finally, the essential metrics were determined. These steps must be repeated to implement the model presented in this thesis in other corporations. The following sections generalize and explain using the industry partner for this research as an example how to implement the mapping methods, and how to implement aforementioned principles for determining metrics.

3.3.2.1 Mapping metrics scope

As noted, the BM&M process is critical to improving project performance in construction industry. Elements to be defined in such a BM&M program in construction are sorted in five categories (see Table 8).

Table 8 Key Elements to Benchmark

Performance:	Including productivity at various levels and for various crafts, and including schedule, cost, safety, quality, etc. at the project level, and including even competitiveness at the corporate level.
Practices:	Including management procedures, policy, work instructions, relevant tools/techniques, explicit and implicit knowledge, and necessary forms
Environment:	Including business environment, project complexity, site layout, weather, location, etc.
Work Package:	Precisely defined and hierarchically aggregated scopes of work.
Time:	Frequency of data collection, project phase of data collection, and duration of projects

Levels of aggregation are defined for the elements in each category according to management requirements. This research only considers aggregation tiers below the corporate level, which is summarized in Table 9.

Table 9 Aggregation Levels Applied To Model Implementation for Functional Demonstration

Category	Element	Aggregation tiers	
Performance:	Productivity	• Corporate	✓
		• Project	✓
		• Craft discipline	✓
		• Component	
	Cost	• Corporate divisions	
		• Project	✓
		• Cost classes (e.g. labour, material, etc.)	
		• Component	
	Schedule	• Project schedule	✓
		• CWP schedule	
		• Short interval schedule	
	Safety	• Corporate annual incident rate	
		• Project incident rate	✓
	Quality	• Project non-conformance	
	Changes	• Cost of change in a project	✓
Practices		• Corporate business practices	
		• Project execution practices	✓

	• Specific management practices (e.g. productivity, safety, HR, etc.) • Construction craft practices	✓
Environment	• Corporate business environment • Geography environment • Project complexity	 ✓ ✓
Work package	• Plant • Area (phase) • Construction work package • Drawing • Piece	
Time	• Project phases • Milestone of delivery • Monthly, weekly, daily	

Applying metrics determination principles to screen metric elements by aggregation tiers, items marked with a check symbol are selected for next step mapping. It should be noted that the factors regarding to "work package" and "time" are not selected for the individual metrics category in the implemented BM&M program. However they will be considered in the productivity data collection process and the productivity evaluation.

3.3.2.2 Mapping project performance metrics

First, review the full list of CII's project performance metrics (the chosen external standard), which is summarized as follows. Detailed definitions of each term are presented in Appendix C.

- Cost Performance Metrics

- Project Budget Factor
    - Delta Budget Factor
    - Project Cost Growth
    - Delta Cost Growth
- Schedule Performance Metrics
    - Project Schedule Factor
    - Delta Schedule Factor
    - Project Schedule Growth
    - Delta Schedule Growth
- Change/Rework Performance Metrics
    - Change Cost Factor
    - Total Field Rework Factor
- Safety Performance Metrics
    - Total Recordable Incidence Rate (TRIR)
    - Days Away Restricted Transfer Rate (DART)
    - Direct-Hire TRIR
    - Direct-Hire DART
    - Subcontractors TRIR
    - Subcontractors DART

Concurrently, the project performance evaluation system of the specific enterprise (Research Partner Company) were also reviewed. A set of similar project performance indices were utilized within the partner company. Within the intersection of this two sets of metrics or indices, one metric was picked for each performance element. This required extensive analysis, consultation with the corporation's expects and stakeholders, and several research team meetings. In the end, the research project team achieved a consensus commitment of project performance metrics (see Table 10). Regarding productivity performance, Table 10 only presents the general definition and calculation formulas to which the team agreed. Productivity performance is evaluated at a deeper level than the project level. The next section will discuss productivity metrics determination at the level of craft disciplines. In addition, within the productivity metrics, the Activity Analysis (Gouett 2010) method is selected to obtain direct work rate.

Table 10 Selected Project Performance Metrics

Performance Element	Metric	Formulas
Productivity	Direct work rate	$\frac{Observations\ of\ Direct\ Work}{Total\ Number\ of\ Observations}$
	Cumulative Labour Productivity	$\frac{Work\ Hours}{Unit\ of\ Physical\ Output}$
Cost	Project Budget Factor	$\frac{Actual\ Total\ Project\ Cost}{Initial\ Predicted\ Project\ Cost\ +Approved\ Changes}$
Schedule	Project Schedule Factor	$\frac{Actual\ Total\ Project\ Duration}{Initial\ Predicted\ Project\ Duration\ +\ Approved\ Changes}$
Safety	TRIR (Total Recordable Incidents Rate)	$TRIR = \frac{Number\ of\ RI \times 200}{Total\ Work\ Hours}$
Changes	Scope Change Cost Factor	$\frac{Total\ Cost\ of\ Scope\ Changes}{Actual\ Total\ Project\ Cost}$

3.3.2.3 Mapping productivity metrics

Similar to mapping project performance metrics, it is important to first review the full list of CII's industrial construction productivity metrics. There are 8 crafting disciplines organized in three aggregation tiers (Park et al. 2005): (1) discipline (e.g. Electrical); (2) function (e.g. wire and cable); (3) component (e.g. power and control cable – 600v). See details in Appendix A.

In order to determine the suitable metrics of productivity for internal benchmarking, the partner company's productivity performance evaluation process was reviewed. In addition, some relevant management processes were also reviewed, including: reviewing cost code structure, project tracking system, and major construction trades in most projects. Those reviews show: (1) the partner company normally engages their own workforces mainly in five crafting disciplines – piping, electrical, mechanical equipment, structural steel, and concrete; (2) most of their project contracts involve two major crafting disciplines – piping and electrical; and (3) in their project tracking system, quantity tracking items are usually broken down just until tier-2 (function). On the basis of the above analysis, the labour productivity metrics are determined as in Table 11. This same sort of analysis would be conducted for application of the model to other industrial construction enterprises.

Table 11 Selected Labour Productivity Metrics

Discipline	Metrics	Unit
Concrete	• Total Concrete	Whr/CY
Structural Steel	• Total Structural Steel	Whr/Ton
Electrical	• Total Electrical Equipment • Total Wire and Cable	Whr/Each Whr/LF
Piping	• Small Bore (2-1/2 inches and smaller) • Large Bore (3 inches and larger)	Whr/LF Whr/LF
Mechanical Equipment	• Total Equipment	Whr/Each

3.3.2.4 Mapping practices

Assessing the practices implementation for a specific enterprise is one of the core functions of this internal BM&M program model. The research reviewed comprehensive practices elements in construction projects.

First, a set of management manuals in the Partner Company were reviewed, which in over 500 pages defines the processes, procedures, methods, and tools that are introduced in their construction management for a project. These manuals are the guideline driving the overall practices implementation level corporate wide for the Partner Company. Most large industrial construction enterprises have a similar set of manuals or process definitions.

Industry best-in-class practices for construction management were also reviewed. CII is a consortium of over 130 leading owners, engineering and construction contractors, and suppliers. The CII funded many research projects with more than 40 leading universities involved. The research results lead to best practices for the entire construction industry to share and implement to improve the likelihood of project success. Therefore, CII's Best Practices are selected as a valuable reference for enterprise internal practices implementation evaluation. Especially, the CII research team RT-252 has recently developed a Best Productivity Practices Implementation Index (BPPII) for the industrial sector of the construction industry (CII 2013b). The author assisted in developing this tool by drafting some of the definitions and by collecting data from 6 project for validation analysis. Best Productivity Practices outlines a set of practices that are widely accepted throughout the construction industry to have positive impact on craft worker productivity. BPPII is selected as a metric for measuring the practice implementation level in this research. It is also a checklist of essential practice elements that need to be planned and implemented in a construction project. In order to efficiently utilize BPPII as a practices assessment tool, it is necessary to map CII's best practices with Partner Company's project management processes. The details of practices mapping will be demonstrated in Chapter 4:.

In summary, the practices implementation metrics being incorporated into the proposed BM&M program focuses on the practices elements listed in BPPII, which involves the practices in six categories (see Table 12). The detail of BPPII and the description of each construction practice are listed in Appendix B

Table 12 Selected Productivity Practice Metrics

Category	Criteria	Metric
Practices	Practices to Improve Craft Productivity	Materials Management Equipment Logistics Craft Information Systems Human Resource Management Construction Methods Environmental Safety and Health

3.3.2.5 Environment metrics determination

As mentioned in section 2.4, a number of factors impact productivity performance, not only management factors. Therefore, tracking construction environment factors supports better evaluation of productivity performance. Table 13 summarizes the selected environment metrics, which includes major factors being considered in project cost estimation. These factors were based on analysis of the literature, meetings and discussions with the research project team members, and those factors used by the Partner Company’s estimating department. This process of determining environment factors to track would be repeated as part of the model defined in this thesis for a typical industrial construction enterprise.

Table 13 Construction Environment Metric

Category	Criteria	Metric
Environment	Labour Market	% of Union employee
		Average years of experience
	Geography environment	Weather (raining days, average temperature)
		Location
	Project complexity	Project size (contract value)
		Construction sector
		Congestion in construction site
		Stack of trades
		Height of job position

3.4 Recording

The main purpose of this process of “Recording” is collecting raw data for all the selected input elements for benchmarking. Raw data includes work-hours, installed quantities, management practices, technologies applied, weather, site condition, and so on. This section introduces the process and data resources for collecting data.

3.4.1 Labour productivity data recording

As the productivity metrics are determined, in order that one can compare the productivity from project to project, as well as compare to external data, it is expected that the productivity data collection should be compliant with the aggregation of the selected metrics. The productivity data collection relies on the existing project progress tracking system, since to not make an extra individual field tracking system is a key principle of the model proposed. The aggregation of the tracking items in existing progress tracking systems normally do not match easily with the selected metrics. This section suggests a set of data mapping functions from existing project progress tracking databases to the proposed BM&M system, which is a more efficient and sustainable way for productivity metrics data collection in a particular corporation. The data collection process and principles and methods of productivity data collection for the BM&M program is summarized below an explored more deeply in the following section.

Data collection process development includes:

- Reviewing the IT infrastructure and corporate processes and management structures of a particular corporation
- Mapping tracking items to the selected productivity metrics
- Mapping work hours counting from tracking items to the selected metrics
- Quantity tracking calibration

3.4.1.1 Review of project tracking processes and IT infrastructure

This step contains of three tasks: (A) examine the validity of the data collected from the existing project progress tracking system of a particular corporation; (B) address the data collection sources in its IT infrastructure; (C) address the data retrieval rules in its project databases (determine the attributes of the data sets).

(A) Productivity raw data in project progress tracking system

Labour productivity raw data includes work-hours and quantity installed, according to its definition. For a particular corporation with a sustainable management system, they usually have their own formal process to track the volume of production output and labour input from field tracking. As an example, Partner Company's project tracking procedures with respect to productivity data is summarized as follows.

Quantity installed = Budget Quantity + Quantity Revision

1. The measurement of quantity installed should be defined by three dimensions: (1) occurred in which work package, (2) being recorded in which tracking code, and (3) in which time period it occurred.

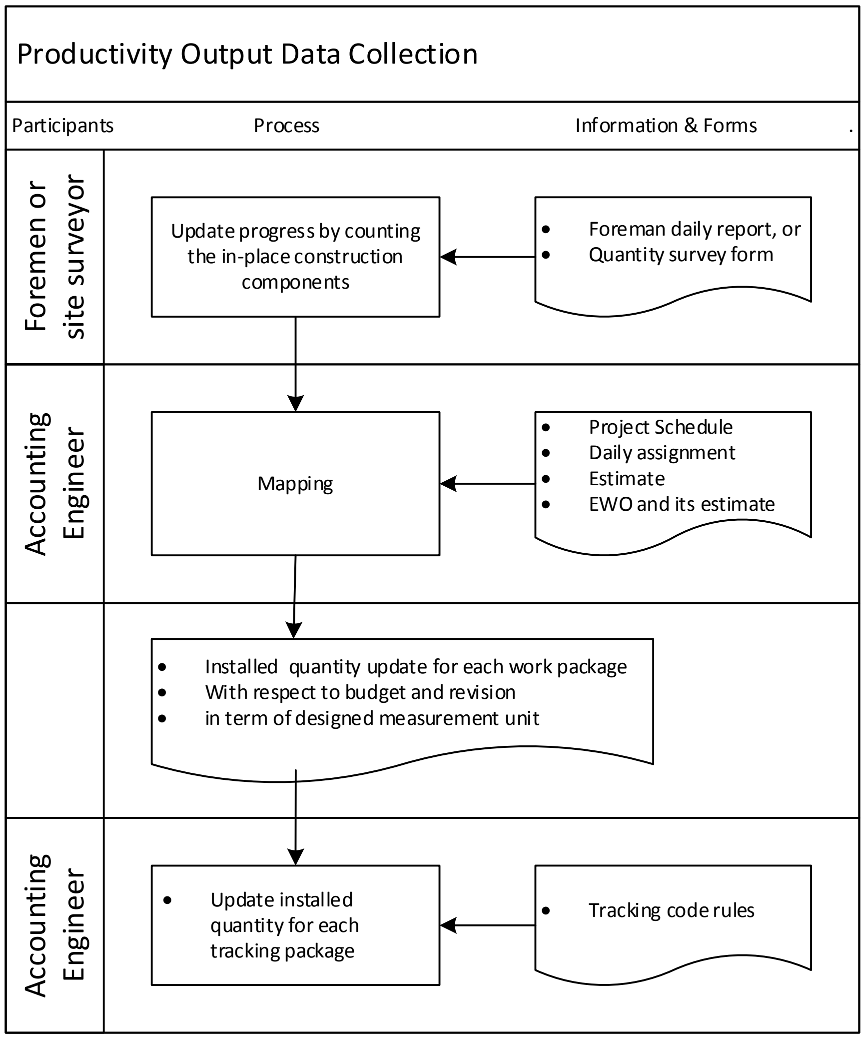

Figure 9 Labour Productivity Output Data Collection

2. The general approach to measure the quantity installed is to count the units of production components. Then, by mapping these components with project schedules, initial estimates, and extra work estimates, the quantity with respect to its inherent measurement unit can be derived. The unit production component in construction is defined as an indivisible object with respect to quantity counting, such as: pipe spool, structure steel component, electrical device etc. However, some of the production components are so

big that they may not be completed with one reporting time cycle, such as: bulk concrete component, turbine placement, earth moving etc. They need to be divided by estimating completed percentage.

3. Another purpose of mapping production components to project schedules, initial estimate, and extra work estimate is to classify the completed quantity into budgeted quantity and quantity revision. This is the basis for cost control and change management.
4. Participants include foremen, site surveyors, and accounting engineers. The foreman or site surveyor is responsible for counting the completed production components; the accounting engineer is responsible for deriving the quantity and feeding to the accounting system.
5. The related forms and files for installed quantity measurement include: short interval schedule, daily assignments and its check list, estimates, extra work order (EWO), and survey form.

Labour work-hours is the only input required for reporting labour productivity

1. The measurement of labour work hours is also defined by three dimensions: (1) occurred in which work package, (2) being recorded in which tracking code, and (3) in which time period it occurred.
2. Information of labour work hours is generally from foreman daily reports and attendance sheets. Work hours for a work package is derived as

$$\text{Work hours} = \text{No. of worker in a crew} \times \text{daily work hour} + \text{overtime menhours}$$

3. In order to apply the above said three dimensional scoping for labour hours, several work sheets have to be introduced in this process. The Mark-up Assignment Work Sheet (see Appendix P) is used to link type of work force to work package, which also defines the

composition of the crew for a specific task. Accounting engineers should identify the appropriate tracking code; with such codes the data can be recorded. Foreman daily reports or attendance sheets should contain the following information: composition of craft crew, daily work hours, overtime, and whether each workforce was full time for the assigned work package.

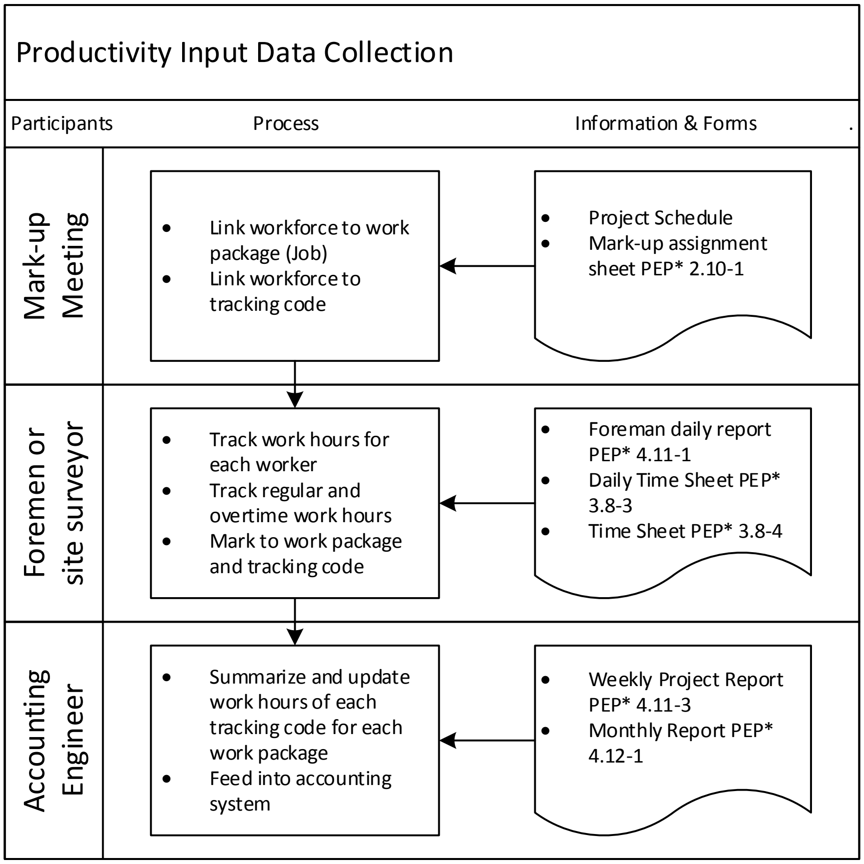

Figure 10 Labour Productivity Input Data Collection

(*PEP: Project Execution Procedure in the Partner Company)

4. Participants include foremen and accounting engineer.
5. The related forms and files for tracking work hours include: short interval schedules, daily assignments, mark-up assignment work sheets, foreman daily reports, and weekly reports.

The summary of the project tracking procedures reviewed the work processes validity with respect to work flow, information flow and accountability, which verified that the data collected from the Partner Company's system is valid for productivity reporting.

(B) IT (Information Technology) infrastructure of project progress tracking

A sustainable database system managing most of the project data is very supportive for establishing an internal BM&M program. There are two system supporting project progress tracking in the partner company, eCMS (Construction Management System) and FPMS (Field Progress Measuring System). FPMS is a specific project progress tracking tool embedded in Microsoft (MS)-Excel. It is an easily manipulated tool for visual demonstration for construction progress with data, percentage, and graphics, but it is just deployed in projects individually for the purpose of storing project data supporting project control. eCMS is a database system that manages most of the project cost accounting data for all projects, including material, labour, equipment, procurement, pay roll, payment, etc. the eCMS database is selected as the main source of productivity data.

(C) Productivity data retrieval from project databases

There are a number of data attributes in a database, which organizes the storage of data records. It is necessary to address the data attributes in the eCMS database that need to be retrieved for calculating labour productivity. The following data attributes are required (Table 14):

Table 14 Data attributes for productivity data retrieval

Name of Attribute	Description
"phase"	Project phases determined in WBS, normally depending to construction area or functional system
"cost type"	It determines the cost type in terms of labour, material, rent, subcontract, extra work, indirect, etc.
"cost code"	It is exactly the cost tracking codes, which defines the aggregation of progress tracking items
"task description"	It describes the tracking items in detail.
"current budget hours"	The estimated labour hours for a construction task.
"current quantity budget"	The estimated quantity for a construction task
"to date hours"	The labour hours spent for a construction task up to date
"to date quantity"	The completed quantity for a construction task up to date
"unite measure"	The measure unit being used to count the quantity

So far, productivity raw data sources (data attributes in the project database) have been addressed. Next it is important to identify the proper tracking items (data records) out of numerous records to fit the calculation of certain productivity metrics.

3.4.1.2 Analysis of the tracking items aggregation

Analysis of tracking items aggregation includes the break down structures of tracking items and the content within a single tracking item. The project cost allocation matrix helps with understanding how the cost elements are wrapped up in tracking items. Further, one can develop the rules for matching tracking items to a specific productivity metric.

Construction activities are organized in a set of work packages by the Work Breakdown Structure (WBS). By mapping construction activities in the matrix of WBS against time with pertinent logic relations, engineers could implement project time (schedule) planning and control. Relevant construction resources, including labour, material, equip, method, work space and relevant required information, are also allocated in the work packaging process. A WBS is typically organized in six levels for industrial construction (CII 2011):

1. Plant, (or station, or unit)
2. Construction work area (CWA), (or work phase, or functional system of plant)
3. Construction work package (CWP)
4. Construction tasks
5. Drawings
6. Piece of component

When the contractor is awarded the project, the WBS is readily expanded into the detailed work package needed for control during project execution. The contractors normally align their manageable work packages with the project contract deliverables. Work packages are also definable increments from which the statement of work can be developed and the schedule, cost and progress reporting can be established (PMI 2006).

To complete a work package, one or more tasks will be performed. Thus, a work package may encompass the work of more than one crew or staff. A construction task is an activity performed by an individual and/or crew(s), with such activity being directly or indirectly required for completion of a work package. Typically, a construction task is selected as the control level of the WBS, so that the estimate is prepared by assigning resources requirements, cost, and durations to it. With the cost and schedule integrated in such a manner, it is possible to develop resource and cost projections into WBS/Time coordination. Each task in a fully defined WBS directory is identified by code and narrative title and all included control elements and their quantities listed.

Construction task will be tracked during the project execution with respect to the quantities of completion and the quantities of relevant resources being consumed, so each task corresponds to its tracking items in the project accounting system.

Cost analysis usually goes much deeper than the level of CWP with control elements integrated. And there is another structure for organizing items with cost implications, which is called Cost Breakdown Structure (CBS). A project accounting system is typically organized in CBS, which integrates all the cost elements (i.e. construction resources). On the basis of tracking the utilization of certain cost element aggregation, one can analyze the utilization efficiency of certain construction resources, such as labour, construction equipment, consumable materials, etc. CBS is normally unified within a corporate with the standard codes for those items with cost implications. Typical CBS is presented in Table 15

Table 15 Typical Cost Breakdown Structure (CBS)

<table>
<tr><td>Markup</td><td colspan="2">• Profit
• Overhead
• Contingency</td></tr>
<tr><td>Indirect</td><td colspan="2">• Staff
• Facilities
• Supplies & services</td></tr>
<tr><td rowspan="2">Direct</td><td>• Force Account Work Package</td><td>Labour
Materials (permanent & consumable)
Equipment (permanent & construction)</td></tr>
<tr><td colspan="2">• Subcontract</td></tr>
</table>

Theoretically, the WBS is included within the CBS (correlated to direct cost portion), but the WBS and the CBS are defined for different perspectives of project management. The WBS is the structure against which a task is controlled in terms of its cost, schedule, and related changes; while the CBS is the structure against which cost is controlled in terms of the resources utilization efficiency. Direct cost, as the essential part of the CBS, is physically initiated from quantities of work, which are determined by quantity takeoffs (i.e. quantity survey) using the work packages and specifications. These quantities of work are the basis of project control in the case of cost, schedule and change. With respect to another orientation, CBS, these quantities of work are also the basis for direct labor, materials, and equipment cost calculations. The quantities of those required resources are a function of the design and specifications (i.e. quantities of work) plus production rate (i.e. efficiency). Their cost is a function of quantities and unit price of resources. Therefore, the relationship between WBS and CBS is present as in Figure 11.

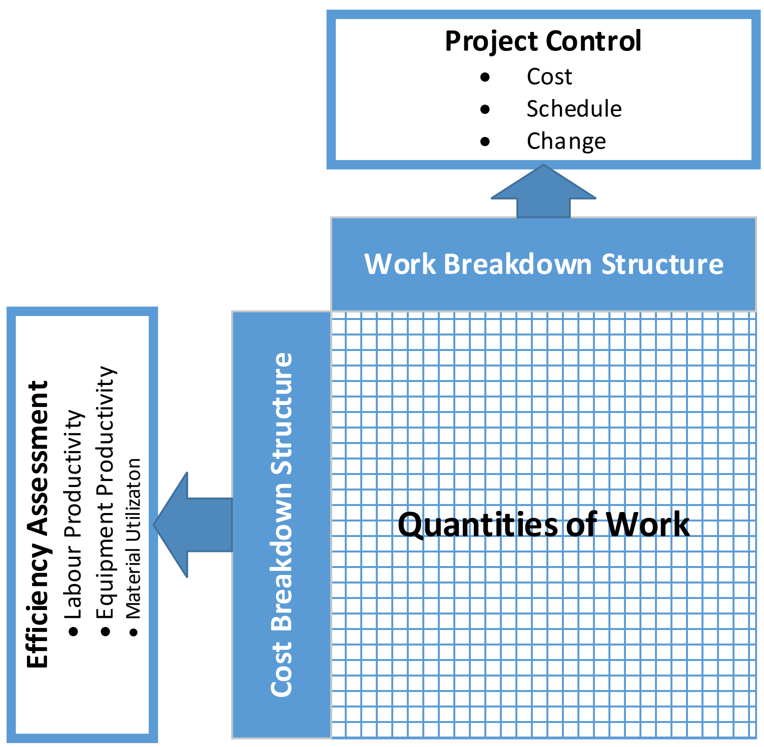

Figure 11 Relationship between WBS and CBS

The company normally has standard cost codes for resource identification. This research focuses on labour productivity. It is already discussed that the productivity metrics are organized in terms of craft disciplines. For the direct cost of labour, the cost code structure is broken down from craft disciplines. So, the cost code is the essential part to organize consistent productivity measures. The cost code for labour is a set of generic task codes to catalog work tasks in the project database. The Partner Company like many of its peers intends to adopt their own cost codes based on their business requirement, even though RS-Means and Richardson's recommends two sets of master accounting codes. For example, the cost code being adopted in the Partner Company is organized in the way presented in Table 16. The cost codes are organized in a hierarchy with 4 tiers, so that cost elements can be addressed deep to a work task for installing a piece of specific construction component. The bottom-up estimate needs to address these sorts of detailed cost elements, while tracking the work-hours for all cost elements individually is too time and cost consuming. In a practical way, work quantities and work-hours tracking are wrapped up (aggregated) to the level of craft disciplines.

Control accounts are selected accounts used by project management as the basis for resource allocation, productivity management, and data collection. Similarly, the productivity metrics in the BM&M program model developed in this thesis are like control accounts being organized in a CBS frame. A productivity metric can involve tracking items for a single work package at a chosen level of the WBS, a task, or can wrap up all work packages or tasks of the same type. Therefore, tracking the work quantities and work-hours is on the basis of work packages.

However, work packaging is not always consistent from project to project, even though cost code introduces a standard structure for wrapping up the construction tasks within a company. Determination of the WBS for a project depends on the nature of the construction with respect to project type (e.g. power generation plant, gas compressing station, and water treatment plant), contract conditions, and even the conventions of a specific owner.

Table 16 Example of the Partner Company's Cost Code

The Partner Company’s Cost Code (4 segments): xx.xx.xx.xx			
L1	**L2**	**L3**	**L4**
Discipline	**Function (or material)**	**Type of Craft**	**Dimension**
• Piping • Electrical • Mechanical • Structural • Civil	e.g. in piping • Carbon steel piping • Stainless steel piping • Cr. MO piping • FRP piping • Plastic piping • Specialty piping • FRP piping • HPDE piping • Specialties • Instrumentation • Automotive • Demolition	e.g. in carbon piping • Std. Wt. • SH • Sch-120 above grade • Sch-120 below grade • Sch-160 above grade • Sch-160 below grade • Heavy Wall above grade • Heavy Wall below grade	e.g. in Piping • 2" & DOWN • 2 1/2" TO 6" • 8" TO 12" • 14" TO 20" • 22" TO 30" • 30" & Above

Another challenge for collecting productivity raw data to fit the selected productivity metrics is to achieve alignment between the tracking items aggregation in a project with the aggregation of work quantities and work-hours defined in productivity metrics, in order to report productivity in a consistent way. This same challenge exists for each industrial construction company.

Therefore, there are two ways to facilitate consistently reporting construction productivity in terms of the selected metrics: (1) Facilitating the consistency of work packaging, which means to use the identical construction tasks as much as possible in work packaging. Let the identical construction tasks have very similar scope, craft discipline, and contain similar generic craft processes, or (2) For the historical data, if the tracking items (tasks) for collecting the data of work quantities and work-hours haven't been aggregated in a consistent way from project to project, it is necessary to create some rule for re-wrapping up tracking items to meet the selected metrics.

3.4.1.3 Calibration of direct work-hours counting and quantities counting

The construction labour productivity calculation requires two sets of raw data: (1) completed work quantities and (2) work-hours. Due to the complexity of the construction tasks aggregation, which has been discussed above, it is necessary to determine the detailed composition of work quantities and work-hours for the specific metric.

Work-hours counting

Work-hours are computed by the summation of all the account hours that are listed as direct in Table 17. All the account hours listed as Indirect are to be excluded from the actual work-hours that are submitted in the productivity calculation. Work-hours should include all the rework hours. If some rework to correct another party's defect has been compensated, the relevant extra work quantities can be added to the quantity revisions.

Regarding the craft labour in the direct account, there are also detailed descriptions below (Table 18) for counting work-hours in each craft trade. As noted earlier, a choice in implementing a BM&M model for a corporation is which external standard with which to map. Here, the standard chosen, as explained and justified earlier is the CII standard.

Table 17 Direct Work-Hours Counting (CII 2008)

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

Table 18 detailed work-hours counting for each craft trade (CII 2008)

Includes	Does Not Include
Piping	
Erecting and installing 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.	Non-destructive evaluation (NDE), steam tracing, stress relieving, underground piping, offloading pipe as it is received, commissioning, scaffolding and field fabrication of large bore.
Electrical	
Electrical Equipment & Devices	
This includes all labour for the installation of transformers, switchgear, UPS systems, MCCs, DCS/PLC racks and panels, etc.	Count includes only actual electrical devices, not supports
Wire and Cable	
This includes all labour for the installation, termination, labeling, and testing of power and control cable	It does not include heat-tracing cable, cable tray and conduit is not counted in this item
Mechanical Equipment	
This includes all labour for the installation, assembly, or packing in the field	Field fabrications are excluded
Structural Steel	
Shake-out, transporting, erection, plumbing, leveling, bolting, and welding.	Fabrication, demolition, and architectural work, such as roofing, siding and vents.
Concrete	
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 placement, curing, finishing, rubbing, mud mats; and anchor bolt installation.	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, precast tees, panels, decks, vaults, manholes, etc.

Table 17 and Table 18 display the rules of work-hours counting in detail for each selected productivity metric. In order to implement these rules for work-hours counting, the practical way is mapping these rules to the tracking items coding system (i.e. enterprise's cost coding system). Take piping as an example. Table 16 displays the piping tracking items breakouts on basis of the four segments cost code. For this research, applying work-hours counting rules for piping, all the tracking items being coded with a specific group of codes were rolled up to the piping work-hours account (see Table 19).

Table 19 Example in Piping: Work-Hours Counting Rule Mapping to an Account Code

	Cost Code				Description
	L1	L2	L3	L4	
✓	03	30	xx	xx	Carbon steel piping
✓	03	31	xx	xx	Stainless steel piping
✓	03	32	xx	xx	Cr. MO piping
✓	03	33	xx	xx	FRP piping
✓	03	34	xx	xx	Plastic piping
✓	03	35	xx	xx	Specialty piping
✓	03	36	xx	xx	FRP piping
✓	03	37	xx	xx	HPDE piping
	03	38	xx	xx	Underground pipe and fittings
✓	03	39	xx	xx	Specialties
	03	40	xx	xx	Instrumentation
	03	48	xx	xx	Automotive
	03	91	xx	xx	Coal distribution piping
	03	92	xx	xx	Demolition

There are a total of 14 items at level 2 of piping cost code. Nine of them are taken into piping work-hours counting, which may contain many tasks (tracking items) with respect to multiple craft processes (being coded at level 3 of the cost code) like pipe fitting, in-line device installation, hydrostatic testing, etc. Chapter 4 will demonstrate the BM&M program implementation including the details of mapping work-hours counting rule to account code for all the craft trades.

Work quantities counting

For each productivity metric, there may be more than one tracking item involved in work-hours counting, but the measurement unit of work quantity is varying for those tracking items. Work quantities counting encompasses measurement unit identification as well. In principle, work quantities are computed by the summation of amounts only in the tracking items with the same measurement unit as the selected metrics. Taking piping as the example, a piping work package usually includes several tasks (tracking items): pipe fitting, in-line specials, and hydrostatic testing (Table 20). Only the amount of pipe fitting is counted as a work quantity. In addition, if the pipe fitting is measured by diameter inch, it has to be converted to footage length by tracing back to design drawings.

Table 20 Example of Quantity Measurement of Piping

Main tracking items in piping work package	Common measure unit
Pipe fitting	**Foot**, Meter, or Diameter Inch.
In-line specials (including valves, devices, pipe hangers or supports, etc.)	Each
Flushing / hydro testing	Each, or Percentage of completion

The selected metrics measure the piping productivity in terms of small bore and large bore classified by less or more than three diameter inches respectively. Theoretically, one can use the account code (at level four for the Partner Company) to identify the small bore or large bore piping tasks.

3.4.2 Practices planning and implementation level measurement

This study recommended the BPPII (Best Productivity Practice Implementation Index) to rate the construction practices planning and implementation level for the projects. There are three groups of data that need to be collected: (1) BPPII survey on projects, (2) BPPII survey on corporate's project management manuals, and (3) Prioritizing the improvement area in terms of practice element. They are explained further below.

1. BPPII survey on projects

The BPPII survey should be carried out during the second half of the construction phase for a project. The person being recommended to carry out the BPPII survey is the project manager or project coordinator who has worked for a project long enough and is familiar with the management process that is applied for the project. They should consider the average level of implementation of each practice element in BPPII across the duration of the construction phase. Finally, for each project, all 53 elements will be rated with one **Planning and Implementation Level (PIL)** each (0 ~5).

2. BPPII survey on corporate's project management manuals

A construction company has a set of management manuals, which defines the processes, procedures, methods, and tools/techniques that should be introduced in project control for a project. These manuals are likely the guidelines driving the overall practices implementation in company wide, even though the project team is generally granted certain autonomies to plan and implement the proper practices in a specific project. The BPPII survey on corporate manuals is very supportive for gaps analysis of the corporate overall practices conducted in the next phase.

In the phase of metrics determination, it was mentioned, that the corporate manuals related to project management should be reviewed carefully, and the procedures and policies of the relevant practices in the manuals were mapped to the BPPII practice elements. On the basis of the mapping, it is possible to rate the corporate manuals with the BPPII scale for each practice element. The following example demonstrates how to rate the planning level of the corporate manual on one practice element. The level definition for practice "short interval planning" is displayed in Table 21.

Table 21 Planning and Implementation Levels (PIL) Definition Example From The BPPII

Practice	CATEGORY III – CRAFT INFORMATION SYSTEMS A.SHORT INTERVAL PLANNING BEST PRACTICES A1. Short Interval Planning
Level 0	The use of short interval plans are not applicable
Level 1	The use of short interval plans has not been addressed.
Level 2	Short interval planning is utilized by taking action based on reported statuses of on-going activities. Activities in the project schedule are not resource loaded and short interval plans do not detail the required materials, tools and equipment, labour, and required project information.
Level 3	Short interval planning is utilized by detailing the required materials, tools and equipment, labour, and project information required to complete each task. Activities in the project schedule are not resource loaded.
Level 4	Continuation of Level 3, plus activities in the project schedule are resource loaded to help with short interval planning. A short interval plan does consider the effects of craft density due to other area activities and potentially related impacts of congestion and coordination issues.
Level 5	Continuation of Level 4, plus constraints from required deliverables, materials, equipment, labour and information are visible by area.

In one of the Partner Company's management manuals – "Project Execution Procedures", the section – "Schedule c/w Resource Loading" introduces some management processes relevant to "Short Interval Planning". It is described as "Deliver a baseline resource loading plan, which will be used for weekly productivity updates". In addition, a proper work sheet – "Two Week Planning" is used to support short interval planning, in which form required equipment and material are tied to the activity schedule. However, the consideration of constraints of deliverables, resources, construction space, and information visible by area is not being shown in management process manual. Therefore, the description for this practice element in the manuals is rated as 4.

3. Prioritizing the improvement area in terms of practice element

The CII research team has already assigned the weights for all the 53 BPPII elements based on their relative importance in influencing labour productivity. This was based on a survey of over 200 experts. However, this does not mean that enterprises should always emphasize improving practice elements with relatively high weights in influencing productivity. Besides the influence on productivity, more factors are usually considered to determine the priority of practice improvement areas, such as the current implementation level of a certain practice, the cost to change the current practice, and corporate strategies. Experts' review is carried out to prioritize the practice element for improvement. The Prioritization uses the number 0, 1, 2, and 3.

- 0 – Do not have to improve this practice
- 1 – This practice likely does not need an improvement
- 2 – This practice likely needs an improvement
- 3 – This practice definitely needs an improvement

Participants of experts review should cover positions at multiple management levels: corporate executives, project managers, project coordinators, and site superintendents. An expert review meeting is recommended to synthesize all the prioritizations from knowledgeable individuals and finalize the priorities of the practice element for improvement. Those processes of prioritization are recommended only when a systematical improvement of a corporate management system is required.

3.4.3 Environment data

The representative data for construction environment is defined and organized as in Table 22. The design of this data structure balances corporate practices and industry norms, and as such might vary with implementation of the model for another corporation. The last column presents the data source in the Partner Company. Collection of environment data is to support a better evaluation of productivity performance in the BM&M program, but it is not the primary task of this research. This research will just take some data from existing project information systems, rather than establishing a specific process for collecting construction project environment data.

Table 22 Environment Metrics and Data Structure for Each Project

<table>
<tr><th></th><th>Category</th><th>Metric</th><th>Data or unit</th><th>Data source from the Partner Company</th></tr>
<tr><td rowspan="10">Environment</td><td rowspan="2">Labour Market</td><td>% of Union employees</td><td>%</td><td>employee hire form</td></tr>
<tr><td>Average years of experience</td><td>years</td><td>employee hire form</td></tr>
<tr><td rowspan="2">Geography environment</td><td>Weather (rain days)</td><td>percentage of raining days</td><td>foreman daily report</td></tr>
<tr><td>Location</td><td>City, Province</td><td>BPPII Survey Form</td></tr>
<tr><td rowspan="5">Project complexity</td><td>Project size (contract value)</td><td>No. of M$</td><td>Project info.</td></tr>
<tr><td>Construction sector</td><td>4 classes</td><td>BPPII Survey Form</td></tr>
<tr><td>Congestion in construction site</td><td>Rate 1-5</td><td>difficulty survey in Post Job Analysis</td></tr>
<tr><td>Stacking of trades</td><td>Rate 1-5</td><td>difficulty survey in Post Job Analysis</td></tr>
<tr><td>Height of job position</td><td>Rate 1-5</td><td>difficulty survey in Post Job Analysis</td></tr>
</table>

3.4.4 Direct work rate

This study uses Activity Analysis to measure the direct work rate. CII developed a practical guide to Activity Analysis, which has been carried out in several projects in the Partner Company. The company intends to carry Activity Analysis continuously in future projects.

3.5 Evaluation

Evaluation is the process to evaluate the project productivity performance deviation from the target, from the best-in-class, from the corporate average and from the industry average. The productivity data is collected based on the selected metrics. The productivity raw data (work quantities, work-hours, and direct work rate) is synthesized to a set of indices for evaluating the productivity performance at three management levels.

3.5.1 Productivity evaluation at the project level

A typical measurement of productivity is cumulative average productivity. Based on the data collected with respect to quantity installed and labour work hours up to date, one can calculate the cumulative average productivity for each metric. The evaluation of cumulative average productivity is calculated as total work hours spent up to the current point in the project divided by total units installed, which is based on the following framework shown in Figure 12.

Whether bottom-up estimating or multiplier estimating, there should be a PEF connecting standard references to estimated productivity. Standard estimate reference productivity represents a company's productivity norm, for a category of work, which is held constant for a long period typically. Variability of actual productivity performance is considered to be driven by three sources: Environmental Factors, Practices Implementation, and Uncertain Factors. In most cases, the PEF is mainly dominated by environment, including weather, labour market, location, work site condition, and so on. PPF is calculated by actual productivity over the estimated productivity, which is mainly affected by practices implementation. The number for PPF for a successful project is generally less than one, while estimators expect PPF approximately equal to one. However, a company doesn't want to take the risk of cost overruns, so normally the estimator conservatively introduces a target (i.e. a "bottom line") of the productivity performance for a project. Therefore, PPF is the first index to evaluate productivity performance in terms of the deviation from target. Based on the above analysis, PPF is the index that can be used to analyze the influence of practices implementation.

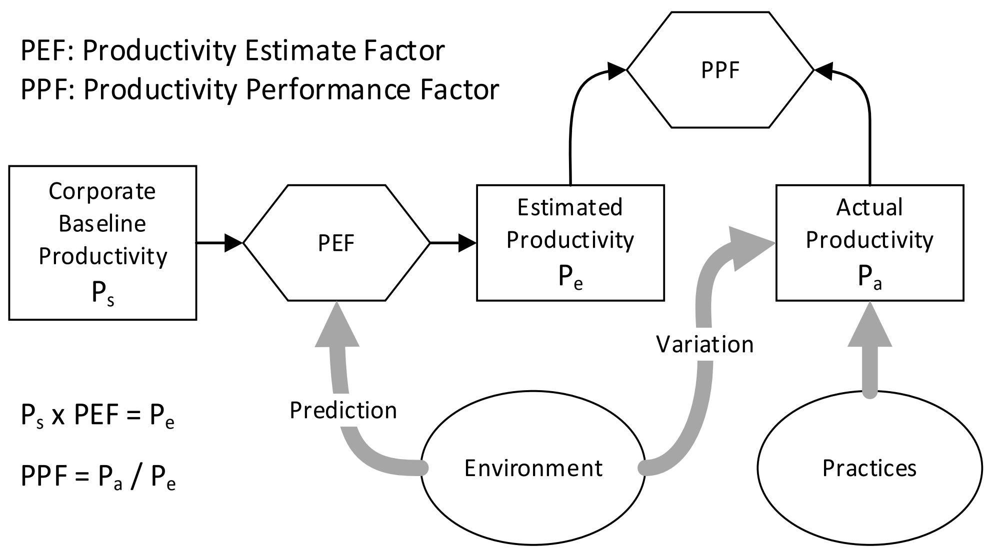

Figure 12 Evaluation Framework for Productivity

Another index for evaluating productivity performance is the actual labour productivity (P_a), which is directly reflected in the utilization efficiency of labour resources. By using this index, it is possible to compare the labour productivity across the projects, and also compare with industry averages in an identical context.

3.5.2 Productivity performance evaluation at the corporate level

Actual productivity performance varies from project to project due to the variation of construction environment and relevant practices implementation. However, the corporate executives care about the overall productivity performance level all over the corporation, which could provide valuable reference for the determination or adjustment of the baseline productivity in a construction enterprise. (Baseline productivity is the important norm for the project estimation and project control.)

Statistically, the common indices of overall productivity performance for an enterprise are the average actual productivity (Pa) in the population of projects, for which the labour productivity was reported. Statistical averages can be used to evaluate the enterprise productivity level in key areas of work by comparing with the industry average. A corporate average measure across all areas of work is difficult to ascertain, however, as the weights of areas or types of work vary over time; it may make sense to use a disaggregated index in such categories from the economics field. Even CII tried and failed to create an overall productivity index. Besides a higher average productivity, better consistency of productivity performance in the projects is also expected, which is represented by a lower statistical variance.

In summary, all these productivity data should be stored in an enterprise productivity database, including project budget productivity, project actual productivity, the phased corporate average productivity, project characteristics and environment, and the project group average productivity (grouped by project type), and if this can be created, refer the preceding discussion. As an important part of productivity analysis, the productivity comparison (the project productivity against the corporate average and the CII average, again, for each type of work) should be added to the productivity analysis section in the project summary report. In the Partner Company, the project PJA (post job analysis) is such a project summary report, which includes a section especially for productivity analysis, although it has tended to be qualitative and incomplete in the past.

3.5.3 Use direct work rate to evaluate productivity at crew level

Activity Analysis is the tool used for improving direct work rate by appropriately adjusting field construction activity. The analysis has the following functions.

1. Compare direct work rate between projects, and analyze the impact factor for it with respect to environment and practices
2. Set up target rates for direct work rates (Shahtaheri 2012)
3. Determine correlation between productivity and direct work rate with statistical analysis
4. Determine correlation between direct work rate and the practices implementation level with statistical analysis.

3.6 Analysis of Gaps for Practices Improvement

Gaps analysis is based on practices implementation level measurement. The BPPII is selected as the scale for the measurement; the BPPII is also the practices check list for the gaps analysis. As aforesaid in section 3.4.2 – practices planning and implementation measurement, PILs (planning and implementation level) data has already been collected for current projects in the Partner Company as well as for the corporate management manuals of the firm. This process is repeated as part of the model for implementation at other firms. Based on the analysis on those PILs data, practices improvement potentials can be described in two sets of gaps. For each set of gaps, the general improvement strategies are introduced. (See details in Figure 13).

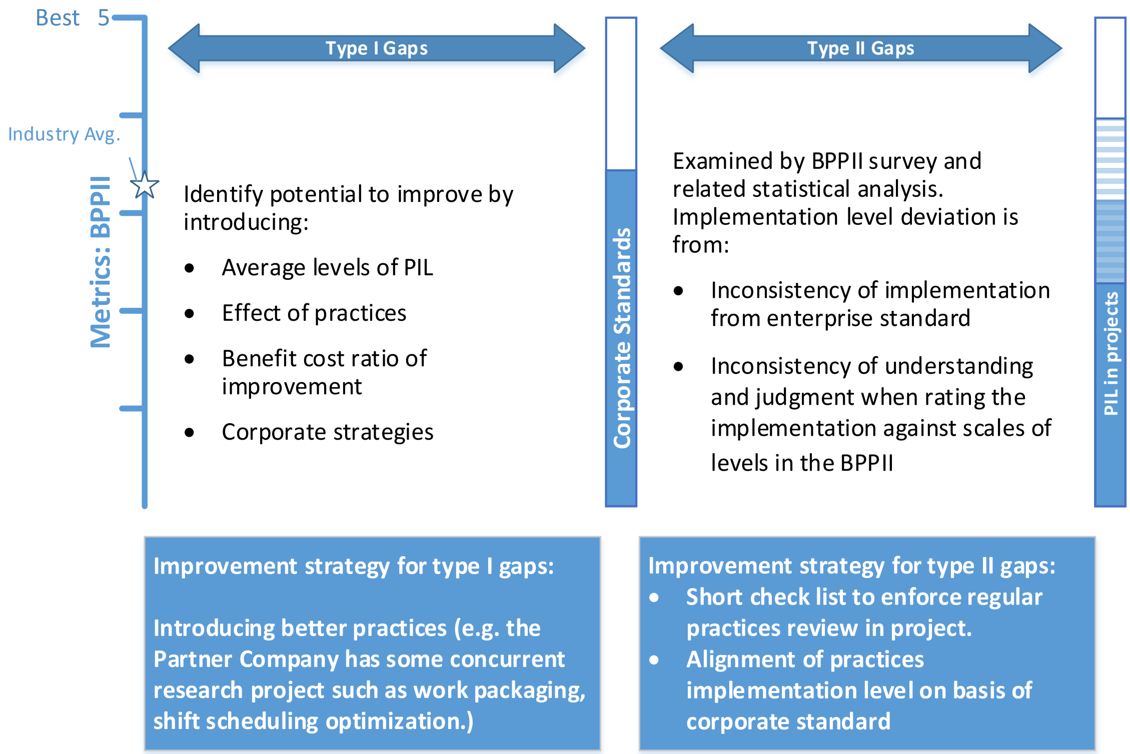

Figure 13 Gaps Analysis Strategy

The "B/C ratio" and "Corporate Strategies" are critical for making decisions around practices improvement but they are outside the scope of the BM&M program as designed, because they are highly situation and not therefore legitimate part of a generalizable model. This BM&M program focuses on analyzing the PIL (planning and implementation level) of each practice element and practices implementation consistency in an enterprise, as well as the effect of practices implementation on productivity performance. The relevant data are summarized as follows.

Table 23 Benchmarking Factors for Gaps Analysis and Their Corresponding Variable Names

For each BPPII element		Corporate	Projects	Industry
PIL	Raw data	Corporate Standards ($PIL_{CorpGuide}$)	PIL/elements/projects (PIL)	
	The best		Best in house (PIL_{best})	Best practices in BPPII
	Average		Average in house (PIL_{avg})	Average of industry wide (CII_{avg})
	Consistency		Standard deviation ($StdDev$)	
BPPII score			BPPII score ($BPPIIscore$)	
Practices effect				Weight of BPPII elements ($WoEffect$)

- Corporate standards represent the practices planning level defined in corporate's manuals. Each of the 53 BPPII practice elements is rated with a number (0-5) based on their degree of implementation within the corporate standards
- Every project should conduct a BPPII survey. PIL is the practices planning and implementation level for each of the 53 practice elements in each project.
- Based on the BPPII survey for the projects, best-in-house level of a certain practice could be sought in a certain project.
- Based on the BPPII survey for the projects, average PIL of each practice element in such projects' population and its statistical variance can be calculated.

- BPPII score is a percentage grade index for a project, which synthesizes the PILs of all practice elements with the weights for all the elements representing their relative importance in influencing labour productivity.
- In order to compare with the industry practices implementation level, average PILs in the CII BM&M database are introduced into the analysis.
- The BPPII also provides the checklist of the best-in-class productivity practices.
- The CII research (RT-252) has already assigned the weights for the entire 53 BPPII practice elements base on their relative importance in influencing labour productivity, which is also one of the important factors for prioritizing the practice elements for improvement.

3.6.1 Gaps analysis model for analyzing practices implementation

Recall the general strategies of practices implementation improvement that are stated in section 3.1 introducing better practices and facilitating implementation consistency. As displayed in Figure 13, Type I Gaps are mainly those corresponding to introducing better practices, while Type II Gaps are mainly corresponding to facilitating practices implementation consistency. Considering economic efficiency, it is not necessary to improve all the practice elements at the same time. Gaps analysis is intended to set up a model to identify the priority of improvement for practice elements based on the above said data. Finally, one can choose a set of practice elements with high priority for improving, which is named “Practices Set for Improving”. Over time, the improvement of practices will influence the PIL value collected from the new BPPII surveys. For a continuously run gaps analysis model, the practice elements within “Practices Set for Improving” will change, which drives the continuous improvement of overall practices implementation for an enterprise.

Gaps analysis model considers five gaps factors for prioritizing each practice element.

1. $Factor\ 1 = 5 - PIL_{avg}$

Factor 1 represents the absolute deviation of corporate average PIL differing from the industry best implementation level. In general, the PIL for each practice element is defined on the basis of the level of utilization of advanced techniques, computer-aids, automation, and integration. Higher PIL of a practice leads to better productivity and requires more implementation cost. In the opposite perspective, high score of factor 1 means much room for improvement for such practice element with relative low implementation cost for a corporation.

2. $Factor\ 2 = CII_{avg} - PIL_{avg}$

Factor 2 is the relative deviation of corporate average PIL differing from industry average PIL, which represents the corporate competitiveness industry-wide in terms of the PIL of a practice element.

3. $Factor\ 3 = 5 - PIL_{CorpGuide}$

Factor 3 is the deviation from the planning level in corporate project management manuals to the industry best level. Corporate project management manuals are the guideline driving the practices implementation from project to project in a corporation. Assessment of the PIL of corporate project management manuals is a very important factor gaps analysis.

4. $Factor\ 4 = StdDev$

Factor 4 represents inconsistency of practices implementation within corporation. For those practice elements with high inconsistency of implementation level within population of corporate projects, the consideration should be put on the development of appropriate practice guideline and the regular review of practices implementation following the guideline.

5. $Factor\ 5 = WoEffect$

Factor 5 (weight of effect) is the significance of a practice element with respect to influence labour productivity. The priority of improvement should be assigned to those practice elements which have relatively high influence to labour productivity.

Consider the priority value for each element as the compound from these five gap factors. Factors important to corporations and given different weights based on current corporate strategy and individual corporate leaders' judgment. In the case of the implementation done for this thesis a survey of project managers were used to address the weights. For example, these factors are considered with equal weights for most cases, the factors' value need be normalized into a uniformed value range. Value range 0-5 is widely used to measure the level of performance and practices implementation, not only in CII's best practices assessment, in BPPII survey, but also in many other performance survey systems. This thesis recommend that all five factors are normalized into a same value range 0 to 5.   The normalization calculations for the gap factors are:

1. Absolute deviation of corporate average PIL from the best level:

$$5 - PIL_{avg}$$

2. Relative deviation of corporate average PIL from industry average PIL:

$$\frac{\left(CII_{avg} - PIL_{avg}\right) + 5}{2}$$

3. Deviation from planning level in corporate manuals to the best level:

$$5 - PIL_{CorpGuide}$$

4. Consistency of practices implementation within corporation: because random variables are belong to [0, 5], with 95% confidence interval, the data point drops in mean ± 2StdDev. Therefore, 2xStdDev is distributed in a value range approximately from 0 to 5.

$$2 \times StdDev$$

5. Importance in influencing labour productivity: WoEffects of 53 practice elements approximately formed into a normal distribution (μ=60, σ=37.5); the following formula shrinks the value of this random variable by 30 times and shift it by 0.5 unit, and convert it into a normal distribution [μ=2.5, σ=1.25], which has a value range approximately from 0 to 5.

$$\frac{WoEffect}{30} + 0.5$$

In addition, there is another set of prioritization data: The prioritization of practice elements by experts review is the judgment based on the perception of experienced practitioners in the enterprise, which will be used to help validate this gaps analysis model.

In summary, gaps analysis is a technique that corporate management uses to determine what steps need to be taken in order to move from its current state to future state. To conduct a gap analysis, three main steps need to be followed: (1) identifying target state, (2) analyzing current state, and (3) identifying how to bridge the gap.

Some organizations, such as CII and Canadian Construction Sector Council (CSC) have established collaborative Benchmarking program from industry perspective, which focuses establishing the benchmarks of best-in-class project performance and best-in-class construction practices. Those benchmarks provides good reference for enterprises to identify the future state.

A recent literature present the development of a construction productivity and project performance benchmarking program under Canadian CSC. Their analysis of project performance in terms of cost and time predictability demonstrated the gaps in relevant management practices (Nasir et al. 2012). This kind of gaps analysis is from the perspective of industry, and mainly focuses on identifying primary shortage of project performance all over the industry.

However, an enterprise management not only considers fill up general gaps to achieving best-in-class, but also considers the most effective actions and/or changes to enforce their competitiveness and to facilitate consistent and sustainable performance. This is why the gaps analysis process model developed in this thesis introduces five gaps factors, especially, Factor 2 (practice competitiveness), Factor 4 (practice implementation inconsistency), and Factor 5 (practice weight of effect) are added on top of Factor 1 and 3 (room for improvement against the best). Those five factors can thoroughly describe the current state with respect to the implementation status of each practice element.

3.7 Improvement Planning, Deploying and Production

Figure 13 introduces the general strategies to fill up the practices implementation gaps. Gaps analysis classifies a practices set for improvement. For the elements in such a practices set, the implementation improvement includes introducing better practices and facilitating consistent implementation.

3.7.1 Introducing better practices

Even though implementing better practices is an indispensable process in the continuous improvement loop, but introducing the better practices involves massive change management for an enterprise, which is broader than the BM&M program's functions. In general, some necessary procedures are recommended for introducing better practices in construction and management:

- Conduct internal questionnaire, experts' interview, and executives' interview to investigate the urgency, necessity and practicality for improvement from the perspectives of site crew, project management, and corporation management. Finally, the commitment from all operational levels of the corporation is very important.
- Investigate pertinent knowledge bases such as CII best practices, IPA best practices, and PMI best practices for project management and construction management, in order to select appropriate methods, techniques, and tools for introducing a good improvement plan to the enterprise.

- Set up the target for the improvement of a specific practice element. The data and information of current level(PIL_{avg}), best-in-house practice(PIL_{best}), best-in-class practice in the industry, and the corporate strategy are the useful data to support the target setup.
- B/C analysis and Risk evaluation have to be done before applying changes to existing construction project management procedures and policies.
- On the basis of the practices mapping table, apply the planned better practices into the existing project management procedures.
- A training plan is very important to drive employee's motivation for adopting modified work processes.

3.7.2 Facilitating consistent practices implementation

Conducting a regular review for the practices implementation within every project execution is a very useful way to facilitate consistent practices implementation. The BPPII survey is one of the method for the practices review. However the BPPII survey is time consuming. It requires reading about 30 pages of the description of practice elements and their implementation level definitions. As well, the surveyor has to match the general definitions in the BPPII to the enterprise's own practices definitions every time.

If focusing on implementation of improvements however, the project management just needs to look at those practices being classified in the "Practices Set for Improving", which should be the main concern of practices improvement at the present stage. A short check list can be a more efficient tool for this regular review than using the whole BPPII survey tool. It should have the following features:

- The check list should require no more than 30 minutes to complete.

- The check list should be composed by using corporation's definitions, terminologies and cultures. A practices mapping table is used to translate the "Practices Set for Improving" to the processes described in corporate's manuals.
- The regular review should emphasize checking the usage of some key factors of the relevant work procedures, including responsibilities, methods, tools, and the required work-sheets.
- The regular review should be done at least two times for a project. First is in the front-end planning meeting (pre-construction planning meeting). The second run should be done at some time in the middle of project duration.

3.8 Summary of Enterprise Internal BM&M Program Model

Many tasks are required to develop and verify a program model (Figure 14) for implementation of internal corporate benchmarking and metrics (BM&M) programs for support of continuous productivity improvement in industrial construction firms. Figure 14 includes reference information as well as graphic reminders of the related figures, charts and tables represented via reduced images. Implementation of an internal BM&M program typically includes the steps of: (1) establishing leadership commitment and forming a benchmarking team, (2) determining metrics, (3) developing data collection processes and tools and collecting data, (4) evaluating project performance (especially in terms of productivity), (5) analyzing practice implementation gaps, (6) planning the corporate strategies for practices improvement, and (7) program deployment and process integration verification. Concurrent with these steps are the underlying strategies referenced in Figure 14. To effectively take action, the BM&M program needs to be established as a continuous improvement cycle, and it needs to be integrated with other management processes of a company. These steps were developed in the preceding sections, and are summarized as follows:

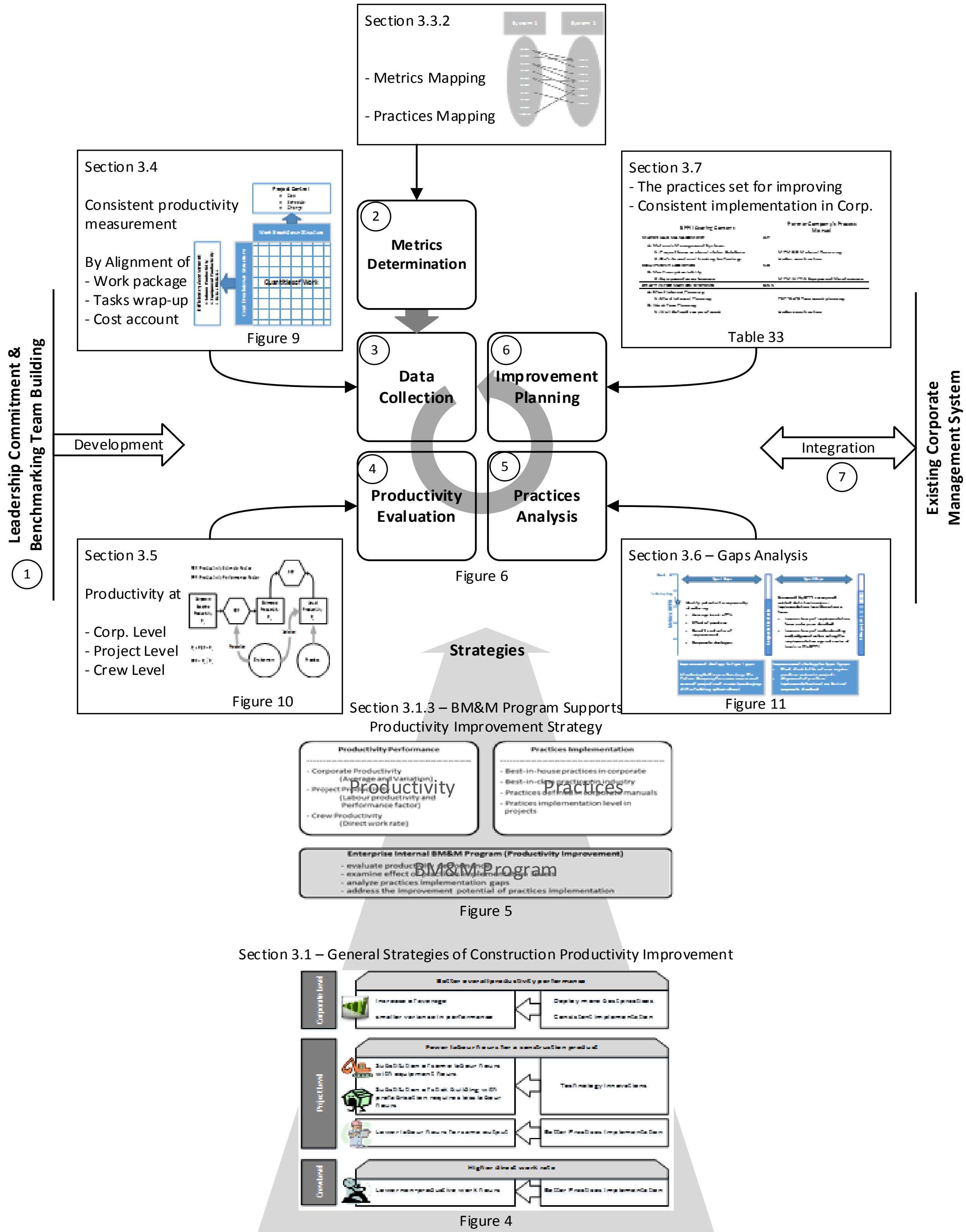

Figure 14 BM&M Program Model Summary

1. Establishing leadership commitment and forming a benchmarking team
2. Determine metrics – what to benchmark. An internal BM&M program differs from the programs run by government agencies, industry associations, and consultants. It should support such programs, but it is primarily intended to work within a specific internal corporate context and to support internal continuous improvement. Therefore, the following sub-tasks must also be performed.
    - Specify the criteria of choosing the proper metrics.
    - Develop methods to map internal productivity data and practices definitions to standard construction productivity metrics and related best practices definitions such as the CII's metrics.
    - Determine a set of metrics in order to measure performance with respect to labour productivity, direct work rate, and other key performance indices.
    - Determine a set of metrics and tools in order to evaluate influential factors on productivity with respect to practices and environment.
    - Identify the leading productivity metrics in the context of a specific firm after one or two pilot studies of productivity data analysis.
3. Developing data collection processes and tools will focus on the metrics defined in the preceding steps and will involve the following sub-tasks.
    - Review existing project data reporting system with respect to the procedures, tools, software, databases, and work sheets.
    - Develop a data collection method for the BM&M program that is consistent, efficient, and results in minimum extra cost for integrating it with existing processes.
    - Map the selected metrics to existing project data reporting systems, further identify data sources in the enterprise's existing management system, and verify the data validation based on the preceding review of the existing data reporting system.

- Metrics calculation is introduced in preceding discussion, which can be adjusted or customized to match the expression context in a specific firm. For example, some organizations might calculate PPF (productivity performance factor) in form of Estimated Productivity / Actual Productivity, such that a "PPF > 1" indicates good performance.

4. Evaluate project performance especially in terms of productivity. The productivity evaluation framework (Figure 12) introduces a set of useful indices (e.g. baseline productivity, estimated productivity, actual productivity, PEF, and PPF) and the correlations between them. Those indices align the ways to compare labour productivity between projects, compare to competitors, and identify performance gaps. Also, those indices help engineers understand the correlations between the performance indices and the impact factors with respect to environment and construction management practices. Evaluate productivity performance at three management level including:

- At the project level, compare project labour productivity against the corporate average and the industry average; and explain the project productivity performance against the planned productivity by using PPF.
- At the corporate level, apply statistical analysis on the productivity data in the population of the projects in a specific construction firm. Based on such analysis, it is possible to set performance targets, make adjustments on the baseline productivity in a construction firm, and address the gaps of productivity performance by comparing with industry leaders.
- At the crew level, direct work rate is the most useful index to demonstrate the productivity performance. Activity Analysis is the tool used to measure the direct work rate and also to improve the direct work rate by appropriately adjusting field construction activities.

5. Analysis of practice implementation gaps. Based on the gaps analysis strategy that was developed in Figure 13, the primary approach of increasing labour productivity focuses on implementing a series of best practices in a consistent way (the practices defined in the BPPII are chosen in this research). The gaps analysis is based on the measurement of best practices planning and implementation level as well as implementation consistency, which includes:
   - Conduct BPPII survey for a number of projects in a specific firm and collect BPPII scores for projects and Planning and Implementation Level (PIL) of each practice element for each project, for which projects productivity data is also collected as part of the preceding steps.
   - Conduct BPPII survey on corporate management manuals, especially relevant to project management procedures, work instructions, software, and tools.
   - Practices effect analysis of influencing productivity improvement can be conducted internally within a firm if there is significant number of projects data; or refer to an external reliable database (such as CII's BM&M database).
   - Gaps analysis of practices implementation for a specific firm synthesizes five types of information: (1) gap between corporate guideline level and the best, (2) gap between corporate implementation level and the best, (3) gap between corporate level and industry average level, (4) inconsistency of practices implementation within the corporation, and (5) effectiveness of practices for influencing labour productivity.
   - Based on preceding gaps analysis, practices implementation deficiencies in a specific construction firm can be identified.
6. Corporate strategies for practices improvement mainly include:
   - Introducing better practices in corporate guidelines, and
   - Facilitating consistent implementation in the projects execution.
7. Program deployment and process integration verification include:

- Identifying an internal champion is critical to the success of the program deployment, which helps in reaching a commitment from the top down in an organization.
- Organizational change management required to implement an internal BM&M program including: resources preparation, buy-in motivation and culture alignment.
- Benefits and cost analysis
- Development of process definition, assignment of responsibilities to people, construction of database frame, and integration of all of this to relevant existing management systems.

All these steps and underlying strategies form the model. In the following chapter, implementation and verification of the model is described.

Chapter 4: BM&M Model Implementation and Verification

This chapter will present the BM&M program model implementation. Valuation aspects of a BM&M program for an industrial construction enterprise were discussed with the Partner Company at the beginning. The BM&M program model has a set of functional processes. This chapter is introducing the implementation of those functional process in a real industrial construction firm (the Partner Company). The model implementation analysis contains multiple aspects including the processes construction/integration, relevant means, and the data analysis reporting. Some key areas analysis is carried out to verify the model functionalities.

4.1 Valuation Aspects

The Partner Company asserts their enterprise core value as to, "safely, profitably and sustainably deliver best-in-class integrated services, products and solutions". An internal BM&M program will provide a platform to regularly measure project performance, review project management processes and construction practices, and identify potential improvement gaps. As developed, this program is a strategic valuable approach to facilitate enterprise competitiveness, as well as to facilitate implementing their enterprise core value. Conservatively, it should result in a 10:1 payoff.

On the basis of the research presented in this thesis, the research project team reported a value proposition to the leadership of the Partner Company in July of 2013. The value proposition report briefly introduced the needs and benefits of deploying an internal BM&M program to the Partner Company, as well as a brief introduction of the BM&M program features, customization and implementation plan. The value proposition is included in **Appendix D**. On September 20th, 2013, the value proposition was presented to the leadership by the research team with a very supportive discussion in an official meeting. The meeting concluded with the Partner Company leadership reaching an agreement for implementation of the strategic plan presented for the Benchmarking and Metrics program for productivity performance improvement. The research team was to assume "full speed ahead" for implementation of the program and integration into the new corporate ERP system. The meeting minutes are presented in **Appendix E**. Some of the basis for the implementation was created in the process of developing the BM&M program model. It included gathering data on many projects and analyzing that data. The results of this analysis is presented as part of the following description of the model implementation that serves as a functional validation of the model itself.

4.2 Model Implementation

The development team worked out a practical scheme for implementing the designed BM&M program. Implementation of the BM&M program will be deployed in phases, following the principle from simple to comprehensive. Specific leading craft productivity metrics and key practice elements benchmarking will be deployed in the initial stage. More comprehensive benchmarking and metrics will be added in future phases with the BM&M program gradually merging into the existing corporate management system and culture. Implementation of the BM&M program requires three levels of leadership:

> Level 1 – organizational change management required to implement a BM&M program includes: leadership (CEO commitment), resources preparation, buy-in motivation and culture alignment, a strategic plan, and persistence.
>
> Level 2 – tasks required to implement a BM&M program: develop process definition, make assignments to people, design trial runs, construct S/W database frame, develop pertinent tools, etc.

Level 3 – functional documentation required to implement a BM&M program: procedure and policy embedded as modification of existing corporate processes, work instructions, work flow charts, relevant forms, software (if required), etc.

On the basis of primary mechanisms and the preceding features, the team developed a set of detailed implementation processes for the Partner Company, which are customized based on the nature of the Partner Company's management, with respect to the construction sector, main craft labour resources, proportion of project types, corporate management procedure and policy, frequent contract conditions, existing information delivery processes and database for project management, etc. The customized processes are constructed in the following sections.

4.2.1 Determine appropriate metrics to benchmark.

In the BM&M program model, the principle metrics have already been determined.

4.2.1.1 Productivity metrics

For the craft labour productivity, piping, structural steel, mechanical equipment, electrical, and concrete productivity are five primary crafting disciplines in industrial construction. These are selected to be the metrics in the BM&M program model. According to the metrics selected in the model, the author collected the productivity data from 12 projects. This was a significant level of effort. Due to the confidential agreement with the Partner Company, project names are hidden. So, each project is identified by a simple project code.

However, not all the projects tracked the productivity data with all five craft disciplines involved, because some projects just have work scope in one or two crafts. Also, some jobs are subcontracted, and the related productivity data cannot be acquired. For each productivity metric, the number of projects that contained relevant productivity data is displayed in Table 25. It shows that piping is the primary crafting discipline for most projects in the Partner Company. While, concrete work occurs only in a few projects or is being subcontracted; and it usually costs a small portion in those projects.

Table 24 List of the Projects in the Research

No.	Project Code	Location	Project Category	Project Nature
1	SH	Spy Hill, SK	Power generation	Greenfield
2	EWCC	Windsor, ON	Power generation	Brownfield
3	DN	Dresden, ON	Gas	Addition, Expansion
4	SC	Dawson, BC	Gas	Greenfield
5	LB	London, ON	Gas	Renovation, Upgrade
6	NB	PT. Lepreau, NB	Nuclear Power	Renovation, Upgrade
7	AP-I	Cambridge, ON	Auto	Renovation, Upgrade
8	AP-II	Woodstock, ON	Auto	Renovation, Upgrade
9	WWTP-US	Hamilton, ON	Wastewater	Renovation, Upgrade
10	WWTP-W	Hamilton, ON	Wastewater	Addition, Expansion
11	AK	Atikokan, ON	Gas	Brownfield
12	BDPS	Estevan, SK	Plant	Brownfield

Table 25 Number of Projects Contain Specific Productivity Data

Crafting Discipline	Metrics	Number of Projects
Concrete	• Total Concrete	3
Structural Steel	• Total Structural Steel	4
Electrical	• Total Electrical Equipment • Total Wire and Cable	4 5
Piping	• Small Bore (2-1/2” & smaller) • Large Bore (3” & larger)	7 9
Mechanical Equipment	• Total Equipment	4

On basis of such analysis, the research team finally chose the metrics of piping productivity as the leading set of productivity metrics to represent the productivity performance level for a project, which is going to be used in the following gaps analysis. The other productivity metrics are just recorded for project documentation.

4.2.1.2 Project management processes review in the Partner Company

Practices review is based on following management manuals:

- Corporate Guideline (Sep 2010)
- ISO Quality Manual Issue 3 (Rev.1)
- ISO MPM Manual Issue 3 (Rev. 1)
- Project Execution Procedure (PEP) (2009 Rev.1)
- PEP Forms

These management manuals define the processes, procedures, methods, and tools that should be introduced in project control. As a result of the review, the process elements relevant to project control and construction activities are sorted into a list. This list is organized with the timeline of project execution phases. The list can be found in **Appendix F**.

4.2.1.3 Practices mapping to CII best practices and the specific best productivity practices

In order to help users translate knowledge, terminologies, and processes between two individual practices definition systems (Corporate vs. CII), and to easily use CII's benchmarking tools (such as the BPPII) to evaluate practice implementation in the Partner Company, two mapping tables were established.

The practices mapping tables are displayed in **Appendix G** and **Appendix H**. They represent several person months of work each. They were all verified by Partner Company research team members after being drafted by the author of this thesis.

4.2.2 Data collection

A dedicated BM&M coordinator is recommended to implement all the data collection, data analysis and reporting to corporate executives. The responsibilities of the dedicated BM&M coordinator includes:

- Working with project teams to collect and review data for selected projects
- Assigning BPPII survey to project managers or project coordinators
- Managing the corporate projects/database, and collects productivity data from corporate project account database.
- Conducting internal data analysis
- Coordinating with a third-party BM&M program (such as CII's BM&M database) to enquire and submit data
- Facilitating an improvement culture to follow-through in the following projects

The following paragraphs will introduce the data collection processes that are customized and deployed in the Partner Company.

4.2.2.1 Productivity data collection

Data collection is based on the Partner Company's existing project reporting system and project management database system. Relevant information delivery can be traced in existing foreman daily reports, daily time sheets, weekly and monthly reports, mark-up assignment sheets, and PJA reports. The intent is to make the best use of the existing project accounting system (eCMS and FPMS) to implement data collection, while minimizing additional work processes. The productivity data collection processes are presented as follows.

1. Productivity raw data retrieval from the eCMS database
    - Select attributes for data retrieval: already determined in Table 14

- Screen data records and reserve all data records related to labour (check the attribute “cost type” with the value “labour” in data retrieval).
- Retrieve all labour cost items and import them into an MS-Excel spreadsheet (MS-Excel is recommended as the IT tool for supporting data fusion and analysis)

2. Classify the labour cost items to meet the selected productivity metrics accounts
   - Apply the work-hours counting rules by using the cost account code mapping table (**Appendix I**), which classifies the cost items using the cost codes at level 1 and 2. Sort & Filter functions, or some VBA codes in MS-Excel, can help in implementing this process easily.
   - Pick up “foremen” (FM) and “general foremen” (GF) cost items from indirect accounts, and take them into work-hours counting. Their cost codes are usually titled with “01.16.3.xx”
   - Manually review the classification by using the description of the cost items, since some cost items might not be marked up with the right account codes. Over time with the implementation of the BM&M program, account codes markup will fit this consistent metrics system.
   - Only the piping need be divided into small bore and large bore according to the diameter size. The diameter sizes can be identified with the account code at level 4. The code “03” indicates small bore piping; and the code “05” and above indicates large bore piping.
   - However, the piping work tracking in many projects is packaged by functional system regardless of the diameter size. Based on the nature of the components in those work packages, some rules are introduced to approximately classify those packages into small bore or large bore piping.

- Water treatment plant projects: all piping is approximately counted into large bore.
- Gas compression station projects:

Piping	Size classification
System 6 HP piping	large bore
System 7 fuel gas piping	small bore
System 8 HP drain and vent	large bore
System 9 fresh water	small bore
System 10 compressed air	small bore
System 11 interconnect piping	large bore
System 12 power gas control	small bore
System 14 HVAC & heating	large bore
System 15 drainage	large bore

3. Roll up work-hours and work quantities
   - Breakdown foremen (FM) and general foremen (GF) hours of certain craft disciplines to every cost tracking item in such craft discipline. The portion (of FM/GF hours) being added to each cost item is weighted by the work-hours amount in each cost item.
   - Roll up the work-hours in those cost items that have been classified into a specific productivity metric in the previous step, which results in the work-hours amount for each specific productivity metric.
   - The work quantities rolling-up only takes into account the numbers in those cost items that represent the counts of final deliverables of such work package. The typical example is in piping and concrete work (see Table 26)

Table 26 Example Of Aggregation (Roll-Up) Of Cost Accounts Into Productivity Metrics Categories

Selected Metrics	Cost Code				Description	UNIT	Work-hours counting	Quantities counting
	L1	L2	L3	L4				
Piping	03	30	xx	xx	Carbon steel piping	FT	✓	✓
	03	31	xx	xx	Stainless steel piping	FT	✓	✓
	03	32	xx	xx	Cr. MO piping	FT	✓	✓
	03	33	xx	xx	FRP piping	FT	✓	✓
	03	34	xx	xx	Plastic piping	FT	✓	✓
	03	35	xx	xx	Specialty piping	FT	✓	✓
	03	36	xx	xx	FRP piping	FT	✓	✓
	03	37	xx	xx	HPDE piping	FT	✓	✓
	03	39	xx	xx	Specialties		✓	
Concrete	06	62	xx	xx	Place concrete	cy	✓	✓
	06	63	xx	xx	Concrete specialties and miscellaneous		✓	
	06	65	xx	xx	Embeds		✓	

4. Calculate the productivity in terms of (1) budgeted productivity, (2) actual productivity, and (3) productivity performance factor.
5. Project labour productivity calculations are displayed in **Appendix J**

4.2.2.2 Example of data collection and calculation of piping productivity

This section takes piping work in project SC as an example to demonstrate the productivity data collection and calculation. Project SC is a Greenfield gas compressor station project. The calculation of productivity is following the steps introduced in section 4.2.2.1.

1. Retrieve productivity raw data from corporate project cost account system and screen out unrelated cost accounts except labour cost accounts. Those cost accounts are listed in Table 27. Productivity raw data for a cost account includes measure unit, work hours and quantities of budget and actual expense up to date respectively.
2. Use cost codes level 1 and 2 to screen the cost accounts that are taken into account:
    a. cost code level 1 = 3
    b. cost code level 2 = 30~37, 39

   All the accounts outside scope of this rule are not taken in to account, which are marked with a delete line through the text in Table 27.

Table 27 Piping Productivity Calculation Worksheet for Case Project SC

Rules Code						Items	unit	Budget			To Date			PPF
Cost Code				Hour	Quan			Hours	Quan.	Prod.	Hours	Quan.	Prod.	
L1	L2	L3	L4											
1						**Indirect**								
1	16	3	29			Pipe fitter FM	%	3270			7191			
						Direct								
3						Piping								
						System 10 PCA piping-compress air								
3	35	1	7	S	S	install piping <12"	FT	1236	492.2		1990	492.2		
3	39	7	3	S		hydrostatic testing	%	110			73			
						System 15 PCD piping-closed drains								
3	35	1	7	L	L	install piping <12"	FT	1192	339.5		1388	339.5		
3	39	7	3	L		hydrostatic testing	%	147			106			
						System 7 PFG piping-fuel gas								
3	35	1	7	S	S	install piping <12"	FT	752	157.4		1427	157.4		
3	39	7	3	S		hydrostatic testing	%	110			132			
						System 14 PHT piping-heat medium								
3	35	1	7	L	L	install piping <12"	FT	2008	663		2669	663		
3	39	7	3	L		hydrostatic testing	%	182			247			
						System 11 PLO piping-lube oil								
3	35	1	7	L	L	install piping <12"	FT	596	197.5		633	195.8		
3	39	7	3	L		hydrostatic testing	%	71			205			
						System 6 PMG piping - main gas								
3	35	1	7	L	L	install piping <12"	FT	1603	175.6		1998	149.6		
3	35	2	9	L	L	install piping >16"	FT	8613	1371		8723	1371		
3	39	7	3	L		hydrostatic testing	%	920			1291			
~~3~~	~~47~~	~~4~~	~~3~~			~~Instl. Gas equip.~~	~~%~~	~~204~~			~~135~~			
						System 12 PPG piping - power gas								
3	35	1	7	S	S	install piping <12"	FT	490	145.7		1071	136.4		
3	39	7	3	S		hydrostatic testing	%	73			137			
						PI piping - instrument								
~~3~~	~~40~~	~~0~~	~~3~~			~~Instl devices~~	~~%~~	~~140~~	~~100~~		~~166~~			
~~3~~	~~40~~	~~0~~	~~7~~			~~Instrument tubing~~	~~%~~	~~1936~~	~~100~~		~~12~~			
						System 8 PV piping - vents								
3	35	1	7	L	L	install piping <12"	FT	485	221.8		1183	131.1		
3	35	2	9	L	L	install piping >16"	FT	1129	131.1		462	221.8		
3	39	7	3	L		hydrostatic testing	%	110			94			
						Piping summary								
						Total hours of piping		22107			24142			
						Pipe fitter FM hours multiplier		1.148			1.298			
							unit	Budget			To Date			PPF
								Hours	Quan.	Prod.	Hours	Quan.	Prod.	
						Small bore	FT	3181	795.3	3.999	6269	786	7.975	1.994
						Large bore	FT	19579	3100	6.316	24658	3072	8.026	1.271

3. Pick up foremen cost items into the calculation worksheet, which are shown as the account – 1.16.3.29 in Table 27.
4. Classify piping cost accounts into small bore and large bore by applying classification rules listed in section 4.2.2.1, which are marked with “S” or “L” in column “hour” under “Rules Code”.
5. First step for work-hours calculation is breaking down foremen hours and distributing them to small bore and large bore piping separately. To make it simple, a multiplier was derived by the formula as below. Foremen hours can be easily added to small bore or large bore piping hours by timing this multiplier.

$$\text{Pipe fitter FM hours multiplier} = 1 + \frac{\text{Pipe fitter FM hours}}{\text{Total piping hours}}$$

6. Respectively sum up work hours for small bore piping and large bore piping according to the classification code in column “Hour” of “Rules Code”, and add up foremen hours by timing the pipe fitter FM hours multiplier, the total work hours of small bore and large bore piping are derived.
7. Quantities of piping production is measured by footage. Even though piping consists of many craft processes which are measured in individual accounts and in different measuring units, overall quantity of piping is just measured by footage of the cost account of pipe fitting (i.e. install piping in Table 27). (In other cases it might be diameter inches where welding predominates). The accounts contain quantities of piping are marked with “S” and “L” in column “Quan” under “Rules Code”, which represent the quantities of small bore piping and large bore piping respectively.
8. So far, total quantities and total work hours are summarized in terms of budget and actual to date respectively. Therefore the estimated productivity, actual productivity, and productivity performance factor are calculated accordingly as shown at the end of Table 27.

4.2.2.3 Practices PIL measurement

Practices PIL measurement includes: (1) BPPII survey on corporation's management manuals, (2) BPPII survey on projects, and (3) prioritization of practice elements for improving.

1. BPPII survey on the corporation's management manuals

The method to rate the corporation management manuals has already been introduced in the model description. On basis of practices mapping, the BPPII PIL rating for the Partner Company's management manuals can be achieved. See **Appendix K**

2. BPPII survey on projects

The BPPII was carried out on 12 projects (10 projects in 2011, 2 projects in 2013). Eleven people contributed to the BPPII survey. They were project manager or project coordinator of the projects. Work time spent on a full BPPII survey is about two and half hours on average. Finally, the BPPII survey results appears in two types of data: the PIL (0-5) for each practice element in each project and the BPPII score (% grade) for each project. The project BPPII survey results are presented in **Appendix L**.

3. Prioritization of practice elements for improving

A prioritization work sheet was distributed to 9 practitioners (1 VP, 1 director, 2 project manager, and 5 project coordinators) in the Partner Company. The prioritization from individuals and the average for each practice element are presented in **Appendix M**.

4.2.3 Productivity evaluation

4.2.3.1 Productivity evaluation at the project level

Actual productivity (P_a) and the productivity performance factor (PPF) for each project are summarized in Table 28 and Table 29 respectively.

Table 28 Actual Labour Productivity for Each Project – Normalized Number

Labour Productivity Metrics	Fossil Power			Gas Compression			Water Treatment		Nuclear Power
	SH	EWCC	AK	DN	LB	SC	WWTP-US	WWTP-W	NB
Piping									
Small Bore (Whrs/FT)	3.12	2.26	3.04	4.48	4.26	7.97			5.16
Large Bore (Whrs/FT)	2.01	3.05	4.51	4.18	5.71	8.03	1.45	0.79	29.75
Electrical									
Electrical Equipment and Devices (Whrs/EA)	2.08	7.87				0.37	0.52		
Wire and Cable (Whrs/FT)	2.57	7.99	3.14			3.71	2.57		
Mechanical Equipment (Whrs/EA)	6.64		3.81			8.76	3.13		
Structural Steel (Whrs/ton)	4.89					8.03	3.91		34.2
Concrete (Whrs/CY)	5.56	4.98						7.99	

Table 29 Productivity Performance Factor for Each Project

Labour Productivity Metrics	Fossil Power		Gas Compression			Water Treatment			Nuclear
	SH	AK	DN	LB	SC	WWTP-US	WWTP-W	BDPS	NB
Piping									
Small Bore	1.77	0.64	0.81	1.14	1.99				0.96
Large Bore	1.40	2.11	0.61	0.74	1.27	1.19	0.84	1.39	1.39
Electrical									
Electrical Equipment and Devices	0.89				1.13	0.64			
Wire and Cable	0.73	1.27			1.24	0.97			
Mechanical Equipment	1.00	1.98	0.76	1.05	0.76	1.86		0.78	
Structural Steel	0.53		1.67	0.92	1.21	0.70			1.28
Concrete									

Not all the 12 projects appropriately reported productivity. Two Auto Plant projects did not have the appropriate productivity data. Some projects do not have estimated productivity data, so the PPF calculations for those projects are not available (e.g. EWCC and NB). For some projects or some productivity metric items, the completed work volume was reported by percentage of completion instead of unit quantities. So, there is only productivity data of budget work-hours and actual work-hours that derives only the PPF for such productivity metric items.

4.2.3.2 Productivity evaluation at corporate level

According to the designed productivity evaluation processes in the BM&M model, the average actual productivity (P_a) in the population of surveyed projects could demonstrate the overall productivity performance level for the Partner Company.

Table 30 Actual Productivity Average Summary (Normalized Number)

Labour Productivity Metrics	CII Average	Corporate Average	Nuclear Power	Fossil Power	Gas Comp.	Water Treatment
Piping						
Small Bore (Whrs/unit)	2.89	4.17	5.16	2.81	5.52	
Large Bore (Whrs/unit)	6.72	3.65	29.75	3.19	5.82	1.12
Electrical						
Electrical Equipment and Devices (Whrs/unit)		2.71		4.98	0.37	0.52
Wire and Cable (Whrs/unit)	2.00	4.00		4.57	3.71	2.57
Mechanical Equipment (Whrs/unit)		5.59		5.22	8.76	3.14
Structural Steel (Whrs/unit)	6.60	5.61	34.20	4.89	8.03	3.91
Concrete (Whrs/unit)	7.48	6.17		5.27		8.00

Comparing the CII average with the average of the Partner Company, it shows that the Partner Company did better in large bore piping, structural steel and concrete, while were only a bit short in small bore piping and wire and cable.

It is also found that labour productivity performed quite different between different project types. The average actual productivities are also calculated for each project type group (including nuclear power, fossil power, gas compressor station, and water treatment). As aforementioned in Table 25, only piping has good sample size to calculate average in project groups. So, just using piping productivity as the leading productivity metric in the productivity evaluation of project group makes sense. That is why the average productivity for rest of metrics is displayed in faded font in Table 30.

4.2.3.3 Project productivity evaluation report in Post Job Analysis (PJA)

In order to visually report productivity evaluation in the Post Job Analysis (PJA), a box plot is introduced to display CII average level, corporate average level, and the project performance within one chart.

For example, a set of box plots are used to demonstrate productivity performance in project AK (see Figure 15). The box demonstrates the value range of the actual productivity in the population of CII projects and the Partner Company's projects. "n=" means the sample size of the project population. The black bold line demonstrates the CII average productivity, the Partner Company average productivity, and the productivity level in project AK. The detailed data information is displayed in a separate table (see Table 31). Again, those charts and tables should be added in the project PJA (post job analysis) report. CII has spent 15 years to get the project data from about 2000 projects, including the data of project performance and practices implementation, only 200 of them reported some appropriate productivity data. And within those 200 projects, there was only for example 35 data points for large bore piping productivity. With this context in mind, 9 projects of productivity data represents a significant commitment of the partner company and a significant level of effort specific to this research effort. The partner company will get more data in the future, because it is fully implementing this internal Benchmarking program.

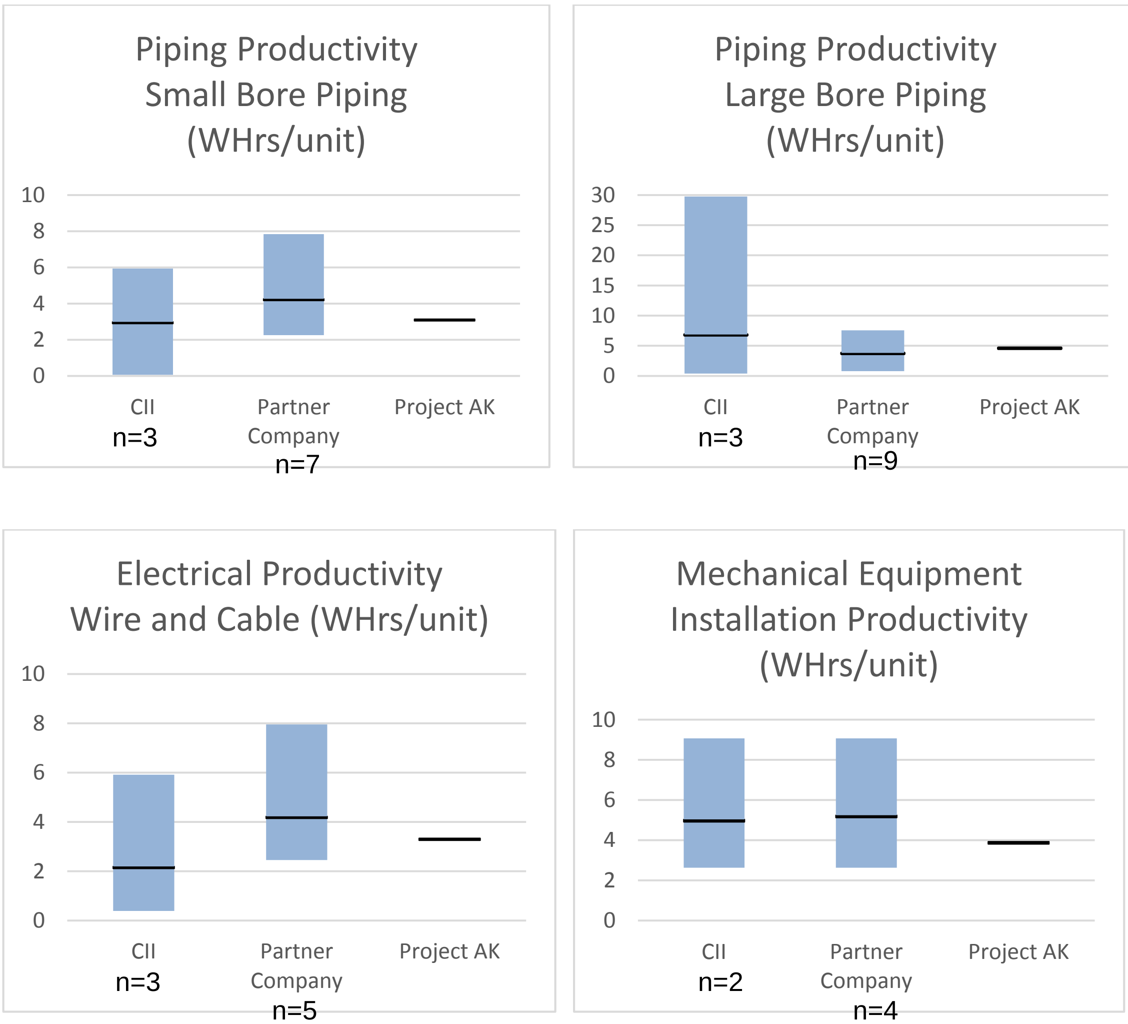

Figure 15 Project Productivity Performance Report by Box-Plot

Table 31 Project Productivity Report Sample (Project AK)

	CII	Partner Company	Project AK
Piping			
Small Bore (Whrs/unit)			
Avg.	2.89	4.17	3.04
Max.	5.93	7.84	
Min.	0.06	2.26	
Large Bore (Whrs/unit)			
Avg.	6.72	3.65	4.51
Max.	29.75	7.57	
Min.	0.39	0.80	
Electrical			
Wire and Cable (Whrs/unit)			
Avg.	2.00	4.29	3.14
Max.	6.00	8.00	
Min.	0.29	2.57	
Mechanical Equipment (Whrs/unit)			
Avg.	5.12	5.59	3.81
Max.	9.07	8.76	
Min.	2.63	3.14	

4.2.4 Analysis of practices implementation

First, let us examine the effect of practice implementation level influencing the productivity performance. The BPPII scores are used to represent the overall practice implementation level in a project; and the PPF of piping is used as the leading index representing the productivity performance in a project. The valid data for these two indices is listed in Table 32.

Table 32 Data Set: BPPII Score vs. PPF

Project Code	SH	AK	DN	LB	SC	WWTP-US	BDPS	NB
BPPII score (%)	61.05	46.70	57.55	45.75	42.70	40.10	40.40	33.45
PPF (ratio)	1.40	2.11	0.61	0.74	1.27	1.19	1.39	1.39

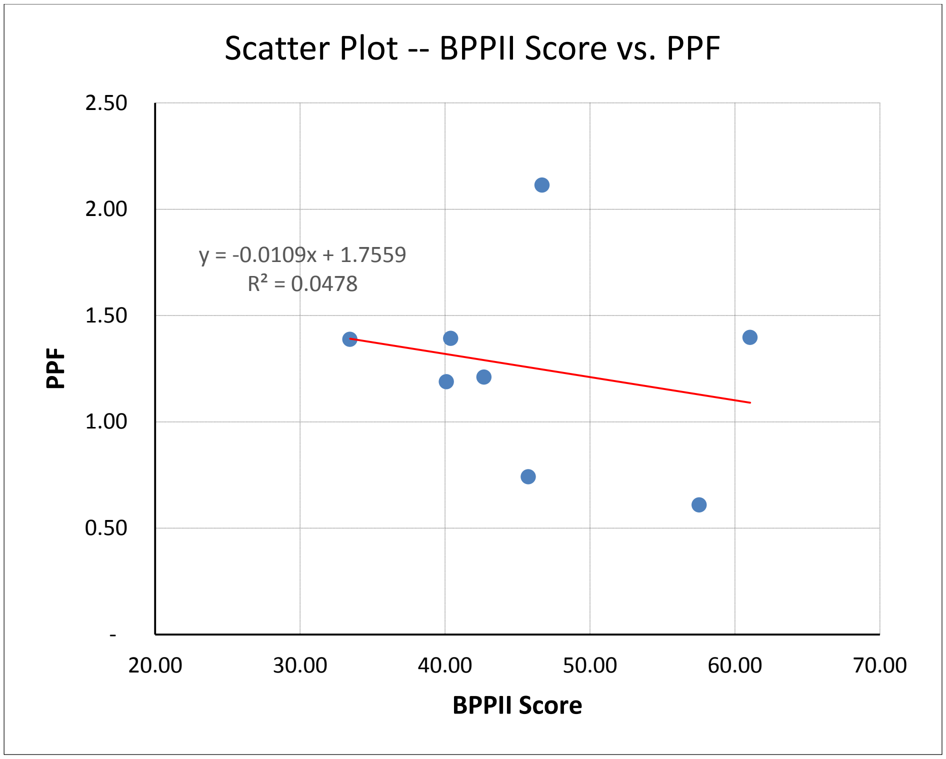

Figure 16 Scatter Plot -- BPPII Score vs. PPF

If those data sets were plotted in a scatter plot (see Figure 16) and the data points were regressed into an approximate trend line, a little bit slope of trend line indicates that higher BPPII scores correspond to better productivity performance. But, the effect demonstrated from those data is not significant. Note that on a larger data set from a number of companies, the relationship was found to be significant (Kim et al. 2014). The author contributed to that study and its analysis. The interpretation of the internal corporate data presented here is as follows:

1. Even though the practices are implemented differently from project to project, the practices implementation within an enterprise is driven by their processes manuals or the conventions in their culture, knowledge, and experience of project management. That is why the BPPII scores of the projects did not change over a very large range within an enterprise. Table 32 shows that the BPPII scores in the Partner Company mainly fall in

the range of 40% to 60%. In this case, the significant effect of practices implementation influencing productivity performance could not be demonstrated.

2. This analysis further indicates that the significant examination of practices effect is not the main objective of the enterprise internal BM&M program. The enterprise internal BM&M program looks at the corporate's overall level of practices implementation and the implementation gaps differing from the best-in-class and the average of industry, assuming those practices are in fact validated empirically. And it also looks at the consistency of practices implementation within an enterprise.
3. Therefore, the practices implementation gaps analysis is based on analyzing practice elements (BPPII elements) individually, based on a systematic assessment for each practice element implementation with respect to the guideline level, the implementation level, consistency, and importance.

In the process of data collection, all the necessary raw data for gaps analysis has already been collected and processed, including the corporate average PIL (PIL_{avg}), PIL standard deviation (*StdDev*), the PIL for corporate management manuals ($PIL_{CorpGyide}$), the CII's average PIL (CII_{avg}), and the importance of each practice element (*WoEffect*). All these data set are displayed in **Appendix N**.

Following the gaps analysis method being introduced in section 3.6.1, the five gaps factors are calculated. Further, the value of them is normalized and finally synthesized into the priority value of each practice element for improvement. The calculations are displayed in **Appendix O**.

The priority of practice elements means that the corporate improvement strategy should first look at those practice elements with higher priority values. Based on those priority values, one can classify a portion of those practice elements for improving, which is "Practices Set for Improving".

Actually, the prioritization was completed in two different ways. One is based on the statistical analysis on the data from the BPPII survey that physically examines the practices implementation level with respect to the projects execution in the field, the guideline in the corporate manual, and the conventions in project management. The other way is the prioritization by experts' judgment based on the perception of experienced practitioners in the enterprise. If the experts' judgment could corroborate the result from the statistical gaps analysis, it should be concluded that the methodology of the statistical gaps analysis introduced in this internal BM&M program model is likely valid. In addition, the statistical gaps analysis is based on the information of solid data representing the current situation of practices implementation in projects, in the corporation, and in the industry, which could substantially support continuous project performance improvement under the functional mechanism of the enterprise internal BM&M program.

Since the range of values for two sets of priorities is quite different, they cannot be directly compared one-to-one. In this case, let us initially set half of the practice elements into the "Practices Set for Improving" based on the priority value, i.e. 26 out of a total of 53 elements. One can examine the coincidence degree of the practice elements in two "Practices Set for Improving" classified in different ways. The priorities of practice elements and the classification from two prioritization methods are displayed in Table 33.

Table 33 Gaps Analysis -- Prioritization of Practice Elements for Improvement

BPPII Scoring Content	By statistical gaps analysis	By experts' review	Coincident
MATERIALS MANAGEMENT			
A. Materials Management Systems			
1. Project team material status database	**11.22**	**21**	yes
2. On-site material tracking technology	**11.81**	**18**	yes
3. Material delivery schedule	10.54	**16**	
4. Procurement plan for materials and equipment	9.97	15	
B. Receipt and Inspection of Materials			
1. Material inspection process	9.31	12	
2. Material inspection team	**11.01**	13	
3. Post receipt preservation and maintenance	10.71	13	

BPPII Scoring Content	By statistical gaps analysis	By experts' review	Coincident
EQUIPMENT LOGISTICS			
A. Site Tool Management			
1. Site tool and consumables management strategy	9.18	**19**	
2. Tool tracking systems	**11.05**	15	
3. On-Site tool maintenance	9.14	12	
4. Control system for tool delays	**10.91**	13	
B. Machinery Availability			
1. Construction machinery productivity analysis	**15.84**	14	
2. Equipment maintenance	**17.02**	**18**	yes
CRAFT INFORMATION SYSTEMS			
A. Short Interval Planning			
1. Short Interval Planning	**10.97**	**18**	yes
B. Work Face Planning			
1. Well defined scope of work	**10.85**	**22**	yes
2. Utilization of software to assist in generating work packages	**11.34**	**18**	yes
3. Project model requirements	**12.84**	**19**	yes
4. Dedicated Planner	**13.85**	**20**	yes
5. Identify required permitting	10.39	14	
6. Engineering Work Packages (EWP)	**13.53**	**19**	yes
7. Construction Work Packages (CWP)	**14.08**	**25**	yes
8. Field Installation Work Packages (FIWP)	**13.68**	**25**	yes
C. Constructability Review			
1. Design readiness for construction	**11.90**	15	
2. PPMOF evaluation	6.66	13	
HUMAN RESOURCE MANAGEMENT			
A. Training and Development			
1. Trades technical training	7.27	11	
2. Career development	**14.25**	**17**	yes
B. Behavior			
1. Nonfinancial Incentive Programs	**14.58**	**19**	yes
2. Financial Incentive Programs	**10.94**	**16**	yes
3. Social Activities	10.51	15	
C. Organizational Structure			
1. Maintain Stability of Organization Structure	10.72	**18**	
2. Clear Delegation of Responsibility	9.89	**17**	
D. Employment			
1. Retention Plan For Experienced Personnel	9.93	**19**	
2. Exit Interview	10.25	15	
CONSTRUCTION METHODS			
A. Sequence and Scheduling of Work			
1. Integrated Schedule	**13.85**	**18**	yes
2. Work Schedule Strategies	**13.04**	**19**	yes
3. Schedule Execution and Management	**14.71**	**24**	yes
B. Start-Up, Commission, and Turnover Plan			

BPPII Scoring Content	By statistical gaps analysis	By experts' review	Coincident
1. Planning for Start-Up	**14.84**	**22**	yes
2. Testing Procedures	7.04	**17**	
3. System Turnover Procedure	8.69	15	
C. New Product Investigation			
1. New equipment investigation	9.61	13	
2. New information system investigation	10.28	14	
3. New materials technologies Investigation	10.66	15	
D. Site Layout Plan			
1. Dynamic site layout plan	**14.63**	**17**	yes
2. Site security plan	**13.92**	15	
3. Equipment positioning strategy	**13.95**	**18**	yes
ENVIRONMENT, SAFETY, AND HEALTH			
A. Job Safety			
1. Zero Accident Techniques	6.45	13	
2. Task Safety Analysis	3.86	9	
3. Identification of Potential Hazards	4.97	12	
4. Housekeeping	10.76	14	
5. System test hazards planning	5.57	8	
B. Substance Abuse Programs			
1. Substance Abuse Programs	5.93	10	
C. Safety Training and Orientation			
1. OSHA Compliance Training	8.87	10	
2. Toolbox safety meetings	7.72	12	
Number of Practice Elements with High Priority	**26**	**26**	**20**

For the two sets of prioritization, the practice elements with the priority value ranked in top 26 are highlighted separately, namely which are classified in the "Practices Set for Improving". The practice elements that are classified in the "Practices Set for Improving" by both two prioritization methods are marked with "yes" in column "coincident". It is observed that the coincidence degree is 20 out of 26 practice elements. All those analyses could lead to the conclusion:

- The gaps analysis of practice implementation within an industrial construction enterprise can be implemented in an internal BM&M program. The enterprise internal BM&M program introduced in this research can provide solid data for the said gaps analysis.

- The statistical gaps analysis is a valid and systematic method to address the deficiency of construction practice implementation from a huge and complicated construction project management system. This method provides effective support with valuable data analysis for making the corporate strategies of management processes improvement, especially aiming at the construction productivity improvement.

4.2.5 Recommendation for improvement

Since the prioritization from two methods resulted in a considerable coincidence, let us address those practice elements that are both chosen by two methods as the deficient practices that need to be primarily improved. Some observations could be summarized as:

Table 34 The Practice Set For Improving

BPPII Scoring Content		Partner Company's Process Manual
MATERIALS MANAGEMENT	2/7	
A. Materials Management Systems		
1. Project team material status database		MPM 8.0 Material Receiving
2. On-site material tracking technology		MPM 8.0 Material Receiving
EQUIPMENT LOGISTICS	1/6	
B. Machinery Availability		
2. Equipment maintenance		MPM WI-7.1 Equipment Maintenance
CRAFT INFORMATION SYSTEMS	8/11	
A. Short Interval Planning		
1. Short Interval Planning		PEP-2.4-3 Two week planning
B. Work Face Planning		
1. Well defined scope of work		Under construction
2. Utilization of software to assist in generating work packages		Under construction
3. Project model requirements		Under construction
4. Dedicated Planner		QM-7.1 Org. and Responsibility
6. Engineering Work Packages (EWP)		MPM-5.1 Pre-Construction Planning
7. Construction Work Packages (CWP)		MPM-5.1 Pre-Construction Planning
8. Field Installation Work Packages (FIWP)		MPM-5.1 Pre-Construction Planning
HUMAN RESOURCE MANAGEMENT	3/9	
A. Training and Development		
2. Career development		HR Manual
B. Behavior		

BPPII Scoring Content		Partner Company's Process Manual
1. Nonfinancial Incentive Programs		HR Manual
2. Financial Incentive Programs		HR Manual
CONSTRUCTION METHODS	6/12	
A. Sequence and Scheduling of Work		
1. Integrated Schedule		PEP-2.4 Schedule & Resource Loading
2. Work Schedule Strategies		PEP-2.4 Schedule & Resource Loading
3. Schedule Execution and Management		PEP-2.4 Schedule & Resource Loading
B. Start-Up, Commission, and Turnover Plan		
1. Planning for Start-Up		Under construction
D. Site Layout Plan		
1. Dynamic site layout plan		Under construction
3. Equipment positioning strategy		Under construction
ENVIRONMENT, SAFETY, AND HEALTH	0/8	

4.2.5.1 Identify bridges to close the gaps

The Partner Company did very well regarding safety and health practices with respect to its implementation level and consistency. They just have to follow their existing pertinent procedures for this practices category.

The practices implementation deficiency mainly focuses on the practice categories "craft information systems" and "construction methods". If exploring the deficiency down to lower tier of practice section, **"Short interval planning", "work face planning", "sequence and scheduling of work", "site layout plan", and "material status and tracking"** are the practices that should be placed in the present improvement strategy.

Based on the practices mapping table (Appendix H – the corporate management manuals mapping to BPPII practice element), the relevant process or procedure items in the Partner Company's management manuals are also listed in Table 34, which are corresponding to each practice element in the practice set for improving. The improvement strategies include (1) raising the practices guideline level by improving the corporate project management manuals, and (2) enhancing the practices implementation compliance with the guideline.

For those practices that have corresponding process items in the existing manuals, they should be adjusted and improved based on the existing procedures. For example, many practice elements point to work process section MPM-5.1 Pre-construction Planning and PEP-2.4 Schedule & Resource Loading, which should be the focus of improvement at the first step.

For those practices that are noted as "under construction", they are just implemented depending on the construction management conventions, personal knowledge and experience, since there is no definite processes or procedures introduced in their existing manuals. The pertinent practice guideline should be constructed to drive the substantial practices implementation.

The approach to close those gaps includes (1) reviewing current situation of a practice, (2) setting up target of improvement, and (3) exploring detailed information from pertinent knowledge bases for planning improvement. An example is presented as follows to demonstrate those steps to bridge gaps.

Determined as a practices deficiency for the partner company, material management systems need improvement especially with respect to (1) material status database and (2) on-site material tracking (see Table 35).

1. Review of current state: The score of PIL_{avg} and $PIL_{CorpGuide}$ from BPPII surveys sufficiently describes the current state of these two practices in the partner company. By Tracing back to BPPII practice element and its PIL description, combining with the information from interview with project managers and project coordinators, the current state is described as:
    a. Corporate manuals introduced a proprietary internal procurement software to track and store the data of material status. Due to the various clients, suppliers, and subcontractors, they didn't plan to integrate their software with other project

stakeholders. However, in actual project execution, some projects still used a paper based system to track material status.

b. Corporate manuals introduced the work processes to track the location information by using Excel™ software + check list + flagging. But most of their projects just assigned material to a laydown yard or storage area and recorded information using paper based or even memory based processes.

Table 35 Example of Planning Close of the Gaps (Material Management)

Practice Element	Current state		Target state
	PIL avg.	PIL CorpGuide	
MATERIALS MANAGEMENT			
A. Materials Management Systems			
1. Project team material status database	2.40	3	4
2. On-site material tracking technology	1.67	3	4

2. Targets of improvement are set in Table 35 with level 4 of PIL for these two practice elements both, which are based on corporate business strategies and analysis of improvement cost. The target state is described as follows (by referencing the BPPII definitions):

   a. Introducing an available software application for procurement management, which can be integrated internally with corporate project control systems. Integrating software application with all project stakeholders is not recommended at this stage, since the partner company, as a construction contractor in most of their business, doesn't have dominance to integrate project management systems from all project stakeholders.

   b. Gradually Integrating barcode tracking system to existing material flagging work processes. More importantly, project management should facilitate utilizing their existing location tracking system and keep the location information updated in a software system. This the most cost efficient improvement at this stage.

3. The pertinent knowledge can be explored from some mature best practices implementation guide, such as PMI best practices, IPA best practices, and CII best practices. Materials management and logistics software and services vendors can also be contacted to get information about what solutions are commercially available. For the improvement of material status and location tracking, this thesis recommend to acquire relevant detail information from CII knowledge base. Following publication references from CII can provide systematic guide for planning the improvement, which can be purchased from CII Web site.
    - CII IR 257-3 – Materials Management Planning Guide provides a systematic
    - CII EM 7-21A – Tools for effective materials management, participant handbook

4.2.5.2 Enhance the consistent practice implementation

In order to enhance the consistent practices implementation, a short checklist is highly recommended for facilitating regular checks on the implementation of some important practices. The short check list should also focus on the practice set for improvement, and should be composed in the context of the corporate project management manuals.

The details of planning practices improvement is out of this research scope. The strategies and principles have already been introduced as above.

Chapter 5: Conclusion and Recommendation

This research provides an internal Benchmarking and Metrics (BM&M) program model for industrial construction enterprises to better understand the impact of practice implementation on construction productivity under circumstances of a specific enterprise. An approach has been developed to consistently benchmark construction productivity and the relevant practices implementation that influence productivity, and address the improvement potential of practices implementation by a systematic gaps analysis.

5.1 Conclusions

This internal Benchmarking and Metrics (BM&M) program provides a set of systematic functional processes. Based on the process model which introduces the relevant theories, strategies, principles, and methodologies, all the processes were customized and implemented in a real industrial construction enterprise. A series of pilot studies of processes integration and exploratory analysis of collected data verified the models functionality. Relevant conclusions can be drawn:

1. The metrics determined in this BM&M system are provided with very good pertinence and validity to support properly measure construction productivity and the relevant factors influencing productivity improvement in an industrial construction enterprise. The pilot studies and trial runs of the program also prove that it is efficient to use that metrics combination.
2. The model implementation experiment in a real construction corporation illustrates that the data collection processes of this BM&M program can be highly integrated to an existing project data reporting system and the existing project account database.

3. A systematic productivity evaluation system is established in this BM&M program model, including: (1) a set of productivity performance indices at three management levels; and (2) using actual productivity (Pa) and productivity performance factor (PPF) to examine the effect from the influencing factors which are classified in two categories (environment and practices). Such a productivity evaluation system is theoretically verified by the exploratory analysis of the collected productivity data.
4. Regarding the gaps analysis process of the BM&M program model, two approaches and their different data processing methods are introduced. By analyzing the coincidence degree between the results from those two gaps analysis approaches, statistical gaps analysis method for practices implement gaps analysis is validated.

5.2 Contributions

The major contribution of this research is the development of an enterprise internal BM&M program model to support construction productivity improvement. The author elaborates the construction productivity improvement mechanism from multiple perspectives including the influencing factors, how productivity improvement behaves in classes of changes corresponding to the productivity measurement at different management levels, and the strategies to adjust those influencing factors that could be manipulated. The functional process model was developed to guide implementation of such a continuous improvement mechanism within a construction enterprise.

Especially in this BM&M program model, the author developed a systematic productivity evaluation system for a corporation. This system introduces a multi levels evaluation framework for a construction enterprise. At crews' level, productivity is assessed from a micro perspective in terms of percentage of value-adding work hours over total work hours. Upon this measure, productivity improvement is understood as reducing non-value-adding work hours by making appropriate adjustment to field management practices. At project level, productivity is assessed by a conventional measure as a ratio of inputs over outputs. Upon this measure, productivity improvement is understood as increasing efficiency of resources utilization and reducing rework. At corporate level, productivity performance is assessed as a quality issue in statistical concept, which is represented with a mean and variance of productivities performed in projects of a corporation. Productivity improvement for a corporation is shown as steady performance from projects to projects, which requires consistent practices implementation driven by corporate construction management practices guideline. Productivity improvement of a construction enterprise is systematically interpreted in this productivity evaluation model.

Another primary contribution of this thesis is the development of a systematic gaps analysis model to address the improvement potential of the practices implementation in a construction corporation. This gaps analysis model not only simply addresses gaps from corporate current performance to the best-in-class, but also thoroughly considers the factors with respect to corporate practices competitiveness, quality of practices implementation in projects in terms of consistency, and effects of practices. More comprehensive information was processed by this gaps analysis model, which lead to address a more practical and efficient approach to bridge the gaps.

5.3 Recommendations

As scheduled in the research timeline, there were only about two years for collecting data from on-going projects. A large number of appropriate on-going projects in one corporation within two years is not quite realistic. Sample size may not be quite enough for some statistical analysis. Therefore, the further solid validation analysis is recommended after the continuous data collection in the future.

- Productivity evaluation should be grouped by project types, since projects of the same type are usually considered under similar conditions with respect to complexity and site environment. Comparing productivity within the population of same type of projects presents more confidence than comparing within a large range of productivity all over all types of projects.

- Continuously collecting data over a large time span could be very valuable, which shall provide solid support with the data in real construction enterprise, for validating the productivity continuous improvement over time through adopt an internal BM&M program.

References:

Aft, L. S. (2000). *Work measurement and methods improvement*. John Wiley & Sons, 468.

Alfeld, L. E. (1988). *Construction Productivity: On-site Measurement and Management*. McGraw-Hill, 234.

Almström, P., and Kinnander, A. (2011). "The productivity potential assessment method: Assessing and benchmarking the improvement potential in manufacturing systems at shop-floor level." *International Journal of Productivity and Performance Management*, 60(7), 758–770.

Arditi, D. (1985). "Construction Productivity Improvement." *Journal of Construction Engineering and Management*, 111(1), 1.

Arditi, D., and Mochtar, K. (2000). "Trends in productivity improvement in the US construction industry." *Construction Management and Economics*, 18(1), 15–27.

Bernold, L. E., and AbouRizk, S. M. (2010). *Managing Performance in Construction*. John Wiley & Sons, 521.

Centre for the Study of Living Standards. (2001). *Productivity Trends in the Construction Sector in Canada: A Case of Lagging Technical Progress*. Ottawa, Canada.

Chang, C.-K., Hanna, A. S., Lackney, J. A., and Sullivan, K. T. (2007). "Quantifying the Impact of Schedule Compression on Labor Productivity for Mechanical and Sheet Metal Contractor." *Journal of Construction Engineering and Management*, 133(4), 287.

Chong, W. K., and Chou, J. S. (2006). "Examining Productivity of Foundation Construction." *ASCE Conference Proceedings*, 197(40865), 39.

CII. (2008). *Benchmarking & Metrics Project Level Survey*. Austin, TX, 104.

CII. (2011). *Advanced Work Packaging: Design through Workface Execution*. Construction Industry Institute™, Austin, TX, 28.

CII. (2013a). *The Construction Productivity Handbook (Implementation Resource 252-2d)*. Austin, TX, 200.

CII. (2013b). *Best Productivity Practices Implementation Index – Industrial Projects*. Austin, Texas, 81.

CII RT-252. (2013). *Construction Productivity Research Program - Phase III*. Austin, Texas, 55.

Cottrell, D. S. (2006). "Contractor Process Improvement for Enhancing Construction Productivity." *Journal of Construction Engineering and Management*, 132(2), 189.

Craig, C. (1973). “Total Productivity Measurement at the Firm Level.” *Sloan Management Review*, (Spring 1973), 13–28.

Dissanayake, M., Robinson Fayek, A., Russell, A. D., and Pedrycz, W. (2005). “A Hybrid Neural Network for Predicting Construction Labour Productivity.” *ASCE Conference Proceedings*, 179(40794), 78.

Drucker, P. F. (1998). *Peter Drucker on the Profession of Management*. (N. Stone, ed.), Harvard Business Press, 201.

Enshassi, A., Mohamed, S., Mayer, P., and Abed, K. (2007). “Benchmarking masonry labor productivity.” *International Journal of Productivity and Performance Management*, 56(4), 358–368.

Ezeldin, A. S., and Sharara, L. M. (2006). “Neural Networks for Estimating the Productivity of Concreting Activities.” *Journal of Construction Engineering and Management*, 132(6), 650.

Fayek, A. R., and Oduba, A. (2005). “Predicting Industrial Construction Labor Productivity Using Fuzzy Expert Systems.” *Journal of Construction Engineering and Management*, 131(8), 938.

Fisher, D., Miertschin, S., and Pollock Jr., D. (1995). “Benchmarking in Construction Industry.” *Journal of Management in Engineering*, 11(1), 50–57.

Fisher, D., Miertschin, S., Pollock Jr., D., Deborah Fisher, Susan Miertschin, and David R. Pollock Jr. (1995). “Benchmarking in Construction Industry.” *Journal of Management in Engineering*, 11(1), 50–57.

Freeman, R. (2008). *LABOUR PRODUCTIVITY INDICATORS*. *pisa.oecd.org*, OECD, 76.

Gong, J., and Caldas, C. H. (2009). “An Intelligent Video Computing Method for Automated Productivity Analysis of Cyclic Construction Operations.” *ASCE Conference Proceedings*, 346(41052), 7.

Gong, J., and Caldas, C. H. (2010). “Computer Vision-Based Video Interpretation Model for Automated Productivity Analysis of Construction Operations.” *Journal of Computing in Civil Engineering*, 24, 252.

Goodrum, P. M., and Haas, C. T. (2004). “Long-Term Impact of Equipment Technology on Labor Productivity in the U.S. Construction Industry at the Activity Level.” *Journal of Construction Engineering and Management*, 130(1), 124.

Goodrum, P. M. P., Haas, C. T., Caldas, C. H., Zhai, D., Yeiser, J., and Homm, D. (2011). “Model to Predict the Impact of a Technology on Construction Productivity.” *Journal of Construction Engineering and Management*, 137(9), 678.

Gouett, M. C. (2010). “UWSpace: Activity Analysis for Continuous Productivity Improvement in Construction.” University of Waterloo.

Gouett, M. C., Haas, C. T., Goodrum, P. M., and Caldas, C. H. (2011). “Activity Analysis for Direct-Work Rate Improvement in Construction.” *Journal of Construction Engineering and Management*, 1(1), 265.

Gulezian, R., and Samelian, F. (2003). “Baseline Determination in Construction Labor Productivity-Loss Claims.” *Journal of Management in Engineering*, 19(4), 160.

Haas, C. T., Borcherding, J. D., Allmon, E., and Goodrum, P. M. (1999). *U.S. CONSTRUCTION LABOR PRODUCTIVITY TRENDS, 1970–1998*. Austin, Texas, 34.

Harris, F., McCaffer, R., and Edum-Fotwe, F. (2006). *Modern construction management*. Wiley-Blackwell, 677.

Humphrey, D. B., Moroney, J. R., and Burras, D. (1975). “Substitution among Capital, Labor, and Natural Resource Products in American Manufacturing.” *Journal of Political Economy*, 83(1), 57–82.

Hwang, S., and Liu, L. Y. (2005). “Proactive Project Control Using Productivity Data and Time Series Analysis.” *ASCE Conference Proceedings*, 179(40794), 179.

Hwang, S., and Liu, L. Y. (2010). “Contemporaneous Time Series and Forecasting Methodologies for Predicting Short-Term Productivity.” *Journal of Construction Engineering and Management*, 136, 1047.

I.I.E., and ANSI. (1982). *Industrial Engineering Terminology: Standard Z94.1-12*. John Wiley & Sons Inc, 420.

Ibbs, W., and Liu, M. (2005). “Improved Measured Mile Analysis Technique.” *Journal of Construction Engineering and Management*, 131(12), 1249.

JENKINS, J. L., and ORTH, D. L. (2004). “Productivity improvement through work sampling.” *Cost engineering*, 46(3), 27–32.

Kendrick, J. W. (1984). *Improving company productivity: handbook with case studies*. Johns Hopkins University Press.

Kim, Y., Caldas, C., Goodrum, P., Haas, C., and Zhang, D. (2014). “A Method to Assess the Level of Implementation of Productivity Practices on Industrial Projects.” *ASCE Journal of Construction Engineering and Management*.

Kumar, A., Minocha, V. K., Abdelhamid, T. S., and Everett, J. G. (2001). “Time Series Analysis for Construction Productivity Experiments.” *Journal of Construction Engineering and Management*, 127(3), 252.

Liberda, M., Ruwanpura, J., and Jergeas, G. (2003). “Construction Productivity Improvement: A Study of Human, Management, and External Issues.” *ASCE Conference Proceedings*, 120(40671), 5.

Lin, C. L., and Huang, H. M. (2010). “Improved baseline productivity analysis technique.” *Journal of Construction Engineering and Management*, 136, 367.

Lu, M., AbouRizk, S. M., and Hermann, U. H. (2000). “Estimating Labor Productivity Using Probability Inference Neural Network.” *Journal of Computing in Civil Engineering*, 14(4), 241.

Maloney, W. F. (1983). “Productivity Improvement: The Influence of Labor.” *Journal of Construction Engineering and Management*, 109(3), 321.

MasterFormat®. (1978). *Masterformat: master list of section titles and numbers*. The Institute of Construction Specification Canada, 136.

Moselhi, O., Leonard, C., and Fazio, P. (1991). “Impact of change orders on construction productivity.” *Canadian Journal of Civil Engineering*, 18(3), 484–492.

Nasir, H., T., H., H., R., Robinson, F., ForguesDaniel, and RuwanpuraJanaka. (2012). “Development and implementation of a benchmarking and metrics program for construction performance and productivity improvement11This paper is one of a selection of papers in this Special Issue on Construction Engineering and Management.” *Canadian Journal of Civil Engineering*, NRC Research Press, 10.1139.

OGCA, and RMCAO. (2005). *Best Practices Guidelines for Concrete Construction*. 82.

Park, H. S. H., Thomas, S. R., Tucker, R. L. R. L., Hee-Sung Park, Stephen R. Thomas, and Richard l. Tucker. (2005). “Benchmarking of Construction Productivity.” *Journal of Construction Engineering and Management*, 131(July), 772–778.

Payne, S. C., Youngcourt, S. S., and Watrous, K. M. (2006). “Portrayals of F.W. Taylor across textbooks.” *Journal of Management History*, 12(4), 385–407.

PMI. (2006). *Practice standard for work breakdown structures*. Project Management Institute, 111.

PMI. (2013). *A Guide to the Project Management Body of Knowledge: PMBOK Guide*. Project Management Institute, 589.

Prokopenko, J. (1987). *Productivity management: a practical handbook*. International Labour Organization, 310.

Salem, O., Galani, N., and Najafi, M. (2003). “Productivity Analysis of Auger Boring Trenchless Pipe Installation Using Simulation.” *ASCE Conference Proceedings*, 130(40690), 113.

Sanders, S. R., and Thomas, H. R. (1991). “Factors Affecting Masonry-Labor Productivity.” *Journal of Construction Engineering and Management*, 117(4), 626.

Sanvido, V. E. (1988). “Conceptual Construction Process Model.” *Journal of Construction Engineering and Management*, 114(2), 294–310.

Shahtaheri, M. (2012). “Setting Target Rates for Construction Activity Analysis Categories.” University of Waterloo.

Smith, S. D. (1999). “Earthmoving Productivity Estimation Using Linear Regression Techniques.” *Journal of Construction Engineering and Management*, 125(3), 133.

Solow, R. M. (1956). “A Contribution to the Theory of Economic Growth.” *The Quarterly Journal of Economics*, 70(1), 65 –94.

Song, L., and AbouRizk, S. M. (2008). “Measuring and Modeling Labor Productivity Using Historical Data.” *Journal of Construction Engineering and Management*, 134(10), 786.

Sonmez, R., and Rowings, J. E. (1998). “Construction Labor Productivity Modeling with Neural Networks.” *Journal of Construction Engineering and Management*, 124(6), 498.

Tavakoli, A. (1985). “Productivity Analysis of Construction Operations.” *Journal of Construction Engineering and Management*, 111(1), 31.

Teicholz, P., Goodrum, P. M., and Haas, C. T. (2001). “U.S. Construction Labor Productivity Trends, 1970–1998.” *Journal of Construction Engineering and Management*, 127(5), 427.

Thomas, H. R. (1991). “Labor Productivity and Work Sampling: The Bottom Line.” *Journal of Construction Engineering and Management*, 117(3), 423.

Thomas, H. R., and Holland, M. P. (1980). “Work Sampling Programs: Comparative Analysis.” *Journal of the Construction Division*, 106(4), 519–534.

Thomas, H. R., Maloney, W. F., Horner, R. M. W., Smith, G. R., Handa, V. K., and Sanders, S. R. (1990). “Modeling Construction Labor Productivity.” *Journal of Construction Engineering and Management*, 116(4), 705.

Thomas, H. R., and Napolitan, C. L. (1995). “Quantitative Effects of Construction Changes on Labor Productivity.” *Journal of Construction Engineering and Management*, 121(3), 290.

Thomas, H. R., Riley, D. R., and Sanvido, V. E. (1999). “Loss of Labor Productivity due to Delivery Methods and Weather.” *Journal of Construction Engineering and Management*, 125(1), 39.

Thomas, H. R., and Sakarcan, A. S. (1994). “Forecasting Labor Productivity Using Factor Model.” *Journal of Construction Engineering and Management*, 120(1), 228.

Thomas, H. R., and Sanvido, V. E. (2000). “Role of the Fabricator in Labor Productivity.” *Journal of Construction Engineering and Management*, 126(5), 358.

Thomas, H. R., Završki, I., and Zavrski, I. (1999). “Construction baseline productivity: Theory and practice.” *Journal of construction engineering and management*, 125(5), 295.

Wikipedia. (2011). “Total factor productivity - Wikipedia, the free encyclopedia.” <http://en.wikipedia.org/wiki/MasterFormat> (Nov. 12, 2010).

Zayed, T. M., and Halpin, D. W. (2005). “Productivity and Cost Regression Models for Pile Construction.” *Journal of Construction Engineering and Management*, 131(7), 779.

Zhai, D., Goodrum, P. M., Haas, C. T., and Caldas, C. H. (2009). “Relationship between Automation and Integration of Construction Information Systems and Labor Productivity.” *Journal of Construction Engineering and Management*, 135(8), 746.

Zink, D. A. (1981). *Construction scheduling & cost control: Course manual*. Federal Publications.

Zink, D. A. (1986). “The measured mile: Proving construction inefficiency costs.” *Cost Engineering*, 28(4), 19–21.

Zink, D. A. (1990). “Impacts and construction inefficiency.” *Cost Engineering*, 32(11), 21–23.

Appendices

Appendix A	CII's construction productivity metrics categories and breakout
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Construction Productivity Metrics Categories and Breakouts

Concrete
- **Total Concrete**
  - **Slabs** (CY)
    - On-Grade (CY)
    - Elevated Slabs/On Deck (CY)
    - Area Paving (CY)
  - **Foundations** (CY)
    - < 5 CY
    - 5 – 20 CY
    - 21 –50 CY
    - > 50 CY
  - **Concrete Structures** (CY)

Structural Steel
- **Total Structural Steel** (Tons)
  - Structural Steel (Tons)
  - Pipe Racks & Utility Bridges (Tons)
  - Miscellaneous Steel (Tons)

Electrical
- **Total Electrical Equipment** (Each)
  - Panels and Small Devices (Each)
  - Electrical Equipment 600V & Below (Each)
  - Electrical Equipment over 600V (Each)
- **Conduit** (LF)
  - Exposed or Above Ground Conduit (LF)
  - Underground, Duct Bank or Embedded Conduit (LF)
- **Cable Tray** (LF)
- **Wire and Cable** (LF)
  - Power and Control Cable – 600V (LF)
  - Power Cable – 5 & 15KV (LF)
- **Other Metrics**
  - Lighting (Each)
  - Grounding (LF)
  - Electrical Heat Tracing (LF)

Piping
- **Small Bore (2-1/2" & Smaller)** (LF)
  - Carbon Steel (LF)
  - Stainless Steel (LF)
  - Chrome (LF)
  - Other Alloys (LF)
- **Large Bore (3" & Larger)**
  - **Inside Battery Limits (ISBL)** (LF)
    - Carbon Steel (LF)
    - Stainless Steel (LF)
    - Chrome (LF)
    - Other Alloys (LF)
  - **Outside Battery Limits (OSBL)** (LF)
    - Carbon Steel (LF)
    - Stainless Steel (LF)
    - Chrome (LF)
    - Other Alloys (LF)

Instrumentation
- **Loops** (Count)
- **Devices** (Count)
- **Instrumentation Wire & Cable** (LF)

Equipment
- **Pressure Vessels** (Each)
- **Atmospheric Tanks (Shop Fabrication)** (Each)
- **Atmospheric Tanks (Field Fabrication)** (Each)
- **Heat Transfer Equipment** (Each)
- **Boiler & Fired Heaters** (Each)
- **Rotating Equipment** (Each)
- **Material Handling Equipment** (Each)
- **Power Generation Equipment** (Each)
- **Pulp & Paper Equipment** (Each)
  - Woodyard Equipment (Each)
  - Pulp Mill Equipment (Each)
  - Bleach Plant Equipment (Each)
  - Stock Preparation Equipment (Each)
  - Wet End Equipment (Each)
  - Dryer Sections (Each)
  - Dry End Equipment (Each)
- **Other Process Equipment** (Each)
- **Modules & Pre-assembled Skids** (Each)

Insulation
- **Equipment Insulation** (SF)
- **Piping Insulation** (LF)

Scaffolding
- **Scaffolding Ratio**
  (Scaffolding Hrs / Total Direct Hrs)

$$\text{Construction Productivity} = \frac{\text{Direct Work-Hours}}{\text{Installed Quantity}}$$

Best Productivity Practices Implementation Index (BPPII)

Introduction

Based on casual observation of typical jobsites, it unfortunately becomes evident that most projects are not implementing historically successful productivity practices. If such practices could be documented and incorporated into one resource, the product would be an overall roadmap about how to effectively manage and improve construction productivity. Such a resource in and of itself would be a significant productivity innovation to construction.

A capital project needs to ensure that its productivity is being effectively managed. To meet this objective, Research Team 252 began the process of developing the Best Productivity Practices Implementation Index (BPPII). The BPPII outlines a new process for building the foundation of the essential practices needed to ensure high levels of productivity by the craft workers. The practices included are those that are widely accepted throughout the construction industry to have a positive impact on craft worker productivity. Some practices that positively impact craft productivity have been known for years, such as materials management, work packaging, IT automation and integration, and yet they are seldom implemented completely or consistently from project to project. Improving implementation of these practices will improve craft productivity. However, one can only improve what one can measure. The BPPII is envisioned as a process and metric for measuring the implementation level of practices that have the potential to improve craft productivity. RT-252 started by identifying practices that are widely accepted on the basis of experience or for which there is strong statistical evidence of impacting craft productivity. Validation of the metric is requiring acquisition of project or activity level craft productivity data to evaluate the strength of the relationship between the metric and craft productivity.

Value- Added Benefits

A significant feature of the BPPII is that it can be utilized to fit the needs of almost any individual project, small or large. The BPPII is:

- A listing of the essential elements that need to be planned and implemented in a project.
- A checklist that a project team can use for determining the level of implementation of best productivity practices.
- A listing to develop strategies for the implementation of best productivity practices.
- A benchmarking tool for organizations to use in evaluation completion of effective managed productivity versus the performance of past projects.

Methodology

The development of the BPPII began by using the knowledge and experience of the members of the research team and studies that have validated management practices that improve craft worker productivity. Each of the practices is organized into sections that include similar practices. Each section has an audit form that includes the practices that are included in that section. Each category includes between 2 and 4 sections. The sections that are included in each category are similar and related, but not the same. An example is Category I – Materials Management, which has two sections: 1) Materials Management Systems and 2) Receipt and Inspection of Materials. The BPPII includes 6 Categories, which contain 18 sections. These sections also are divided into elements. A complete list of the BPPII's six categories, 18 sections and 53 elements is given in the Validation Questionnaire. Approximately 30 pages of detailed descriptions have been developed to support completion of the scope.

Validation Questionnaire
Best Productivity Practices Implementation Index (BPPII)

Construction Industry Institute (CII) Research Team 252

Part A – Project Information

General Information

a. Your Company Name:____

b. Your Name: ____

c. Project Name: ____

d. Owner: ____

e. Primary Designer: ____

f. Primary Constructor: ____

g. Project Construction Location:

City:__________, (State or Province):_________, Country: __________________

Project Description

Which of the following best describes the industry group of this project?

☐ Heavy Industrial

☐ Light Industrial

☐ Buildings

☐ Infrastructure

Project Nature

From the list below, please select the category that best describes the primary nature of this project.

☐ Grass Roots, Greenfield

☐ Brownfield (co-locate)

☐ Modernization, Renovation, Upgrade

☐ Addition, Expansion

Part B – Project BPPII Assessment

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

INSTRUCTIONS FOR ASSESSING A PROJECT

The Best Productivity Practices Implementation Index (BPPII) is intended to measure the implementation levels of practices that can improve craft productivity. The BPPII is intended to be used during the construction phase. When rating a project, the team involved in the construction phase should consider the **average level of implementation of each element in BPPII across the duration of the construction phase of the project.**

The BPPII consists of six mains categories, each of which is broken down into a series of sections which, in turn, are further broken down into elements. Scoring is performed by evaluating and rating the individual elements. Element should be rated numerically from 0 to 5 based on its average level of planning and implementation during the construction phase.

To asses an element, first refer to the Project Score Sheet (below). Next, read its corresponding description in the Description section of the 53 BPPII Elements Description document (on the separate "RT 252 BPPII Elements Description" document file). The elements contain a list of items to be considered when evaluating their level of definition. These lists can be used as checklists.

Please choose only one definition level (0, 1, 2, 3, 4, or 5) for that element based on the perception of how well it has been addressed. All elements are well described and all different levels have a specific definition for each element. Thus all participants will understand the elements. Once the appropriate definition level for the element is chosen, **please check (√) the corresponding box.** Do this for all the 53 elements in the Project Score Sheet. Be sure to assess each element.

<u>Example: How to assess "Project team material status database" element?</u>

1. Look at the project score sheet

MATERIALS MANAGEMENT

Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database *(p4)*						
2. On-site material tracking technology *(p4)*						

(p4) refers to the RT 252 BPPII Elements Descriptions document.

2. Go to page 4 in the RT 252 BPPII Elements Description document and read the element definition

A1. Project team material status database

The project team material status database should consider the following:

- Identify which software system will be used.
- If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.

3. Collect data that you may need
4. Analyze the level of implementation of the element using the definition of the 6 levels below the definition in the yellow document

A1. Project team material status database

The project team material status database should consider the following:

- Identify which software system will be used.
- If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.

Level 0	Project team material status database is not applicable
Level 1	No formal paper based system is used to track material status.
Level 2	There is a formal paper based system to track material status.
Level 3	A proprietary internal procurement software tool is used but it is not integrated or used by other contractors.
Level 4	An available software application is used but it is only integrated internally with your company's project control systems.
Level 5	An available software application is used by all contractors that is integrated with your supply chain and other project control systems.

5. Select the appropriate definition level. (E.g.: there is a formal paper based system to track material status. **Definition Level = 2**). **Check (√) the corresponding box in the white sheet.**

MATERIALS MANAGEMENT

Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database *(p4)*			√			
2. On-site material tracking technology *(p4)*						

6. Move to the next element

Elements Description

The following descriptions have been developed to help generate a clear understanding of the terms used in the Project Score Sheet located in Appendices A and B. Some descriptions include checklists to clarify concepts and facilitate ideas when scoring each element. Note that theses checklists are not all-inclusive and the user may supplement these list when necessary.

The descriptions are listed in the same order as they appear in the Project Score Sheet. They are organized in a hierarchy by category, section, and element. The Project Score Sheet consists in six main categories, each of which is a series of sections and that have elements. Scoring is performed by evaluating the levels of definition of the elements. The categories, sections and elements are organized as follows:

CATEGORY I - MATERIALS MANAGEMENT

This category consists of the information in respect to material receipt and inspection lay down area planning, procurement management, and delivery plans to address the principles of material logistics. Other areas include controlling and administering the process plan purchases and acquisitions, plan contracting, requesting seller response, selection of sellers, contract administration and contract closure to ensure the project need's are being met in regards to having the necessary construction materials when and where they are needed.

Sections:

A- Material Management Systems
B- Receipt and Inspection of Materials

CATEGORY II - EQUIPMENT LOGISTICS

This category describes best practices in respect to the tools and equipment tracking, maintenance, equipment positioning and lift planning to improve the availability of construction equipment.

Sections:

A- Site Tool Management Best Practices
B- Machinery Availability

CATEGORY III - CRAFT INFORMATION SYSTEMS

This category describes best practices in respect to providing necessary information about how the work should be done.

Sections:

A- Short Interval Planning
B- Work Face Planning
C- Constructability Review

CATEGORY IV - HUMAN RESOURCE MANAGEMENT

This category describes the best practices about how best to leverage the human resources on a project including practices centered on training and development, human behavior, project organization, and employment strategies.

Sections:

A- Training and Development
B- Behavior
C- Organizational Structure
D- Employment

CATEGORY V – CONSTRUCTION METHODS

This category consists of the information in respect to the construction methods that are determined during planning of the project that need to be used to create the highest benefit for the project in terms of productivity.

Sections:

A- Sequence and Scheduling of Work
B- Start-Up, Commission, and Turnover Plan
C- New Product Investigation
D- Site Layout Plan

CATEGORY VI – ENVIRONMENTAL SAFETY AND HEALTH

This category consists of the information in respect to all practices that must be followed to ensure the health and safety of all persons that will be on the jobsite during the construction of the project and in the surrounding community.

Sections:

A- Job Safety
B- Substance abuse Programs
C- Safety Training and Orientation

The following pages contain detailed descriptions for each element and each level of definition in the BPPII.

CATEGORY I - MATERIALS MANAGEMENT

A. MATERIAL MANAGEMENT SYSTEMS BEST PRACTICES

A1. Project team material status database

The project team material status database should consider the following:

- Identify which software system will be used.
- If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.

Level 0	Project team material status database is not applicable
Level 1	No formal paper based system is used to track material status.
Level 2	There is a formal paper based system to track material status.
Level 3	A proprietary internal procurement software tool is used but it is not integrated or used by other contractors.
Level 4	An available software application is used but it is only integrated internally with your company's project control systems.
Level 5	An available software application is used by all contractors that is integrated with your supply chain and other project control systems.

A2. On-site material tracking technology

The project team needs to decide whether an on-site material system will be needed. The decision is partly based on quantity of materials, criticality of schedule, and complexity of project. On-site material tracking technology allows the project team to locate materials in either the warehouse, lay down or staging area or all when needed. Technologies that enable on-site material tracking include:

- Barcodes
- RFID Tags
- Global Positioning Systems

Level 0	On-site material tracking technology is not applicable.
Level 1	No tracking is done on site beyond receivables.
Level 2	Material is assigned a lay down and storage area and the information is recorded.
Level 3	Continuation of 2, plus the location information is kept updated in a software system and well defined and followed processes for developing pick lists, flagging, warehouse organization (if applicable) etc. are established.
Level 4	Continuation of 3, plus the system is supported by tracking software and also supplemented by barcode, GPS, or RFID systems for automated location tracking.
Level 5	Continuation of 4, plus the tracking system is completely automated and integrated with other project processes.

A3. Material delivery schedule

A good material delivery schedule needs to address the following details:

- Dates that material will be received on site
- Dates that the material is required at the site (RAS date)
- Adheres to the material procurement plan
- Quantity of materials that can be stored onsite. If there is little room for storage, the project may need to use a just-in-time delivery schedule.

Level 0	Material delivery schedule is not applicable.
Level 1	There is no documented material delivery schedule
Level 2	Material delivery is planned early in the project and is integrated with a project schedule.
Level 3	Continuation of Level 2 plus the schedule is automatically updated on receipt of new information as procurement proceeds.
Level 4	Continuation of Level 3 plus the schedule is automatically linked with procurement materials management and overall project scheduling systems.
Level 5	Continuation of Level 4 plus material delivery planning and management is completely integrated with other automated project processes including automated materials tracking throughout the supply chain.

A4. Procurement plan for materials and equipment

The procurement scope may include the following:

- Coordinate the construction procurement schedule with the construction schedule
- Facilitate a purchasing system that has the capability of allowing field purchase of consumables.
- Identify items requiring a long lead time for procurement.
- Develop a list of authorized suppliers
- Coordinate with equipment logistics to determine the required at site dates for required rental machinery
- Require fabricator/vendor to take back all cribbing, packaging, and shipping aids when they leave. This will reduce waste removal and promote the reuse of shipping materials.

Level 0	A procurement plan for materials and equipment is not applicable
Level 1	There is no documented procurement plan for materials and equipment.
Level 2	A procurement plan and schedule exists only for large materials and equipment and costly items.
Level 3	Continuation of Level 2, plus plan includes all materials, equipment, and consumables. Also, there is an established protocol for identifying reputation of potential vendors.
Level 4	Continuation of Level 3, plus plan identifies necessary equipment and onsite resources to support delivery.
Level 5	Continuation of Level 4, plus the procurement schedule is automated to a project database that updates as the construction schedule changes

B. RECEIPT AND INSPECTION OF MATERIALS BEST PRACTICES

B1. Material inspection process

It is necessary to have a material inspection process for all deliveries of material to the site. A material inspection process should include the following:

- Organize material receipt inspections immediately upon delivery of material
- Separate material into categorical stages of the receipt process (e.g. awaiting inspection, storage area restocking, scrap, and/or awaiting for shipment)
- Verify if the materials conform to specifications, ASME standards, drawings etc.
- Record the location of the materials and mark the materials for tracking
- Prioritize quality

Level 0	A material inspection process is not applicable
Level 1	There is no material inspection process.
Level 2	A material inspection process is only utilized for large items or the more costly items on a project.
Level 3	Continuation of Level 2, plus it includes all items delivered to the site. There is a lack of organization of the process, and material is not separated into stages of the receipt process nor does it record the location of the materials and mark the materials for tracking
Level 4	Continuation of Level 3, plus inspection are done both at the supplier and onsite, and organizes material receipt inspections immediately upon delivery of material, verifies that materials conform to standards, and organizes materials for tracking.
Level 5	Continuation of Level 4, plus the process includes separation of material into categorical stages of the receipt process (e.g. awaiting inspection, storage area restocking, scrap, and/or awaiting for shipment, verification if the materials conform to specifications, ASME standards, drawings, etc., record of the location of materials and marked materials for tracking, and prioritization quality).

B2. Material inspection team

The people on the inspection team, both onsite and offsite at the suppliers, should be trained and qualified in the following aspects:

- Inspection processes and procedures
- Knowledge of how to inspect materials
- Material specifications (MSDS, material test reports (MTR) etc)

Level 0	Material inspection team is not applicable.
Level 1	There is no material inspection team.
Level 2	There is a designated material inspection team but no training and qualifications of the individual's skill level is specified.
Level 3	Continuations of Level 2, plus inspections are performed by project managers or craft workers rather than the team.
Level 4	Continuation of Level 3, plus the inspection team can adequately inspect materials and understand the material specifications.

Level 5	Continuation of Level 4, plus the members of the inspection team are experts at inspection processes and procedures, and knows how to inspect materials and understands the material specifications.

B3. Post receipt preservation and maintenance

A plan for a complete post receipt preservation and maintenance of the stored material after it has been delivered to the site and passed inspection should be in place for the purpose of knowing the status, location, and maintenance of the material. The inventory of materials should be documented by recording the following characteristics of the stored materials:

- Location
- Preservation of the material after delivery to the jobsite
- Description
- Quality
- Marking

Level 0	Post receipt preservation and maintenance is not applicable
Level 1	There is no post receipt preservation and maintenance plan.
Level 2	There is a plan for post receipt preservation and maintenance.
Level 3	Continuation of Level 2, plus plan is used for large and/or costly items.
Level 4	Continuation of Level 3, plus plan includes all material delivered to the site. A plan for a complete inventory of the material after it has been delivered to the site and passed inspection is in place for the purpose of knowing the status and location of the material. Material is stored in manner so it will be best preserved and maintained.
Level 5	Continuation of Level 4, plus there is a process in place to notify the inspection team of what must be done to preserve and maintain material while in storage. The inventory of materials is documented by recording the following characteristics of the stored materials: location, description, quality, and marking.

Performance Metric Formulas and Definitions

Performance Metric Category: COST

Metric: ***Project Cost Growth***	**Formula:** $\frac{\text{Actual Total Project Cost - Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$
Metric: ***Delta Cost Growth***	**Formula:** $\lvert \text{Cost Growth} \rvert$
Metric: ***Project Budget Factor***	**Formula:** $\frac{\text{Actual Total Project Cost}}{\text{Initial Predicted Project Cost + Approved Changes}}$
Metric: ***Delta Budget Factor***	**Formula:** $\lvert \text{1- Budget Factor} \rvert$
Metric: ***Phase Cost Factor*** *(Owner data only)*	**Formula:** $\frac{\text{Actual Phase Cost}}{\text{Actual Total Project Cost}}$
Metric: ***Phase Cost Growth*** *(Owner data only)*	**Formula:** $\frac{\text{Actual Phase Cost – Initial Predicted Phase Cost}}{\text{Initial Predicted Phase Cost}}$

Definition of Terms

Actual Total Project Cost:

- Owners –
  - All actual project cost from front end planning through startup
  - Exclude land costs but include in-house salaries, overhead, travel, etc.
- Contractors – Total cost of the final scope of work.

Initial Predicted Project Cost:

- Owners – Budget at the time of authorization.
- Contractors – Cost estimate used as the basis of contract award.

Actual Phase Cost:

- All costs associated with the project phase in question.
- See the Project Phase Table for phase definitions.

Initial Predicted Phase Cost:

- Owners – Budget at the time of authorization.
- Contractors – Budget at the time of contract award.
- See the Project Phase Definition Table.

Approved Changes:

- Estimated cost of owner-authorized changes.

Performance Metric Category: SCHEDULE

Metric: ***Project Schedule Growth***	**Formula:** $\frac{\text{Actual Total Proj. Duration - Initial Predicted Proj. Duration}}{\text{Initial Predicted Proj. Duration}}$
Metric: ***Delta Schedule Growth***	**Formula:** **| Schedule Growth |**
Metric: ***Project Schedule Factor***	**Formula:** $\frac{\text{Actual Total Project Duration}}{\text{Initial Predicted Project Duration + Approved Changes}}$
Metric: ***Delta Schedule Factor***	**Formula:** **| 1- Schedule Factor |**
Metric: ***Phase Duration Factor*** *(Owner data only)*	**Formula:** $\frac{\text{Actual Phase Duration}}{\text{Actual Overall Project Duration}}$
Metric: ***Total Project Duration***	Actual Total Project Duration (weeks)
Metric: ***Construction Phase Duration***	Actual Construction Phase Duration (weeks)

Definition of Terms

Actual Total Project Duration:
(Detail Engineering through Start-up)

- Owners – Duration from beginning of detail engineering to turnover to user.
- Contractors - Total duration for the final scope of work from mobilization to completion.

Actual Overall Project Duration:
(Front End Planning through Start-up)

- Unlike Actual Total Duration, Actual Overall Duration also includes time consumed for the Front End Planning Phase.

Actual Phase Duration:

- Actual total duration of the project phase in question. See the Project Phase Definition Table.

Initial Predicted Project Duration:

- Owners – Predicted duration at the time of authorization.
- Contractors - The contractor's duration estimate at the time of contract award.

Approved Changes

- Estimated duration of owner-authorized changes.

Performance Metric Category: SAFETY

Metric: ***Total Recordable Incident Rate (TRIR)***	**Formula:** $\frac{\text{Total Number of Recordable Cases x 200,000}}{\text{Total Site Work-Hours}}$
Metric: ***Dart Rate (LWCIR)***	**Formula:** $\frac{\text{Total Number of DART Cases x 200,000}}{\text{Total Site Work-Hours}}$

Definition of Terms

- Recordable Cases: All work-related deaths and illnesses, and those work-related injuries which result in: death, loss of consciousness, restriction of work or motion, transfer to another job, or require medical treatment beyond first aid.
- DART Cases: Incidents resulting in days away from work, restricted activity, or transfer.

Performance Metric Category: CHANGES

Metric: ***Change Cost Factor***	**Formula:** Total Cost of Changes / Actual Total Project Cost
Metric: Project Development ***Change Cost Factor***	**Formula:** Total Cost of Project Development Changes / Actual Total Project Cost
Metric: Scope ***Change Cost Factor***	**Formula:** Total Cost of Scope Changes / Actual Total Project Cost

Definition of Terms

Total Cost of Changes:

- Total cost impact of scope and project development changes.

Total Cost of Project Development Changes:

- Total cost impact of project development changes.

Total Cost of Scope Changes:

- Total cost impact of scope changes.

Actual Total Project Cost:

- Owners –
  - All actual project cost from front end planning through startup
  - Exclude land costs but include in-house salaries, overhead, travel, etc.
- Contractors – Total cost of the final scope of work.

Performance Metric Category: REWORK

Metric: ***Total Field Rework Factor***	**Formula:** Total Direct Cost of Field Rework / Actual Construction Phase Cost

Definition of Terms

- Total Direct Cost of Field Rework: Total direct cost of field rework regardless of initiating cause.
- Actual Construction Phase Cost: All costs associated with the construction phase. See the Project Phase Definition Table for construction phase definition.

Value Proposition

– An Internal Benchmarking and Metrics (BM&M) Program

for Industrial Construction Enterprise to Support Performance Improvement

Aecon industrial's mission is to "safely, profitably and sustainably deliver best-in-class integrated services, products and solutions". An internal BM&M program will provide a platform to regularly measure project performance, review project management processes and construction practices, and identify potential improvement gaps. As developed, this program is a strategic valuable approach to facilitate enterprise competitiveness, as well as to facilitate implementing Aecon's enterprise core value. Conservatively, it should result in a 10:1 payoff.

Needs

Construction is a labour intensive activity. Labor cost as a portion of the project cost is usually over 25%. Better labour productivity, since it is known to be correlated with other aspects of project performance such as cost and schedule, typically indicates better project performance. Thus, good labour productivity is considered core to the competitiveness of a construction enterprise.

Empirical observations and statistical analyses by industry organization such as CII and IPA both find that project performance is highly influenced by good practices implementation. A BM&M program is a way of systematically and continuously measuring business or management processes and comparing them with those of leaders in the field as a means of identifying areas for potential improvement. It has been proved successful in the manufactory industry. While, Most BM&M programs in the construction industry have to date been implemented as collaborative exercises in scientific enquiry, many companies which include owners and also constructors such as Bechtel, Fluor and SNC-Lavalin have expressed a pressing need for an internal BM&M model that can be used to direct implementation at the enterprise level. Specifically, they wish to know how to measure degree of implementation of their corporate practices at the project level and to understand the influence this has on project performance. They believe this kind of research can help them retain a competitive edge and efficient resources utilization.

Program Features

In order to efficiently implement a BM&M program in Aecon, the development team designed an internal Benchmarking and Metrics (BM&M) model to understand the impact of practice implementation level on construction productivity. The model has the following key features:

1. Evaluates enterprise overall productivity performance by using statistical methods to process project productivity performance data.
2. Illustrates the strategic mechanisms by which practices implementation level and practices implementation consistency impact overall productivity performance.
3. Defines functional processes to support continuous improvement of construction productivity.
4. Establishes primary method and policy for data processes, including data collection, data fusion, and metrics registry, to deal with multi-dimension data with respect to labour productivity, direct work rate, practices implementation level, and environment factors.
5. Defines metrics for evaluation of productivity performance with respect to estimated productivity, actual productivity, productivity performance factor, and direct work rate and the underlying relationships between these indicators correlated to construction practices and construction environment.
6. Presents general strategies and policies for analysis of practice implementation gaps in order to identify improvement potential.

Your Custom Program

On the basis of primary mechanisms and the preceding features, the team developed a set of detailed implementation process for Aecon Industrial, which are customized based on the nature of Aecon's management, with respect to the construction sector, main craft labour resources, proportion of project types, corporate management procedure and policy, frequent contract conditions, existing information delivery processes and database for project management, etc. The customized processes are defined as follows:

1. Determine appropriate metrics to benchmark. For the craft labour productivity, Aecon Industrial's main jobs are in mechanical and electrical work. So, piping, structural steel, mechanical equipment, and electrical productivity are selected as the essential metrics. And, concrete productivity is selected to represent civil work, which is usually a small portion in most Aecon Industrial projects.

2. Data collection is based on Aecon's existing project reporting system and project management database system. Relevant information delivery can be traced in existing foreman daily report, daily time sheet, weekly and monthly report, mark-up assignment sheet, and PJA report. The intent is to make the best use of Aecon's existing project accounting system (eCMS and FPMS) to implement data collection, while minimizing additional extra work processes.
3. Develop several specific processes for data fusion to examine specified productivity metrics including: (1) Productivity performance factors (PPF) are used as internal productivity metrics for specified crafts. A work instruction will be developed to facilitate consistency of cost code combinations to fuse into specific craft productivity metric. Well regulated implementation of Cost codes is a focal point of this process. (2) Craft labour productivity metrics in term of "hours/unit" are selected as external metrics in order to check a third-party benchmark. The development team summarized a set of rules that interpret certain common patterns by which the cost code is marked up to work packages (with respect to WBS and CBS). These rules are used to translate Aecon productivity data to external industry metrics, while avoiding modification of the existing project accounting system.
4. Develop practical processes for analysis of practices implementation, which includes full BPPII (Best Productivity Practices Implementation Index) survey process and simplified check list for facilitating regular review of practices implementation in projects. Applying the simplified check list is intended to minimize additional workload for project management staff, while simultaneously enforcing practice review and further identifying improvement potential.
5. If there is IT support, automated data processing can be implemented.

Implementation

The development team worked out a practical scheme for implementing the designed BM&M program. Implementation of the BM&M program will be deployed in phases, following the principle from simple to comprehensive. Specific leading craft productivity metrics and key practice elements benchmarking will be deployed in the initial stage. More comprehensive benchmarking and metrics will be added in future phases with the BM&M program gradually merging into the existing corporate management system and culture.

Implementation of the BM&M program requires three levels of leadership:

Level 1 – organizational change management required to implement a BM&M program includes: leadership (CEO commitment), resources preparation, buy-in motivation and culture alignment, a strategic plan, and persistence.

Level 2 – tasks required to implement a BM&M program: develop process definition, design assignment to people, design trial runs, construct S/W database frame, develop pertinent tools, etc.

Level 3 – functional documentation required to implement a BM&M program: procedure and policy embedded as modification of existing processes, work instruction, work flow chart, relevant forms, software (if required), etc.

Benefits

Benefits of implementing the BM&M program in Aecon include the following:

Information sufficiency

- Provide company management full insight into corporate productivity performance and implementation level of management practices and construction practices in real time.
- Provide a regulated platform for comparing performance across projects, as well as comparing with a third party benchmark.
- Provide a new approach to facilitate lessons learned.

Productivity improvement

- Facilitate regular review of practices implementation in projects and further appropriate improvement.
- Effectively identify practices implementation gaps and facilitate developing corporate strategy for improving overall practices implementation.
- Labour productivity data in time series provides reliable reference data for adjustment of estimate norms.

The bottom line

Let us assume the revenue is about $ 200 M/year in average, $ 50 M/year on labour cost.

Benefit of implementing the BM&M program
• CII and IPA demonstrate ±25% labour productivity based on level of practice implementation

• Let's assume 5%-10% average and consistent improvement as a result of the program within the next 1-2 years in Aecon Industrial.
*Therefore, **$ 2.5 M – $ 5.0 M savings/year** (or 25 – 50 % profit increase)*

Cost of implementing the BM&M program	
• Cost based on leadership time	100 K
• Cost based on Enterprise change process	50 K
• Cost based on Research so far	100 K
• Operating costs per year to collect, analyze, manage data; to integrate into management meetings; and etc.	100 K/year
• Cost of higher implementation levels based on achieving Aecon's process definitions should be zero (can be absorbed in existing system), but let's estimate it at	150 K/year
*Therefore, **$ 375 K cost/year***	

B/C ratio in summary:	***approximately 7:1 to 14:1 payoff annually***

Meeting Minutes

Performance Improvement Models for Industrial Construction Enterprises

20th Research Project Management Meeting, September 20th, 2013

Cambridge, ON

Attendees:

Aecon:

1. Ian Turnbull
2. Hugh Loughborough
3. Jeff Myhal
4. Rob Frasca
5. Katherine McCrory
6. George Bekhit

UW:

1. Carl Haas
2. Di Zhang
3. Hassan Nasir
4. Maryam Shahtaheri

Discussions

- New ERP (SAP 2015) system requires internal preparation and alignment of Aecon.
- New ERP consists of three different elements: 1. Bedrock, 2. Pinnacle (a subset of bedrock that determines best practices toward project controls), and 3. Benchmarking and Metrics program for productivity improvement (uWaterloo). Among these three elements, internal alignment is required.
- As Aecon's practice definitions and code structure is under revision, it may be necessary to go back and revise some of the relationship mapping done as part of the uWaterloo research.

- Review of schedule, list of tasks and recent progress memo

  Recent progress memo appropriately recorded research from January 2011 to September 2013. Research tasks have been achieved on schedule.

Conclusions

Aecon leadership reached an agreement for implementation of the strategic plan presented for the Benchmarking and Metrics program for productivity performance improvement. The research team should assume full speed ahead for implementation of the program and integration into the new ERP system.

Action Items and Responsibility:

- ✓ Analyze alignment of uWaterloo program with Pinnacle and Bedrock and degree of complementary nature **(Rob, George)**
- ✓ Analyze future alignment opportunities with CII **(Aecon, Di assists)**
- ✓ Define manual procedures, including checklists **(Aecon, Di assists)**
  - Manual
  - Spreadsheet
  - SAP/ERP embedded
- ✓ Systems implementation **(Aecon, Di assists)**
- ✓ Training **(Aecon, Di assists)**
- ✓ Roll-out **(Aecon, Di assists)**
- ✓ Trial runs **(Aecon, Di assists)**
- ✓ BPPII data on Rob’s project **(Rob)**
- ✓ BPPII data on Atikoken project **(George)**
- ✓ BPPII data on Katherine’s project **(Katherine)**

Next meeting’s date and location:

TBD

Construction management processes list by reviewing the corporate management manuals

Project Phase	Process section	Process Element	Instructions
Bidding		Receive request for quotation	
		estimate project and prepare bid	FC-2.1 Project Estimating Flowchart
		submit bid to customer	
		award of contract or purchase order	
Team	Team building	Assign Project Manager	QM-7.1
		Assign project management team	QM-7.1
		Assign Supervisors	QM-7.1
		Org-chart	QM-7.2
	Team Alignment	Clearly defined individual accountability	QM-7.1
		Determine lines of communication, reporting	QM-7.1, PEP-3.10
		Clarify internal relations (SBU)	QM-7.1
Pre-Construction	Contract review	Obtain required construction documents	FC-3.1 Contract Review Flowchart
		Perform bid to contract review	FC-3.1 Contract Review Flowchart
		Finalize bid to contract issue with client	FC-3.1 Contract Review Flowchart
		Acknowledge contract	FC-3.1 Contract Review Flowchart
		Review, accept and sign contract	FC-3.1 Contract Review Flowchart
		Return signed contract to client	FC-3.1 Contract Review Flowchart
	Front-end Planning	Turnover meeting	MPM-4.0
		Budget (Job Setup) (as-sold estimate review)	as-sold estimate review & WBS & Cost Code Structure
		Pre-fab evaluation and new technology investigation	Evaluation of prefabrication, modular construction and preassembly
		Prepare manpower plan	PEP-2.4
		Prepare schedule & resource loading	PEP-2.4
		Prepare quality plan (as required)	WI-5.1, WI-5.2
		Prepare job plan	MPM-5.4.7
		Safety plan	MPM-5.4.2
		Site layout plan	Under construction
		Trade Assignment	PEP-2.10
		Prepare material requisitions	WI-6.2, FC-6.1
		Prepare tools and equipment requisitions	WI-6.3
		Subcontracting	PEP-5.5
		Prepare permit applications	PEP-3.4
	Project risk assessment		
Commencement	Pre-Mobilization communication	Kick-off/Pre-planning meeting	PEP-2.12
	Mobilize project site	Set up site office	
		Hiring and indoctrination	PEP-3.8, 3.9, Safety education
	Documentation system	Filing system	PEP-3.2
		Document control	PEP-3.3, MPM-10

Project Phase	Process section	Process Element	Instructions
Construction	Safety management	Job hazard analysis	
	Site material & tools management	Receiving inspection	WI-8.1, 8.2, 8.3
		On-site material & tools tracking system	Under construction
		Return tools & Equipment and Maintenance	WI-7.1
	Change management	Contract revisions (scope changes)	PEP-4.9, WI-11.1&11.2
		Extras quotations, change order and claims	PEP-4.8, MPM-11
		Subcontract administration	PEP-5.5
	Schedule updates	Baseline updates	
		2-weeks planning	
		Weekly review	PEP-4.11
	Material requisition updates	Material delivery schedule updates	PEP-4.8
		Material EWO request	
	? Workface Planning	Day work assignment	
	Progress tracking (Cost control)	Labour and quantity tracking	PEP-4.5
		Productivity capture	PEP-4.6
		Job cost reporting	PEP-4.2
		Monthly review	PEP-4.12
	Billings	Accounts payable	PEP-3.12, BP-0015
		Accounts receivable	PEP-3.13
	Contract deliverables	Submittals	PEP-3.14
	Quality management	Nonconformance	
		Inspection and testing	MPM-14, WI-14.1,2,3,4
Final inspection			
Contract close out	Project Demobilization		
	Contract close out	Contract close out	PEP-4.17, MPM-17
		Record keeping	PEP-4.18
		PJA	PEP-4.19
		Customer survey	PEP-4.20
		Management review	

Appendix G

Practices to improve project performance

The Partner Company	CII	
Related Elements in the Partner's Procedure	Practice Definition	Elements
• Corporate Guideline 1 Project Set-up • PEP 2.4 Schedule c/w Resource Loading • ISO MPM 5 Pre-Construction Planning	***Front End Planning:*** Front End Planning is defined as the process of developing sufficient strategic information with which owners can address risk and make decisions to commit resources in order to maximize the potential for a successful project. Front End Planning is also known as front end loading, pre-project planning, feasibility analysis, conceptual planning, programming/schematic design, and early project planning. Front end planning is an owner-driven process that must be tied closely to business goals	• Options analysis • Scope definition and boundaries • Life-cycle cost analysis • Cost and schedule estimate • Site investigation • Environmental analysis • Process design basis • Initial engineering design • Space planning, including room data • sheets and stacking diagrams • Site layout • Project execution approach, including • project control plan • Procurement plan • Architectural renderings • Appropriation submittal package
• PEP 2.6 Turnover meeting • PEP-2.12 Kick-Off Meeting with Customer • PEP 2.10 Trade assignment mark-up meeting • PEP 3 Administration Procedures • ISO Documentation Control • PRP-3.7-1, Information Transmittal	***Alignment:*** 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.	• Project objectives are aligned in three dimensions: Top-to-Bottom Alignment, Cross-Organizational Alignment, and Project Life Cycle Alignment. • Issues that affect alignment during project planning can be divided into five categories: culture, execution process, information, project planning tools, and barriers. • In order to enhance alignment, management must ensure that: o Project leadership is defined, effective, and accountable. o Communication within the team and with stakeholders is open and effective. o Team meetings are timely and productive. o The team culture fosters trust, honesty, and shared values. o The teamwork and team building programs are effective. o Planning tools (e.g., checklist, simulations, and work flow diagrams) are effectively utilized.

<table>
<tr><th>The Partner Company</th><th colspan="2">CII</th></tr>
<tr><td>Related Elements in the Partner's Procedure</td><td>Practice Definition</td><td>Elements</td></tr>
<tr><td>PEP 4.1 Acceptance of the Site
PEP 4.2 Job Cost Report
PEP 4.3 Timesheets
PEP 4.4 Overtime and Premium Labour Costs
PEP 4.7 Alternate Methods and Value Analysis</td><td>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 in the best possible time and accuracy at the most cost-effective levels.</td><td>Establishing project objectives considering constructability.
Selecting organization responsible for constructability.
Selecting project contracting strategy, which impacts project constructability.
Identifying available in-house constructability resources.
Identifying and addressing project barriers.
Consulting applications matrix and lessons-learned file.
Developing constructability procedures and integrating into project activities.
Requiring constructability as part of contractor pre-qualification process.
Securing contractors, suppliers, and consultants.
Considering use of incentive clauses tied to constructability performance.
Implementing constructability. …</td></tr>
<tr><td>FC-6.1 Procurement Flowchart
Wl-6.2, Material Requisition Preparation
Wl-6.3, Purchase Order Preparation
QCP 306.5, Control of Suppliers
QCP 302.4, Quality Assurance Auditing
Wl-8.1, Material Receiving
Wl-8.2, Identification and Traceability
Wl-8.3, Handling, Storage, Packaging & Shipping</td><td>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 system combines and integrates takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.</td><td>Corporate Strategy
Personnel and Organization
IT Systems
Materials Requirements Planning (MRP)
Project Acquisition Strategy (PAS)
Purchasing
Subcontracting
Expediting
Supplier Quality Management
Transportation and Logistics
Site Materials Management
Materials Management for Operations and Maintenance</td></tr>
<tr><td></td><td>Planning for Startup:

Startup is defined as the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Critical steps within the startup phase include systems turnover, check-out of systems, commissioning of systems, introduction of feedstock, and performance testing.</td><td>Recognize the impact of startup on project economics in initial phase
Update the Startup Execution Plan in conceptual development and feasibility
Finalize the Operations & Maintenance organization and management systems in design, engineering, and procurement planning
Complete Check-out systems in construction phase
Commission systems
Finalize documentation</td></tr>
</table>

The Partner Company	CII	
Related Elements in the Partner's Procedure	Practice Definition	Elements
• Proposal Preparation Team (Review & Analysis) • Select team member when capacity analysis (Detailed Project) • availability of workers • WI-21.1 Skills/experience/qualification Training • Final team member selection (Handover) • PEP 3 Administration Procedure	***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.	Elements of the team building process include the following: • Shared commitment to work together. • Shared sense of team's accountability. • Clearly defined individual accountability. • Pride in being a member of the team. • Open communication and feedback. • Effective conflict management. • Increased sense of work satisfaction.
• Client, Consultant analysis (reasonable and fair?) (Review & Analysis) • JV Partner analysis (Detailed Project) • Subcontractor, supplier assessment (Detailed Project) • Client analysis (Detailed Project) • PEP 2.12 Kick-off meeting with customer • PEP 5.5 Subcontracts • PEP 5.9 Approved Suppliers List • Rate Subcontractor (PJA)	***Partnering:*** Partnering may be a long-term commitment between two or more organizations as in an alliance or it may be applied to a shorter period of time such as the duration of a project. The purpose of partnering is to achieve specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is based on trust, dedication to common goals, and the understanding of each other's individual expectations and values.	• Internal Alignment o Identify Business Drivers o Evaluate Partnering o Prepare and Align • Partner Selection o Identify Selection Criteria o Identify Partner Candidates o Select Optimal Partner • Partnering Relationship Alignment o Align Objectives o Develop Measures o Develop Reward System • Project Alignment o Develop "Win/Win" Objectives o Reward Accomplishment of Objectives • Work Process Alignment o Establish Intra-project Goals o Establish Processes to Support Measures

<table>
<tr><th>The Partner Company</th><th colspan="2">CII</th></tr>
<tr><td>Related Elements in the Partner's Procedure</td><td>Practice Definition</td><td>Elements</td></tr>
<tr><td>

ISO Quality Manual
Quality Control Manual
Quality Assurance Manual
Quality Control Procedure
Wl-5.1, Quality Plans
Wl-5.2 Inspection and Test Plan
Wl-14.1, In Process Inspection
Wl-14.2, Final Inspection
Wl-14.3, Nondestructive Examination
Wl-14.4, Inspection and Test Status
QCP 309.34, Fabrication Shop Status Indicators
Wl-18.1 Nonconformance Control
Wl-18.2 Nonconforming/Noncompliant Material Review

</td><td>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 startup elements of construction projects.</td><td>

ISO 9001 is the starting point for most QM systems.
Modern QM systems are based on a work processes approach
QM systems are also closely linked with business excellence systems e.g. Malcolm Baldrige, Lean Six Sigma, Phillip Crosby

</td></tr>
<tr><td>

PEP-4.19 Post Project Analysis
PEP-4.20 Customer Survey
PEP-4.20-1, Project Performance & Service Questionnaire

</td><td>Lesson Learned

A Lesson Learned is knowledge gained from experience, successful or otherwise, for the purpose of improving future performance.

A Lessons Learned (LL) program is comprised of the people, processes, and tools that support an organization’s collection, analysis, and implementation of validated Lessons Learned. The ultimate goal of this program is to add value to the organization by promoting the communication of information.</td><td>Examples include:

A lesson that is incorporated into a work process
A tip to enhance future performance
A solution to a problem or a corrective action
A lesson that is incorporated into a policy or a guideline
An adverse situation to avoid

</td></tr>
<tr><td>

PEP 4.6 Productivity Analysis

</td><td>Benchmarking and Metrics

Benchmarking is the systematic process of measuring an organization's performance against recognized leaders for the purpose of determining best practices that lead to superior performance when adapted and utilized.</td><td>

Process (structured/systematic)
CII Best Practice oriented
Part of a continuous improvement process
Understanding what is important to your organization (critical success factors)
Measurement, comparison, gap analysis against leaders
Adapting practices to your organization

</td></tr>
</table>

<table>
<tr><th>The Partner Company</th><th colspan="2">CII</th></tr>
<tr><td>Related Elements in the Partner's Procedure</td><td>Practice Definition</td><td>Elements</td></tr>
<tr><td>Notice the contract terms about change order (PRC Meeting)
Wl-11.1, Scope Change on a Contract
Wl-11.2, Cost Change on a Contract
PEP-4.8-1, Extra Work Order (EWO) Request
PEP-4.8-2, Confirmation of Verbal instructions
PEP-4.8-3, Time and Material Report
PEP-4.8-4, Subcontractor Extra Work Order (EWO) Request
PEP-4.8-5, EWO Log
PEP-4.9-1, Change/Clarification Request
PEP-4.9-2, Change/Clarification Request Log
PEP-4.9-3, Change Proposal Cost Summary
PEP-4.9-4, Change Notice</td><td>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. These changes include: scope, error, design development, estimate adjustments, schedule adjustment, changed condition, elective, or required.</td><td>Promote a Balanced Change Culture
Encourage beneficial change
Discourage detrimental change
Recognize Change
Education
Communication
Documentation
Trending
Evaluate Change
Elective
Required
Decide quickly
Implement Change
Authorization
Documentation
Tracking
Continuously Improve
Share lessons learned
Be prepared to improve</td></tr>
<tr><td></td><td>Disputes Prevention & Resolution
Dispute resolution techniques include the use of a Disputes Review Board as an alternate dispute resolution process to eliminate the necessity to take disputes to litigation. The Dispute Review Board technique provides a process for addressing disputes in their early stages before the dispute affects the progress of the work, creates adversarial positions, and leads to litigation.</td><td>Dispute Review Board Methodology
Contract Requirements
Member Qualifications
Member Selection
Operating Procedures
Conduct of Hearings
Timing and Sequence of Events
Limitations of Authority
Subsequent Proceedings
Cost</td></tr>
<tr><td>Identify Contract type (Initiation)
Determine Bid strategy, Execution strategy at stage of PRC meeting
Contract review (Handover)
Scope review &WBS (Handover)</td><td>Project Delivery and Contract Strategy
Techniques that include the use of a disputes Review Board as an alternate dispute resolution process for addressing disputes in their early stages before affecting the progress of the work, creating adversarial positions, and leading to litigation.</td><td></td></tr>
</table>

<table>
<tr><th>The Partner Company</th><th colspan="2">CII</th></tr>
<tr><td>Related Elements in the Partner's Procedure</td><td>Practice Definition</td><td>Elements</td></tr>
<tr><td>Business risk analysis (Review & Analysis)
Overall risk profile (Pre-PRC)
Set up risk management log (Detailed Project)
Risk check list (Detailed Project)
Risk evaluation with respect of Design, Execution, Site Risk, Commercial, Partner, Insurance, and Contract Condition (PRC)
Regular toolbox meeting (Project Execution)
Rate Project Difficulty (PJA 9.7 Project difficulty chart)</td><td>Project Risk Assessment
Project Risk Assessment is the process to identify, assess and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.</td><td></td></tr>
<tr><td>ISO MPM 5.4.2 Pre-Project Safety Planning
ISO MPM 5.4.4 Project Quality Plan
WI-18.1 Nonconformance Control
QCP 309.55, Corrective Action
Toolbox meeting (Construction)
Job Safety Analysis</td><td>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 mindset that all accidents are preventable and that zero accidents is an obtainable goal.</td><td>Zero accidents/safety will be a major topic at all pre-construction and construction meetings.
A written, site-specific zero accident/safety program will be developed for each project.
A site safety professional will be assigned full time for safety for each project.
A zero accident/safety orientation will be conducted for all new personnel including subcontractor personnel.
A zero accident/safety incentive and award program will be developed for each project.
Weekly zero accident/safety toolbox meetings will be conducted for each project that all personnel, including subcontractors' personnel, are required to attend.
Project zero accident/safety inspections will be conducted by site supervisory personnel daily.
A substance abuse program will be developed that includes random testing and testing for cause.
Mandatory documentation that is required for each project
…</td></tr>
</table>

PRACTICES	Relevant Project Control Process	Process Instruction in Management Manuals
MATERIALS MANAGEMENT		
A. Materials Management Systems		
1. Project team material status database	* Receiving inspection	* WI-8.1 Material Receiving * WI-8.2 ldentification-Traceability-Traceability * WI-8.3 Handling & Storage
2. On-site material tracking technology	* On-site material & tools tracking system	* Monitor material & tools requirement; storage; Location
3. Material delivery schedule	* Prepare material requisitions * Material delivery schedule updates	* WI-6.2 Material Requisition * FC-6.1 Procurement Flowchart * PEP-4.8 ExtraWork Procedure
4. Procurement plan for materials and equipment	* Prepare material requisitions	* WI-6.2 Material Requisition * FC-6.1 Procurement Flowchart
B. Receipt and Inspection of Materials		
1. Material inspection process	* Receiving inspection	* WI-8.1 Material Receiving * WI-8.2 ldentification-Traceability-Traceability * WI-8.3 Handling & Storage
2. Material inspection team	* Orgchart * Clearly defined individual accountability * Receiving inspection	* QM-7.2 Organization Charts * QM-7.1 Organization and Responsibility * WI-8.1 Material Receiving * WI-8.2 ldentification-Traceability-Traceability * WI-8.3 Handling & Storage
3. Post receipt preservation and maintenance	* Record keeping	* PEP-4.18 Record Keeping
EQUIPMENT LOGISTICS		
A. Site Tool Management		
1. Site tool and consumables management strategy	* Prepare tools and equipment requisitions	* WI-6.3 Purchase Orders
2. Tool tracking systems	* On-site material & tools tracking system	* Monitor material & tools requirement; storage; Location (under construction)
3. On-Site tool maintenance	* Return tools & Equipment and Maintenance	* WI-7.1 Equipment Maintenance
4. Control system for tool delays		

PRACTICES	Relevant Project Control Process	Process Instruction in Management Manuals
B. Machinery Availability		
1. Construction machinery productivity analysis		
2. Equipment maintenance	* Return tools & Equipment and Maintenance	* WI-7.1 Equipment Maintenance
Craft Information Systems	* Return tools & Equipment and Maintenance	* WI-7.1 Equipment Maintenance
A. Short Interval Planning		
1. Short Interval Planning	* 2-weeks planning * Weekly review	* PEP-4.11 Daily andWeekly Job Reports
B. Work Face Planning		
1. Well defined scope of work	* Budget (Job Setup) (as-sold estimate review)	* As-sold estimate review & WBS & Cost Code Structure
2. Utilization of software to assist in generating work packages	* Budget (Job Setup) (as-sold estimate review)	* As-sold estimate review & WBS & Cost Code Structure
3. Project model requirements	* Budget (Job Setup) (as-sold estimate review)	* As-sold estimate review & WBS & Cost Code Structure
4. Dedicated Planner	* Clearly defined individual accountability	* QM-7.1 Organization and Responsibility
5. Identify required permitting	* Prepare permit applications	* PEP-3.4 Permits and Business Licenses
6. Engineering Work Packages (EWP)	* Prepare job plan	* MPM-5.1 Pre-Construction Planning
7. Construction Work Packages (CWP)	* Prepare job plan	* MPM-5.1 Pre-Construction Planning
8. Field Installation Work Packages (FIWP)	* Prepare job plan	* MPM-5.1 Pre-Construction Planning
C. Constructability Review		
1. Design readiness for construction		
2. PPMOF evaluation	* Pre-fab evaluation and new technology investigation	* Evaluation of prefabrication, modular construction and preassembly (under construction)
HUMAN RESOURCE MANAGEMENT		
A. Training and Development	* Hiring and indoctrination	* PEP-3.8 Hourly Payroll * PEP-3.9 Contract Scope Changes
1. Trades technical training		
2. Career development		
B. Behavior		
1. Nonfinancial Incentive Programs		
2. Financial Incentive Programs		
3. Social Activities		
C. Organizational Structure		
1. Maintain Stability of Organization Structure	* Orgchart	* QM-7.2 Organization Charts

PRACTICES	Relevant Project Control Process	Process Instruction in Management Manuals
2. Clear Delegation of Responsibility	* Clearly defined individual accountability	* QM-7.1 Organization and Responsibility
D. Employment		
1. Retention Plan For Experienced Personnel		
2. Exit Interview		
Construction Methods		
A. Sequence and Scheduling of Work		
1. Integrated Schedule	* Prepare schedule & resource loading	* PEP-2.4 Schedule c/w Resource Loading
2. Work Schedule Strategies	* Prepare schedule & resource loading	* PEP-2.4 Schedule c/w Resource Loading
3. Schedule Execution and Management	* Baseline updates	
B. Start-Up, Commissioning, and Turnover Plan		
1. Planning for Start-Up		
2. Testing Procedures	* Inspection and testing	* MPM-14.1 Inspection and Testing * WI-14.1 * WI-14.2 * WI-14.3 * WI-14.4
3. System Turnover Procedure		
C. New Technology Investigation		
1. New equipment investigation	* Pre-fab evaluation and new technology investigation	* Evaluation of prefabrication, modular construction and preassembly (under construction)
2. New information system investigation	* Pre-fab evaluation and new technology investigation	* Evaluation of prefabrication, modular construction and preassembly (under construction)
3. New materials technologies Investigation	* Pre-fab evaluation and new technology investigation	* Evaluation of prefabrication, modular construction and preassembly (under construction)
D. Site Layout Plan		
1. Dynamic site layout plan	* Site layout plan	* Site layout, security, heavy lift
2. Site security plan	* Site layout plan	* Site layout, security, heavy lift
3. Equipment positioning strategy		
ENVIRONMENT, SAFETY, AND HEALTH		
A. Job Safety		
1. Zero Accident Techniques	* Job hazard analysis	* Red-Book
2. Task Safety Analysis	* Job hazard analysis	* Red-Book
3. Identification of Potential Hazards	* Job hazard analysis	* Red-Book

Appendix H

PRACTICES	Relevant Project Control Process	Process Instruction in Management Manuals
4. Housekeeping		* Red-Book
5. System test hazards planning	* Safety plan	* MPM-5.1 Pre-Construction Planning
B. Substance Abuse Programs		
1. Substance Abuse Programs		* Non
C. Safety Training and Orientation		
1. OSHA Compliance Training	* Hiring and indoctrination	* PEP-3.8 Hourly Payroll * PEP-3.9 Labour Relations
2. Toolbox safety meetings	* Job hazard analysis	* Red-Book

Appendix I

Cost Code Mapping to the Selected Metrics

Selected Metrics	Cost Code				Description	UNIT
	L1	L2	L3	L4		
Piping - Small Bore (2-1/2” and Smaller) - Large Bore (3” and Larger)	03	30	xx	xx	Cabon steel piping	FT
	03	31	xx	xx	Stainless steel piping	FT
	03	32	xx	xx	Cr. MO piping	FT
	03	33	xx	xx	FRP piping	FT
	03	34	xx	xx	Plastic piping	FT
	03	35	xx	xx	Specialty piping	FT
	03	36	xx	xx	FRP piping	FT
	03	37	xx	xx	HPDE piping	FT
	03	38	xx	xx	Underground pipe and fittings	
	03	39	xx	xx	Specialties	
	03	40	xx	xx	Instrumentation	
	03	48	xx	xx	Automotive	
	03	91	xx	xx	Coal distribution piping	
	03	92	xx	xx	Demolition	
Mechanical Equipment	04	40	xx	xx	Prefab tanks	EA
	04	41	xx	xx	Knock down tanks	EA
	04	42	xx	xx	Pumps	EA
	04	43	xx	xx	Compressors	EA
	04	44	xx	xx	Fire protection, plumbing	EA
	04	45	xx	xx	HVAC (heat generation, refrigeration, heat transfer, air handling, air distribution)	EA
	04	46	xx	xx	Power generation built-up systems (steam turbine, gas turbine, recipricating engine)	EA
	04	47	xx	xx	Misc. equipment (Cranes, Trollies, Hoists, Conveyors & Chutes	EA
	04	48	xx	xx	Millwrighting (body weld, weld curtain)	EA
	04	49	xx	xx	Door line	EA
	04	54	xx	xx	Automotive	
	04	91	xx	xx	Coal burner work	
	04	92	xx	xx	Demolition	
Structural Steel	05	50	xx	xx	Structural erect	tn
	05	51	xx	xx	Structural Materials	tn
	05	52	xx	xx	Stairs and handrails, decking and grating, checkerd plate	tn
	05	53	xx	xx	Misc. steel, field painting	
	06	60	xx	xx	Earth work	cy
	06	61	xx	xx	Formwork	sf
Concrete	06	62	xx	xx	Place concrete	cy
	06	63	xx	xx	Concrete specialites and miscellaneous	
	06	65	xx	xx	Embeds	
	06	64	xx	xx	Precast concrete	
	06	66	xx	xx	Architectural	
	06	67	xx	xx	Landscaping	y^2
	06	68	xx	xx	Doors/Hardware	
	06	69	xx	xx	Specialities	lt
	06	70	xx	xx	Wood and stave penstocks	
	06	71	xx	xx	Finish painting	
	07	70	xx	xx	Electrical & instrument (above grade conduit)	
	07	71	xx	xx	Electrical & instrument (below grade conduit)	
	07	72	xx	xx	Cable tray and fittings	
Wire and cable	07	73	xx	xx	Wire and cable	FT
Equipment	07	74	xx	xx	Equipment	EA
	07	75	xx	xx	Lighting	
	07	76	xx	xx	Controls, grounding systems	
	07	77	xx	xx	Instrumentation, special systems	
	07	78	xx	xx	Communications, alarm system, catholic protection system	
	07	79	xx	xx	Testing and commissioning	

Productivity calculation example – Project SC (Mar. 2012)

Items	Rules Code						unit	Budget			To Date			PPF
	Cost Code				Hour	Quan		Hours	Quan.	Prod.	Hours	Quan.	Prod.	
	L1	L2	L3	L4										
Indirect	1													
Pipe fitter FM	1	16	3	29			%	3270			7191			
Electical FM	1	16	3	33			%	2864			4463			
M/R FM	1	16	4	29			%	1150			1769			
Direct														
Piping	3													
System 10 PCA piping-compress air														
install piping <12"	3	35	1	7	small	small	FT	1236	492.2		1990	492.2		
hydrostatic testing	3	39	7	3	small		%	110			73			
System 15 PCD piping-closed drains														
install piping <12"	3	35	1	7	large	large	FT	1192	339.5		1388	339.5		
hydrostatic testing	3	39	7	3	large		%	147			106			
System 7 PFG piping-fuel gas														
install piping <12"	3	35	1	7	small	small	FT	752	157.4		1427	157.4		
hydrostatic testing	3	39	7	3	small		%	110			132			
System 14 PHT piping-heat medium														
install piping <12"	3	35	1	7	large	large	FT	2008	663		2669	663		
hydrostatic testing	3	39	7	3	large		%	182			247			
System 11 PLO piping-lube oil														
install piping <12"	3	35	1	7	large	large	FT	596	197.5		633	195.8		
hydrostatic testing	3	39	7	3	large		%	71			205			
System 6 PMG piping - main gas														
install piping <12"	3	35	1	7	large	large	FT	1603	175.6		1998	149.6		
install piping >16"	3	35	2	9	large	large	FT	8613	1371		8723	1371		
hydrostatic testing	3	39	7	3	large		%	920			1291			
Instl. Gas equip.	3	47	4	3			%	204			135			
System 12 PPG piping - power gas														
install piping <12"	3	35	1	7	small	small	FT	490	145.7		1071	136.4		
hydrostatic testing	3	39	7	3	small		%	73			137			
PI piping - instrument														
Instl devices	3	40	0	3			%	140	100		166			
Instrument tubing	3	40	0	7			%	1936	100		12			
System 8 PV piping - vents														
install piping <12"	3	35	1	7	large	large	FT	485	221.8		1183	131.1		
install piping >16"	3	35	2	9	large	large	FT	1129	131.1		462	221.8		
hydrostatic testing	3	39	7	3	large		%	110			94			
Piping summary														
Pipe fitter FM hours multiplier							%	1.148			1.298			
							unit	Budget			To Date			PPF
								Hours	Quan.	Prod.	Hours	Quan.	Prod.	
Small bore							FT	3181	795.3	3.999	6269	786	7.975	1.994
Large bore							FT	19579	3100	6.316	24658	3072	8.026	1.271

Productivity calculation example – Project SC (Mar. 2012)

Items	Rules Code						unit	Budget			To Date			PPF
	Cost Code				Hour	Quan		Hours	Quan.	Prod.	Hours	Quan.	Prod.	
	L1	L2	L3	L4										
Mechanical and Structure Steel	4													
MCB mech-compress build	4													
Instl supports/misc.	4	45	1	11	Steel	Steel	ton	1062	118.8	8.937	1930	152.6	12.645	
instl inlet air & ex	4	45	5	9	Mech	Mech	EA	987	40		838	38		
Instl solar skids	4	46	2	3	Mech	Mech	EA	758	40		781	40		
Erect comp bldg	9	0	0	6			%				194	32		
MCB mech-yard area	4													
instl yard stl&stile	4	45	1	15	Steel	Steel	ton	2274	473.4	4.803	1996	474.7	4.204	
erect aftercooler	4	45	2	15	Mech	Mech	EA	731	120		267	120		
set buildings	4	45	3	11	Mech	Mech	EA	677	120		421	140		
paint touch-up	5	53	2	3							12			
pre-fab building ext	9	0	0	1							66			
structural steel ext	9	0	0	2							139			
aftercooler extras	9	0	0	3							8			
Mechanical and Structural Steel Summary														
M/R FM hours multiplier								1.177			1.284			
							unit	Budget			To Date			PPF
								Hours	Quan.	Prod.	Hours	Quan.	Prod.	
Mechanical							EA	3712	320	11.599	2962	338	8.763	0.755
Structural steel							ton	3927	592.3	6.631	5040	627.4	8.034	1.212

Productivity calculation example – Project SC (Mar. 2012)

Items	Rules Code						unit	Budget			To Date			PPF
	Cost Code				Hour	Quan		Hours	Quan.	Prod.	Hours	Quan.	Prod.	
	L1	L2	L3	L4										
Electrical	7							15368			15181			
COM COMMISSIONING														
Pre-Commission Elect	7	72	1	1			%	1390			601			
Commissioning Allow	7	72	1	3			%	1000			650	73		
EAC ELEC-AFTERCOOLER ARE	7													
Install Tray	7	72	0	9			FT	238	260		100	387		
Inst Cable #10&Small	7	73	3	1			FT	626	378.7		110	116		
Inst Cable #8&larger	7	73	3	3			FT	587	262.5					
Terminate & Tag	7	73	4	3			EA	196	650		80	290		
Devices & Fixtures	7	75	2	2	device	device	EA	47	250		20	250		
Grounding	7	76	1	5			FT	32	550		58	836		
ECB ELEC-COMPRESSOR BLDG														
Install Tray	7	72	0	9			FT	563	1085		920	761		
Inst Cable #10&Small	7	73	3	1			FT	969	635		1244	1296		
Inst Cable #8&larger	7	73	3	3			FT	154	55.3		252	66.5		
Terminate & Tag	7	73	4	3			EA	411	1300		904	2010		
Devices & fixtures	7	75	2	2	device	device	EA	389	2100		828	2450		
Grounding	7	76	1	5			FT	152	1685		357	2381		
EGM ELEC-GENTR/MCC/CROOM														
Install tray	7	72	0	9			FT	179	370		252	284		
Inst Cable #10&Small	7	73	3	1			FT	725	468.7		527	311		
Inst Cable #8&larger	7	73	3	3			FT	277	89.25		285	56.95		
Terminate & Tag	7	73	4	3			EA	828	1842		1231	1194		
Devices & fixtures	7	75	2	2	device	device	EA	480	1075		347	1175		
Grounding	7	76	1	5			FT	101	1079		228	1834		
EYD ELEC - YARD AREA														
Install tray	7	72	0	9			FT	1779	1915		1027	1568		
Inst Cable #10&Small	7	73	3	1			FT	1897	1025		2050	861.4		
Inst Cable #8&larger	7	73	3	3			FT	231	133.4		597	159		
Terminate & Tag	7	73	4	3			EA	542	1833		691	614		
Devices & Fixtures	7	75	2	2	device	device	EA	330	1025		391	1600		
Grounding	7	76	1	5			FT	585	7451		622	4395		
Heat Trace	7	76	2	3			FT	283	1391		323	1703		
Temporary Power	7	79	2	9			%	377	100		486	10		
Electrical Summary														
Electical FM hours multiplier								1.186			1.294			
							unit	Budget			To Date			PPF
								Hours	Quan.	Prod.	Hours	Quan.	Prod.	
Electrical equipment and devices							EA	1478	4450	0.332	2052	5475	0.375	1.128
Wire and calbe							FT	8830	3047	2.898	10314	2867	3.597	1.241

Cost Code	Description	Unit	Current Budget Hours	Current Quantity Budget	Est Prod. Hr/Unit	To Date Hours	To Date Quantity	To Date Prod. Hr/Unit	PPF
Piping		FT	3903			1966			
	Large bore		**2872**	**1342**	**2.14**	**1882**	**417.62712**	**4.51**	**2.11**
03.30.0.05	NEW SERVICE WATER PI	FT	1292	542		1350	418		
03.30.0.05	NEW PA PIPING INSTAL	FT	834	800		12			
	Small Bore		**2401**	**503.87597**	**4.76**	**1227**	**403.10078**	**3.04**	**0.64**
03.49.1.01	NEW CORE AIR PIPING	FT	1777	504		776	403		
03.01.0.xx	Foremen Hours for piping	%	1370			1143			
Electrical									
Wire and cable		**FT**	**7546**	**3045**	**2.48**	**3713**	**1184**	**3.14**	**1.27**
07.73.3.01	BURNER TECK AND INST	FT	243	188		278	94		
07.73.4.99	TERMINATE BURNER CAB	EA	141	452		56	90		
07.73.3.01	EC&I TECK CABLE&INST	FT	371	165		774	91		
07.73.4.99	TERMINATE EC&I CABLE	EA	85	156		115	31		
07.73.3.01	FAHS TECK INST. CABL	FT	1165	827		988	703		
07.73.4.99	TERMINATE FAHS CABLE	EA	702	2394		360	1436		
07.73.3.01	INSTALL FUEL FEED TE	FT	523	322		159			
07.73.4.99	TERMINATE FUEL FEED	EA	140	474					
07.73.3.01	PA COLLER TECK&INSTR	FT	358	313					
07.73.4.99	TERMINATE PA COOLER	EA	263	848					
07.73.3.01	PULVERISER TECK CABL	FT	896	988		95	296		
07.73.4.99	TERMINATE PULVERISER	EA	699	2200					
07.73.1.91	DISC&RMV TRNFRM RCTF	EA	256	4					
07.73.3.01	INST ESP TECK CABLE	FT	326	242					
07.73.4.99	TERM ESP CABLE&LABEL	EA	194	496					
07.01.0.xx	Foremen Hours for wiring	%	1184			888			
Electrical equipment and device		EA	247	4	62				
07.74.1.23	INST NW TRNS & RCNCT	EA	208	4					
07.01.0.xx	Foremen Hours for electrical equip	%	39						
Mechanical Equipment		**EA**	**5743**	**2980**	**1.93**	**8268**	**2170**	**3.81**	**1.98**
04.41.8.13	INSTALL BURNER	EA	1928	300		3617	297		
04.47.4.05	NEW BLOWER SKID	FT	904	630		2242	560.7		
04.47.2.05	INSTALL NEW DRAG CON	%	1518	100		2328	96		
04.47.3.03	INSTALL NEW CHUTES	%	582	100		597	68		
04.47.3.03	INSTALL HOPPERS AND	EA	282	100		260	87		
04.48.1.11	INSTALL NEW INTERNAL	EA	466	100		727	100		
04.45.5.09	XISTING DUCT REMOVAL	%	460	100		575	100		
04.45.5.17	NEW PA SUPPORT STEEL	%	280	100		273	100		
04.45.5.25	COOLER TRANSITION IN	EA	200	40		1005	40		
04.45.5.45	PA COOLER INSTALLATI	%	400	100		1791	99		
04.45.5.46	PA COOLER FITTING	%	240	100		189	83		
04.41.5.05	INSTALL NEW NOZZLES	EA	294	700		724	441		
04.44.1.05	INSTALL EXPLOSION	EA	588	700		245	357		
04.44.1.17	INSTALL FIRE NOZZLES	EA	378	300		83	108		
04.45.5.21	SET EXISTING DAMPERS	EA	206	100		210	100		
04.46.4.03	INSTALL ROTATION THR	EA	618	40		446	40		
04.48.1.05	INSTALL JACKING SCRE	EA	206	300			300		
04.48.1.09	INSTALL PULVERISER	EA	577	300		951	300		
04.47.3.02	REMOVE HOPPERS	EA	211	100		301	100		
04.48.1.09	REMOVE FUEL FEEDS	EA	368	100		554	100		
04.48.1.03	REMOVE WHEELS	EA	601	300		1195	300		
04.48.1.07	REMOVE STATIONARY TH	EA	293	40		290	40		

Project DN 2011-10-21 Productivity calculation (normalized number) Appendix J

						unit	Budget			To Date			PPF
Cost Code							Hours	Quan.	Productivit	Hours	Quan.	Productivity	
				indirect									
1	13	5	7	operating engineer		%							
1	16	3	29	Pipe fitter FM		%	3000			3154			
1	16	3	33	Electical FM		%							
				Direct									
				Piping									
				System 6 HP piping									
3	35	1	7	install piping <12"	3	FT	1544	104		777	126		
3	35	2	9	install piping <16"	3	FT	4572	692		3405	782		
3	39	7	3	hydrostatic testing	3	%	500			242			
				System 7 fuel gas piping									
3	35	1	7	install piping <12"	2	FT	2342	596		2599	800		
3	39	7	3	hydrostatic testing	2	%	414			388			
				System 8 HP drain and vent									
3	35	1	7	install piping <12"	3	FT	1417	509		2145	793		
3	39	7	3	hydrostatic testing	3	%	151			178			
				System 9 fresh water									
3	35	1	7	install piping <12"	2	FT	839	112		603	112		
3	39	7	3	hydrostatic testing	2	%	42						
				System 10 compressed aire									
3	35	1	7	install piping <12"	2	FT	1971	498		2157	598		
3	39	7	3	hydrostatic testing	2	%	180			83			
				System 11 interconnect piping									
3	35	1	7	install piping <12"	3	FT	898	147		809	147		
3	39	7	3	hydrostatic testing	3	%	329			31			
				System 12 power gas control									
3	35	1	7	install piping <12"	2	FT	379	105		524	183		
3	39	7	3	hydrostatic testing	2	%	37			35			
				System 14 HVAC & heating									
3	35	1	7	install piping <12"	3	FT	2242	584		2637	1129		
3	39	7	3	hydrostatic testing	3	%	239			251			
				System 15 drainage									
3	35	1	7	install piping <12"	3	FT	420	50		210	50		
3	39	7	3	hydrostatic testing	3	%	30						
				Mechanical									
4	45	2	17	Instl solar compress		%							
4	45	5	9	instl inlet air & ex		%	748			1341			
4	45	6	9	Misc. equipment instl		%	1072			339			
4	46	2	3	Instl solar compress		%	727			261			
4	46	4	17	Commissioning Assist		%	400			172	95		
				Structure Steel									
5	50	1	3	Misc. steel erection		%	858			1437			

Project DN 2011-10-21 Productivity calculation (normalized number) Appendix J

						unit	Budget			To Date			PPF
Cost Code							Hours	Quan.	Productivity	Hours	Quan.	Productivity	
				Summary									
3				piping summary									
3				Small bore		FT	6204	1311		6389	1693.02		
3				large bore		FT	12342	2087		10685	3026		
3				Small bore		FT	7208	1311	5.498	7569	1693.02	4.471	0.813
3				large bore		FT	14338	2087	6.869	12659	3026.47	4.183	0.609
4				mechanical summary		%	2547			1941			0.762
5				structural steel		%	858			1437			1.675

Project LB 2012-03-26 Productivity calculation (normalized number) Appendix J

						unit	Budget			To Date			PPF
Cost Code							Hours	Quan.	Productivit	Hours	Quan.	Productivity	
				indirect									
1	13	5	7	operating engineer		%							
1	16	3	29	Pipe fitter FM		%	4983			3757	100		
1	16	3	33	Electical FM		%							
				Direct									
				Piping									
				System 6 HP piping									
3	35	1	7	install piping <12"	3	FT	3,870	616		4,051	887		
3	35	2	9	install piping <16"	3	FT	16,268	2909		18,437	4003		
3	39	7	3	hydrostatic testing	3	%	2,052			1,094			
3	92	0	1	Piping Demo	3	%	2,133			1,931			
4	47	4	3	Install HP Gas Equip		%	348			265			
				System 8 HP drain and vent									
3	35	1	7	install piping <12"	3	FT	1,030	425		3,333	821		
3	39	7	3	hydrostatic testing	3	%	290			240			
				System 10 compressed aire									
3	35	1	7	install piping <12"	2	FT	91	22		103	33		
				System 11 interconnect piping									
3	35	1	7	install piping <12"		%	2,228			3,061			
3	92	0	1	Piping Demo		%	110			470			
				System 12 power gas control									
3	35	1	7	install piping <12"	2	FT	962	343		1,721	520		
3	39	7	3	hydrostatic testing	2	%	94			276			
				Mechanical									
4	45	2	17	Instl aftercooler		%	705	100		690	100		
4	46	2	3	Instl compressor		%	125	100		180	100		
				Structure Steel									
5	50	1	0	Instl. Structural steel		%	420	100		386	100		
				Summary									
3				piping summary									
3				Small bore		FT	1360	364.341	3.734	2353	552.713	4.257	1.140
3				Large bore		FT	30413	3950.42	7.699	32590	5710.92	5.707	0.741
4				Mechanical		%	830			870			1.048
5				Structure Steel		%	420			386			0.919

					unit	Budget			To Date			PPF
Cost Code						Hours	Quan.	Productiv	Hours	Quan.	Productivity	
				indirect								
1	16	3	0	General Foreman	%	5063	100		8699.5	85%		
1	16	3	1	Foreman	%	14681	100		19458	85%		
1	16	3	23	Operators	%	1865	100		4182	85%		
0				Direct		1.207			1.321			
3				Piping								
3	30	0	5	Butt Weld CS Pipe/Ftgs 2-1/2" to 24"	M	3849.6	1279.03		3245	1181.77		
3	30	0	33	Socket Weld CS Pipe/Ftgs	M	2012.49	408.66		2478	313.06		
3	31	3	33	Socket Weld SS Pipe/Ftgs	M	1501.05	265.77		2560	260.48		
3	30	0	31	Field Run Small Bore Threaded Piping	EA	313.49	403		163	350		
3	39	9	0	Valve Installation & Boltups	EA	1575.64	558		2674	529		
3	39	5	0	Pipe Supports	EA	4132.92	858		2074	747		
3	39	7	0	Pressure Testing	EA	2051	21		1851	18.5		
3	39	7	0	Pipe Cleaning/Flushing/Purging/Air Blows	EA	3836	10		1421	8		
3	40	0	7	Tubing	M	910.61	340.19		721	310.48		
3	40	0	3	Instrument Install	EA	745.5	122		155	86		
3	39	7	22	Underground Pipe Tape Coating and Jeep	EA	57.75	2		122	1.94		
4				Mechanical Equipment								
4	40	1	0	Tanks, Towers, Vessels,Reactors, Drums	EA	1102	400		187	400		
4	46	2	0	Install Gas Turbine & Generator & Clutch	EA	3874	40		2943	40		
4	46	2	8	Install Air Inlet Filter Housing	EA	3643	40		1582	36		
4	46	2	7	Install Gas Turbine & Generator & Clutch -	EA	664	40		1166	40		
4	46	2	8	Install Accessory Skids	EA	1189	440		560	426		
4	42	3	0	Install Horizontal Pumps / Rotating equipm	EA	485	300		300	296		
4	43	1	3	Install Air Compressor, Dryer, Reciever, Fi	EA	739	160		287	160		
4	47	4	99	Structural Steel Erection	MT	2944	384		1413	381		
4	45	1	7	Install Stack	EA	1352	40		2244	40		
5	50	1	0	Set Buildings at Site	EA	624	100		183	96		
5	50	1	0	Mechanical Touch-Up Paint	EA	323	120		89	109		
6				Civil								
6	60	1	3	Earthwork & Grading	m3	1749	37846		6827.5	31370		
6	60	2	5	Excavate and Backfill	m3	2261.78	44782		10625.6	42404		
6	62	2	3	Tank bases / Containment	EA	72	3		96	3		
6	60	3	5	Drainage Piping	m	501.62	896		80	861		
6	61	0	0	Formwork	m2	3161.36	2264		10473.5	2245		
6	65	1	0	Embedded materials (Anchor Bolts and Bo	ea	1272.31	580		350	517.547		
6	62	0	0	Cast in Place Concrete	m3	1944.73	2894	0.5137	2245	2695	0.63693	
6	63	2	3	Finish, Patch and Rub Walls	m2	1953.84	7897		1776	7743		
6	65	3	0	Cementitious	m3	917.43	5		1888	5		
6	60	3	7	Thermal Moisture Protection	m2	598.01	4126		336	4096		

Project SH 2011-08-13 Productivity Calculation (normalized number) Appendix J

					unit	Budget			To Date			PPF
Cost Code						Hours	Quan.	Productiv	Hours	Quan.	Productivity	
7				Electrical								
7	73	3	0	Pulling Cabling / Wiring	M	16715	2378	2.143	8283	2242	1.126	
7	76	1	0	Grounding	M	5076	6598		1815	5697		
7	72	0	0	Engineering Cable Tray Installation	M	2000	1718		2816	1524		
7	70	3	0	Conduit Installation	M	1746	3571		1148	2974		
7	74	1	21	Elec. Equip./Devices/JB's / Panels Installa	EA	5563	1200	4.636	1281	926	1	
7	74	1	31	Lighting / Receptacles Installation	EA	1168	2275	0.514	529	225	2	
7	72	0	11	Install Elec. Supports	M	1949	1858		2466	1802		
7	73	4	0	Terminations	EA	5892	8592	0.686	6008	7502	0.801	
7	79	1	3	Testing - Loop,Cont.,Megger	EA	0	0		0	0		
7	76	2	0	Electrical Heat Tracing	M	3067	6374		273	497		
				Summary								
3				Piping								
3				Small bore	FT	9483.78	5382	1.762	5872.58	1878	3.127	1.77
3				Large bore (ISBL)	FT	8652.04	6029	1.435	7836.67	3909	2.005	1.40
3				Large bore (OSBL)	FT							
4				Mechanical	EA	14113	1420	9.939	9280	1398.04	6.638	0.67
5				Structural steel	ton	3553	384	9.247	1866	381	4.895	0.53
6				Concrete	CY	10054	3786	2.656	19609	3525	5.563	2.09
7				Electrical								
7				Electrical equipment and devices	EA	8123	3475	2.338	2391	1151	2.078	0.89
7				Wire and cable	FT	27279	7801	3.497	18878	7357	2.566	0.73

Project WWTI				2011-10-21		Productivity calculation (normalized number)						Appendix J
					unit	Budget			To Date			PPF
Cost Code						Hours	Quan.	Productivity	Hours	Quan.	Productivity	
				indirect								
1	13	5	7	operating engineer	%	800			606			
1	16	3	17	Iron Worker FM								
1	16	3	29	Pipe fitter FM	%	3095			1606	56		
1	16	3	33	Electical FM	%	2852			1173	49		
				direct								
				piping		0.296087			0.753283			
3	30	0	3	Carbon Steel pipe	FT	2363	3768		325	575		
3	31	3	5	Stainless Steel pipe	FT	635	1595		299	531		
3	33	1	5	FRP pipe	FT	5540	3976		1148	1082		
3	34	1	5	HDPE pipe	LF	74	987					
3	39	2	5	Galvanized/Copper pipe	LF	431	669		360	397		
3	39	2	9	Identification	ea	94	760					
3	39	7	1	Hydrotesting	%	1158	100					
3	40	0	3	Instruments	ea	158	129					
				Mechanical								
4	48	1	1	Equipment setup	EA	573	340		1067	340		
4	91	1	1	Mob/Demob	%	312			102			
				Structural Steel								
5	50	2	3	Solids building structure	%	441			347	100		
5	50	4	3	Utility rack	%	3193			1584	73		
5	53	1	5	Stairs/railings/ladders	%	1726			253	15		
				Electrical		0.258896			0.587087			
7	1	0	0	Commisioning	%	510	100					
7	72	0	15	Cable tray/ dect ban	FT	1633	2244		865	1562		
7	73	1	1	Instrumentation cable	FT	1511	674		15	7		
7	73	3	1	Cable	FT	2760	1845		481	320		
7	73	4	9	Terminations	EA	856	3522		34			
7	74	1	31	Lighting / recepticles	EA	622	1850		166	775		
7	76	0	19	Devices	EA	1268	1075		260	525		
7	76	1	5	Grounding	FT	258	4248		156	1177		
7	76	2	3	Heat Tracing	FT	1394	8400		21			
7	79	3	99	Labelling	EA	204	2162					
3				piping summary	FT	13390	10994.96	1.218	3738	2584.034	1.447	1.188
4				Mechanical Summary	EA	573	340	1.685	1067	340	3.138	1.862
5				Structural Steel	ton	3634	647	5.613	1931	494	3.911	0.697
7				Electrical								
7				Electrical equipment and	EA	2379	2925	0.813	676	1300	0.520	0.639
7				wire and cable	FT	6711	2519	2.664	841	327	2.571	0.965

Project WWTI 2012-03-29 Productivity calculation (normalized number) Appendix J

					unit	Budget			To Date			PPF
Cost Code						Hours	Quan.	Productivity	Hours	Quan.	Productivity	
				indirect								
1	13	5	7	operating engineer	%							
1	16	3	29	Pipe fitter FM	%	696	200		829	200		
1	16	3	33	Electical FM	%	8	100					
				Direct								
				Piping								
3	34	5	5	Miscellaneous piping	%	1318	200		820	200		
3	35	1	7	Digester sludge piping		1665	2563		768	2563	0.300	
3	35	1	9	WAS waste activated	FT	635	933		403	262		
3	38	1	7	W1 firemain/potable	FT	739	513		955	937		
3	38	1	8	Effluent line	FT	202	168		204	209		
				Subcontract								
				Concrete	CY				40283	4132	9.749	
3				piping summary		3937	4176.471	0.943	3159	3971.429	0.795	0.844
				Subcontract								
				Concrete								

Appendix K

BPPII survey for the Partner Company's Management Manual

BPPII Practice Element	Manuals' Level
MATERIALS MANAGEMENT	
A. Materials Management Systems	
1. Project team material status database (p4)	3
2. On-site material tracking technology (p4)	3
3. Material delivery schedule (p5)	4
4. Procurement plan for materials and equipment (p5)	4
B. Receipt and Inspection of Materials	
1. Material inspection process (p6)	4
2. Material inspection team (p6)	5
3. Post receipt preservation and maintenance (p7)	5
EQUIPMENT LOGISTICS	
A. Site Tool Management	
1. Site tool and consumables management strategy (p8)	5
2. Tool tracking systems (p8)	3
3. On-Site tool maintenance (p9)	5
4. Control system for tool delays (p9)	3
B. Machinery Availability	
1. Construction machinery productivity analysis (p10)	0
2. Equipment maintenance (p10)	0
CRAFT INFORMATION SYSTEMS	
A. Short Interval Planning	
1. Short Interval Planning (p11)	4
B. Work Face Planning	
1. Well defined scope of work (p11)	3
2. Utilization of software to assist in generating work packages (p12)	2
3. Project model requirements (p13)	1
4. Dedicated Planner (p13)	
5. Identify required permitting (p14)	2
6. Engineering Work Packages (EWP) (p14)	0
7. Construction Work Packages (CWP) (p15)	0
8. Field Installation Work Packages (FIWP) (p16)	0
C. Constructability Review	
1. Design readiness for construction (p16)	2
2. PPMOF evaluation (p17)	4

Appendix K

BPPII survey for the Partner Company's Management Manual

BPPII Practice Element	Manuals' Level
HUMAN RESOURCE MANAGEMENT	
A. Training and Development	
1. Trades technical training (p18)	5
2. Career development (p18)	0
B. Behavior	
1. Nonfinancial Incentive Programs (p18)	0
2. Financial Incentive Programs (p19)	4
3. Social Activities (p19)	3
C. Organizational Structure	
1. Maintain Stability of Organization Structure (p20)	3
2. Clear Delegation of Responsibility (p20)	5
D. Employment	
1. Retention Plan For Experienced Personnel (p20)	5
2. Exit Interview (p21)	5
CONSTRUCTION METHODS	
A. Sequence and Scheduling of Work	
1. Integrated Schedule (p22)	0
2. Work Schedule Strategies (p22)	0
3. Schedule Execution and Management (p23)	0
B. Start-Up, Commission, and Turnover Plan	
1. Planning for Start-Up (p24)	0
2. Testing Procedures (p24)	5
3. System Turnover Procedure (p25)	5
C. New Product Investigation	
1. New equipment investigation (p25)	2
2. New information system investigation (p26)	3
3. New materials technologies Investigation (p26)	2
D. Site Layout Plan	
1. Dynamic site layout plan (p27)	0
2. Site security plan (p28)	0
3. Equipment positioning strategy (p28)	0
ENVIRONMENT, SAFETY, AND HEALTH	
A. Job Safety	
1. Zero Accident Techniques (p30)	5
2. Task Safety Analysis (p30)	5
3. Identification of Potential Hazards (p31)	5
4. Housekeeping (p31)	0
5. System test hazards planning (p31)	5
B. Substance Abuse Programs	
1. Substance Abuse Programs (p32)	5
C. Safety Training and Orientation	
1. OSHA Compliance Training (p33)	5
2. Toolbox safety meetings (p33)	5

Appendix L

BPPII Survey for 12 Projects

BPPII Practice Element	SH	EWCC	DN	LB	SC	NB	AP-I	AP-II	WWTP-US	WWTP-W	AK	BDPS	Average	Variance
MATERIALS MANAGEMENT														
A. Materials Management Systems														
1. Project team material status database (p4)	2	2	4	0	1	0	0	0	3	0	2	1	1.25	1.84
2. On-site material tracking technology (p4)	2	1	3	0	1	1	0	0	2	0	2	1	1.08	0.99
3. Material delivery schedule (p5)	3	2	3	0	2	2	0	0	2	1	4	2	1.75	1.66
4. Procurement plan for materials and equipment (p5)	3	2	3	0	2	2	0	0	3	2	2	2	1.75	1.30
B. Receipt and Inspection of Materials														
1. Material inspection process (p6)	4	4	3	0	4	3	0	0	4	2	4	3	2.58	2.81
2. Material inspection team (p6)	5	3	1	0	5	3	0	0	1	1	5	3	2.25	4.02
3. Post receipt preservation and maintenance (p7)	4	4	1	0	4	1	0	0	1	2	2	1	1.67	2.42
EQUIPMENT LOGISTICS														
A. Site Tool Management														
1. Site tool and consumables management strategy (p8)	5	5	4	3	3	1	2	2	4	2	4	2	3.08	1.72
2. Tool tracking systems (p8)	2	2	1	3	3	2	1	1	1	2	2	3	1.92	0.63
3. On-Site tool maintenance (p9)	2	2	2	2	1	1	1	1		1	1	3	1.55	0.47
4. Control system for tool delays (p9)	2	2	2		1	1	1	1		1	1		1.33	0.25
B. Machinery Availability														
1. Construction machinery productivity analysis (p10)	1	1	1	3	1	2	1	1	2	1	1	1	1.33	0.42
2. Equipment maintenance (p10)	2	2	2	3	0	3	1	1	2	1	2	1	1.67	0.79
CRAFT INFORMATION SYSTEMS														
A. Short Interval Planning														
1. Short Interval Planning (p11)	4	3	4	2	3	2	0	0	2	2	3	3	2.33	1.70
B. Work Face Planning														
1. Well defined scope of work (p11)	3	2	4	2	1	3	0	0	3	1	1	2	1.83	1.61
2. Utilization of software to assist in generating work packages	2	0	1	0	2	0	0	0	0	1	2	2	0.83	0.88
3. Project model requirements (p13)	1	1	3	1	1	0	0	0	1	0		1	0.82	0.76
4. Dedicated Planner (p13)	2	1	3	2	1	1	0	0	3	0	1	1	1.25	1.11
5. Identify required permitting (p14)	2	2	3	3	2	2	2	2	3	2	1	2	2.17	0.33
6. Engineering Work Packages (EWP) (p14)	2	1	2	1	2	0	0	0	0	0			0.80	0.84
7. Construction Work Packages (CWP) (p15)	2	1	2	1	1	1	0	0	0	0	3	2	1.08	0.99
8. Field Installation Work Packages (FIWP) (p16)	2	1	4	3	2	1	0	0	3	0	2	2	1.67	1.70
C. Constructability Review														
1. Design readiness for construction (p16)	4	4	4	4	3	2	0	0	4	2	1	2	2.50	2.45
2. PPMOF evaluation (p17)	5	5	5	4	5	0	0	0	4	3	4	2	3.08	4.27
HUMAN RESOURCE MANAGEMENT														
A. Training and Development														
1. Trades technical training (p18)	4	4	4	4	4	3	4	4	3	2	3	3	3.50	0.45
2. Career development (p18)	5	5	3	3	2	2	1	1	2	2	3	2	2.58	1.72
B. Behavior														
1. Nonfinancial Incentive Programs (p18)	5	5	2	2	1	2	2	2	2	2	4	4	2.75	1.84
2. Financial Incentive Programs (p19)	5	5	2	2	4		1	1	0	1	3	3	2.45	2.87

Appendix L

BPPII Survey for 12 Projects

BPPII Practice Element	SH	EWCC	DN	LB	SC .	NB	AP-I	AP-II	WWTP-US	WWTP-W	AK	BDPS	Average	Variance
3. Social Activities (p19)	2	2	2	2	1	1	1	1	0	1	5	3	1.75	1.66
C. Organizational Structure														
1. Maintain Stability of Organization Structure (p20)	2	3	2	5	0	3	0	0	2	2	1	2	1.83	2.15
2. Clear Delegation of Responsibility (p20)	5	5	5	4	2	5	1	1	3	1	5	2	3.25	3.11
D. Employment														
1. Retention Plan For Experienced Personnel (p20)	5	5	2	2	1	0	2	2	0	2	2	1	2.00	2.55
2. Exit Interview (p21)	1	1	4	5	1	0	1	1	0	1	2	3	1.67	2.42
CONSTRUCTION METHODS														
A. Sequence and Scheduling of Work														
1. Integrated Schedule (p22)	4	2	4	3	4	2	0	0	4	2	3	5	2.75	2.57
2. Work Schedule Strategies (p22)	5	2	3	5	2	3	0	0	3	3	3	4	2.75	2.57
3. Schedule Execution and Management (p23)	5	2	3	2	1	3	0	0	3	2	3	3	2.25	2.02
B. Start-Up, Commission, and Turnover Plan														
1. Planning for Start-Up (p24)	5	4	2	2	1	2	0	0	0	2	0		1.64	2.85
2. Testing Procedures (p24)	5	5	3	5	4	3	0	0	3	3	4	4	3.25	2.93
3. System Turnover Procedure (p25)	4	4	3	5	2	5	0	0	2	2	4	3	2.83	2.88
C. New Product Investigation														
1. New equipment investigation (p25)	2	3	2	3	3	3	0	0	0	0	3	3	1.83	1.97
2. New information system investigation (p26)	4	3	2	3	1	1	0	0	0	3	3	3	1.92	2.08
3. New materials technologies Investigation (p26)	3	3	2	3	1	0	0	0	0	0	3	3	1.50	2.09
D. Site Layout Plan														
1. Dynamic site layout plan (p27)	4	5	5	5	2	1	0	0	5	1	3		2.82	4.36
2. Site security plan (p28)	4	3	3	2	4	1	0	0	2	2	3		2.18	1.96
3. Equipment positioning strategy (p28)	2	2	3	2	3	1	0	0	2	1	3		1.73	1.22
ENVIRONMENT, SAFETY, AND HEALTH														
A. Job Safety														
1. Zero Accident Techniques (p30)	5	5	5	5	5	2	5	5	5	4	5	5	4.67	0.79
2. Task Safety Analysis (p30)	5	5	5	5	5	5	5	5	5	5	5	5	5.00	-
3. Identification of Potential Hazards (p31)	4	4	5	5	5	5	5	5	5	5	5	5	4.83	0.15
4. Housekeeping (p31)	3	4	5	4	5	5	5	5	4	5	4	5	4.50	0.45
5. System test hazards planning (p31)	5	5	5	4	5	3	0	0	0	4	4		3.18	4.56
B. Substance Abuse Programs														
1. Substance Abuse Programs (p32)	0	0	0	0	0	0	0	0	0	0	0	0		
C. Safety Training and Orientation														
1. OSHA Compliance Training (p33)	5	5	5	4	5	4	2	2	4	2	1	2	3.42	2.27
2. Toolbox safety meetings (p33)	3	4	5	5	5	4	4	4	5	4	5	3	4.25	0.57
BPPII Score (%)	61.05	53.75	57.55	45.75	42.70	33.45	14.65	14.65	40.10	26.20	46.70	40.40	39.75	231.2

Prioritization of practice elements for improving in the Partner Company

BPPII Practice Element	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Sub-Total
MATERIALS MANAGEMENT										
A. Materials Management Systems										
1. Project team material status database (p4)	3	2	3	2	2	1	3	2	3	21
2. On-site material tracking technology (p4)	2	1	2	2	2	2	2	3	2	18
3. Material delivery schedule (p5)	2	2	1	2	2	3	2	1	1	16
4. Procurement plan for materials and equipment (p5)	1	2	0	3	2	3	2	1	1	15
B. Receipt and Inspection of Materials										
1. Material inspection process (p6)	3	1	3	2	0	2	1	0	0	12
2. Material inspection team (p6)	3	1	0	2	0	2	1	2	2	13
3. Post receipt preservation and maintenance (p7)	2	1	0	1	1	2	2	2	2	13
EQUIPMENT LOGISTICS										
A. Site Tool Management										
1. Site tool and consumables management strategy (p8)	3	2	2	3	1	2	3	2	1	19
2. Tool tracking systems (p8)	2	2	0	2	2	2	3	1	1	15
3. On-Site tool maintenance (p9)	1	1	0	2	1	2	3	1	1	12
4. Control system for tool delays (p9)	1	2	1	1	2	2	2	1	1	13
B. Machinery Availability										
1. Construction machinery productivity analysis (p10)	2	3	0	1	1	2	2	2	1	14
2. Equipment maintenance (p10)	2	3	3	1	2	2	2	1	2	18
CRAFT INFORMATION SYSTEMS										
A. Short Interval Planning										
1. Short Interval Planning (p11)	1	2	1	3	3	3	2	2	1	18
B. Work Face Planning										
1. Well defined scope of work (p11)	3	2	2	2	3	3	3	2	2	22
2. Utilization of software to assist in generating work packages	3	1	0	1	2	3	3	3	2	18
3. Project model requirements (p13)	2	2	2	2	2	3	2	2	2	19
4. Dedicated Planner (p13)	3	1	3	2	2	2	3	2	2	20
5. Identify required permitting (p14)	2	1	2	2	1	2	2	1	1	14
6. Engineering Work Packages (EWP) (p14)	3	2	3	2	2	2	2	3	0	19
7. Construction Work Packages (CWP) (p15)	3	3	3	2	2	3	3	3	3	25
8. Field Installation Work Packages (FIWP) (p16)	3	3	2	2	3	3	3	3	3	25
C. Constructability Review										
1. Design readiness for construction (p16)	2	3	0	3	0	2	3	2	0	15
2. PPMOF evaluation (p17)	1	3	0	3	0	2	3	1	0	13
HUMAN RESOURCE MANAGEMENT										
A. Training and Development										
1. Trades technical training (p18)	1	0	0	3	1	2	3	1	0	11
2. Career development (p18)	1	2	1	3	2	2	3	1	2	17
B. Behavior										
1. Nonfinancial Incentive Programs (p18)	1	3	3	2	2	2	2	1	3	19

Prioritization of practice elements for improving in the Partner Company

BPPII Practice Element	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Sub-Total
2. Financial Incentive Programs (p19)	1	1	2	2	3	2	2	1	2	16
3. Social Activities (p19)	1	3	0	1	2	1	3	2	2	15
C. Organizational Structure										
1. Maintain Stability of Organization Structure (p20)	1	2	2	3	2	2	3	2	1	18
2. Clear Delegation of Responsibility (p20)	1	2	2	3	2	1	3	1	2	17
D. Employment										
1. Retention Plan For Experienced Personnel (p20)	2	0	3	2	3	1	3	2	3	19
2. Exit Interview (p21)	1	3	0	1	3	2	2	0	3	15
CONSTRUCTION METHODS										
A. Sequence and Scheduling of Work										
1. Integrated Schedule (p22)	2	1	3	3	2	2	1	2	2	18
2. Work Schedule Strategies (p22)	1	1	3	3	3	2	2	2	2	19
3. Schedule Execution and Management (p23)	3	2	3	3	3	2	3	2	3	24
B. Start-Up, Commission, and Turnover Plan										
1. Planning for Start-Up (p24)	1	2	2	3	3	3	3	2	3	22
2. Testing Procedures (p24)	2	1	3	3	2	2	2	1	1	17
3. System Turnover Procedure (p25)	1	1	2	2	2	3	2	1	1	15
C. New Product Investigation										
1. New equipment investigation (p25)	1	1	0	2	0	2	3	2	2	13
2. New information system investigation (p26)	1	1	0	2	2	1	2	3	2	14
3. New materials technologies Investigation (p26)	1	2	0	2	2	1	2	3	2	15
D. Site Layout Plan										
1. Dynamic site layout plan (p27)	3	2	1	3	1	1	3	1	2	17
2. Site security plan (p28)	1	2	1	2	2	2	2	1	2	15
3. Equipment positioning strategy (p28)	1	3	2	2	2	2	3	1	2	18
ENVIRONMENT, SAFETY, AND HEALTH										
A. Job Safety										
1. Zero Accident Techniques (p30)	1	0	3	0	0	3	3	1	2	13
2. Task Safety Analysis (p30)	1	0	3	0	0	3	2	0	0	9
3. Identification of Potential Hazards (p31)	1	0	3	3	0	3	2	0	0	12
4. Housekeeping (p31)	1	2	3	3	0	3	2	0	0	14
5. System test hazards planning (p31)	1	0	3	0	0	2	2	0	0	8
B. Substance Abuse Programs										
1. Substance Abuse Programs (p32)	1	1	3	0	0	0	3	2	0	10
C. Safety Training and Orientation										
1. OSHA Compliance Training (p33)	1	1	3	0	0	2	2	1	0	10
2. Toolbox safety meetings (p33)	1	0	3	3	0	2	2	1	0	12

Appendix N

Raw Data Set for Practices Implementation Gaps Analysis

BPPII Element	PIL_{avg}	StdDev	$PIL_{CorpGuide}$	CII_{avg}	WoEffect
MATERIALS MANAGEMENT					
A. Materials Management Systems					
1. Project team material status database (p4)	2.40	1.14	3	2.68	36
2. On-site material tracking technology (p4)	1.67	0.82	3	2.35	45
3. Material delivery schedule (p5)	2.14	0.69	4	2.82	59
4. Procurement plan for materials and equipment (p5)	2.43	0.53	4	3.35	56
B. Receipt and Inspection of Materials					
1. Material inspection process (p6)	3.43	0.79	4	3.56	63
2. Material inspection team (p6)	2.71	1.80	5	3.76	48
3. Post receipt preservation and maintenance (p7)	2.43	1.51	5	3.32	50
EQUIPMENT LOGISTICS					
A. Site Tool Management					
1. Site tool and consumables management strategy (p8)	3.10	1.37	5	3.65	38
2. Tool tracking systems (p8)	1.80	0.79	3	2.41	29
3. On-Site tool maintenance (p9)	1.44	0.53	5	2.65	28
4. Control system for tool delays (p9)	1.38	0.52	3	2.21	25
B. Machinery Availability					
1. Construction machinery productivity analysis (p10)	1.40	0.70	0	2.62	67
2. Equipment maintenance (p10)	1.89	0.95	0	2.65	106
CRAFT INFORMATION SYSTEMS					
A. Short Interval Planning					
1. Short Interval Planning (p11)	2.75	0.89	4	3.71	74
B. Work Face Planning					
1. Well defined scope of work (p11)	2.38	1.06	3	3.32	19
2. Utilization of software to assist in generating work packages	1.50	0.58	2	2.15	11
3. Project model requirements (p13)	1.33	0.82	1	1.62	12
4. Dedicated Planner (p13)	1.86	0.90		2.68	15
5. Identify required permitting (p14)	2.30	0.48	2	2.88	13
6. Engineering Work Packages (EWP) (p14)	1.60	0.55	0	2.74	14
7. Construction Work Packages (CWP) (p15)	1.33	0.52	0	3.09	15
8. Field Installation Work Packages (FIWP) (p16)	2.29	1.11	0	2.76	15
C. Constructability Review					
1. Design readiness for construction (p16)	3.38	0.92	2	3.79	67
2. PPMOF evaluation (p17)	4.43	0.79	4	2.79	40
HUMAN RESOURCE MANAGEMENT					
A. Training and Development					
1. Trades technical training (p18)	3.60	0.70	5	3.41	47
2. Career development (p18)	2.60	1.43	0	2.38	33
B. Behavior					
1. Nonfinancial Incentive Programs (p18)	2.50	1.35	0	3.65	24
2. Financial Incentive Programs (p19)	2.63	1.77	4	2.82	28
3. Social Activities (p19)	1.44	0.53	3	2.18	16
C. Organizational Structure					
1. Maintain Stability of Organization Structure (p20)	2.71	1.11	3	3.00	32
2. Clear Delegation of Responsibility (p20)	3.20	1.81	5	3.74	36
D. Employment					
1. Retention Plan For Experienced Personnel (p20)	2.63	1.51	5	2.65	46
2. Exit Interview (p21)	1.88	1.64	5	2.15	21

CONSTRUCTION METHODS					
A. Sequence and Scheduling of Work					
1. Integrated Schedule (p22)	3.13	0.99	0	3.97	47
2. Work Schedule Strategies (p22)	3.25	1.16	0	3.18	30
3. Schedule Execution and Management (p23)	2.63	1.19	0	3.47	46
B. Start-Up, Commission, and Turnover Plan					
1. Planning for Start-Up (p24)	2.57	1.40	0	3.41	36
2. Testing Procedures (p24)	3.88	0.99	5	3.88	28
3. System Turnover Procedure (p25)	3.38	1.30	5	4.03	34
C. New Product Investigation					
1. New equipment investigation (p25)	2.67	0.52	2	1.82	20
2. New information system investigation (p26)	2.43	1.13	3	2.24	16
3. New materials technologies Investigation (p26)	2.40	0.89	2	1.74	18
D. Site Layout Plan					
1. Dynamic site layout plan (p27)	3.50	1.85	0	3.82	38
2. Site security plan (p28)	2.63	1.06	0	3.53	29
3. Equipment positioning strategy (p28)	2.00	0.76	0	2.47	36
ENVIRONMENT, SAFETY, AND HEALTH					
A. Job Safety					
1. Zero Accident Techniques (p30)	4.60	0.97	5	4.29	38
2. Task Safety Analysis (p30)	5.00		5	4.32	36
3. Identification of Potential Hazards (p31)	4.80	0.42	5	4.38	34
4. Housekeeping (p31)	4.50	0.71	0	4.12	31
5. System test hazards planning (p31)	4.43	0.79	5	3.68	24
B. Substance Abuse Programs					
1. Substance Abuse Programs (p32)	0.00	0.00	5	3.68	88
C. Safety Training and Orientation					
1. OSHA Compliance Training (p33)	3.80	1.32	5	3.74	62
2. Toolbox safety meetings (p33)	4.30	0.67	5	4.24	81

Appendix O

BPPII Scoring Content	Normalized Gaps Factors					Priority
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	
	5-PIL_{avg}	CII_{avg}-PIL_{avg}	5-$PIL_{CorpGuide}$	StdDev	WoEffect	
MATERIALS MANAGEMENT						
A. Materials Management Systems						
1. Project team material status database (p4)	2.60	2.64	2	2.28	1.70	11.22
2. On-site material tracking technology (p4)	3.33	2.84	2	1.63	2.00	11.81
3. Material delivery schedule (p5)	2.86	2.84	1	1.38	2.47	10.54
4. Procurement plan for materials and equipment (p5)	2.57	2.96	1	1.07	2.37	9.97
B. Receipt and Inspection of Materials						
1. Material inspection process (p6)	1.57	2.57	1	1.57	2.60	9.31
2. Material inspection team (p6)	2.29	3.03	0	3.60	2.10	11.01
3. Post receipt preservation and maintenance (p7)	2.57	2.95	0	3.02	2.17	10.71
EQUIPMENT LOGISTICS						
A. Site Tool Management						
1. Site tool and consumables management strategy (p8)	1.90	2.77	0	2.74	1.77	9.18
2. Tool tracking systems (p8)	3.20	2.81	2	1.58	1.47	11.05
3. On-Site tool maintenance (p9)	3.56	3.10	0	1.05	1.43	9.14
4. Control system for tool delays (p9)	3.63	2.92	2	1.04	1.33	10.91
B. Machinery Availability						
1. Construction machinery productivity analysis (p10)	3.60	3.11	5	1.40	2.73	15.84
2. Equipment maintenance (p10)	3.11	2.97	5	1.90	4.03	17.02
CRAFT INFORMATION SYSTEMS						
A. Short Interval Planning						
1. Short Interval Planning (p11)	2.25	2.98	1	1.77	2.97	10.97
B. Work Face Planning						
1. Well defined scope of work (p11)	2.63	2.97	2	2.12	1.13	10.85
2. Utilization of software to assist in generating work packages	3.50	2.82	3	1.15	0.87	11.34
3. Project model requirements (p13)	3.67	2.64	4	1.63	0.90	12.84
4. Dedicated Planner (p13)	3.14	2.91	5	1.80	1.00	13.85
5. Identify required permitting (p14)	2.70	2.79	3	0.97	0.93	10.39
6. Engineering Work Packages (EWP) (p14)	3.40	3.07	5	1.10	0.97	13.53
7. Construction Work Packages (CWP) (p15)	3.67	3.38	5	1.03	1.00	14.08
8. Field Installation Work Packages (FIWP) (p16)	2.71	2.74	5	2.23	1.00	13.68
C. Constructability Review						
1. Design readiness for construction (p16)	1.63	2.71	3	1.83	2.73	11.90
2. PPMOF evaluation (p17)	0.57	1.68	1	1.57	1.83	6.66
HUMAN RESOURCE MANAGEMENT						
A. Training and Development						
1. Trades technical training (p18)	1.40	2.41	0	1.40	2.07	7.27
2. Career development (p18)	2.40	2.39	5	2.86	1.60	14.25
B. Behavior						

Appendix O

BPPII Scoring Content	Normalized Gaps Factors					Priority
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	
	5-PIL.avg	CII.avg-PIL.avg	5-PIL.manual	St.Dev	W.effect	
1. Nonfinancial Incentive Programs (p18)	2.50	3.07	5	2.71	1.30	14.58
2. Financial Incentive Programs (p19)	2.38	2.60	1	3.54	1.43	10.94
3. Social Activities (p19)	3.56	2.87	2	1.05	1.03	10.51
C. Organizational Structure						
1. Maintain Stability of Organization Structure (p20)	2.29	2.64	2	2.23	1.57	10.72
2. Clear Delegation of Responsibility (p20)	1.80	2.77	0	3.63	1.70	9.89
D. Employment						
1. Retention Plan For Experienced Personnel (p20)	2.38	2.51	0	3.01	2.03	9.93
2. Exit Interview (p21)	3.13	2.64	0	3.28	1.20	10.25
CONSTRUCTION METHODS						
A. Sequence and Scheduling of Work						
1. Integrated Schedule (p22)	1.88	2.92	5	1.98	2.07	13.85
2. Work Schedule Strategies (p22)	1.75	2.46	5	2.33	1.50	13.04
3. Schedule Execution and Management (p23)	2.38	2.92	5	2.38	2.03	14.71
B. Start-Up, Commission, and Turnover Plan						
1. Planning for Start-Up (p24)	2.43	2.92	5	2.79	1.70	14.84
2. Testing Procedures (p24)	1.13	2.50	0	1.98	1.43	7.04
3. System Turnover Procedure (p25)	1.63	2.83	0	2.60	1.63	8.69
C. New Product Investigation						
1. New equipment investigation (p25)	2.33	2.08	3	1.03	1.17	9.61
2. New information system investigation (p26)	2.57	2.40	2	2.27	1.03	10.28
3. New materials technologies Investigation (p26)	2.60	2.17	3	1.79	1.10	10.66
D. Site Layout Plan						
1. Dynamic site layout plan (p27)	1.50	2.66	5	3.70	1.77	14.63
2. Site security plan (p28)	2.38	2.95	5	2.12	1.47	13.92
3. Equipment positioning strategy (p28)	3.00	2.74	5	1.51	1.70	13.95
ENVIRONMENT, SAFETY, AND HEALTH						
A. Job Safety						
1. Zero Accident Techniques (p30)	0.40	2.35	0	1.93	1.77	6.45
2. Task Safety Analysis (p30)	0.00	2.16	0	0.00	1.70	3.86
3. Identification of Potential Hazards (p31)	0.20	2.29	0	0.84	1.63	4.97
4. Housekeeping (p31)	0.50	2.31	5	1.41	1.53	10.76
5. System test hazards planning (p31)	0.57	2.12	0	1.57	1.30	5.57
B. Substance Abuse Programs						
1. Substance Abuse Programs (p32)		2.50	0	0.00	3.43	5.93
C. Safety Training and Orientation						
1. OSHA Compliance Training (p33)	1.20	2.47	0	2.63	2.57	8.87
2. Toolbox safety meetings (p33)	0.70	2.47	0	1.35	3.20	7.72

The Partner Company

MARK-UP ASSIGNMENT WORK SHEET

Project # **Location:** **Area:** **Date:**

Item	Equipment / Activity	Proposed Assignment	Trade Claim	Final Assignment

Unions

IBEW - electrician
UA - Plumbers,fitters
IW - ironworkers
MW - Millwrights
SM - Sheet Metal
Lab - Labourers
OE - Operating eng
Carp - Carpenters
INS - Insulators
Team - Teamsters
BM - Boilermakers

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