Best Productivity Practices Implementation Index (BPPII) for Infrastructure Projects

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Civil Engineering

Waterloo, Ontario, Canada, 2013

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.

I understand that my thesis may be made electronically available to the public.

Abstract

According to the Nobel Prize winner Paul Krugman, "*productivity isn't everything, but in the long-run it is almost everything*". It is unfortunate that the productivity in the construction industry has lagged behind the manufacturing industry for the last several decades. The research presented in this thesis aims to improve productivity in the infrastructure sector of the construction industry by developing and validating Best Productivity Practices Implementation Index (BPPII) for Infrastructure projects.

The BPPII Infrastructure is a check list of practices that are considered to have a positive influence on labour productivity at the project level for infrastructure projects. These practices have been identified through a literature review and consultation with industry experts, and have been anecdotally proven to positively affect productivity. These practices have been grouped together into a formalized set of BPPII's categories, sections, and elements. Each practice and its planning and implementation levels have been completely defined. Each practice in the index has been assigned a relative weight based on its importance in affecting labour productivity. In total, there are 61 elements, 20 sections, and 6 categories. The six categories of the BPPII Infrastructure are: (1) Materials Management; (2) Construction Machinery and Equipment Logistics; (3) Execution Approach; (4) Human Resources Management; (5) Construction Methods; and (6) Health and Safety.

The productivity factor defined as a ratio of estimated productivity and actual productivity was used as a metric to collect information about labour productivity. Data were collected for infrastructure projects on the planning and implementation level of practices, on the productivity factor, and on project schedule performance.

The research hypothesis tested was that projects that have a high level of implementation of best practices as defined by the BPPII Infrastructure will have a better productivity performance than projects which have a low level of implementation of best practices. The regression analysis confirms that the BPPII score has a strong positive relationship with the productivity factor. ANOVA tests confirm that there is statistically significant difference between the productivity of projects that have a high level of implementation of practices and those that have a low level of implementation. Also, it was found that projects that have a high score on the index perform better in terms of project schedule performance than projects which have a low score on the BPPII Infrastructure.

Acknowledgements

With utmost humbleness, I thank God for giving me the courage, strength, and patience to complete this research. First of all, I would like to acknowledge the efforts of my supervisor, Dr. Carl T. Haas for guiding me through this journey. I have learned a lot from him during the past six years in which I completed my Master's degree and this research. Besides his academic excellence, technical skills, and visionary thinking, I find him to be a true gentleman.

I also want to thank my committee members, Prof. Ralph Haas, Prof. Jeffrey West, Prof. Keith Hipel, and Prof. Mohamed Al-Hussein. I am grateful that they agreed to be my committee members and their constructive feedback is much appreciated.

I would also like to acknowledge the members of the Construction Industry Institute's Research Team 252, particularly, Prof. Paul M. Goodrum, University of Colorado at Boulder and Prof. Carlos Caldas, University of Texas at Austin. I am indebted to them for making my research as part of their team work and providing valuable feedback.

A special thank you goes to the Natural Sciences and Engineering Research Council of Canada for awarding me the Postgraduate Scholarship for doctoral studies. Without their financial assistance, this research would not have happened. Also, I would like to acknowledge the Construction Sector Council of Canada for providing funding for the earlier part of my research.

I have enjoyed the friendship and company of a number of people during my stay at the University of Waterloo. It is difficult to mention all the names here; however, they will always have a special place in my life.

Finally and most importantly, I must acknowledge the support, love, and prayers of my family, without them nothing would have been possible. My stay at Waterloo kept me away from my mother who has always prayed for my success. My wife, Safia has supported me unconditionally throughout my life and took extra responsibilities which allowed me to focus on my work. My sons Abdul Ahad and Ahmed Hassan did not get the full attention from me that they deserve because of my busy schedule and missed my presence on several occasions. I am sure my family will feel proud of me and jointly share my success.

Dedication

I dedicate this thesis to

My Family

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Chapter 1

Introduction

1.1 Introduction

Infrastructure projects are vital for the economic, social, and environmental well-being of a country. It is widely accepted that the quality of our infrastructure directly impacts the quality of life and economic prosperity of our communities. The construction industry is a major contributor to the economy of a nation, and infrastructure projects account for a major portion of the construction business.

In recent years, Canada's federal government announced expanding federal investments in infrastructure with the Building Canada plan launched in 2007 with $33 billion in investments. The Economic Action Plan 2013 has initiated a new Building Canada plan to build bridges, subways, commuter rail and other public infrastructure in partnership with provinces, territories, and municipalities. Overall, the new Building Canada plan, together with other federal investments will result in $70 billion in federal funding over the next 10 years (Canada Federal Budget 2013). The volume of infrastructure construction in the United States of America is much higher than Canada. These amounts are in addition to that required for the maintenance and rehabilitation of the existing infrastructure, the majority of which has reached its service or design life. In a study undertaken by the Federation of Canadian Municipalities (FCM) in 2007, the infrastructure deficit of municipal governments has been reported as a staggering $123 billion (Mirza 2007). Similar studies have shown that this deficit is increasing at an alarming rate and the infrastructure assets need immediate attention in terms of repair, maintenance, or renewal (FCM & McGill 1996; CSCE, CCPE, CPWA, NRC 2003; Mirza 2007). According to the Report Card of the American Society of Civil Engineers (ASCE) on infrastructure of the United States of America (USA), $3.6 Trillion are required to bring the country's infrastructure system to acceptable levels (ASCE 2013).

All together, the volume of infrastructure construction will grow and with it the need to improve the construction productivity in order to optimize current and future construction expenditures. Construction productivity directly affects the prices of construction projects and the robustness of the national economy. It also affects the outcomes of the national efforts for the renewal of existing infrastructure systems, for building new infrastructure, and competitiveness in the global market (NRC 2009).

Improving productivity is a management issue, and the use of new technologies and techniques may be helpful, but not a sufficient condition (Rojas and Aramvareekul 2003). While there are certainly opportunities in new innovations to improve construction productivity, innovations are likely to have little impact on productivity, if established processes and practices that are recognized as being necessary to control and improve productivity are not being effectively utilized first. Analysis by the Construction Industry Institute's (CII) Research Teams 240 and 252 of CII Benchmarking and Metrics (BM&M) data has clearly shown that productivity typically deviates 25% more or less from the norm on any particular project within a group with similar characteristics and environments (CII 2009).

The research presented lays out a strategy to help improve the productivity of the infrastructure construction sector. It is based on the premise that what is measured will be improved. To effectively manage an industry, a project, or an activity, measurement tools are required. As a result, the proposed research was designed to improve the measurement of practices and the performance of productivity at the project level of the infrastructure construction sector by developing the Best Productivity Practices Implementation Index (BPPII) for infrastructure projects.

Development of the Best Productivity Practices Implementation Index (BPPII) as a measurement tool as this research intends, has the potential to have a substantial impact in terms of its influence on improving the productivity of the industry during an especially crucial time in our history. Because of the total investments required in the infrastructure construction sector, improving construction labour productivity by only a few percent could save many tens or hundreds of millions of dollars in the years ahead.

1.2 Research Need

According to the European Construction Industry Federation (FIEC), the construction industry constitutes 9.7 percent of the gross domestic product (GDP) in the European Union (EU) with a total construction value of 1,186 billion € in 2010, providing 6.6% of Europe's total employment (FIEC, Annual Report, 2011). In Canada, the construction industry is estimated to have contributed 5.6% of the GDP in 2010 (Statistics Canada, 2010); and in the US, the construction industry accounted for 5.3% of the GDP in 2011 (US Census Bureau 2012; US Bureau of Economic Analysis (BEA), 2012). This difference between the contribution of construction industry to the GDP in the European Union and North America is due to measurement definitions. Almost 11 million people, about 8 percent of the total US workforce, were directly employed in the construction industry (BLS, 2008). In order for the construction industry to contribute to economic growth with other industries, construction productivity must grow along with other industries. Therefore, the productivity of a major sector like construction in a national economy is of great importance. Improving productivity in the infrastructure construction sector will help in improving productivity in the overall construction industry as it represents a major portion of the overall construction industry.

There are opposite views between researchers whether productivity in the construction industry has declined or increased over the years. Different studies have contrasting opinions about this issue. One possible reason for this difference of opinion is looking at the macro and micro level of the construction industry. Some reports for the construction industry as a whole indicate that the productivity has declined for the last 30 years or more. Other studies report that productivity has improved at project and task level (NRC 2009; Nasir et al. 2012a).

Studies undertaken by Triplett and Bosworth (2004) have concluded that productivity in the construction industry in the United States (US) has declined between the periods form 1995 to 2001. Abdel-Wahab et al. (2008) found that construction productivity in United Kingdom (UK), measured in Gross Value Added (GVA) per worker, was generally flat from 1995 to 2006. Their graphs show that it increases during the periods of stable employment and decreases during periods of rapid employment growth. Statistics Canada carried a

Canadian Productivity Review for the period from 1961 to 2008 and reported that the construction industry did not contribute to the negative growth; however, rate of increase was minimal. Between the periods from 2000-2007, the Canadian construction industry labour productivity growth was a positive 0.1% per year compared to the United States negative growth of 0.3% per year (Baldwin and Gu 2009). Harrison (2007) also estimated that between 1961 and 2005, the construction productivity in the US declined at 1.44% annually, whereas between 1961 and 2006, the construction productivity in Canada increased at 1.09% annually.

However, studies based on micro-economic data have painted a different picture. The research conducted by Goodrum et al. (2002) and Goodrum and Haas (2002), examined labour and partial factor productivity trends using microeconomic data for 200 construction activities to examine the relationship between equipment technology and construction productivity. Their analyses indicated considerable improvement in construction labour productivity across multiple construction divisions ranging from 0.2% to 2.8% per year between 1976 and 1998, particularly in machinery related divisions such as site work. Similar improvement was noticed in partial factor productivity for the 200 construction activities. In another work, to analyze the relationship between material technology and construction productivity, the average percentage change in the labour productivity of an additionally sampled 100 activities was noticed to have an annual improvement compound rate of 0.47% between 1977 and 2004 (Goodrum et al. 2009). More recently, Nasir et al. (2012a) reported that labour productivity remains almost the same in the building sub-sector and that partial factor productivity has improved roughly at an annual compound rate of 0.66% from 1995 to 2009 in the US. In addition to these measured improvements, there is also anecdotal evidence shared among some industry experts which has indicated that construction productivity has actually improved (Bernstein 2003; Tuchman 2004).

No matter whether the construction productivity has increased or decreased depending on how the productivity is measured, there is no reason to disagree that there is room for improvement of construction productivity. Even if it is believed that the productivity is increasing, the rate of increase is not desirable. While rates of productivity improvement seem to decline with higher absolute levels of productivity for countries, there is no evidence that a high absolute productivity level precludes significant growth rates (Nasir et al. 2012a).

One possible way of improving productivity at a project level is the use of practices that have the potential to positively affect productivity. The Construction Industry Institute (CII) has developed a set of practices for improving project performance. The CII's practices are called as the "Best Practices". It is important to understand that the CII best practices are not just developed for use at the construction phase; they are also developed for earlier phases of projects. They are developed at a highest or Meta level and measures of their implementation for Benchmarking and Metrics have not defined implementation levels for practices. One of the major drivers of a Best Productivity Practices Implementation Index (BPPII) is to define a set of practices that are defined completely in terms of implementation levels. The CII best practices can be described as a set of key indicators; whereas, in the

BPPII we are not just looking for a set of key indicators, it consists of a completely defined, comprehensive set of best practices for productivity performance. There is a large amount of literature available on factors that influence productivity, but no index exists for a set of completely defined best practices for improving it on a project. For the purpose of this research, “best” practices, are defined as those that indicate potential for positive influence based on literature or expert opinion. The CII definition of “best” practices is not being used in this thesis.

There is a research gap to find the relationship between the implementation level of practices and productivity. Various research studies have been performed to find the factors that affect productivity. Factors have been categorized into those that improve productivity and those that cause productivity losses. Also, practices have been identified that have the potential to improve performance and productivity in the construction industry, such as CII’s. However, there has been little or no research work done to develop an index based on the implementation level of practices to improve productivity for the infrastructure construction sector. Also, little or no research work has been performed to see if there are any statistically significant differences between productivity of projects having a high level implementation of practices and those having a low implementation level of practices. This research fills this gap by developing the BPPII for infrastructure projects, gathering data to explore its potential effectiveness, and analyzing that data.

1.3 Related Work on the Best Productivity Practices Implementation Index

The Construction Industry Institute (CII) Research Team 252 (RT 252) "Craft Productivity Research Program" has developed the Best Productivity Practices Implementation Index (BPPII) for the industrial sector of the construction industry (CII 2013). 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 industry workshops, and on research that has validated construction practices that improve craft worker productivity.

Construction processes on infrastructure projects are inherently different than processes on industrial projects; therefore, the industrial sector BPPII cannot be directly applied to infrastructure construction projects. Infrastructure projects require significantly more utility realignment, traffic control, coordination with right-of-way acquisition, balancing haul trucks, load trucks, and other heavy machinery as well as other project processes that are not addressed in the BPPII Industrial. They are also significantly more capital intensive.

It is pertinent to mention here that widely used sets of practice indices exist for the construction industry of which an index exists for each sector. For example, there are different CII Project Definition Rating Indices (PDRI) for buildings, industrial, and infrastructure sectors of the construction industry (CII 2010a; Gibson et al. 2010). These are explained in more detail in the next chapters. The reason for separate PDRIs for buildings, industrial, and infrastructure sectors is because all these sectors have different requirements or needs, which require that a separate index should be designed for them. Therefore, a separate BPPII for infrastructure projects is also needed.

1.4 Objectives

The main objective of this research is to develop a process for improving project labour productivity in the infrastructure construction sector. This objective would be achieved by developing the Best Productivity Practices Implementation Index (BPPII) for infrastructure projects. The following sub-objectives are required to achieve the main research objective:

- Identify and define the categories, sections, and elements of the BPPII for Infrastructure Projects

- Validate that there is a relationship between the BPPII score for infrastructure projects and project productivity

These research objectives are achieved by identifying, mapping, and measuring processes or practices which are essential for improving construction productivity at the project level for the infrastructure construction sector and by collecting and analyzing data for validation.

1.5 Scope

The scope of the research was to identify potential best practices based on literature review and expert opinions like those of members of the Construction Industry Institute (CII) Research Team 252, and develop an implementation index based on these practices for increasing productivity at the project level for the infrastructure construction sector. Practices which have the potential of increasing construction productivity were identified and grouped together, and an implementation index was developed. The scope of the research was limited to the infrastructure construction sector and to differences in labour productivity at the project level.

1.6 Hypothesis Statement

This research is based on the hypothesis that, "a higher level of implementation of the practices defined in the BPPII relates significantly to a higher level of productivity performance."

1.7 Methodology

The methodology used in this research builds on the efforts and methodology used in the development of the BPPII for industrial projects by the CII RT 252 and on the Construction Sector Council's (CSC), Canada, benchmarking and metrics program for improving labour productivity and project performance. Both of these programs focused on improving labour productivity through the use of best practices. The CII's initial efforts were mainly directed towards the labour productivity improvement in the industrial construction sector, for which they developed BPPII Industrial. Later on, the RT 252 also decided to develop a similar tool for infrastructure projects. However, the CSC's program was specifically focused on the improvement of labour productivity for infrastructure projects (Nasir et al. 2012b).

The development of the BPPII for the infrastructure sector involves a thorough investigation of the available literature on the improvement of construction productivity. The available literature on the reasons for low productivity and different techniques, practices, and methods for productivity improvements were analyzed and synthesized. After the literature review, several steps were required to develop and validate the BPPII infrastructure. These were: (1) Identify best productivity practices for the infrastructure sector; a structured process was used to derive, categorize and produce an ontology of best practices for infrastructure construction; (2) Synthesize the initial input into a formalized set of BPPII's categories, sections, and elements; (3) Assign weights to each of the individual elements, sections, and categories that are part of the BPPII based on their relative importance in influencing labour productivity; (4) Validate the index by obtaining data on projects' scores on the BPPII and their productivity performance; and (5) Analyze validation data to obtain preliminary results describing relationships between best practices and productivity and project performance. Extensive collaboration with industry was required to complete these steps. Figure 1.1 illustrates the overall research methodology adopted in this research.

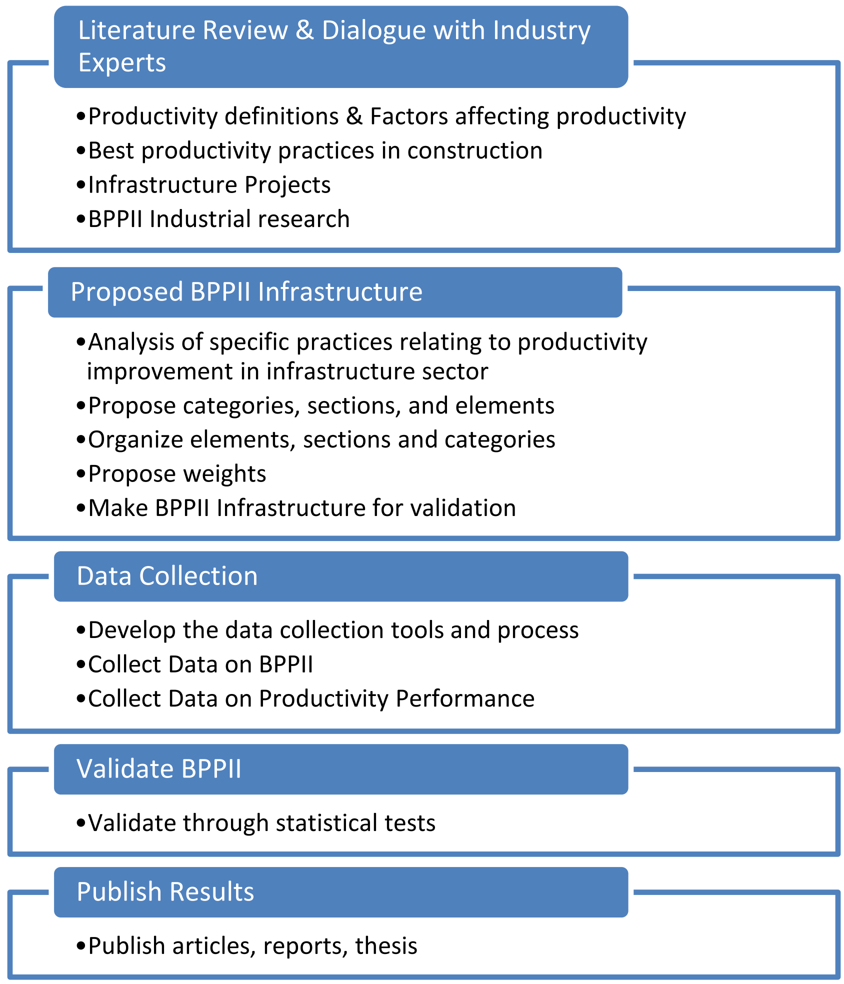


Figure 1.1: Research methodology and development of BPPII Infrastructure

1.8 Organization of this Proposal

This thesis is organized in nine chapters. The first chapter provides the introduction, background information, problem statement, research hypothesis, objectives, scope and methodology of the proposed BPPII for infrastructure projects. The second chapter discusses various definitions of labour productivity, literature review of factors affecting labour productivity, and framework for measuring and improving productivity in the construction industry. The third chapter deals with the use of practices in the construction industry, and provides a review of a few indices based on the use of practices in the construction industry. Chapter 4 explains the BPPII for infrastructure projects. It explains the organization and descriptions of all elements, sections, and categories of the index. Chapter 5 explains the data collection process and data collection tool used to collect the validation information for this research. This chapter also explains the use of productivity factor as a metric for collecting labour productivity performance information. The sixth chapter describes the weighting procedure for assigning relative weights to the elements, sections, and categories of the BPPII Infrastructure. Chapter 7 deals with the data analyses, which include both the descriptive and inferential statistics. The validation of the BPPII Infrastructure is also discussed in this chapter. Chapter 8 explains how the BPPII Infrastructure should be used by companies. The last chapter mentions the contributions of this research and suggests some recommendations for future research work.

Chapter 2

Background

This chapter provides background information on the measurement of construction productivity and factors that affect it. The first part of the chapter provides some definitions of construction productivity available in the literature. It is followed by a literature review of the factors that affect productivity. A framework for productivity improvement in the construction industry is also discussed. The last part of this chapter provides definitions for infrastructure construction projects.

2.1 Construction Productivity Definitions

The word productivity sounds simple however; it is complex and hard to define, particularly in the construction industry. There are many definitions found in the literature about productivity. Productivity can be expressed as the ratio of output divided by input or vice versa. Inputs in the construction industry include labour, energy, capital in the form of tools and equipment, and materials. Outputs in the construction industry are deliverables that add to the completion of a task or project. They are not products or tons of resources, as in the manufacturing and resource industries respectively. In construction, productivity is the amount of resources used to produce a given unit as output. Examples are labour hours per cubic metre of concrete poured or hours per square metre of area painted or hours per linear metre of conduit laid.

Productivity in construction is a complex issue in terms of its measurement and the factors which affect it. In fact there is no standard definition of productivity in the construction industry, because each company defines productivity depending on its own unique project controls system. Park et al. (2005) reported that there are no standard definitions or survey tools that can be used to collect productivity data in the US. The following definition will explain some of the complexities associated with the definition of productivity in construction industry.

> *"Productivity is the average direct labor hours to install a unit of material. In a perfect world, perfect productivity (1.0) would be accomplished in a 40-hour work week, with everyone taking all of their holidays and vacation days as planned. All of the engineering drawings would be 100 percent complete, there would be no delays of any kind, everyone would work safely, everything would fit perfectly the first time, the weather would be 70 degrees Fahrenheit, and there would be no litigation at the end of the project."* (Whiteside 2006)

There are several definitions or terms widely used for productivity in construction industry, depending upon the number of variables used in its calculation. The definitions and equations of the commonly used productivity terms are presented below.

2.1.1 Total Factor Productivity (Multi Factor Productivity)

The term Total Factor Productivity (TFP) is also called Multi Factor Productivity, and it represents multiple factors for producing an output. It is typically given by the equation:

Total Factor Productivity (TFP) =

$$\frac{\text{Total Output (\$)}}{\text{Labour (\$)+Material (\$)+ Equipment(\$)+ Energy (\$)+ Capital (\$)}}$$

$$= \frac{\text{Dollars of Output}}{\text{Dollars of Input}}$$

Total Factor Productivity (TFP) provides information about long-term economic growth and is a useful industry level productivity measure (Zhi et al. 2003). TFP is usually used in economic studies and represents an economic model measured in terms of dollars, as dollars are the only measures common to both inputs and outputs. This definition of productivity is useful for policy making and evaluating the state of the economy, however, it is not considered useful for construction projects (Thomas et al. 1990; Park 2002). It is not possible to accurately apply this to a specific construction project or site, because of the problems in tracking or estimating the various inputs.

2.1.2 Factor Productivity

A more reliable definition of productivity that is useful for government agencies for specific program planning and also by the private sector for conceptual estimates on individual projects is given by the equation Thomas et al. (1990):

$$\text{Factor Productivity} = \frac{\text{Physical Output (Units)}}{\text{Labour (\$)+ Circulating Capital (\$)+ Fixed Capital (\$)}}$$

$$\text{Factor Productivity} = \frac{\text{square feet}}{\text{Dollars}}$$

This definition of productivity is useful for project-specific purposes.

2.1.3 Labour Productivity/Single Factor Productivity

For construction projects, contractors are mostly interested in labour productivity. Labour productivity is defined by the following equation (Thomas and Mathew 1985; Thomas et al. 1990):

$$\text{Labour productivity} = \frac{\text{Output}}{\text{Labour cost (\$)}}$$

$$\text{Or Labour productivity} = \frac{\text{Output}}{\text{Work}-\text{hour}}$$

There is no standard definition of productivity, and contractors also use the inverse of above equation for defining labour productivity (Thomas et al. 1990).

$$\text{Labour productivity} = \frac{\text{Labour costs or Work}-\text{hours}}{\text{Output}}$$

$$\text{Labour productivity} = \frac{\text{Actual Work}-\text{hours}}{\text{Installed quantity}}$$

The above equation is also called the unit rate (Thomas et al. 1990). This definition of labour productivity comes under the single factor productivity definition, because a single factor that is labour is considered as the single input to calculate productivity. The above equation shows that labour productivity is measured in actual work-hours per installed quantity; that is, the actual number of work-hours required in completing the desired units of work, for example, hours per cubic metre of concrete. This is the predominant understanding of the term, “productivity” in the construction industry. It is very seldom modified with the adjective, “labour” in the industry, though “labour” is almost always implied.

2.1.4 Productivity Factor

Some contractors are interested in measuring productivity in terms of performance. The term Productivity Factor is used for measuring productivity performance. McDonald and Zack in a report for the American Association of Cost Engineers have provided an equation for productivity factor (McDonald & Zack 2004) as:

$$\text{Productivity Factor} = \frac{\text{Actual Productivity}}{\text{Baseline or Planned Productivity}}$$

Thomas et al. (1990) have stated that productivity can also be measured in terms of Performance Factor. Their equation for Productivity Performance Factor is given as:

$$\text{Productivity Performance Factor} = \frac{\text{Estimated unit rate}}{\text{Actual unit rate}}$$

Productivity Factor is used to measure labour productivity in this research and more details for using this as a metric are provided in Section 5.4.

As can be seen from the above discussion, the concept of construction productivity can be difficult to define, measure, and communicate as a result of incomparable inputs and outputs between varying projects, companies, and industry sectors. Another difficulty in analyzing productivity statistically arises from the fact that it has different units of measurement for each construction activity. However, for the purpose of the research work described in this thesis, the word productivity or construction productivity would mean labour productivity and is expressed in terms of work-hours per unit. It should be noted that labour productivity improvement and measurement is important for the construction industry because of the unique nature of the industry as well as the fact that it constitutes a large portion of the total cost of construction. Labour constitutes on average 30 to 40% of the total construction cost depending on the type of project (Mohammadian and Waugh 1997). Rivas et al. (2011) mentioned that researchers have reported that labour costs constitutes between 30 and 50% of total project cost. It may be as low as 10% for heavy infrastructure construction and as high as 50% for residential construction.

2.2 Long Term Industry Productivity Improvement vs. Site to Site Productivity Improvement

There is a difference between the long term productivity improvement of the construction industry and productivity improvement from one construction site to another. A schematic representation of this difference between the long term industry improvement and between projects is shown in Figure 2.1. The Best Productivity Practices Implementation Index (BPPII) is intended to help in improving the labour productivity at a project level. It is expected that the productivity of a project at a particular point in time would be higher for projects implementing the use of best practices compared to projects that don't use the same level of practices as measured by the BPPII, and keeping other things the same.

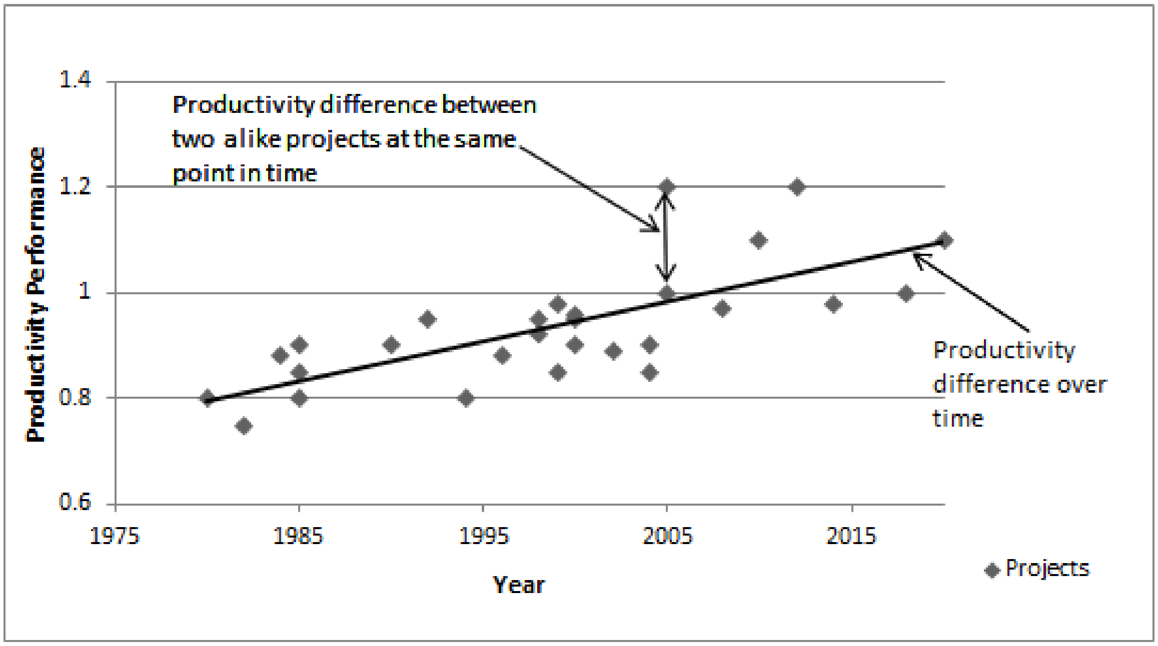


Figure 2.1: A schematic sketch of productivity improvement between projects over time

The use of BPPII as an implementation tool can help in improving labour productivity at a construction job site; however, the long term industry productivity improvement cannot be achieved beyond a certain extent with the BPPII. To improve the long term industry productivity, some fundamental changes in construction methods, use of innovative materials, technological advances, etc. are required. Analysis of historical data has shown significant improvements in labour productivity due to changes in the functional range, energy output, and automation of construction equipment, reductions in unit weight of selected construction materials, modularization, and the improved ability to install materials under harsh conditions, and the automation and integration of project information systems. Labour productivity improvements related to the use of these technologies ranged from 30 to 45% (Goodrum and Haas 2002; Goodrum et al. 2002; CII 2008; Goodrum et al. 2009; Zhai et al. 2009).

The construction industry has seen substantial improvements in long term industry productivity in certain sectors/activities of the industry, due to the use of new technologies and machinery. For example, there has been a substantial increase in the productivity related to civil works and the paving sector due to the introduction of automated heavy equipment and machinery. However, it is important to implement the use of best practices on a project; otherwise, new technologies or innovations would have little impact on improving productivity at the project site and at the industry level.

2.3 Factors Affecting Construction Productivity

The construction industry has not been as successful in productivity improvement or growth as compared to other sectors of the economy. Finding the factors that affect labour productivity in the construction industry has received more attention during the past four decades, and many research studies have been conducted to assess the factors affecting labour productivity. Different approaches and techniques were used to identify these factors. Some of these studies include work by authors such as: Thomas et al. (1990); Dozzi and AbouRizk (1993); Hanna and Heale (1994); Teicholz (2001); McTague and Jergeas (2002); Rojas and Aramvareekul (2003); Kazaz and Ulubeyli (2007); Mojahed and Aghazadeh

(2008); Dai et al. (2009); Rivas et al. (2011); Chanmeka et al. (2012); and Tabassi et al. (2012).

This section provides an overview of some of these research efforts. Productivity issues can be dealt with at the macro-level and micro-level. At the macro-level, issues such as government laws, regulations, local unions, contracting methods, labour legislation, and labour organization are dealt with; whereas at the micro-level, one deals with the matters related to management and operations of a project, particularly at the job site. As the focus of the research is on improving productivity at the job site, a more in-depth literature review on factors affecting productivity at micro-level is provided in the following paragraphs.

Thomas et al. (1990) categorized the factors affecting productivity into the following broad classifications of: (1) Manpower-labour; (2) design features-work content; (3) environmental-site conditions; (4) management practices-control; (5) construction methods; and (6) project organizational structure. Dozzi and AbouRizk (1993) identified several factors from a study conducted by a task force for Construction Industry Development Council (CIDC). A questionnaire of factors impairing construction productivity was developed by the task force. The report identified seven categories and 95 factors. Table 2.1 provides the list of these seven categories and the factors within each of these categories having serious impact on construction productivity.

Table 2.1: Factors seriously affecting construction productivity (Dozzi and AbouRizk 1993)

Category	**Factors**
Project Conditions	Weather variability
Market Conditions	Material shortages Lack of experienced design and project management personnel
Design and procurement	Large number of changes
Construction Management	Ineffective communications Inadequate planning and scheduling Lack of sufficient supervisory training
Labour	Restrictive union rules
Government Policy	Slow approvals and issue of permits
Education and Training	Lack of management training for supervision, project management

Hanna and Heale (1994) conducted a research project to find out the factors that affect construction productivity by conducting a questionnaire survey among the members of Canadian Construction Association. They received responses from 58 respondents which included project managers, foremen, project engineers, and owners. The survey questionnaire consisted of six main groupings of factors, and each group contained a number of elements. The major groupings were:

1. Contract environment,
2. Planning,
3. Site management,
4. Working conditions,
5. Working hours, and
6. Motivation.

The respondents concurred that: fixed price contracts have better productivity and that lowest bid contracts had a negative effect on productivity; planning and scheduling were critical for project productivity; working drawings have greatest effect on productivity among site management factors; issues concerning construction equipment have more significance in factors related to working conditions; in terms of working hours, there was national consensus that occasional overtime had a positive effect on productivity whereas scheduled overtime and shift work had a negative effect on productivity; foreman supervision, team work, and employee motivation are major elements in increasing productivity in the area of motivation. They also concluded that site management factors like availability of working drawings, task sequencing, material management, and change orders have greater impact on labour productivity.

Teicholz (2001) identified the possible causes for decline in labour productivity as: (1) inadequate training for workers and managers; (2) fewer younger workers entering the workforce; (3) more safety procedures; (4) increased complexity of projects; (5) greater time pressure on project completion; and (6) greater fragmentation of the work process. In a study related to the causes of cost overruns on mega projects (oil and gas projects over $300 million Canadian), low labour productivity rates was identified as one of the major reasons for low performance (McTague and Jergeas 2002). The factors identified as causes for this low productivity included; lack of front end planning, poor constructability of design, inefficient procurement, human resource issues, and incomplete or late data for project controls (McTague and Jergeas 2002).

Rojas and Aramvareekul (2003) conducted a survey to determine the relative level of importance of construction labour productivity drivers and opportunities. Management skills and manpower were found as the two areas with higher relevancy for affecting productivity compared to external factors, which are often considered responsible for low productivity in the construction industry. Their study showed that respondents believe that the construction productivity is more under their reach and control than external conditions. The top 5 opportunities from the survey are: (1) improve methods; (2) improve training programs; (3) enhance worker motivation; (4) improve strategic management; and (5) improve procurement management.

Kazaz and Ulubeyli (2007) performed a research to study the factors that affect productivity in the construction workforce in Turkey through a survey questionnaire sent to managers, engineers, architects and other technical staff. Their analyses show that monetary factors are the most important in influencing productivity, but socio-psychological factors are also becoming an important factor in affecting productivity. However, their study found only a small difference between the importance given to economic and socio-psychological factors in improving productivity. The socio-psychological factors included: work discipline, health and safety conditions, work satisfaction, giving responsibility, social activity opportunities, worker participation in decision making.

Mojahed and Aghazadeh (2008) conducted a survey with construction contractors working in the water and waste water treatment plants to find the major factors that influence productivity. The five major drivers found were: skills and experience of workforce, management, job planning, workers motivation, and materials availability. In response to an open ended question, the contract type was also identified as a driving factor for productivity. The type of contract can influence the productivity depending on the situation, for example, fast track jobs. They concluded that productivity improvements are possible by changing the work practices in the field and through use of best practices at construction jobsites.

Awad and Fayek (2008) grouped the factors that affect labour productivity into four categories based on the literature review of factors affecting labour productivity (Table 2.2).

Table 2.2: Factors affecting labour productivity (Awad and Fayek 2008)

Project-related factors	Management-related factors	Industry-related factors	Labour-related factors
project type	planning and scheduling	market conditions	labour skill
project size	management control	research and development	labour turnover
project location	site management	demand and supply	absenteeism
construction methods & techniques	contract type	Building codes and by-laws	motivation
tools availability	supervision	learning and training	crew size
material availability	communication	Specification and standard	crew composition
weather conditions	constructability		scheduled overtime
complexity	Inspection delay		unions and labour organizations
design errors or Incomplete drawing	safety		nature of employment
Rework	congestion (Overcrowding)		
Tools/equipment breakdown	Interference		
changes			
Changing of foremen			
Work overload			

These four categories are: (1) Project related factors; (2) Management-related factors; (3) Industry-related factors; and (4) Labour-related factors

Dai et al. (2009) performed research to identify the latent factors affecting construction labour productivity. Through 18 focus groups with craft workers and their immediate supervisors, their research identified 83 factors that affect construction labour productivity on nine job sites in the Unites States (U.S.). They sent a nationwide survey to 1996 craft workers to assess the impact of these factors on construction labour productivity. Principal factor analyses were carried out to identify 10 latent factors that represent the underlying structure of 83 productivity factors. These 10 latent factors in descending order of their negative impact on construction productivity (according to craft workers' opinions) are:

1. Construction equipment,
2. Materials,
3. Tools and consumables,
4. Engineering drawing management,
5. Direction and coordination,
6. Project management,
7. Training,
8. Craft workers qualification,
9. Superintendent competency, and
10. Foreman competency.

They further concluded, based on regression analysis of the latent factors, that construction equipment, project management, and craft workers' qualification are the three areas that have the greatest potential for project productivity improvement based on craft workers' perspectives. Their research was distinct in that it was one of the few which has focused on the craft workers' perception regarding construction productivity improvement which has been generally ignored by researchers and site management teams.

Rivas et al. (2011) analyzed case studies on three mining projects to study the factors that decrease labour productivity. They found that materials, tools, equipment, trucks, rework, and workers' motivation are the main factors that influence productivity. They also found that four factors: materials, tools, design interpretation and equipment and trucks account for 59% of the total waiting time.

Tabassi et al. (2012) studied the correlation of Human Resources Development (HRD) strategies of employee training and motivation practices with team work improvement and task efficiency in construction projects. Their research found a strong relationship between training and motivation practices with teamwork improvement and task efficiency.

The literature review provided in the above paragraphs lists several factors that affect productivity. These factors can be grouped into common themes and categories of management practices. The majority of these factors can be grouped under management practices related to materials management, human resources management, construction methods, construction machinery and equipment, execution approach, and safety. These categories were identified through the literature review discussed above and organized into a formal structure to develop the Best Productivity Practices Implementation Index (BPPII).

These set of practices are also part of the framework for productivity improvement described in the next section.

2.4 Framework for Productivity Improvement in Construction

It is easier to understand productivity improvement in construction when the construction process is visualized as a complete system. Figure 2.2 shows a systems model for the construction process. This model is used in the Construction Sector council's (CSC) labour productivity and project performance benchmarking program (Nasir et al. 2012b).

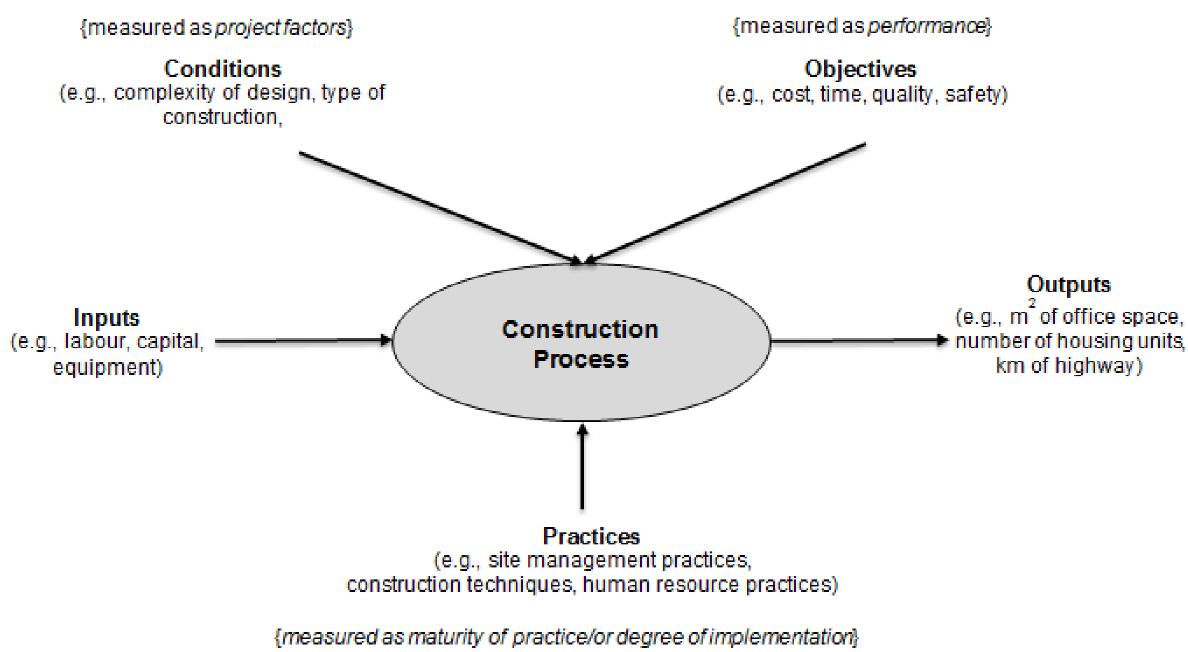


Figure 2.2: A systems model for the construction process (Fayek et al. 2008; Nasir et al. 2012b)

The system consists of the construction project which requires inputs, in the form of materials, personnel, equipment, management, and money. These inputs are used by the system in the process of producing the construction outputs, such as number of housing units, km of highway, and cubic metre of concrete. The construction process is subject to a number of conditions, such as complexity of design, type of construction, and environmental factors. The objectives of the process typically include, cost, time, quality, and safety. A set of practices are implemented on the construction process to achieve the objectives and desired output. Productivity is the ratio of inputs to outputs.

This figure also provides a conceptual model for assessment of the construction industry performance. It explains that to measure the performance of a process at some level of detail such as activity, project, organizational, or industry, the ratio of outputs to inputs are typically measured. The productivity of an activity or process is measured and compared to the estimated or budgeted values. When the actual productivity is less than the budgeted or estimated values; inputs, namely materials timeliness, labour effectiveness, and management practices affecting productivity should be examined.

There are several factors that affect labour productivity such as motivation, job safety, environmental factor, and physical limitations. These factors should be addressed to improve labour productivity. Similarly, management practices such as scheduling, planning, data collection, job analysis, and control can also affect productivity positively. Materials timeliness can be achieved by proper procurement scheduling, site layout, and handling.

The framework for the research in this thesis is similar to that presented in Figure 2.2. It describes the construction process as a system which needs inputs to produce outputs. The system is also affected by factors and practices. Inputs in the form of labour, materials, equipment, and capital are required to complete a construction process, activity, or task. Output is the final or desired product, for example, cubic metres of concrete or square feet of area painted. It should be noted here that although inputs to the construction process include materials, equipment, and capital besides labour work-hours; the focus of the research is to increase labour productivity. Materials, equipment, and capital could also be utilized in an effective manner when labour efficiency is increased. Best productivity practices should be identified that can increase labour productivity.

The construction process at the job site is affected by a number of factors besides the input required to complete the process. These factors have both negative and positive effects on the process and can increase or decrease the productivity. The construction process can also be affected by practices; however, usually the practices have a positive effect on the process. The basic premise of this research is that generally accepted good productivity practices will increase labour productivity at the construction job sites. These practices if implemented will mitigate the effects of factors that have negative impact on construction productivity.

2.5 What are infrastructure construction projects?

Construction projects can be broadly divided into: building including residential and commercial, light industrial, heavy industrial, and infrastructure. Hudson et al. (1997) in their book *"Infrastructure Management"* stated that infrastructure has been defined in many ways; for example, The American Public Works Association defines infrastructure as *"facilities to provide public service to achieve social and economic objectives."* The National Science Foundation states that, *"Civilization depends on the ability to feed, shelter, defend itself, this ability require infrastructure --- it is the foundation of wealth and quality of life."* In their book they consider "infrastructure" as:

"All these combined facilities that provide essential public services of transportation, utilities (water, gas, electric), energy, telecommunication, waste disposal, park lands, sports, and recreational and housing. Infrastructure also provides the physical systems used to provide other services to the public through economic and social actions."

Infrastructure projects can be classified into: (a) Transport (roads, bridges, transit, airports, ports, pipelines, etc.); (b) Utilities (sewer, water, waste water, electric, gas, telecommunication, etc.); (c) Public spaces (park lands, stadia, etc.); (d) Solid waste treatment; (e) Public buildings (post offices, public schools, etc.) ; (f) Communications (satellites, cellular, computer infrastructure); (g) Energy (generation and distribution for electric and gas).

The CII research report 268-2 on PDRI- Infrastructure has given a comprehensive definition of infrastructure projects. It defines infrastructure projects as (Gibson et al. 2010): *"An infrastructure project is defined as a capital project that provides transportation, transmission, distribution, collection or other capabilities supporting commerce or interaction of goods, service, or people. Infrastructure projects generally impact multiple* *jurisdictions, stakeholder groups and/or a wide area. They are characterized as projects with a primary purpose that is integral to the effective operation of a system. These collective capabilities provide a service and are made up of nodes and vectors into a grid or system (e.g., pipelines (vectors) connected with a water treatment plant (node))."*

Vector examples:

People and Freight:

- Highways
- Railroads
- Access ramps
- Tunnels
- Airport runways
- Security fencing

Energy:

- Electricity transmission/distribution
- Fibre optic networks
- Towers
- Wide areas networks

Fluids:

- Pipelines
- Aqueducts
- Pumping and compressor stations
- Locks, weirs
- Reservoirs
- Meters and regulator stations
- Pig launchers and receivers
- Canals
- Water control structures
- Levees

Nodes/Centralized facilities examples:

- Dams
- Power Generation Facilities
- Steam or chilled water production
- Marine, Rail, or Air Terminals
- Water/Waste Water/Solid Waste Processing
- Refineries

2.6 Summary

This chapter provided a review of the definitions related to productivity in the construction industry. It also synthesized the literature on the practices that affect labour productivity. The available literature on the practices affecting productivity only lists these practices; however, these practices have not been properly defined and described in detail. Also, no literature is currently available that describes the different implementation levels of these practices to improve labour productivity. This research fills this gap by defining the practices and describing their implementation levels. The next chapter provides an overview of some of the existing indices based on the use of practices in the construction industry.

Chapter 3

Practices in the Construction Industry

As mentioned in the previous chapters, the use of good practices in the construction industry has the potential to: increase labour productivity; reduce rework; improve project performance, job-site safety, and project quality; and increase direct work rate (McTague and Jergeas 2002; CII 2003; Lozon and Jergeas 2008; Abdel-Wahab et al. 2008; NRC 2009; Nasir et al. 2012b; Rojas and Aramvareekul 2003; Kazaz and Ulubeyli 2997; Mojahed and Aghazadeh 2008; Tabassi et al. 2012; Chanmeka et al. 2012). This chapter will discuss the different practices introduced in the construction industry. The information about various programs, which are based on implementing practices in the construction industry, will be provided. A literature review about some of the existing indices in construction industry based on the use of practices will also be provided. These discussions will provide a basis for identifying and making the Best Productivity Practices Implementation Index (BPPII) for Infrastructure Projects.

3.1 Best Practices of the Construction Industry Institute

The Construction Industry Institute (CII) is a consortium of over one hundred leading owners, engineering and construction contractors, and suppliers with the mission to improve the cost effectiveness of the capital facility project life cycle, from pre-project planning through completion and commissioning. The CII has funded research programs through leading universities for thirty years. The research sponsored by CII has resulted in a number of unique products for the construction industry. The research has also resulted in identifying best practices for sharing and implementation to improve the chances of project success (CII 2006a). The Construction Industry Institute (CII) has developed a list of practices known as "Best Practices" which include fourteen (14) practices listed below:

1. Pre project planning (PDRI)
2. Alignment
3. Constructability
4. Design Effectiveness
5. Materials Management
6. Planning for Startup
7. Team Building
8. Partnering
9. Quality Management
10. Implementation of Products
11. Benchmarking and Metrics
12. Change Management
13. Disputes prevention & Resolution
14. Safety: Zero Accident Techniques

CII defines Best Practice as *"a process or method that, when executed effectively, leads to enhanced project performance."*(CII 2006a). These are mostly validated statistically with project performance data, but a few are considered validated as much by their near universal adoption. Examples include alignment, implementation of products, and benchmarking and metrics. These Best Practices are meant for implementation at different levels such as project, organizational or both.

The CII Benchmarking and Metrics Program provides a platform to quantitatively measure the value of CII Best Practices. It also provides quantitative feedback to members on the impact of project performance measures such as cost, time, and quality that may be attributed to using CII Best Practices. The analyses of CII Benchmarking data indicates that implementation of Best Practices has resulted in substantial benefits in project performance such as safety, quality, schedule, and cost. However, certain CII Best Practices have greater relative benefits than others depending on their use by the owners or contractors. The CII Best Practices of Project Change Management, Planning for Startup, and Pre-Project Planning have contributed to great impact in reducing and controlling cost growth for owners companies (Figure 3.1).

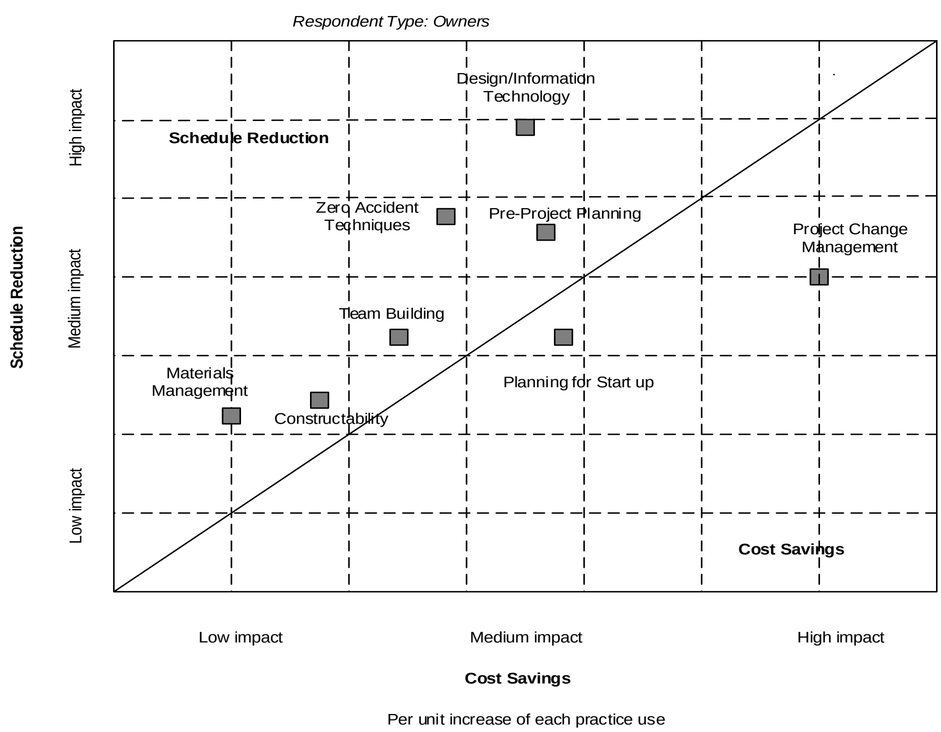


Figure 3.1: Owner benefit of practice use (CII, 2006a)

Project Change Management, Zero Accident Techniques, Constructability, and Team Building have produced great benefits on cost performance for contractors (Figure 3.2).

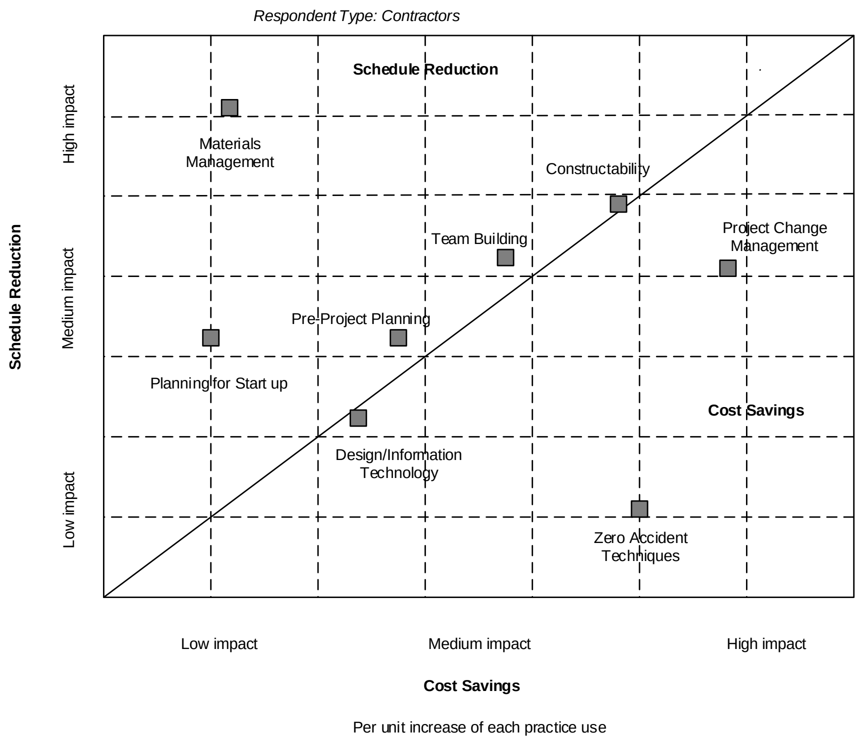


Figure 3.2: Contractor benefit of practice use (CII, 2006a)

Olumide et al. (2012) performed a research project to see the applicability of CII Best Practices to four different industry sectors of building, infrastructure, heavy industrial, and light industrial. It was found that a majority of 13 Best Practices are more applicable to some industry sectors than others. Materials management, planning for start-up, and benchmarking and metrics are Best Practices that are more applicable to the heavy and light industrial sectors. The average applicability of Best Practices was lower in the buildings and infrastructure sectors than heavy and light industrial sectors for many of the Best Practices.

This shows the need for having Best Practices defined specifically for infrastructure and building sectors.

3.2 Independent Project Analysis (IPA)

IPA is a private international construction benchmarking and metrics corporation headquartered in the US and was founded in 1987. IPA consults on project evaluation and project system benchmarking. Its web site claims to have a staff of over 200 project and research analysis professionals at seven offices on five continents that serve hundreds of clients (IPA Website 2013). This primarily includes large oil companies, chemical producers, pharmaceutical companies, minerals and mining companies, and consumer products manufacturers. IPA's data and methods are proprietary. As of 2012, the IPA database contains more than 11,000 projects of all sizes having a range from $20,000 to $25 billion (IPA 2013) located throughout the world. The IPA has developed a list of twelve practices, called "Value Improving Practices" (VIPs). Following is the list of VIPs:

1. Classes of Facility Quality
2. Constructability Reviews
3. Customized Standards & Specifications
4. Design to Capacity
5. Energy Optimization
6. Predictive Maintenance
7. Process Reliability Modeling
8. Process Simplification
9. Technology Selection
10. Traditional Value Engineering

11. Waste Minimization
12. 3D CAD

The completion level of these VIPs is used in evaluating a project's performance. The use of VIPs is considered to have a positive impact on the project performance, increase labour productivity, and reduce rework (Lozon and Jergeas 2008). Some of these practices such as constructability reviews, standards and specifications, maintenance, and 3D CAD are also included in the BPPII Infrastructure. However, they have been defined specifically for infrastructure projects.

3.3 Review of Construction Practice Indices

This section will describe some of the existing indices developed for use by the construction industry. Most of these indices have been developed for a specific industry group, such as; building, industrial, and infrastructure. The majority of these indices have been developed and validated on industrial or capital facility projects. Following is a representative sample of indices developed and used in practice for construction project management (not design related, such as Leadership in Energy and Environmental Design (LEED) :

- Project Definition Rating Index (Dumont et. al. 1997; CII 2010a)
- Project Health Indicator (CII 2006b)
- Decision Tool for Prefabrication, Preassembly, Modularization, and Offsite Prefabrication (Haas et al. 2002)
- International Project Risk Assessment (Dinneen et al. 2003)

- Alignment Thermometer (Gibson 2005)
- Communications Project Assessment Tool (Kelly and Tucker 1996)
- Disputes Potential Index (Bramble 1995)
- Voice of the Craft Worker (Dai and Goodrum 2007)

The Project Definition Rating Index (PDRI) is the only index which is available for each broad sector of the industry. Different PDRIs exist for building, industrial, and infrastructure sectors of the construction industry. Some of the indices have been developed for project assessments, such as the PDRI, International Project Risk Assessment (IPRA), and the Project Health Indicator (PHI). Some of the tools have been developed to help in providing effective alignment and communications of the project team, such as, Alignment Thermometer, and Communications Project Assessment Tool (Compass). Some were developed for reducing the chances of disputes and litigations on projects, such as Dispute Potential Index. These indices are used at different stages in the project life cycle. They are not developed for improving productivity at the project site except Voice of the Craft Worker (VOW). The BPPII supplement these indices with a focus on improving productivity through the use of practices. The BPPII is designed for use at the end of the Front End Planning (FEP) phase and at the beginning of the execution phase to support in the preparation of the Project Execution Plan (PEP). Figure 3.3 illustrates the application of BPPII, PDRI, and PHI in the project life cycle. Only those indices are described below, which are complementary to the BPPII. It would be beneficial for the projects to use these indices at the right time in the project timeline.

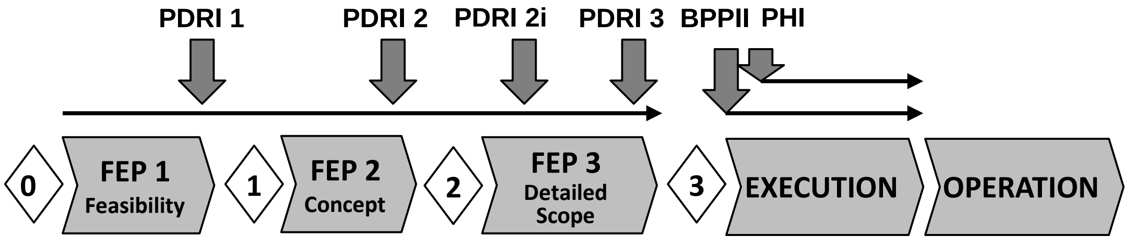


Figure 3.3: Application stages of BPPII with other complimentary indices

3.3.1 Project Definition Rating Index (PDRI)

The PDRI was developed by the Front End Planning Research Team of the Construction Industry Institute (CII). The main purpose of the PDRI is to measure the project scope definition for completeness. It identifies and describes elements in a scope definition package and assists a project team in indicating factors that are considered a project risk. The PDRI was initially developed for industrial projects, such as oil/gas production facilities, textile mills, power plants, and manufacturing facilities. Later on, the PDRI tool was also developed for building projects, such as schools, banks, apartments, warehouses, and airport terminals (Dumont et. al. 1997; CII 2010a). Recently, PDRI- Infrastructure has been developed for measuring the completeness of project scope definition for infrastructure projects (Gibson et al. 2010).

The PDRI is intended for use during the front end planning, which includes activities up to the decision to proceed with final design and construction. The "front end planning" is also known as front end loading, pre-project planning, programming, schematic design, design development, sanctioning, and others (CII 2010a). The PDRI consists of a comprehensive checklist of scope definition elements that are required to be evaluated based on the level of completeness by project personnel before the detailed design and construction should begin.

The elements of the PDRI are given different weights based on their level of importance for successfully defining the project scope. The weights were assigned to the elements through organizing workshops attended by representatives of owner and contractor companies. The PDRIs are organized into sections, categories, and elements. Each section includes a portion of the categories, and each category includes a number of elements. Each of the individual elements is given a definition level score that ranges from zero to five, with zero defined as not applicable, 1 defined as a complete definition, and 5 defined as an incomplete definition. Each of the elements has a weighted score that is based on its relative importance (CII 2010a). The scores of each category and section are calculated and summed, and compared to a total possible score of 1000 points. The project which scores 200 or less is considered to have complete project scope definitions or have high chances of avoiding project risks (CII 2010a). Elements which have incomplete project scope definitions, receive a high score; therefore, a low score on the PDRI is considered better.

The PDRI can be useful for owners, designers, and constructors. Owners can use it as an assessment tool for deciding whether they should move forward with the full design and construction phases of the projects or that there are certain issues which should be looked into more detail. The PDRI helps contractors in ensuring that right input from owner regarding different aspects of project such as operations and maintenance, process engineering, research and development, manufacturing and business have been obtained. The contractors can also perform PDRI assessment as a risk analysis to find the degree of definition and identify the potential weaknesses and concerns before responding to the request for proposal (RFP).

The PDRI's have been validated by dividing the projects into two groups; one scoring below the 200 point cutoff score and the second above the 200 point score. The PDRI building has been scored for a sample of 108 building projects having worth of $2.3 billion using the 200 point cutoff score. Table 3.1 shows the comparison of project performance for these building projects. The data in the table represents the mean performance for the projects versus execution estimate for design and construction and the absolute value of changes as a percentage of total project cost. Projects with a PDRI score of less than 200 performed better compared to projects with a score of more than 200 in performance measures of cost, schedule, and change orders.

Table 3.1: Comparison of projects with PDRI-Building, projects score above and below 200 (CII 2010a)

Performance	**PDRI Score**	
	< 200	**>200**
Cost	3% above budget	9% above budget
Schedule	5% behind schedule	21% behind schedule
Change Orders	8% of budget	11% of budget
	(N=25)	(N=83)

Similar evaluation was made for industrial projects. Table 3.2 shows the performance comparison for a sample of 129 industrial projects using the 200 point PDRI cutoff score. It can be seen that projects having lower PDRI scores performed better than projects with higher score in terms of cost performance at the 95% confidence interval (CII 2010a). This indicates that projects having complete project scope definitions performed better than projects having less defined scope definitions.

Table 3.2: Comparison of projects with PDRI-Industrial, project scores above and below 200 (CII 2010a)

Performance	**PDRI Score**	
	< 200	**>200**
Cost	4% below budget	4% above budget
Schedule	4% behind schedule	10% behind schedule
Change Orders	7% of budget	8% of budget
	(N=75)	(N=54)

3.3.2 Project Health Indicator (PHI)

The Project Health Indicator (PHI) is a tool based on leading indicators that provide warning signs if the project is not going on a proper course. These leading indicators can have a significant impact on a project's success and the PHI tool identifies and quantifies the impact of these leading indicators. There are 43 leading indicators in the PHI tool that provide real-time early warning signs of an unhealthy project. These leading indicators are measured on five-point scale that measures serious problem, major problem, moderate problem, minor problem, and no problem (CII 2006b).

Five projects health outcomes are assessed through the PHI tool, they are: cost, schedule, quality, safety, and stakeholder satisfaction. The leading indicators have different impact on each of the five outcomes, and therefore, the indicators have been ranked differently from highest impact to lowest impact for each of the five outcomes. The 43 leading indicators are grouped under eight project practice categories. Six of these practices are the same as Best Practices categories of the CII and the other two were identified from CII knowledge areas and are considered important for a project success (CII 2006b). The eight project practices are:

1) Alignment
2) Change Management
3) Constructability
4) Contracting
5) Quality Management
6) Safety Practices
7) Project Control
8) Team Building

The PHI tool was developed with the assumption that the project has completed the front-end planning process with the help of Project Definition Rating Index (PDRI). Therefore, those leading indicators that are relevant to the front-end planning phase were not included in the PHI tool. The PHI tool should be used during the detailed engineering, procurement, and construction phases of a project. It is most effective when used after the completion of the front-end planning. It is designed to bridge the gap between completion of the PDRI and project execution phases.

3.3.3 Voice of the Craft Worker (VOW)

The main objective for the tool development was to involve the craft workers in assessment of the problems that cause productivity losses on jobsites. The tool was specifically designed to assist members of the project team that work on the project jobsite to identify the factors that affect craft workers' productivity and allow the craft workers to provide their input (Dai and Goodrum 2007).

The tool was developed based on an extensive literature review and a workshop. The literature review was aimed to find out from previous research work what factors affect the craft workers' productivity on project jobsites from craft workers' perspective. The workshop included projects representing several different types of construction, union and non-union projects, different locations, different levels of completion, and different project sizes. This approach was used to obtain a perspective of all of the construction industry. The workshop came up with a list of 83 factors organized into 11 categories. A survey was developed from this information to quantify the importance of the factors (Dai et al. 2009).

The survey for craft workers comprised 3 sections: (1) demographic information of the craft worker, such as union status, trade, and position; (2) the craft workers assessed 26 factors for their frequency of occurrence and their effect on productivity; and (3) the craft workers assessed their agreement with 57 statements and their effect on productivity. This survey was completed by 1,996 craft workers from 28 projects (Dai et al. 2009).

The data analyses of this survey showed that the categories of tools and consumables and materials are perceived to have greater impact on craft workers' productivity. The most significant productivity factor is "I have to wait for people and/or equipment to move the material I need" (Dai et al. 2009). Table 3.3 and Table 3.4 show the severity scores for the productivity categories and the top 10 most significant productivity factors respectively.

Table 3.3: Normalized severity scores for productivity categories (Dai et al. 2009)

Category	Average normalized severity score
Tools and Consumables	69.0
Materials	57.1
Engineering Drawing Management	53.8
Construction Equipment	50.5
Supervision Direction	30.5
Safety	23.8
Communication	21.3
Project Management	21.0
Labor	14.4
Foremen	8.7
Superintendents	5.3

The VOW tool is designed for use in the pre-project planning and the construction phases of a project. During the pre-project phase, it allows the craft workers to assess how each factor will affect the upcoming project. When used during the construction phase of the project, the VOW tool helps in identifying the most significant factors occurring on the project. The tool can be performed multiple times during a project that has many activities and phases, because the most significant factors are likely to change as activities change.

Table 3.4: Top 10 most significant productivity factors (Dai et al. 2009)

Issue	Normalized severity score
I have to wait for people and/or equipment to move the material I need.	100.0
There are errors in the drawings that I use.	91.7
When there is a question or problem with drawings, the engineers are slow to address the issue.	89.9
If I need a manlift to do my job, there aren't any available.	84.3
When I need a crane or a forklift to help me, there aren't any available	83.6
I can't get the consumable I need to do my job.	82.2
I have to search in a lot of places to find the tools I need to do my job.	78.4
When I go to install prefabricated items, work has to be done on them to fix quality problems.	75.2
I can't get the power tools from the contactor that I need to do my job.	74.7
My supervisor does not provide me with enough information to do my job.	72.0

3.3.4 Best Productivity Practices Implementation Index (BPPII) for Industrial Projects

The Construction Industry Institute (CII) has sponsored Research Team 252 (CII RT-252), "Construction Productivity Research Program", in order to increase craft labour productivity. This team has been working to develop a tool that can be used by members of a construction project's planning team to assist in the planning and implementation of the best practices for improving craft productivity on industrial construction projects. This tool is called the, "Best Productivity Practices Implementation Index" (BPPII) Industrial. This BPPII developed by the CII is specifically designed for the industrial sector of the construction industry (CII 2009).

The aim of the BPPII for the industrial sector is to develop comprehensive check lists in the form of audit sheets that describes the best practices that are necessary for the improvement of craft worker productivity on industrial projects. The tool also provides a scoring system to quantitatively judge the preparedness of the project's management team to deal with these issues. The BPPII Industrial is designed with the aim of using it during the conceptual design and scope definition of pre-project planning through the engineering and design, procurement, and construction phase of the project.

There are 53 elements in total divided between 18 sections and 06 categories. Each category includes between two and four sections and each of the sections includes elements which is a list of practices that are similar in nature, but not the same. The six categories are; 1) materials management, 2) equipment logistics, 3) craft information systems, 4) human resource management, 5) construction methods, and 6) environmental safety and health. These six categories were developed based on the expertise of the Research Team 252 of the CII and other research efforts in the construction industry that have identified these issues as those that have a significant effect on craft productivity.

The BPPII-Industrial score is obtained by assigning the planning and implementation level (PIL) to each element in the index. Each element has different PIL definitions that are specific to the element. However, the PILs are defined to be consistent throughout the tool. Therefore, the actual definition for each of the elements will differ; however, the definitions for each element will correspond to the same level of planning and implementation. The PIL are organized on a scale ranging from 0 to 5. The planning and implementation level 0 means that the PIL is not applicable, whereas PIL from 1 to 5 shows increased or higher level of practice implementation. Therefore, PIL 1 would mean that there is minimum level of implementation, whereas PIL 5 would represent the maximum or full extent of the implementation.

Each of the elements in the index has been assigned weights based on the effect the element has on labour productivity. The relative weights were assigned based on the ranking of these elements by industry and academic experts. By using a weighted system, each PIL for each element corresponds to a different score rather than a simple 0 to 5 scale. When all of the elements' PILs are scored, their weighted element scores are obtained using the weighting system, and finally all the element scores are summed to obtain the total BPPII score.

The BPPII Industrial was validated in two phases by obtaining data from industrial projects. In the first phase, it was decided to validate it by using unit rate (hours/unit) as a metric for measuring labour productivity. The actual unit rates of labour productivity for different work categories of industrial projects were collected and compared with BPPII scores. No statistically significant relationship was observed that can confirm that projects having high BPPII scores will have higher productivity. Using unit rate for comparing productivity performance and comparing the effects of using best practices failed, because it is an absolute measure of productivity and is not useful because of the differences in projects' characteristics. Each project has different characteristics such as industry group, contract type, nature, size, location, complexity, and so on. For example, comparing concrete work for footings with concrete work for slabs is not useful as the two concrete work categories have different estimated unit rates based on their quantities and complexities of work. These differences can make the direct comparison of labour productivity if measured in unit rates very difficult and meaningless (Nasir et al. 2012b; CII 2013).

In the second phase of the BPPII Industrial validation, the relationship between the BPPII score and labour productivity was confirmed by using the productivity factor as a metric for measuring labour productivity based on discussions among the research team of which the author partook. Productivity factor (PF) is defined as the ratio between the estimated productivity and actual productivity. The PF was found to be a useful metric for validation of the BPPII Industrial, because it is a relative metric and is useful than unit rate for measuring the productivity performance when comparing projects. The PF can countervail the effects coming from differences in projects that have different characteristics. A detailed explanation for using the productivity factor for measuring the productivity performance of projects and its use as metric for measuring labour productivity is provided in section 5.4 of this thesis. The idea of using PF as a metric for validation of the BPPII was suggested by the author and his supervisor, based on the lessons learned in the development and implementation of a benchmarking and metrics program for project performance and productivity improvement (Nasir et al. 2012b).

For validation purposes, two groups of projects were created based on the scores obtained on the BPPII, projects with high and low BPPII scores. The high BPPII group consists of projects with BPPII scores of 5% or more above the median score, and the low BPPII group had projects with scores of 5% or more below the median score. The median score was about 64%. A one-way ANOVA test was conducted with 95% confidence level and it was found that the two groups had statistically significant differences between their productivity factors (CII 2013). Table 3.5 provides the results of the ANOVA and Figure 3.4 shows the results of the productivity differences graphically. There was no regression analysis performed to see if the variability in the productivity factor can be explained by the BPPII score.

Table 3.5: One-Way ANOVA analysis for BPPII Industrial and PFs (CII 2013)

ANOVA Statistics	Low BPPII (<=60.7%)	High BPPII (>= 67.1%)
Sample Size	12	11
Sample Mean	0.9625	1.2447
Sample Standard Deviation	0.1962	0.4013
F-Ratio (Between Variation)	4.72	
p-Value (Between Variation)	0.0414 (<0.05)	

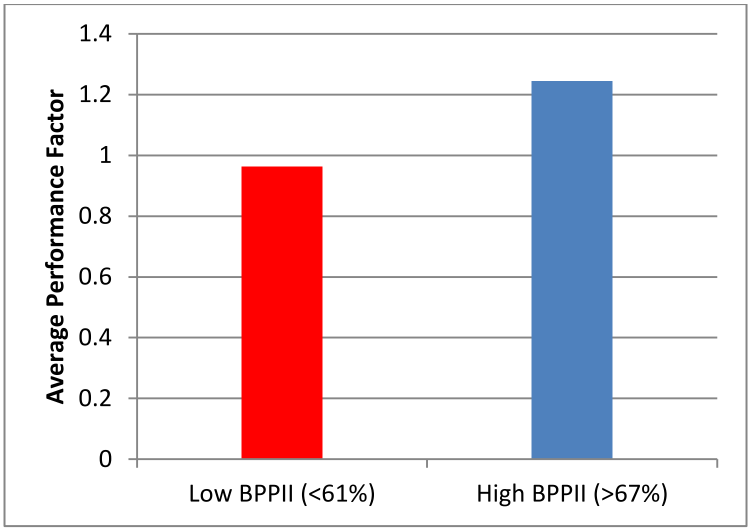


Figure 3.4: Average PFs for low and high BPPII Industrial groups (CII 2013)

3.4 Development of the BPPII Infrastructure

This section explains the development and transformation of the BPPII Infrastructure from BPPII Industrial. This follows the concept used in the transformations of the PDRIs from industrial and buildings to the infrastructure sector of the industry. Different PDRIs have been developed for buildings, industrial, and infrastructure sectors of the construction industry. The reason for these different indices is that each of these sectors is inherently different from each other in terms of planning, designing, execution, site characteristics, labour requirements, regulatory requirements, and best practices. There are some overlapping areas; however, an index developed for a specific sector cannot be used in totality for another sector. The categories and their weights will differ.

PDRIs

All of the three PDRIs have the same format. All of them have same three common sections which are: (1) Basis of Project Decision; (2) Basis of Design; and (3) Execution Approach. These sections are divided into categories, which are then divided into elements. The PDRI-Industrial has 15 categories and 70 elements; the PDRI-Building has 11 categories and 64 elements; and the PDRI-Infrastructure consists of 13 categories and 68 elements. Figure 3.5 explains the development of the three PDRIs. Besides the same three sections, some of the categories and elements in all the three PDRIs are also similar. For example, there are 7 similar categories and 32 similar elements between the PDRI-Industrial and PDRI-Infrastructure. The reasons for these similar categories and elements are that there are some basic requirements of projects which are similar in all different types of construction projects. For example every type of project would need information related to site, procurement strategy, project control, execution plan, etc., in order to perform the front end planning and assess the potential risks, before going into the detailed design and construction phase of the project. Therefore, there exist some similar categories. Some of these common elements do serve the same purpose. At the same time it should be noted that as infrastructure projects are different from industrial and building projects; therefore, the elements in these different PDRIs serve different purposes. It is also important to remember that as each element has been assigned a weight based on its relative importance with respect to other elements; therefore, though we may find some similar elements, but they have different weights assigned to them in a different index. This way, they also serve a different purpose.

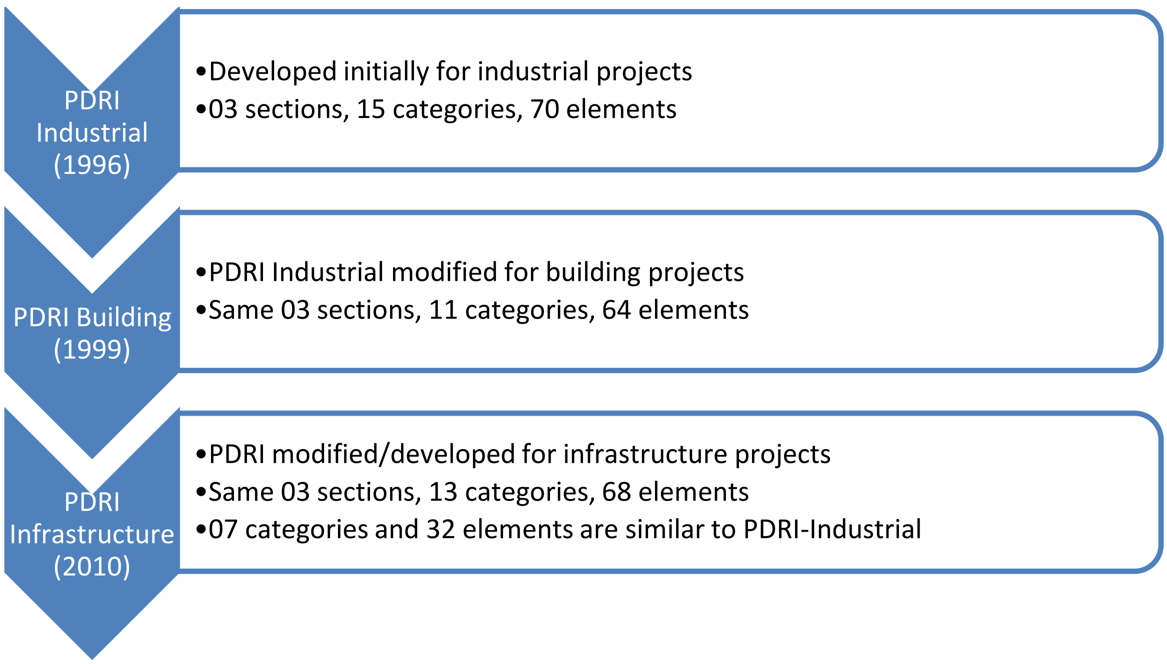


Figure 3.5: Development of different PDRIs

The development of BPPII Infrastructure also follows the same concept. As the industrial construction sector is different from infrastructure construction sector, we need a different BPPII for each sector. However, in order to provide consistency, some of the categories and elements would be similar in both of the BPPIIs. Again, the reasons are that all projects have some basic requirements which are similar in all sectors of the construction industry. For example, materials management and human resources management are categories which are common in both the indices. However, it should be noted that not all the elements and sections in a category would be same even if they are in a same category. Also, when there are some elements in a category which are similar, it should be noted that they have different definitions and different weights based on their relative importance with respect to other elements, and the weights are assigned based on their importance for the particular sector of the construction industry.

3.5 Summary

This chapter discussed the different practices introduced in the construction industry. The information about various programs which are based on implementing practices in the construction industry was provided. It also discussed some of the existing indices in the construction industry based on the use of practices. These discussions provided a basis for identifying and making the Best Productivity Practices Implementation Index (BPPII) for Infrastructure Projects. The next chapter describes in detail the organization and structure of the BPPII Infrastructure.

Chapter 4

Best Productivity Practices Implementation Index (BPPII) for Infrastructure Projects

The Best Productivity Practices Implementation Index (BPPII) for infrastructure construction projects is described in this chapter. The index is developed based on the factors that affect construction productivity and good practices having positive influence on productivity as mentioned and discussed in the literature review earlier in this thesis. It also incorporated the experiences learned from the Construction Sector Council's (CSC) Performance and Labour Productivity Benchmarking Program that was specifically focused on the infrastructure construction sector of the industry (Nasir et al. 2012b). Feedback and input was also obtained from the Construction Industry Institute's Research Team 252 (CII RT 252), Construction Productivity Research Program.

4.1 Organization of the BPPII Infrastructure

Figure 4.1 shows the organizational structure of the BPPII Infrastructure. The Infrastructure BPPII consists of six categories. Each category of the BPPII has at least two or more sections, and each section has at least one or more elements. Figure 4.2 shows the six categories of the BPPII Infrastructure. The six categories are: (1) Materials Management, (2) Construction Machinery and Equipment Logistics, (3) Execution Approach, (4) Human Resources Management, (5) Construction Methods, and (6) Health and Safety.

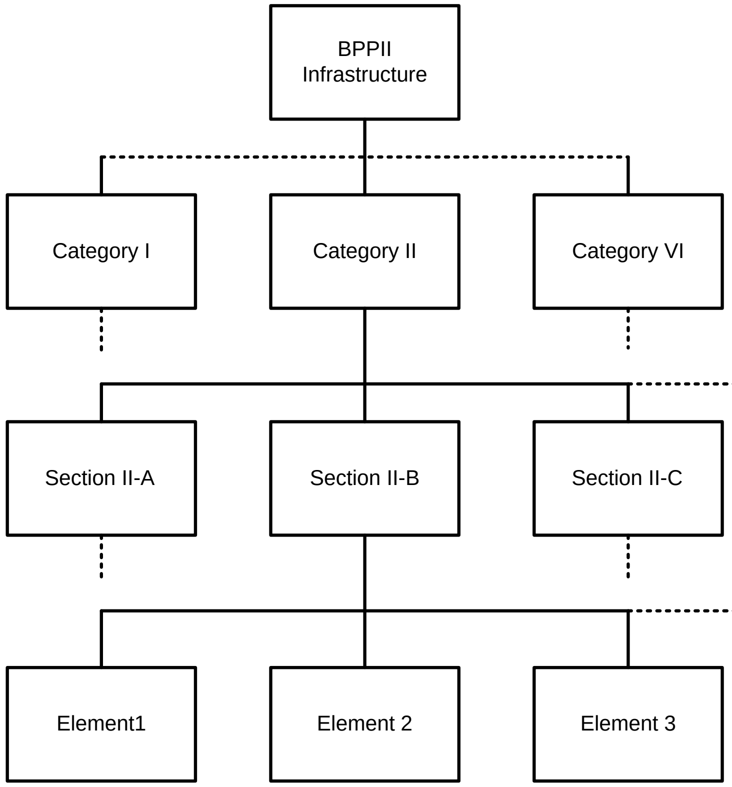


Figure 4.1: Organizational structure of the BPPII Infrastructure

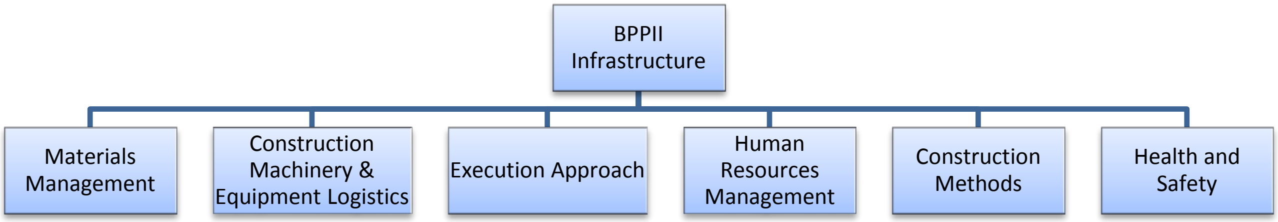


Figure 4.2: BPPII Infrastructure categories

The general structure mirrors that of the BPPII Industrial, but its sections, elements, and weights are unique. The structure therefore is based on expert knowledge captured through a Delphi process used in the BPPII Industrial, while its elements, as described in the following sections derive from the author's analysis of the literature. The elements represent specific practices that are known to have a positive effect on labour productivity. The sections and their elements are organized into individual audit forms or score sheets. Each element or practice is scored by filling the audit form or assessment score sheet.

4.2 Categories, Sections, and Elements of BPPII Infrastructure

Table 4.1 provides a complete list of elements, sections, and categories that constitute the Best Productivity Practices Implementation Index (BPPII) for Infrastructure projects. The BPPII Infrastructure consists of six categories, 20 sections, and 61 elements as shown in Table 4.1. The sections in each category are numbered alphabetically and the elements are numbered alpha-numerically in this list. These categories and sections are described in detail below. **The detailed definition and description of each individual element or practice and its implementation levels are provided in Appendix A.**

Table 4.1: BPPII Infrastructure, categories, sections, and elements

I - MATERIALS MANAGEMENT

A. Procurement Strategy
- A1. Procurement Procedures & Plans for Materials & Equipment
- A2. Long-Lead/Critical Equipment & Materials Identification
- A3. Procurement Team

B. Materials Management Systems
- B1. Project Team Materials Status Database
- B2. On-Site Material Tracking Technology
- B3. Materials Delivery Schedule

C. Receipt and Inspection of Materials
- C1. Materials Inspection Process
- C2. Materials Inspection Team
- C3. Post Receipt Preservation & Maintenance

II – CONSTRUCTION MACHINERY & EQUIPMENT LOGISTICS

A. Construction Machinery & Equipment Availability
- A1. Procurement Procedures & Plans for Construction Machinery
- A2. Construction Machinery Productivity Analyses
- A3. Construction Machinery and Equipment Maintenance

B. Tools and Equipment Management Best Practices
- B1. Site Tools and Equipment Management Strategy
- B2. Tools & Equipment Tracking
- B3. On-site Tools Maintenance
- B4. Construction Machinery & Equipment Utility Requirements

III – EXECUTION APPROACH

A. Planning
- A1. Short Interval Planning
- A2. Well defined scope of work
- A3.Use of Software
- A4.Dedicated Planner
- A5.Construction Work Packages (CWP)

B. Constructability Reviews
- B1. Design readiness for construction
- B2. Utility Alignment & Adjustments
- B3. Contract Types/Strategies
- B4. Model Requirements/3D Visualization

C. Acquisition Strategy
- C1. Right of Way, Land, and Utilities Acquisition Strategy
- C2. Contracts & Agreements with Agencies
- C3. Utility Agreements

D. Regulatory Requirements/Reviews
- D1. Environmental Requirements
- D2. Regulatory Requirements/Permitting Requirements

IV - HUMAN RESOURCES MANAGEMENT

A. Planning
- A1.Crews Composition/Crew Formation
- A2. Skills Assessment and Evaluation

B. Training and Development
- B1. Employees / Trades Technical Training
- B2. Career development

C. Behavior
- C1. Nonfinancial Incentive Programs
- C2. Financial Incentive Programs
- C3. Social Activities

D. Organizational Structure
- D1. Maintain Stability of Organization Structure
- D2. Clear Delegation of Responsibility

E. Employment
- E1. Retention Plan For Experienced Personnel
- E2. Exit Interview

V - CONSTRUCTION METHODS

A. Project Schedule Control
- A1. Integrated Schedule
- A2. Work Schedule Strategies
- A3. Schedule Execution and Management

B. Site Layout Plan
- B1. Dynamic site layout plan
- B2. Traffic Control Plan
- B3. Site security plan
- B4. Machinery & Equipment positioning strategy

C. Design/Construction Plan & Approach
- C1. Communications, Coordination, & Agreements
- C2. Project start-up plan
- C3. Project Completion Plan
- C4. Innovations & New Technologies
- C5. House Keeping

VI - HEALTH AND SAFETY

A. Job Site Safety
- A1. Formal Health and Safety Policy
- A2. Health and Safety Plans/Zero Accident Techniques
- A3. Task Safety Analysis
- A4. Hazards Analysis
- A5. Hazards Planning

B. Substance Abuse Program
- B1. Drugs and Alcohol Testing Program

C. Health and Safety Training & Orientation
- C1. Health and Safety Training Programs
- C2. Toolbox Safety Meetings

4.2.1 Category I - Materials Management

The first category in the index is materials management, and practices related to materials management are grouped in this category. Materials management is concerned with the availability of the right materials at the right time and at the right place in the construction process. Materials management has been identified as one of the most important factors affecting construction projects in several research efforts (Hanna and Heale 1994; McTague and Jergeas 2002; Rojas and Aramvareekul 2003; Mojahed and Aghazadeh 2008; Dai et al. 2009; Rivas et al. 2011). Materials management has been identified as a best practice by CII (CII 2006a).

Effective materials management on a construction project has the ability to improve productivity and reduce crew idle time. Bell and Stukhart (1987) in their research conducted for the CII found that on projects where there is lack or absence of a materials management system, craft foremen spend up to 20% of their time searching for materials and an additional 10% on tracking purchase orders and expediting. Thomas et al. (1989) conducted a research on the impact of materials management on labour productivity. They found a benefit/cost ratio of 5.7/1.0 for effective materials management. Thomas and smith (1992) found that generally, for all types of materials management deficiencies, the daily productivity is reduced by about 40%. Akintoye (1995) concluded that an effective materials management and control system could potentially increase productivity by 8%. This increase in productivity is possible due to the availability of right materials prior to the start of work and the ability to better plan the work activities due to availability of materials. Thomas and

Sanvido (2000) performed a research through three case studies on subcontractor and fabricator relations. They found that inefficient materials management could be responsible for an increase in field labour hours of 50% or more. Rojas and Aramvareekul (2003) ranked procurement management as the fifth most powerful opportunity (out of 16) to improve craft labor productivity.

In the last two decades, research efforts have focused on automation of materials management systems. Automation of materials management systems can help in quantity takeoff, inventory control, delivery and inspection, identification and location, etc. The use of Automated Data Collection (ADC) technologies for materials management have been successfully tested for construction projects and these include; bar codes, Radio Frequency Identification (RFID) tags, Global Positioning Systems (GPS), and Ultra Wide Band (UWB). These technologies have been successfully prototyped on large construction projects (Jaselskis et al. 1995; Caldas et al. 2006; Ergen et al. 2007; Grau et al. 2009; Nasir et al. 2010), and are now used on a full scale by some companies as part of their corporate materials management systems.

Materials Management is made up of three sections: (1) Procurement Strategy, (2) Materials Management Systems, and (3) Receipt and Inspection of Materials as shown in Figure 4.3.

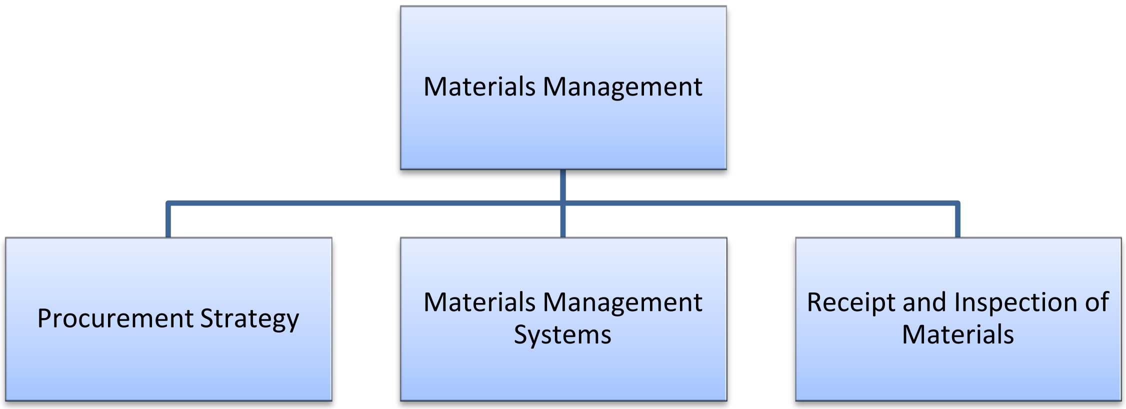


Figure 4.3: Materials management category

4.2.1.1 Procurement Strategy

This section of the BPPII Infrastructure groups together best practices related to the procurement of materials and equipment. The procurement strategy deals with procurement procedures and plans, identification of long-lead and critical equipment and materials and the procurement team. This section contains three elements:

- *Procurement procedures & plans for materials and equipment* include procedures, guidelines, requirements, or systems for purchasing, expediting, and delivery of materials and equipment for the project.
- *Long-Lead/Critical Equipment & Materials Identification* deals with the planning, identification, and tracking of critical and long-lead equipment and material and their timely procurement at the construction site.

- *Procurement team* is necessary for procurement of materials and equipment and implementing the procurement plans.

4.2.1.2 Materials Management Systems

This part of BPPII focuses on the use of an integrated set of systems used to identify, track, report, and facilitate control of project materials. It consists of three elements:

- *Project Team Material Status Database* is an automated system that manages aspects such as the delivery date, date of installation, and storage location of all material used on a project.
- *On-site Material Tracking Technology* is the system that the project team uses to track and locate material that is delivered to the project site.
- *Material Delivery Schedule* is a documented schedule of when material deliveries occur and when material needs to be on site for installation.

4.2.1.3 Receipt and Inspection of Materials

Receipt and Inspection of Materials is defined as the examination of the materials before acceptance to note completeness of the delivery and any obvious external damage of the delivered materials. It consists of three elements:

- *Material Inspection Process* is the documented plan for the inspection of all materials delivered to the project site.
- *Material Inspection Team* includes the employees that are hired to perform the material inspection process.

- *Post Receipt Preservation and Maintenance* is the upkeep, inventory, and inspection of material stored on the project site.

4.2.2 Category II - Construction Machinery and Equipment Logistics

The CII conducted the Voice of the Worker Index research project and determined that the factors having the most significant impact on craft labor productivity was the availability of appropriate construction equipment and tools on jobsites (CII, 2006c). Dai et al. (2009) reported that the most significant factor affecting craft labor productivity in workers' view is that, "I have to wait for people and/or equipment to move the material I need". Dai et al. (2009) supported the importance of using a site tool management plan to ensure tools are present on site, stored in a location that is organized and easy to locate, and in proper condition to perform designated tasks. Rivas et al. (2011) found that tools, equipment, and trucks are some of the main factors that can decrease productivity if they are not managed properly. They also reported that tools and equipment and trucks account for a major portion of the total waiting time. Hanna and Heale (1994) reported that construction machinery have high significance in factors related to working conditions.

Construction Machinery and Equipment Logistics consist of two sections: (1) Construction Machinery and Equipment Availability, and (2) Tools and Equipment Management Best Practices as shown in Figure 4.4.

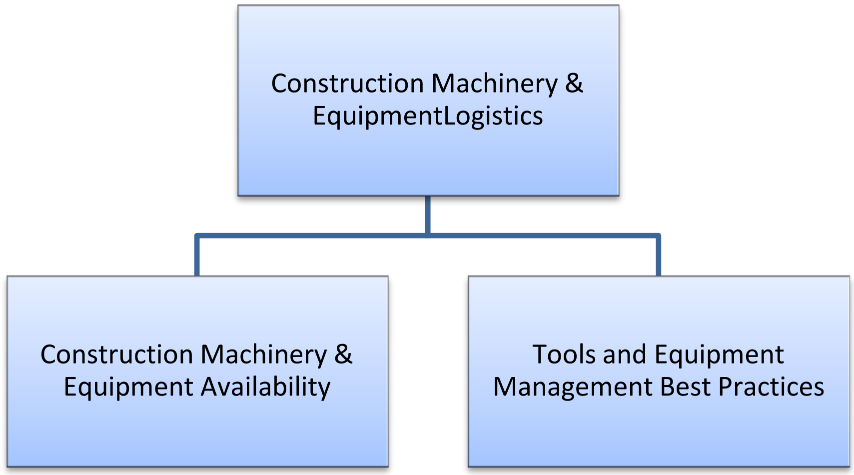


Figure 4.4: Construction machinery & equipment logistics category

4.2.2.1 Construction Machinery and Equipment Availability

Construction Machinery and Equipment Availability is defined as the planning and organization of all construction machinery and equipment that may be used on site. These practices ensure the availability of all light and heavy machinery, effective maintenance and optimized location of earthwork, lifting and hauling equipment. It consists of three elements:

- *Procurement Procedures and Plans for Construction Machinery* are documented plans for procurement of construction machinery to make sure that it is available at the job site when needed.
- *Construction Machinery Productivity Analysis* is the determining and understanding of the cost to use a piece of equipment and the maximization of trades' productivity related to the use of the equipment.

- *Construction Machinery and Equipment Maintenance* is the practice of maintaining machinery and equipment used on a jobsite to ensure that all equipment is performing at optimum levels.

4.2.2.2 Tools and Equipment Management Best Practices

Tools and Equipment Management is the planning and organization of all tools and equipment used on the project. Infrastructure projects require use of routine tools such as saws, hammers, grinders, and other equipment that is operated and guided by hand as well as the power sources required for their operation. These projects use heavy and light construction machinery that have fuel and power requirements. This section consists of four elements:

- *Site Tools and Equipment Management Strategy* is the development of a plan to acquire, organize, store, inventory, and maintain tools, equipment, and consumables that are necessary to complete a project.
- *Tools and Equipment Tracking* is a formal plan to monitor the location and/or responsible parties for tools and equipment when they are checked out of the storage area for use in the field.
- *On Site Tools Maintenance* is the practice of maintaining all tools necessary on the project to ensure that they are performing up to specifications.

- *Construction Machinery and Equipment Utility Requirements* is the practice for determining the utility requirements of construction machinery and equipment to ensure that they operate at their optimum capacity.

4.2.3 Category III – Execution Approach

This category deals with issues which are required to be planned and settled so that the construction work can be properly executed and progresses without stopping. The practices in this category are related to planning, constructability reviews, utility alignments, acquisition strategies, and regulatory requirements.

Thomas et al. (1990) identified environmental site conditions and design features-work content as two of the five broader categories affecting productivity. Dozzi and AbouRizk (1993) mentioned project conditions and government policies such as approval and issue of permits as major factor influencing productivity. Hanna and Heale (1994) found that contract types can influence productivity. They reported that fixed price contracts have better productivity and that lowest bid contracts had a negative effect on productivity. They also mentioned that planning, scheduling, and availability of working drawings are critical for project productivity. McTague and Jergeas (2002) reported that lack of front end planning and poor constructability of design are some of the major reasons for low productivity on large projects. Mojahed and Aghazadeh (2008) reported that the contract type is a driving factor for productivity. The type of contract can influence the productivity depending on the situation, for example, fast track jobs.

Right-of-way (ROW) and Utilities are two functions which are on the critical path in transportation projects. Caldas et al. (2007) conducted an extensive research project for the Texas Department of Transportation and developed the Advance Planning Risk Analysis (APRA) tool, which is useful in determining the right-of way (ROW) requirements during the project development process. Improving the ROW process is important for timely delivery of projects. The determination of ROW requirements during the project development process depends on factors such as; proposed alignment, typical sections, access control, and accommodation for construction, drainage, clear zone, highway access maintenance, accessible pedestrian design, and environmental mitigation (Caldas et al. 2007).

Execution Approach is composed of four sections (Figure 4.5): (1) Planning, (2) Constructability Reviews, (3) Acquisition Strategy, and (4) Regulatory Requirements/Reviews.

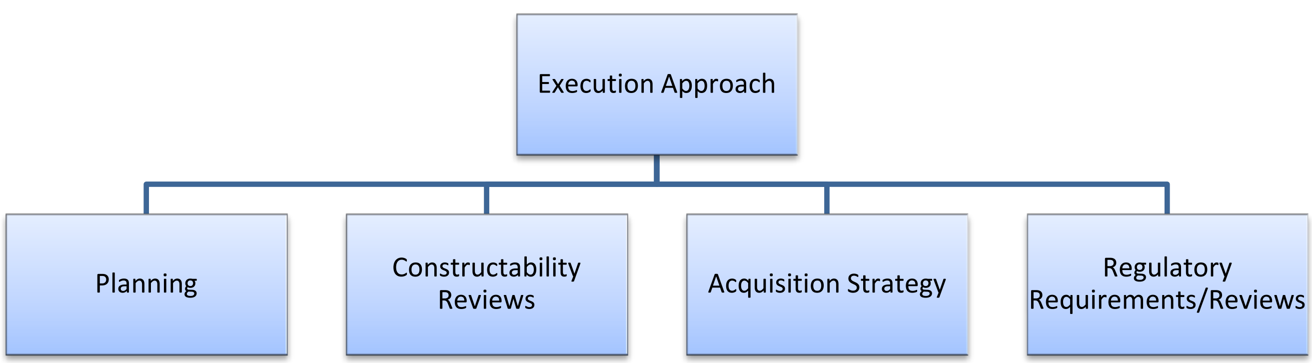


Figure 4.5: Execution approach category

4.2.3.1 Planning

This section consists of five elements that are required for best planning of an infrastructure projects. Planning has been identified as an important factor for efficiently executing projects. The elements are:

- *Short Interval Planning* is defined as a short-term plan in response to updated progress. It involves short-term construction schedules that include tasks to be performed, scheduling, and allocating the use of shared resources such as the tower crane; the craft workers needed on site; the duration of each task; and the required materials, tools, and equipment.
- *Well-Defined Scope of Work* is a clear description of the basic requirements, goals, timeframe, and the owner's vision of the project.
- *Use of Software in Planning* is the practice of using automated software for assisting in creating schedules for project tasks and material deliveries and identifying the necessary materials needed to complete a task.
- *Dedicated Planner* is a person that is appointed to plan, organize, and approve all work activities that take place on the construction site.
- *Construction Work Packages* define in detail specific scopes of work and each should include a budget and schedule that can be compared with actual performance.

4.2.3.2 Constructability Reviews

Constructability Review is defined as the incorporation of construction knowledge in the planning, design, and execution of a project. Research has shown that constructability reviews provide potential improvement in many different areas such as labor productivity. These reviews encourage simplified design and the utilization of optimal construction systems that lead to a reduction of work hours. The section consists of four elements:

- *Design Readiness for Construction* is a review of the design documents to ensure that they are correct and complete and the schedule can be made and completed before actual construction begins and relevant phases are mobilized.
- *Utilities Alignment/Adjustments* is the review of existing utilities in the vicinity of construction project. Arrangements should be made for working around these utilities and in some cases, the existing services have to be removed, modified, and reinstated after the construction.
- *Contract Types/Strategies* deals with situations when there are multiple sub projects in a large infrastructure project. Different types of project delivery methods and contracting strategies for project design and construction are reviewed.
- *Model Requirements/3D Visualization* is a scaled physical or digital representation of the project that is built.

4.2.3.3 Acquisition Strategy

Infrastructure projects usually deal with matters about acquisition of right of way, land, and utilities. Right of way and land acquisition are usually on the critical path of infrastructure projects. Research has identified that adequate acquisition strategies can help the project to progress smoothly. This section has three elements:

- *Right of Way, Land, and Utilities Acquisition Strategy* deals with identification and acquisition of right of way, land, and utilities. The process may include consultation with public and owners of lands.
- *Contracts and Agreements with Agencies* determine and state the responsibilities regarding the acquisition of right of way, adjustment of utilities and cost sharing between the public agencies and owner/contractor. It describes the contractual agreements with local public agencies.
- *Utility Agreements* and contracts for joint use effectively allow the utility to share space on public or private right-of-way. It also enables completion of utility adjustments. It is important to pay attention to utility arrangements in order to ensure that the review and approval processes are coordinated in a timely and efficient manner.

4.2.3.4 Regulatory Requirements/Reviews

Infrastructure projects require having extensive environmental assessments and permits to proceed before construction work can start. This section has two elements:

- *Environmental Requirements* deals with the environmental assessments and mitigation techniques. These environmental assessments depend on the type, size, and scope of the project. The project's environmental classification and funding sources usually determine the type and nature of environmental studies/assessments to be performed. These assessments can influence the project's design, engineering and construction.
- *Regulatory Requirements/Permitting Requirements* are the identification and acquiring of various permits and official project execution authorization documents from the owner, city, county, state, and nation.

4.2.4 Category IV - Human Resources Management

As labour productivity involves humans, it is imperative that proper management of this resource is essential. Human Resources Management deals with the planning, training and development, organizational structure, and employment issues of people working in the company. Thomas et al. (1990) found manpower or labour and project organization structure to be the main categories that influence productivity. Dozzi and AbouRizk (1993) identified lack of experienced design and project management personnel, restrictive union rules, and lack of management training for supervision and project management as the main factors affecting productivity. Hanna and Heale (1994) identified motivation as a major area that affects productivity, and foreman supervision, team work, and employee motivation are major elements in increasing productivity in the area of motivation. Teicholz (2001) has identified inadequate training for workers and managers and fewer younger workers entering the workforce as the possible causes for decline in labour productivity. McTague and (Jergeas 2002) reported human resources issues as a factor for low productivity.

Rojas and Aramvareekul (2003) conducted a research project through a survey to determine the relative level of importance of construction labour productivity drivers and opportunities. Based on the 64 survey responses received, it was concluded that management skills and manpower issues were the two areas with the greatest potential to affect productivity. They reported that improving training programs, enhancing worker motivation, and improving strategic management are the three out of top five opportunities for improving productivity. Kazaz and Ulubeyli (2007) found that monetary factors are the most important in influencing productivity, but socio-psychological factors are also becoming an important factor in affecting productivity. However, their study found only a small difference between the importance given to economic and socio-psychological factors in improving productivity. The socio-psychological factors included: work discipline, health and safety conditions, work satisfaction, giving responsibility, social activity opportunities, worker participation in decision making. Mojahed and Aghazadeh (2008) conducted a research project on finding major factors influencing productivity on water and wastewater treatment plant construction. Skills and experience of workforce, management, and workers motivation were the three out of top five productivity drivers. Dai et al. (2009) identified training, craft workers qualification, superintendent competency, and foreman competency as four out of ten most important factors according to craft workers' opinion to have a negative impact of construction productivity. Rivas et al. (2011) mentioned workers' motivation as a main factor that influences productivity. Tabassi et al. (2012) studied the correlation of Humana Resources Development (HRD) strategies of employee training and motivation practices with team work improvement and task efficiency in construction projects. Their research found a strong relationship between training and motivation practices with teamwork improvement and task efficiency.

Human Resource Management is made up of five sections (Figure 4.6): (1) Planning, (2) Training and Development, (3) Behavior, (4) Organizational Structure, and (5) Employment.

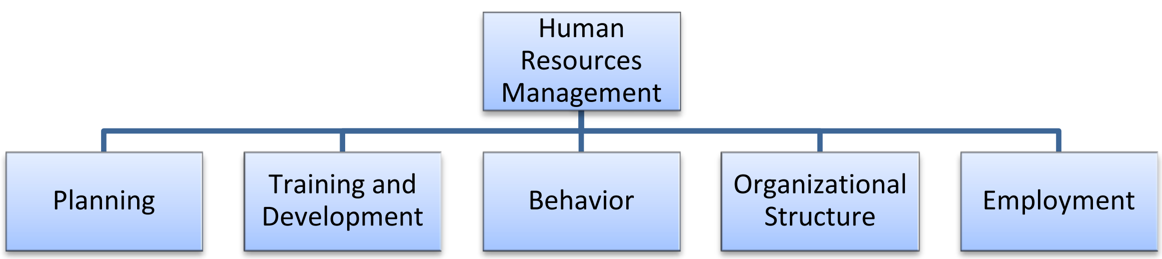


Figure 4.6: Human Resources Management Category

4.2.4.1 Planning

Planning is essential for every aspect of project, and the availability of highly-skilled and highly-valued construction workers may be a challenge to find and sometimes even not available in the labour market. Planning helps in the hiring of skilled workers and crew formation. This section has two elements:

- *Crews Composition/Crew Formation* ensures that proper crew is available for different tasks, activities, phases, and locations of project. It considers combination of different skills levels of workers and may require agreements with local or national labour unions.
- *Skills Assessment and Evaluation* ensures that craft workers are assessed before hiring them for the project or organization.

4.2.4.2 Training and Development

Training and Development is defined as the development of craft skills through training, to help ensure that workers have the proper skills to effectively and efficiently perform their designated tasks. This section is made up of the following two elements:

- *Employees/Trades Technical Training* prepares employees and workers to perform specific tasks and covers the tools usage, installation procedures, drawings reading, scheduling, etc.
- *Career Development* is a long-term career path which includes training, advancement, and promotion options for the craft workers.

4.2.4.3 Behavior

Behavior is defined as addressing both craft workers' motivation and satisfaction in their work. Workers' behavior on a jobsite is driven by motivation. The following are the three elements of this section:

- *Nonfinancial Incentive Programs* are formal programs that track and record craft worker safety performance and frequently reward craft workers with non-monetary rewards.
- *Financial Incentive Programs* are formal programs that track and record craft worker safety performance and frequently reward craft workers with monetary rewards.
- *Social Activities* are company or project-planned activities involving craft workers and other senior employees for improving relationship and creating a positive work environment.

4.2.4.4 Organizational Structure

Organizational Structure is defined as the development of a clearly defined line of authority on the jobsite that reduces the cycle time of the processing and exchange of information. This section consists of two elements:

- *Maintain Stability of Organization Structure* means working towards a stable organizational structure by avoiding changes in key personnel on a project.

- *Clear Delegation of Responsibility* is a defined structure of project parties' roles and responsibilities and applies to both owners and contractors.

4.2.4.5 Employment

Employment is defined as the employment strategy that retains productive, effective, and experienced workers. This section consists of two elements:

- *Retention Plan for Experienced Personnel* is a company/project-specific program put in place to retain highly skilled and experienced craft workers.
- *Exit Interview* is an interview with craft workers that resign from the company/project intended to determine their reasons for leaving. These reasons may then be addressed.

4.2.5 Category V - Construction Methods

Construction methods used for the completion of a project play an important role in project success. This category groups together best practices related to site layout planning, scheduling controls, and design/construction planning and approach.

Thomas et al. (1990) categorized construction methods as a major group affecting productivity. Dozzi and AbouRizk (1993) identified ineffective communications and inadequate planning and scheduling as major impediments in productivity improvement. Hanna and Heale (1994) mentioned scheduling, overtime strategies, and task sequencing have greater impact on labour productivity. McTague and Jergeas (2002) mentioned project controls as a major factor having influence on productivity. Rojas and Aramvareekul (2003) reported that scheduling is one of the most relevant factors in determining labour productivity in the management systems and strategies category. They also reported that the use of technologies in construction methods is important for the improvement of labor productivity.

Site Layout Planning enables the project managers to organize the construction site in the most efficient and safe manner. The plan includes but is not limited to a lay-down area, tool storage, break areas, and equipment storage. For infrastructure projects, a traffic control plan is also a part of the site layout plan. Because of the nature of a construction project, the site layout should be dynamic. For infrastructure projects, the communications, coordination, and agreements between different agencies and stakeholders are important.

Construction Methods is composed of three sections (Figure 4.7): (1) Project Schedule Control, (2) Site Layout Plan, and (3) Design/Construction Plan and Approach.

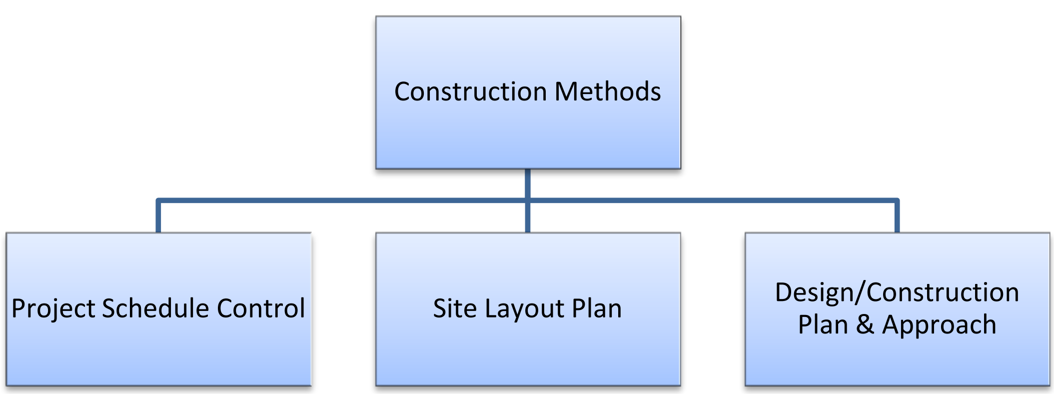


Figure 4.7: Construction methods category

4.2.5.1 Project Schedule Control

The project Schedule Control deals with scheduling and controlling project activities. This includes determining when craft workers will need equipment, materials, and information. To ensure that the project completion date is met, the project team develops daily, weekly, monthly, and overall schedules. Forward and backward techniques help the team effectively plan activities to avoid negatively impacting the completion date. This section is made up of three elements:

- *Integrated Schedule* is creating a schedule for all project activities using forward and backward techniques.
- *Work Schedule Strategies* is the specific work schedule approach used on the project.
- *Schedule Execution and Management* is the oversight of the work performed to meet a project schedule, as well as the updating of the schedule and the measuring of a project's progress.

4.2.5.2 Site Layout Plan

Site Layout Plan allows the project managers to organize the construction site in the most efficient and safe manner. The plan includes but is not limited to a lay-down area, tool storage, break areas, and equipment storage. For infrastructure projects, a traffic control plan is also a part of the site layout plan. The plan should ensure optimal craft worker productivity. This section is composed of the following four elements:

- *Dynamic Site Layout Plan* is the organizing of the land on the construction site in the most efficient and safe manner to allow workers to effectively perform their tasks to complete the project.

- *Traffic Control Plan* is used to provide safe and efficient operations of all modes of transportation around the project site and include safety of construction workers and inspection personnel. The plan should ensure compliance with local, regional, and national jurisdictional requirements.
- *Site Security Plan* is a plan to keep the site safe for the workers, the pedestrians or citizens that will operate close to the site, the people that will be making deliveries to the site, and will keep tools and equipment away from situations that will make vandalism and theft easy.
- *Machinery and Equipment Position Strategy* is the plan developed regarding equipment location to perform their designated activities without interfering with other on-site activities.

4.2.5.3 Design/Construction Plan and Approach

This section deals with the communications, coordination, and agreements, project start-up and completion plan, innovation and new technologies, and housekeeping issues. This section is composed of the following five elements:

- *Communications, Coordination, and Agreements* between the contractor, owner, public and private agencies, local, provincial, and federal governments, and the public are very important in project execution for infrastructure projects. Improper communication and coordination can cause delays and negatively affect productivity.

- *Project Start-Up Plan* is the planning for a successful project start-up and depends on management commitment, start-up objectives, and start-up execution plan.
- *Project Completion Plan* deals with the documentation and planning in advance to ensure a smooth transition to operations.
- *Innovation and New Technologies* is the process of investigating advances in new materials, equipment, information systems, technologies, work methods, management techniques and determining the implementation costs and maturity of it.
- *House Keeping* includes scheduling weekly times that are taken to ensure that the work face is organized and the jobsite is clean from debris and hazards.

4.2.6 Category VI – Health and Safety

Health and Safety category relates to the implementation of practices that ensure the safety and health of workers and managers on construction sites. The CII Benchmarking and Metrics program have metrics related to health and safety measurement (CII 2006a) and the Construction Sector Council Canada’s Labour Productivity and Project Performance Improvement Program has also metrics defined for health and safety related practices (Nasir et al. 2012b). CII developed practices such as Zero Accident Techniques that should be implemented to protect workers' safety on a jobsite (CII 2006a).

The construction industry is one of the hazardous industries. Helander (1991) analyzed the numbers of fatalities and injuries in the construction industry. His research found that accidents can be avoided by establishing procedures and regulations to enhance safety. Different job classifications have safety hazards related to them and usually the construction workers underestimate the hazards. The cost of accidents in construction accounts to approximately 6% of total building costs (Helander 1991). Therefore, if health and safety practices are enforced, it can reduces accident costs and keep the workers safe.

Hinze and Wilson (2000) reported that the industrial sector of the construction industry has seen significant improvements in its safety performances compared to other sectors of the industry. Their study was conducted with large, mainly industrial, firms to find if any changes had been made since the Construction Industry Institute introduced its findings on effective means to improve safety performance. They found that additional changes have been made by many of these firms and that benefits were also observed. It was concluded that firms with good safety records can still make improvements by implementing specific safety practices. It also reduces injury rates.

Hinze and Gambatese (2003) conducted a research trough surveys to identify factors that significantly influence the safety performance of specialty contractors. It was found that minimizing worker turnover, implementing employee drug testing, and training with the assistance of contractor associations have a positive effect on the safety performance of speciality contractors. It was also found that growth in the company size is associated with improved safety performance. Kazaz and Ulubeyli (2007) found that health and safety conditions are a key socio- psychological factor in affecting productivity.

In recent years, the CII's Construction Productivity Research Program Team 252 analyzed the CII Benchmarking and Metrics data to examine the relationship between project practices in various management areas and productivity performance in mechanical, electrical, concrete and steel trades. It was found that the high level of implementation of safety management practices were related to better productivity across all trades (CII 2009; CII 2010b; CII 2011; CII 2013).

Health and Safety category is made up of three sections (Figure 4.8): (1) Job Site Safety, (2) Substance Abuse Program, and (3) Health and Safety Training and Orientation.

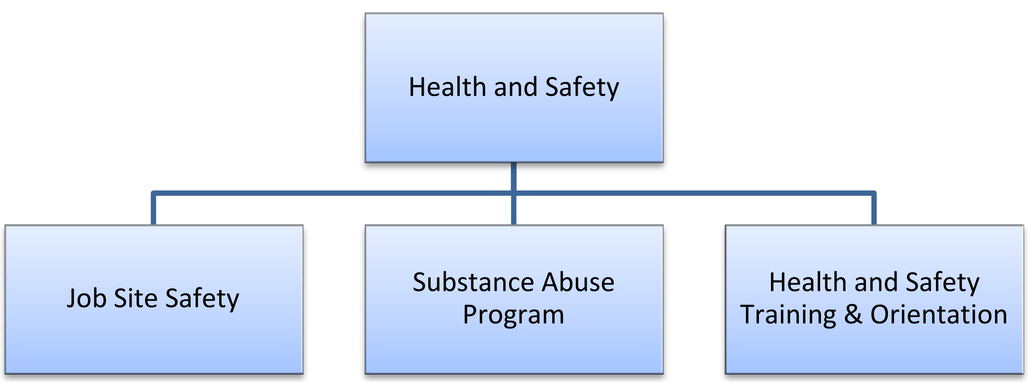


Figure 4.8: Health and Safety Category

4.2.6.1 Job Site Safety

Job Site Safety is defined as identifying hazards associated with each step of a task and determining how to control the hazards. CII developed practices such as Zero Accident Techniques that should be implemented to protect workers' safety on a jobsite (CII 2003). This section is composed of the following five elements:

- *Formal Health and Safety Policy* guides the approach of an organization regarding health and safety issues. The policy should adhere to the concerned health and safety code of practice.
- *Health and Safety Plans/Zero Accident Techniques* are the CII identified practices that help reduce injuries and are projected to achieve the goal of zero accidents.
- *Task Safety Analysis* is the identification of risks and hazards associated with construction tasks and the development of mitigation strategies.
- *Hazards Analysis* is the process to identify all on-site situations that could potentially lead to a hazardous or dangerous environment for the workers.
- *Hazards Planning* is the development of a plan to address hazardous materials that may appear onsite during construction.

4.2.6.2 Substance Abuse Programs

A Substance Abuse Program is defined as a program that includes both pre- and post-hiring testing for illicit drugs use. CII's report on the zero accident techniques research program states that "studies show that when random tests for drugs are conducted, better safety performance results" (CII, 2003). This section only has one element, the *Drugs and Alcohol* Testing *Program*.

4.2.6.3 Health and Safety Training & Orientation

Safety Training Orientation ensures that all project participants and authorized visitors have adequate knowledge to protect their health and safety as well as the safety of others. Specific practices need to be implemented to ensure the efficiency of safety training orientation. This orientation covers jobsite layout, site-specific safety hazards, and location of performed work. This section is composed of the following two elements:

- *Health and Safety Training Programs* are essential for any project site. For example, Canadian Centre for Occupational Health and Safety (CCOHS) and Occupational Safety and Health Administration (OSHA) in Unites States).
- *Toolbox Safety Meetings* are regularly scheduled meetings on the jobsite where constructor managers and craft workers discuss the risks and hazards of activities currently performed on site.

4.3 Scoring of the BPPII Infrastructure

Each element of the BPPII is scored using a system that ranks the planning and implementation level (PIL). The PIL definitions are organized on a scale from 0 to 5 and are provided in Appendix A. Each of the level definitions is different based on the definition of each element. Therefore, each element has planning and implementation levels definitions that are specific to that element. This is used to eliminate user bias and create transparency. Typically, in less well defined approaches, some of the users may determine the PIL average score for an element, while other users may rank the same element as above or below average. The aim is that this scoring system will help in reducing this problem. It is important to note that while the PIL definitions differ for each element, they are defined to be consistent throughout the tool. This means that the actual definition for each of the elements is different, but the definitions for each correspond to the same level of planning and implementation. The guideline for each PIL is explained as below:

1. **Planning and Implementation Level 0:** The planning and implementation of the element is not applicable.
2. **Planning and Implementation Level 1:** The planning and implementation of the element is not addressed in any capacity on the project.
3. **Planning and Implementation Level 2:** The planning and implementation of the element is addressed up to a certain extent, but in a below average manner.
4. **Planning and Implementation Level 3:** The element has average level of planning and implementation.
5. **Planning and Implementation Level 4:** The planning and implementation of the element is thorough, above average, but not perfect.
6. **Planning and Implementation Level 5:** The element has the highest possible planning and implementation level, i.e. at most state of the art and technologically advanced level. It is expected that few projects would achieve this level.

4.4 Summary

This chapter described in detail the Best Productivity Practices Implementation Index (BPPII) for infrastructure construction projects. The index was developed based on the factors that affect construction productivity and good practices having positive influence on productivity as mentioned and discussed in the literature review earlier in this thesis. The organization structure of the BPPII Infrastructure was explained. In total, there are 61 elements, 20 sections, and 6 categories. The six categories of the BPPII Infrastructure are: (1) Materials Management; (2) Construction Machinery and Equipment Logistics; (3) Execution Approach; (4) Human Resources Management; (5) Construction Methods; and (6) Health and Safety. Each of the six categories and 20 sections were explained in this chapter. The scoring of the BPPII Infrastructure was also explained in this chapter. The next chapter describes the methodology and process used in the data collection.

Chapter 5

Data Collection

This chapter explains the methodology used in the data collection for BPPII Infrastructure. It describes the data collection process and the data collection tool used for gathering the information required for this research. The use of productivity factor as a metric to measure labour productivity is also discussed in this chapter.

5.1 Data Collection Methodology

The Construction Sector Council (CSC), Ottawa, Canada, had started the benchmarking and metrics program for performance and labour productivity improvement in the construction sector in Canada. This program was mainly focused on performance and productivity improvement in the infrastructure construction industry. The goal of the program was to develop a method of measuring and benchmarking labour productivity and project performance that will result in a repository of data for use by industry, academia, and governments and that will support a process of continuous improvement (Nasir et al. 2012b). Some companies who provided data for that program were identified as potential sources for validating BPPII Infrastructure. The CII Research Team 252 (CII RT 252) working on improving construction productivity was also involved in the development of the BPPII Infrastructure as a tool to improve productivity. Therefore, member companies of CII were also identified and contacted for providing data for BPPII Infrastructure. Besides these two major sources, the BPPII Infrastructure was introduced to several other companies.

After identifying the potential sources of data, a number of strategies were used to collect validation information for BPPII. These included: presentations and meetings with individuals and associations representing various construction companies, emails, telephone contacts, and CII Research Team meetings. The participants of these meeting were explained what the BPPII Infrastructure means and were explained the objectives of the research. They were described what type of information we were looking for and what they need to do in order to complete the survey forms. A commitment was made to distribute final copies of this thesis to them as well.

5.2 Data Collection Process

A data collection package was developed to collect data for validation of the BPPII Infrastructure. The data collection package was sent to contact persons nominated by the companies who showed willingness to provide data for their projects for this research. The package consisted of three documents, which were:

(1) ***Introduction to BPPII infrastructure:*** this document provided a brief introduction to the BPPII Infrastructure and explained the objectives of the research. It is provided in Appendix B.

(2) ***Data collection form:*** the data collection form that was to be filled by the participating companies, which is explained in detail below. The complete data collection tool is provided in Appendix C, and

(3) ***Elements description:*** this document provided the detailed description and definitions of each element, section, and category of the index. It also provided the planning and implementation level of each element on a scale of 0 to 5. This document is provided in Appendix A.

5.2.1 Data Collection Form/Survey Questionnaire

A data collection tool was developed to collect the data required for validation of BPPII Infrastructure. This questionnaire was designed for collecting information related to the Best Productivity Practices Implementation Index for Infrastructure projects. The tool was designed to be simple and easy to interpret. Also, the information requested was kept to the minimum and absolutely necessary amount. One of the lessons learned in the development of the CSC's benchmarking and metrics program for performance and productivity improvement was to keep the survey tool simple (Nasir et al. 2012b). This questionnaire is composed of four parts, which are: Project Background Information; Project Performance Information; Construction Productivity Information, and Project Score Sheet. Table 5.1 shows the four parts of the survey questionnaire.

Table 5.1: Survey questionnaire sections for BPPII Infrastructure

Items	Purpose
Project Background Information	Grouping and analyzing projects in various aspects
Project Performance Information	Analyzing projects' performance for cost and time schedule
Construction Productivity Information	Analyzing relationships between BPPII Score and labour productivity
Project Score Sheet	Collect BPPII Score

The purpose of each section is as follows:

5.2.1.1 Project Background Information

This section of the survey tool collected information about the basic characteristic of projects which are:

General Information: Company name, project name, contact person name and address, and date of completing the form.

Project Description: to describe the type of infrastructure project, such as: water pipes, waste water pipes, water treatment plants, Waste Water Treatment Plants, Roads/Highways, Transmission Towers/Lines, Dam(s), Railroad(s), Other Subcategory.

Project Nature: to describe the nature of the project if it is Grass Roots, Greenfield, Modernization, Renovation, Upgrade, Addition, Expansion, Other Project Nature.

Project Size: to report the project size in terms of cost, such as: Less than 1 Million Dollars, (1- 5) Million Dollars, (6- 50) Million Dollars, (51 -100) Million Dollars, (101- 500) Million Dollars, More than 500 Million Dollars.

Scope of Construction Contract: to report the type of construction contract, i.e. Construct Only, Design and Construct, EPCM (Engineer, Procure, Construct, and Manage), Construction or Project Management Only, Other.

Type of Construction Contract: to specify the contract type of the project, i.e. Fixed Price, Unit Price, Cost Plus % Fee, Cost Plus Lump Sum Fee, Guaranteed Maximum Price, PPP (Public Private Partnership), Other.

5.2.1.2 Project Performance Information

This section of the survey questionnaire asked for project performance information in terms of cost and time. The estimated cost of construction at tender award and actual cost of construction at completion of project were asked from respondents. Also, the estimated time of construction at tender award and the actual time of construction at completion of the project were requested.

5.2.1.3 Construction Productivity Information

This section collected information for labour productivity in terms of the productivity factor. The productivity factor information was asked for major activities such as; concrete work, earthwork, road base, and asphalt wearing course if any. The use of productivity factor as a metrics for measuring labour productivity is explained and justified in detail in Section 5.4 of this chapter.

5.2.1.4 Project Score Sheet

This section of the survey tool was designed to collect information about the BPPII Infrastructure elements. Detailed instructions were provided for the respondents to complete this part of the survey tool. Scoring is performed by evaluating and rating the individual elements. Elements should be rated numerically from 0 to 5 based on its average level of planning and implementation (PIL) during the construction phase. The PIL scoring has been explained in Section 4.3. It is likely that a thorough audit of each company’s operations would produce a more accurate score than the self-reporting approach used here; however, the resources required for first-hand audits were not available. Also, there are no obvious incentives for inaccurate reporting of the score.

5.3 Example on BPPII Scoring Sheet

Scoring is performed by evaluating and rating the individual elements. The following example explains how to score each element in the survey questionnaire.

Example: How to assess "Procurement Team" element?

This element is listed under Section A "Procurement Strategy" in the Category I "Materials Management" Look at the project score sheet (Figure 5.1).

CATEGORY I: MATERIALS MANAGEMENT

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials and Equipment						
2. Long-Lead/Critical Equipment & Materials Identification						
3. Procurement Team						

Figure 5.1: Example of an element in the BPPII Infrastructure

Next, read the element definition in the BPPII Element Description document (Figure 5.2).

3. Procurement Team

A procurement team is necessary for procurement of materials and equipment and implementing the procurement plans. Issues to consider include:

- Clear expression of and understanding of authority and responsibility for procurement of materials and equipment
- Knowledge about procurement of engineered equipment, bulk materials, fabrication/modularization
- Integration with engineering, design, and construction schedules
- Reuse of existing materials and equipment in case of renovation and rehabilitation projects

Figure 5.2: Example of procurement team element's Definition

Collect the information that may be needed. Analyze the level of implementation of the element using the definitions of the 6 levels provided in the BPPII Element Description document (Figure 5.3).

Level 0	A procurement team for materials and equipment is not applicable
Level 1	There is no procurement team for materials and equipment.
Level 2	There is a designated procurement team at the main office but none at the project site.
Level 3	There is a designated procurement team at the project level, but they can procure daily consumable materials and are not qualified and authorized to procure costly, long-lead critical materials and equipment.
Level 4	Continuation of Level 3, plus the procurement team is qualified and authorized to procure all materials and equipment for the project.
Level 5	Continuation of Level 4, plus the procurement team has been integrated with other project teams such as engineering, design, construction, etc., and it is integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.

Figure 5.3: Example on PILs of procurement team's element

Then, select the appropriate definition level. (For example, a procurement team exists at the main office but not at the project site. Definition Level = 2. Check (√) the corresponding box in the BPPII score sheet (Figure 5.4)**.**

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials and Equipment						
2. Long-Lead/Critical Equipment & Materials Identification						
3. Procurement Team			√			

Figure 5.4: Example on selecting the PIL of procurement team element

In the same manner, all of the elements in the index are scored based on their planning and implementation level (PIL) after reading their definitions and determining their PILs. All of the elements and their PILs have been defined in the elements description document (Appendix A).

Each element in the index is assigned a weight based on the effect the element has on productivity. By using a weighted system, each element's PIL corresponds to a different score rather than a simple 0 to 5 scale. The relative weights assigned to each element are explained in chapter 6. The respondents were asked to provide the PIL of each element on a scale from 0 to 5. They were not aware of the relative weights of each element or the actual weights of each individual element. This helped to ensure that the respondents were not biased towards assigning high or low scores to certain elements.

Once the data collection forms were sent to the respondents, follow-up enquiries were made with the companies through emails, telephones, and personal meetings when possible. The persons completing the forms were helped with explanations if they needed any clarification. Once the returned forms were received, they were checked for accuracy and missing information. If some information was missing or not clear, a follow-up call was made, and the information was collected again.

The data collected were entered into an Excel spreadsheet and later exported to the Statistical Package for the Social Sciences (SPSS) version 16.0 for making statistical analyses. No personal information about the persons completing the forms and companies' identities was exposed. The projects were assigned a numerical identification number based on when the data were received without any other consideration. All the participating companies were ensured that all the information would be kept confidential and their names and numbers would not be disclosed in any manner.

5.4 Productivity Factor as Metric for Measuring Labour Productivity

The term Productivity Factor is used for measuring productivity performance. McDonald and Zack in a report for the American Association of Cost Engineers have provided an equation for productivity factor (McDonald & Zack 2004) as:

$$\text{Productivity Factor} = \frac{\text{Actual Productivity}}{\text{Baseline or Planned Productivity}}$$

Thomas et al. (1990) have stated that productivity can also be measured in terms of Performance Factor. The equation for Productivity Performance Factor is given as:

$$\text{Performance Factor} = \frac{\text{Estimated unit rate}}{\text{Actual unit rate}}$$

Therefore, the term productivity factor is synonymous with the term productivity performance and can be further expressed as:

$$\text{Productivity Factor} = \text{Performance Factor} = \frac{\text{Estimated Productivity}}{\text{Actual Productivity}}$$

Whereas,

$$\text{Actual Productivity} = \frac{\text{Actual Work–Hours}}{\text{Installed Quantity}}$$

And,

$$\text{Estimated Productivity} = \frac{\text{Estimated Work–Hours}}{\text{Estimated Quantity}}$$

The estimated productivity includes any revisions made in the quantities to be installed after the original estimates and would represent the current estimate. If the above equation is used, a productivity factor greater than one is considered ideal because actual work-hours per unit of output are less than planned or estimated work-hours per unit of output. The next sub-section explains how the estimated productivity and actual productivity are linked with each other.

5.4.1 Evaluation of Actual Productivity

Figure 5.5 explains the evaluation framework of actual productivity. The cumulative average productivity for each work category can be calculated by collecting data with respect to quantity installed and labour work hours.

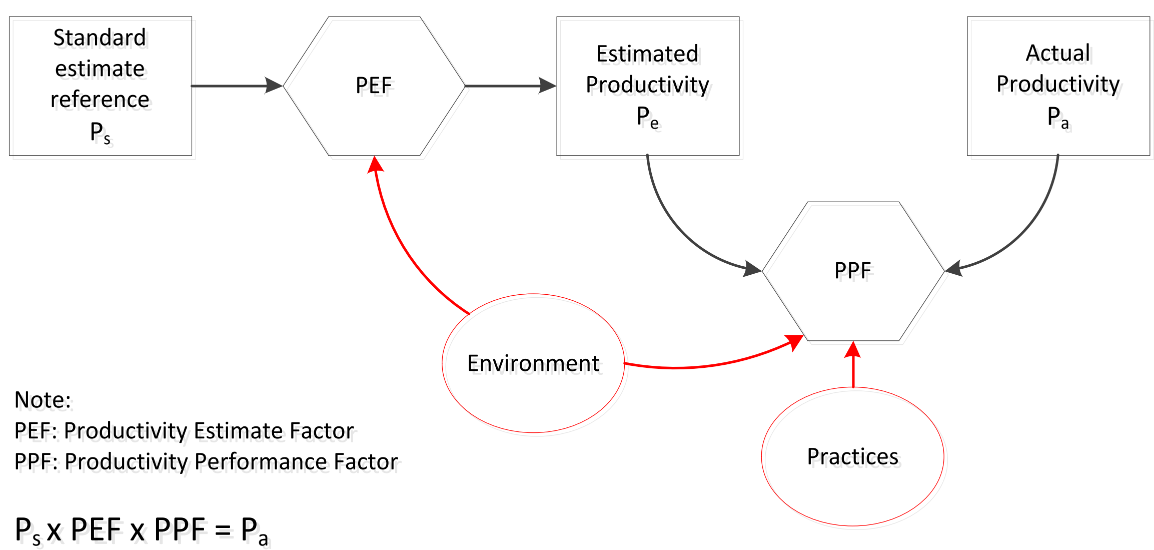


Figure 5.5: Evaluation framework of actual productivity (Zhang 2012)

The estimated productivity is obtained by connecting Productivity Estimate Factor (PEF) with standard estimate reference. The standard estimate reference productivity represents the productivity norm of a company, which is usually stable for a long period. The variability of actual productivity performance is affected by three sources: environmental factors, practices implementation, and some unknown random error. Usually, the PEF is mostly affected by environment factors, such as weather, location, working conditions, labour market, and so on. The Productivity Performance Factor (PPF) is calculated as estimated productivity over the actual productivity. The PPF is affected by both the environmental factor and practices performance (Zhang 2012). Therefore, PPF is a useful metric to evaluate productivity performance. The Productivity Performance Factor (PPF) or Productivity Factor (PF) of a successful project is generally greater than 1, showing that actual work hours required for a unit of output are less than estimated work hours.

5.4.2 Issues with Using Unit Rate as a Metric for Labour Productivity

The labour productivity information for this research work was collected using Productivity Factor (PF). The PF was used as a metric to measure labour productivity instead of unit rate which is hours per unit of output because of several reasons, which are explained below.

5.4.2.1 Concept of absolute vs. relative

Alby (1994) mentioned that measuring labour productivity as work-hours per unit of output which represents absolute productivity is not always useful. He recommended that a much more useful definition of productivity is the concept of relative productivity or productivity factor (PF). The PF is defined as *"the ratio of the quantity of physical work produced by a unit of labour on a specific project and activity, to the quantity of the same* *work produced by a unit of labour on a standard project in standard conditions"* (Alby, 1994). This concept of measuring productivity in terms of productivity factor is very useful and has practical advantages compared to the absolute measure of productivity represented by hrs/unit. Some of the advantages include: PF is independent of the units of measure used on a project such as tons or pounds, English or metric; it allows the calculation of weighted average productivities, by allowing one to define and measure project productivities, or regional productivities, or productivity changes through time; it allows measuring the productivity of any project against a single accepted standard (i.e. "standard project"), making productivity measurement objective, not only a measure of performance relative to a budget for a given project (Alby, 1994). However, the problem in the construction industry is that there is no "standard project". The majority of construction projects are one-of-a-kind. Similarly, as discussed in chapter 2, there is no standard definition of productivity in the construction industry that is accepted by all the stakeholders and which can be applied across the industry sectors without modifications. All definitions are specific for particular uses.

5.4.2.2 Practical issues in measuring unit rate

There are several practical issues in calculating the labour productivity in terms of unit rates, i.e. hours per unit quantity installed. Park et al. (2005) developed metrics for measuring labour productivity for different categories of work under a CII sponsored program. These CII's metrics were developed for measuring labour productivity for concrete, structural steel, electrical, piping, instrumentation, equipment, and insulation. These productivity metrics are also used by the CII in their benchmarking and metrics program

(Park et al. 2005). They are based on the installed quantity and actual work hours. Actual work hours are the summation of work hours of direct accounts. Indirect account hours are to be excluded from the work hours reported. The CII have developed a list of accounts to be considered direct or indirect. The problem which arises is that not all companies keep track of their direct and indirect accounts and even if they keep track, they are not consistent throughout the industry. Every company has a different system to account for their direct and indirect hours. Also different contractors may have a different definition for the scope of work included in each category and subcategory of work.

The example of the metrics for concrete productivity is considered to give an idea of the complexities involved. The CII metrics on concrete productivity consist of three main categories which include; foundations, slabs, and concrete structures. These categories are then further divided into sub-categories. For example, the slabs category is divided into: on-grade; elevated slabs/on deck; area paving; and others. The foundations are divided into: < 4 m^3; 4-15 m^3; 16-38 m^3 and; > 38 m^3. If someone has to compare the productivity performance of different companies even for a single work category of concrete, there are problems in using the absolute or unit-rates comparisons, because the productivity is very different for slabs than for foundations and different for other concrete structures. So the volume of work in each category matters. Even at the subcategory level, productivity would be different if the work includes only for example; foundations less than 4 m^3 and foundations greater than 38 m^3. Thomas and Zavrski (1999) reported that there are different standard items even for a single category of work and for defining the baseline productivity, the data had to be processed and converted to standard items of work using conversion factors. This is the case for almost every company. The work required to convert their productivity rates from projects (and only a small percentage of companies record them) to the CII definitions can take person months per company (Zhang 2012).

5.4.2.3 General contractors vs. specialty contractors

There are also differences in labour productivity between the jobs performed by general contractors and specialty contractors. Thomas and Zavrski (1999) found that projects that were performed by specialty contractors were better in terms of productivity that those performed by the general contractors.

5.4.2.4 Benchmarking the effects of productivity drivers/practices

Mohamed (1996) reported that Benchmarking in construction is not as straightforward in implementation in the construction industry mainly because of the nature of the industry in collecting data and the considerable fluctuation in the productivity. Another main issue is that even if the data is available, it is highly biased on the special characteristics of the project, such as size, type, budget, and even design. Therefore, it is a challenge to use the data effectively as a basis for comparison.

PF is a useful metric when the research is intended to compare the effects of productivity drivers. It helps in assessing the impacts of practices and other drivers on productivity improvement or performance on any particular project, as the other absolute measures of productivity such as unit rate and factor productivity do not allow observation of the effects of productivity drivers. Crawford and Vogl (2006) mentioned that because of biased productivity measurements, the simple way of calculating the output/labour input ratios which are used more commonly do not allow the establishment of cause-and-effect relationships. These output/input ratios based on labour hours and quantities installed do not provide help in assessing the drivers of performance and their effects.

5.4.2.5 Project characteristics

There are no vigorous individual measures to account for the intangible inputs of the construction process such as quality of materials, labour, capital, and management. There are also measurement issues at project level related to design quality, client expertise and involvement, and local conditions such as site quality. There are several problems in using the actual or absolute productivity numbers when the intent is to compare projects having different characteristics. Some of these issues include:

- local weather
- availability of skilled workers,
- nature of job and activity
- industry group
- contract type
- size
- location
- complexity

- quality of materials, labour, capital and management
- client expertise and involvement
- design quality
- site quality

Productivity factor (PF) is a useful measure in comparing productivity between different projects. As PF measures performance, it is more suitable for comparing projects than absolute productivity numbers. Unless we are comparing the projects that are almost identical in all respects, using PF to see the effects of practices and other productivity drivers is a more reliable measurement metric than just simply using the absolute productivity or unit rates. As PF is a relative metric, it can be used to compare different categories of projects such as, roads, WWTP, bridges, dams, and so on, which have different construction techniques. It is not possible to compare these different kinds of projects to each other and asses the effects of practices on these projects, if they have completely different working environments and construction methods.

The PF was also recommended as a metric for measuring and comparing labour productivity performance in the Construction Sector Council's (CSC) benchmarking and metrics program (Nasir et al. 2012b). Another advantage of using productivity factor in terms of feasibility of research data collection is that Companies who do not want to provide their own productivity information may be willing to provide their productivity factor information for their projects. They can share their productivity information without disclosing their direct productivity rates. Nasir et al. (2012b) found that companies are willing to provide their estimated productivity information but hesitant to disclose their actual productivity numbers.

Therefore, based on the above discussion, and in consultation with the CII RT 252 members, it was decided to use productivity factor as a metric to measure labour productivity for validation purposes of the BPPII Infrastructure. The PF is a useful metric for validation of the BPPII, because it is a relative metric. PF can countervail the negative effects stemming from differences in projects (i.e., industry group, contract type, nature, size, location, complexity), and because of measurement issues.

5.5 Selecting Concrete Work Category for Analysis

Construction activities can be broadly grouped into few major work categories. The Construction Industry Institute (CII) had developed metrics for measuring labour productivity for concrete, structural steel, electrical, piping, instrumentation, equipment, and insulation in their benchmarking and metrics program (Park et al. 2005). Each of these categories is further divided into sub-categories at different levels.

The labour productivity information for this research work was obtained for concrete work involved in infrastructure projects and compared with the BPPII score. The construction project consists of several activities. The activities related to concrete are common in every type of construction project whether it is a building, industrial, or infrastructure project. Concrete work consists of activities related to slabs, foundations, and structures such as columns and beams. Concrete work is a major and common activity in most of the infrastructure projects, such as; bridges, dams, airport runways, tunnels, canals, access ramps, water control structures, and so on. The other reason for using concrete work for measuring labour productivity was that the Construction Sector Council (CSC), Canada has collected information on concrete labour productivity in its Labour Productivity and Project Performance Benchmarking Program (Nasir et al. 2012b). The author has worked with CSC on this program and some of the data were collected from companies working with the CSC. The labour productivity information for concrete work was collected using productivity factor as explained in the previous section.

5.6 Summary

This chapter explained the methodology used in the data collection for BPPII Infrastructure. It described the data collection process and the data collection tool used for gathering the information required for this research. The use of productivity factor as a metric to measure labour productivity performance was also discussed in detail in this chapter. The next chapter explains the methodology used in assigning the relative weights to the elements, sections, and categories of the BPPII Infrastructure.

Chapter 6

Weighting Methodology of BPPII Infrastructure

As mentioned in the previous chapters, each element in the BPPII Infrastructure will be assigned a relative weight with reference to other elements in the index based on its importance on affecting productivity in the infrastructure sector. This chapter describes the procedure adopted for assigning relative weights to the elements, sections, and categories of the BPPII Infrastructure. The ranking of categories, sections, and elements based on their scores is also discussed in this chapter.

6.1 Methodology used in BPPII Industrial and other CII Indices

The elements, sections, and categories in BPPII Industrial and also in most of other CII developed tools, such as Project Definition Rating Index (PDRI) have been assigned relative weights based on the importance of individual elements compared relatively to other elements. The weights in these indices were assigned based on the ranking of these elements by industry and academic experts based on the importance of relevant industry sectors. These experts were asked to rank the elements through survey questionnaires and workshops. After getting these weights recommended by experts, some statistical methods were applied to assign relative weights to each individual element, section, and category. The weighting methodology used in BPPII Infrastructure is different than this approach and is explained in detail below.

6.2 Weighting Methodology for BPPII Infrastructure

6.2.1 Scoring Procedure

Data from projects on the implementation level of each element or practice and productivity factor were collected. Each element is scored based on its planning and implementation level (PIL). The PIL scale ranges from 0 to 5. A score of 0 is assigned to elements that are not applicable to the particular project. Elements that are applicable are assigned a score from 1 to 5, with 1 as no implementation and 5 as the highest possible implementation.

The scores of each element in a section are summed to obtain a section score and the scores of each section in a category are summed to obtain the category score. Only un-weighted scores were used in all the steps described below. As some of the elements may not be applicable to certain projects, the scores were normalized to consider only those elements that were applicable and excluded those that were not applicable in calculating the scores of sections and categories.

6.2.2 Weighting Procedure

The weights were first assigned to the categories relative to each other, based on their importance to the productivity after statistical analysis. Instead of assigning weights based on experts' opinion, the weights are assigned after conducting correlation analysis. Correlations analysis was performed to see the bivariate relationship between productivity factor and each of the six individual categories, which make up the index. This was done in order to find how the productivity factor is related to each individual category and what the direction of the relationship is. Pearson's correlation coefficient is used to see the direction and strength of the relationship between the two variables. The objective was to see the effect of each element with productivity without considering the effect of other elements, and the Pearson' correlation coefficient is best suited for this purpose.

The following steps explain the procedure followed in assigning relative weights:

Step 1: Pearson's correlation coefficients were calculated between productivity factor and each of the elements in the index.

Step 2: Scores of the six categories were calculated after excluding the scores of elements with negative correlations between PF and individual practice element. This was done in order to not give disadvantage to categories which have some elements with negative correlations.

Step 3: Pearson's correlation coefficients were calculated between productivity factor and each of the categories in the index.

Step 4: Relative Importance Weights (RIW) were assigned to the categories based on the correlation coefficients by using the following formula:

$$\textit{Relative Importance Weights (RIW)} = \frac{r_i}{\sum_{i=1}^{n} r_i} \times 100$$

where r_i = Pearson's correlation coefficient,

and n= 6 (for 6 categories)

The RIW for each category is obtained as the ratio between the individual score and the total scores of all the categories on the basis of correlation coefficients.

Step 5: Relative weights were assigned to sections in the categories using the same process as described in step 4 for assigning RIW.

Step 6: Relative weights were assigned to elements in the sections using the same process as described in step 4 for assigning RIW.

Figure 6.1 explains the process for assigning relative weights to the categories, sections, and elements in the BPPII Infrastructure. The correlation coefficients between the productivity factor and each element in the index are shown in Appendix D. It should be noted that those elements/practices which had shown negative or weak correlation with productivity factor were still allowed to be part of the index. However, these elements were assigned less weights relatively to others. These elements should be taken out of the index if there is negative correlation found even when data from hundreds of projects are obtained.

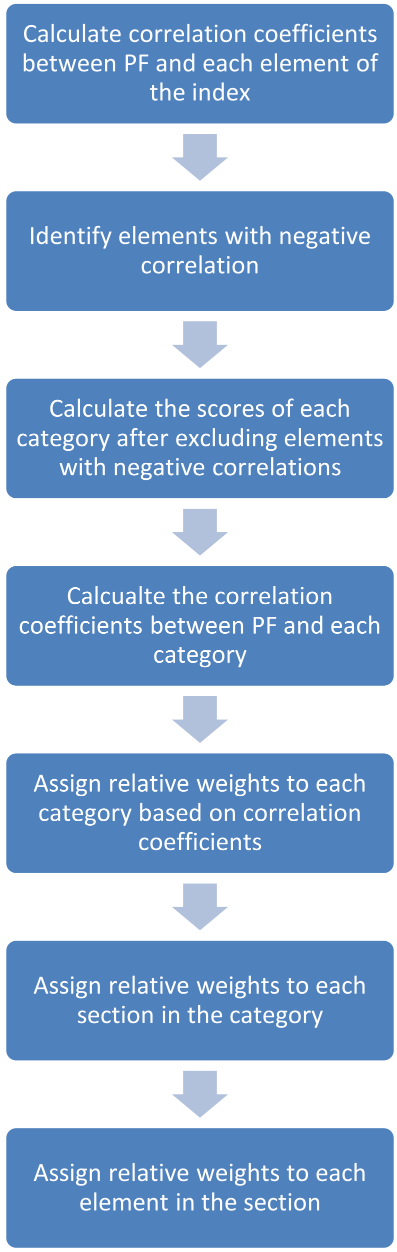


Figure 6.1: Relative weights assigning process in BPPII Infrastructure

Table 6.1 provides the correlations coefficients between productivity factor and the six categories of the index along with their significance levels. Data for these projects were obtained from different types of infrastructure projects, such as, water/waste water treatment plants, roads, dams, railroads, interchanges, and pipelines. The projects' size were from less than a millions dollars to over 100 million dollars. The projects were executed through different contract strategies. Based on the characteristics of the projects, we can state with confidence that we had a fairly representative sample collected to perform the analysis and assign weights to the elements, sections, and categories of the index. It should be noted that data for only 26 projects were obtained at the time of doing analysis for assigning relative weights. Later on, more data were obtained. The detailed sample characteristics have been provided in section 7.3 of this thesis.

Table 6.1: Correlation between productivity factor and the 6 categories of the BPPII Infrastructure

		PF	MM	CMEL	EA	HRM	CM	HS
PF	Pearson Correlation	1	.253	.409*	.617**	.673**	.577**	.683**
	Sig. (2-tailed)		.213	.038	.001	.000	.002	.000
	N	26	26	26	26	26	26	26

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

(PF = Productivity Factor; MM = Materials Management; CMEL = Construction Machinery and Equipment Logistics; EA = Execution Approach; HRM = Human Resources Management; CM = Construction Methods; HS = Health and Safety)

After finding the Pearson's correlation coefficients, the relative weights were assigned to each category by the relative importance weights formula. Table 6.2 provides the calculations for assigning relative weights to each category by using correlation coefficients. The RIWs were then rounded off to assign the final weights to each category.

Table 6.2: Relative weights calculations for the categories of the BPPPII Infrastructure

Category	**Pearson's Correlation Coefficients (r)**	**Relative Importance Weight (RIW) (%age)**	**Rounded**
Materials Management	0.253	7.87	9
Construction Machinery and Equipment Logistics	0.409	12.73	13
Execution Approach	0.617	19.20	19
Human Resources Management	0.673	20.95	20
Construction Methods	0.577	17.96	18
Health and Safety	0.683	21.30	21
Sum	3.212	100.00	100.00

Different analyses were carried out with different data sets to see how the weights assigned to different categories would change. The data sets were organized by adding and removing projects that had high and low scores on the index. Similarly, projects that had high or low productivity factor were added and removed from the data set. In summary, different combinations of projects were tried to see the correlations between the categories of the index and the productivity factor. The different combinations resulted in slightly different weights to the categories. However, all the combinations resulted in lowest weight to materials management category and highest weight to health and safety category. Therefore, the relative weights were assigned to the categories, sections, and elements based on the data set which included all projects (Table 6.2).

In theory the higher scores assigned to elements corresponds to its greater influence in improving productivity. Therefore, if the practice is fully planned and implemented, it should be assigned with a higher score. Similarly, if the practice is poorly implemented, it should be represented by a low score. In some cases, an element or practice may not be applicable due to the unique characteristics of the construction project. The CII RT 252 decided that the maximum possible score on the BPPII would be 2000. This corresponds to the situation when all the elements have a planning and implementation level (PIL) of 5. The lowest score, in theory is zero when all the elements would be non-applicable. The BPPII score can also be represented as a percentage of the maximum score that can be achieved, when none of the non-applicable elements is considered.

Once the relative weights were calculated for all the categories, sections, and elements, the total score of 2000 was divided between them based on their relative weights. These scores assigned to each element would correspond to the PIL of 5. Table 6.3 shows the maximum scores assigned to the categories.

Table 6.3: Maximum scores of the BPPII categories

Categories	**Scores**
Materials Management	180
Construction Machinery and Equipment Logistics	260
Execution Approach	380
Human Resources Management	400
Construction Methods	360
Health and Safety	420
Sum	2000

After assigning the maximum scores to each category, the next step is to assign the relative scores to each PIL of all the 61 elements in the BPPII Infrastructure. The elements that are not applicable to a construction project are given a score of 0. A level one of planning and implementation was given a score of 1 for all the elements. The scores of the PIL 2 to PIL 4 were determined based on linear interpolation between PIL 1 and PIL 5 using the following formulas:

$$\text{PIL 2 Score} = (\text{PIL 5 Score} - 1)/4 + 1$$

$$\text{PIL 3 Score} = (\text{PIL 5 Score} - 1)/4 + \text{PIL 2 Score}$$

$$\text{PIL 4 Score} = (\text{PIL 5 Score} - 1)/4 + \text{PIL 3 Score}$$

The PIL scores of each element were rounded to its nearest integer. An example of the distribution of the PIL scores for the elements of the Construction Machinery and Equipment Availability section is shown in Figure 6.2.

SECTION	**(PIL)**					
Element	0	1	2	3	4	5
A. Construction Machinery & Equipment Availability						
1 Procurement Procedures & Plans for Construction Machinery	0	1	10	19	28	37
2. Construction Machinery Productivity Analyses	0	1	15	29	43	59
3. Construction Machinery and Equipment Maintenance	0	1	15	29	43	59

Figure 6.2: Example PIL scores of the elements of construction machinery and equipment availability

The un-weighted project score sheet is shown in Appendix E. The complete list of weighted scores for each PIL for all the elements of the BPPII Infrastructure is provided in Appendix F. These weighted scores are used in the final analyses for validation of the BPPII.

6.3 Comparison of BPPII Infrastructure and BPPII Industrial Scores

Table 6.4 provides a comparison of the scores assigned to each category in the BPPII Industrial and BPPII Infrastructure. It should be noted that some of the categories may have different names in the two BPPIIs; however, they represent the same group of practices. The category of health and safety has been assigned the highest score in both the BPPII Industrial and BPPII Infrastructure. It is interesting that in the CII benchmarking and metrics data analysis, safety practices had the highest and most consistent (across trades) correlation with productivity of all practices in the benchmarking and metrics database (CII 2010b; CII 2011; CII 2013).

Table 6.4: Comparison of BPPII Industrial and BPPII Infrastructure scores

Category	**BPPII Infrastructure**		**BPPII Industrial**	
	Scores	Relative Weight (%)	Scores	Relative Weight (%)
Materials Management	180	9	357	17.85
Construction Machinery and Equipment Logistics	260	13	293	14.65
Execution Approach	380	19	295	14.75
Human Resources Management	400	20	283	14.15
Construction Methods	360	18	378	18.9
Health and Safety	420	21	394	19.7
Sum	2000	100	2000	100

The category related to construction methods has almost same weights assigned in both the BPPIIs. Similarly the weights assigned to the category which represents the practices related to construction machinery and equipment has a very small difference in weights assigned in both the BPPIIs. There is a considerable difference between the weights assigned to the practices related in the execution approach between the BPPII Infrastructure and BPPII Industrial. This infers the fact that infrastructure and industrial projects have different execution requirements because of the differences in the nature of the projects. Infrastructure projects have different requirements in terms of planning, constructability approaches, acquisition strategies, right of way, utilities, and regulatory requirements. Therefore, the practices related to the execution approach have been assigned a high score in the BPPII Infrastructure than the BPPII Industrial.

The category of materials management has been given the lowest score in the BPPII Infrastructure. The materials management category has almost double weight in the BPPII Industrial than BPPII Infrastructure. However, it is in agreement with the research done about the applicability of CII Best Practices for different industry sectors. Olumide et al. (2012) reported that Best Practices related to materials management are more applicable to light and heavy industrial sectors than infrastructure sector. The reasons that materials management is more applicable on projects in the heavy and light industrial sectors could be partly due to the use of processes involved in the procurement of prefabricated materials, modules, and assemblies which are not usually found in infrastructure projects. Whereas, materials used in majority of the infrastructure projects are easily available, tend to be in bulk quantities, and not specialized or one of a kind.

6.4 Ranking of Categories in the BPPII Infrastructure

Table 6.5 shows the ranking of the 6 categories in the BPPII Infrastructure based on the scores assigned to each of them. The category of health and safety has the highest ranking followed by human resources management. The category of health and safety has also been assigned the highest score in the BPPII Industrial. Infrastructure projects have different characteristics and requirements than industrial and building projects. The category of materials management has the lowest rank; however, this is consistent with the research done about the applicability of CII Best Practices for different industry sectors as mentioned in the previous section.

Table 6.5: Ranking of categories in the BPPII Infrastructure

Category	**Relative Score (%age)**	**Points**
CATEGORY VI: Health and Safety	21	420
CATEGORY IV: Human Resources Management	20	400
CATEGORY III: Execution Approach	19	380
CATEGORY V: Construction Methods	18	360
CATEGORY II Construction Machinery and Equipment Logistics	13	260
CATEGORY I: Materials Management	9	180
Sum	100	2000

6.5 Top Ranked Sections in the BPPII Infrastructure

Table 6.6 provides the ranking of the top 10 sections in the BPPII Infrastructure. The section related to the practices of Job Site Safety has the highest score, followed by Design/Construction Plan and Approach. These two sections together make over 25% of the total index score. The sections of Construction Machinery and Equipment Availability, Constructability Reviews, and Behavior are ranked third, fourth, and fifth respectively. Together the top 5 sections constitute over 45% of the index score.

Table 6.6: Top ranked sections in the BPPII Infrastructure

Ranking	Section	Score
1	Job Site Safety	302
2	Design/Construction Plan & Approach	202
3	Construction Machinery & Equipment Availability	156
4	Constructability Reviews	125
5	Behaviour	120
6	Planning (Execution Approach)	114
7	Site Layout Plan	108
8	Health and Safety Training & Orientation	105
9	Tools and Equipment Management Best Practices	104
9	Planning (Human Resources Management)	104
10	Procurement Strategy	103

The top 10 sections account for over 77% of the index score. It should be noted that these top sections belong to different categories, and are not just from the top two or three categories. For example, the section on Procurement Strategy is in the top 10 sections;

however, it belongs to the category of Materials Management, which is ranked the lowest in categories.

6.6 Top Ranked Elements in the BPPII Infrastructure

Table 6.7 provides the listing of top 10 ranking elements in the BPPII Infrastructure. It can be seen that some elements or practices have the same score.

Table 6.7: Top ranked elements in the BPPII Infrastructure

Ranking	Element	Score
1	Formal Health and Safety Policy	64
1	Health and Safety Plans/Zero Accident Techniques	64
2	Innovations & New Technologies	60
2	Hazards Planning	60
2	Health and Safety Training Programs	60
3	Construction Machinery Productivity Analyses	59
3	Construction Machinery and Equipment Maintenance	59
4	Task Safety Analysis	57
4	Hazards Analysis	57
5	Crews Composition/Crew Formation	54
6	Dynamic Site Layout Plan	53
7	Environmental Requirements	51
8	Communications, Coordination, & Agreements	50
8	Skills Assessment and Evaluation	50
9	Tools & Equipment Tracking	49
9	Employees / Trades Technical Training	49
9	Long-Lead/Critical Equipment & Materials Identification	49
10	Social Activities	48

Practices of having a Formal Health and Safety Policy and Health and Safety Plans/Zero Accident Techniques have the highest ranking among the 61 elements of the index. These two practices are followed by Innovation and New Technologies, Hazards Planning, and Health and Safety Training Programs, which share the same ranking. These practices are followed by practices related to construction machinery. There are 18 practices in the top 10 ranked and it makes almost 50% of the total index score. This shows the importance of these particular practices for the improvement of productivity on infrastructure construction projects.

6.7 Summary

This chapter described the procedure adopted for assigning relative weights to the elements, sections, and categories of the BPPII Infrastructure. Each element in the BPPII Infrastructure was assigned a relative weight with reference to other elements in the index based on its importance on affecting productivity in the infrastructure sector. The weights to the elements, sections, and categories of the index were assigned after conducting correlation analysis. A comparison of the weights assigned between the BPPII Industrial and BPPII Infrastructure was also performed. Finally, the ranking of categories, sections, and elements based on their scores was also discussed in this chapter. The next chapter provides the results of data analyses.

Chapter 7

Data Analyses and Validation of the BPPII Infrastructure

This chapter provides the results of data analyses. First, data analysis techniques are described which are used in the analyses. Data were mainly collected for the implementation level of practices for all the elements of the BPPII and for labour productivity using the productivity factor (PF) as a metric. Data analyses are presented in both descriptive and inferential statistics. Regression analysis results are provided for the BPPII and PF. The results of one-way ANOVA for hypothesis testing are also discussed. Finally, regression analysis performed for BPPII and performance measure of project schedule growth is also provided.

7.1 Data Analysis Techniques

7.1.1 Scatter Plots (Correlation and graphical plots)

The scatter plots are very helpful in determining the relationship between two variables. "For example, if there are n pairs of observations, (x_1, y_1), (x_2, y_2), ..., (x_n, y_n), of two variables X and Y, a preliminary indication of the correlation is obtained through a scatter diagram" (Kottegoda and Rosso, 2008) . In this plot, the coordinates show the observed pair of values. Figure 7.1 shows an annotated sketch of a scatter plot. Data points will be displayed using the scatter plot to provide a degree and direction of the correlation. For this research, BPPII scores will be shown on the X-axis and the productivity factor (PF) values will be shown on Y-axis. Similarly, scatter plots are drawn for BPPII and project schedule growth.

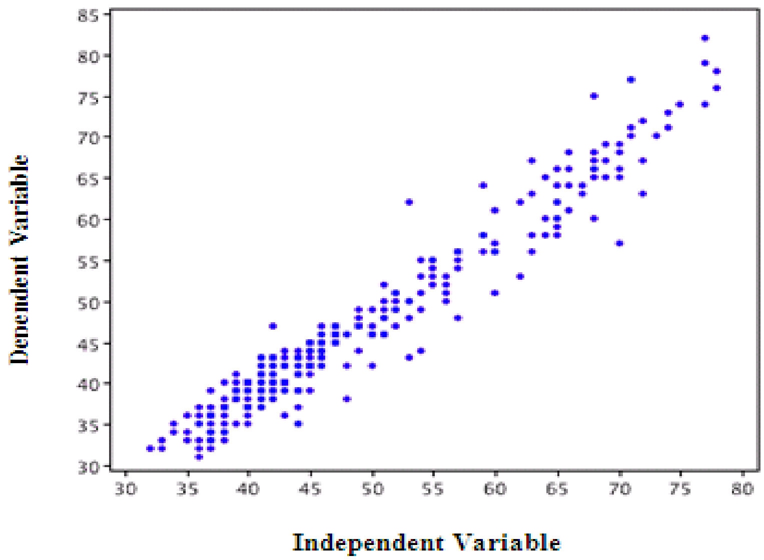


Figure 7.1: Annotated sketch of a scatter plot

7.1.2 Pearson's Correlation Coefficients

Pearson's correlation coefficient (r) is the most commonly used index of the relationship between dependent and independent variables. The values of "r" ranges from -1 to 1; an "r" value of -1 shows a perfect negative linear relationship between the two variables, and an "r" value of 1 indicates a perfect positive relationship between the variables. An "r" value of 0 indicates no relationship between variables. It is important to mention that with real data, it is not expected to get values of "r" exactly equal to -1, 0, or 1. A rule of thumb is that a correlation between 0 to just less than 0.30 is a weak correlation, a correlation of 0.30 to 0.50 is considered moderate, and over 0.50 is considered a strong correlation (Cohen, 1988).

7.1.3 Regression Analysis

Regression analysis is a technique to evaluate the relationship between variables. It is commonly used to model the relationship between the dependent variable and one or more independent variables. In simple linear regression, the dependent variable represented by Y is predicted from a set of predictor variables X (x_1, x_2, x_3…..x_n). The equation for simple linear regression is given as:

$$Y = \beta_0 + \sum_{i=1}^{N} \beta_i X_i + \varepsilon$$

where Y is the dependent variable,

β_0 and β_i are the model coefficients,

X_i is a set of predictor variables, and

$\mathcal{E}$ represents the unknown random error assumed as normally distributed, $\mathcal{E} \sim N\ (0, \sigma^2)$

In this research, BPPII score is the independent variable. The PF and project performance metrics will be dependent variables. Regression analysis will be performed between BPPII and PF, and between BPPII and project performance metrics.

7.1.4 Analysis of Variance (ANOVA)

The statistical technique for testing the variation among the means of two or more groups is called the analysis of variance (ANOVA). This technique compares two estimates of population variance; one, the within-group estimate, and the other the between-groups estimate. The with-in groups estimate is calculated by averaging the population variance estimates from each of the samples, and the between-groups estimate is based on the variation among the means of the samples (Aron et al. 2011).

The *F* ratio is calculated by dividing the between-groups estimate by the with-in groups estimate. The null hypothesis is that all the samples come from populations having the same mean. If the null hypothesis is true, the *F* ratio should be about 1, because the two population variance estimates are based on the same thing, i.e. the variation within each of the populations. If the samples comes from populations with different means, the *F* ratio should be larger than 1.

When only one factor is considered in the analysis, the test is called one-way ANOVA. As in our research, we are concerned with one factor only; therefore, we will be conducting one-way ANOVA tests.

Assumptions for ANOVA

The assumptions for the analysis of variance are the same as for *t* test. They are; the populations must be normally distributed, with equal variances. The ANOVA is adequately accurate even when these assumptions are moderately violated. A general rule is that if the variance estimate of the group with the largest estimate is not more than four or five times that of the smallest and that the sample sizes are equal, the conclusions drawn using the *F* distribution should be reasonably accurate (Aron et al. 2011).

7.2 Hypothesis

The research hypothesis is that "a higher level of implementation of the practices defined in the BPPII relates significantly to a higher level of productivity performance." The hypothesis test is described as follows:

$$H_0: P_H = P_L$$

$$H_1: P_H \neq P_L$$

P_H represents the productivity of projects that have a high level of implementation of best practices, and therefore, have a high score on the BPPII Infrastructure. P_L represents the productivity of projects that have a low level of implementation of best practices and therefore, have a low score on the BPPII Infrastructure. The hypothesis will be tested through one-way ANOVA test.

7.3 Sample Characteristics

Data from 13 companies for 31 projects were obtained for this research. It should be noted that data for 26 projects were obtained at the time of assigning relative weights. Later on more data were obtained from additional projects. Based on the characteristics of the projects reported below, we can state with confidence that we had a fairly representative sample collected to perform the analyses. Table 7.1 provides the distribution of these projects based on project type, scope of work, contract type, and size.

Table 7.1: Distribution of projects

Category		**No. of Projects**
Project Description	Water Treatment Plants	1
	Waste Water Treatment Plants	6
	Roads/Highways	12
	Dams	3
	Railroad	1
	Interchanges	2
	Airports	2
	Others (utilities, pipelines)	4
Project Nature	Grass Roots, Greenfield	8
	Modernization, Renovation, Upgrade	20
	Addition, Expansion	3
Project Size	Less than 1 Million Dollars	1
	1 - 5 Million Dollars	8
	6 - 50 Million Dollars	11
	51 - 100 Million Dollars	6
	101 - 500 Million Dollars	5
Scope of Construction Contract	Construct Only	21
	Design and Construct	1
	Construction or Project Management Only	7
	Other (Please specify):	2
Type of Construction Contract	Fixed Price	19
	Unit Price	11
	Cost Plus Lump Sum Fee	1

The data were collected from several companies working in different parts of the world. The projects for which data were collected were different types of infrastructure projects, such as roads, bridges, water/waste water treatment plants, dams, and interchanges**.** Figure 7.2 provides the distribution of projects by type of infrastructure project. The size of the projects varied from less than a million dollars to over 100 million dollars. Figure 7.3 shows the distribution of projects by project size or cost. Different types of contract strategies were used in the execution of these projects. Also, some of these projects were grass roots; some were modernization, renovation and upgrades; and some were additions and expansions. Figure 7.4 provides the distribution of these projects by location.

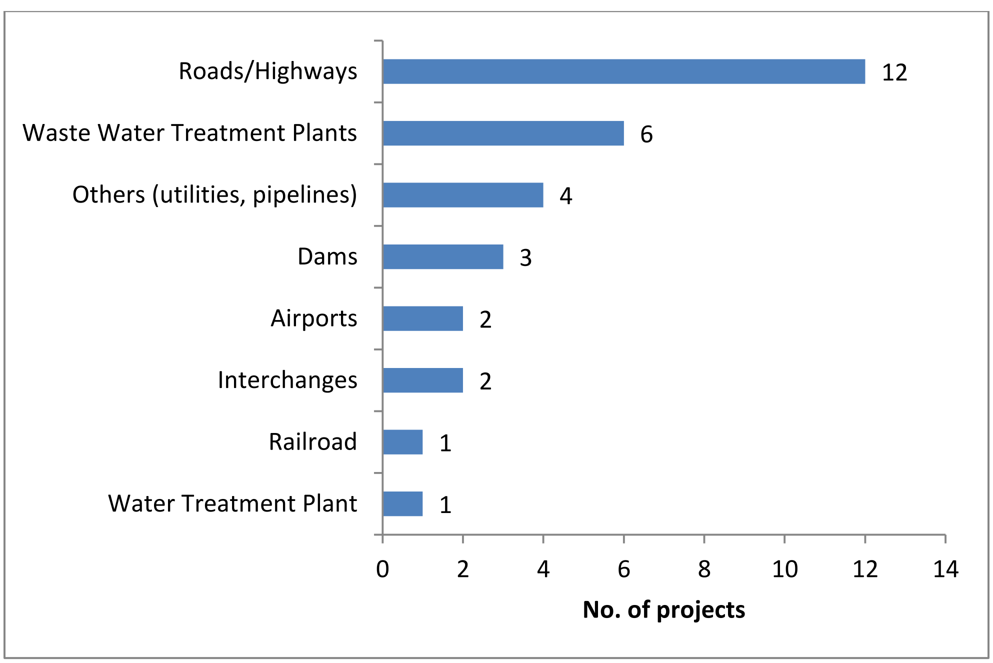


Figure 7.2: Distribution of projects by infrastructure type

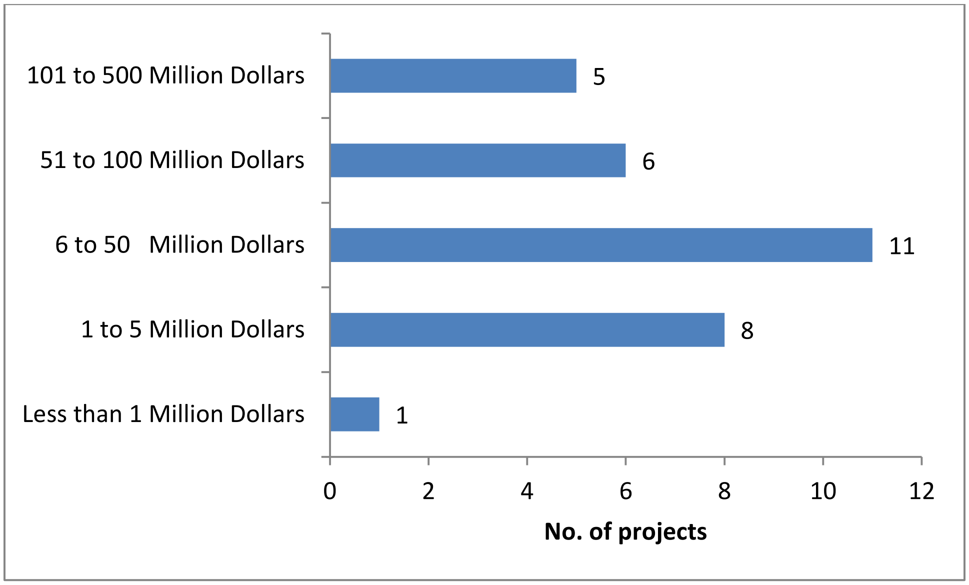


Figure 7.3: Distribution of projects by size

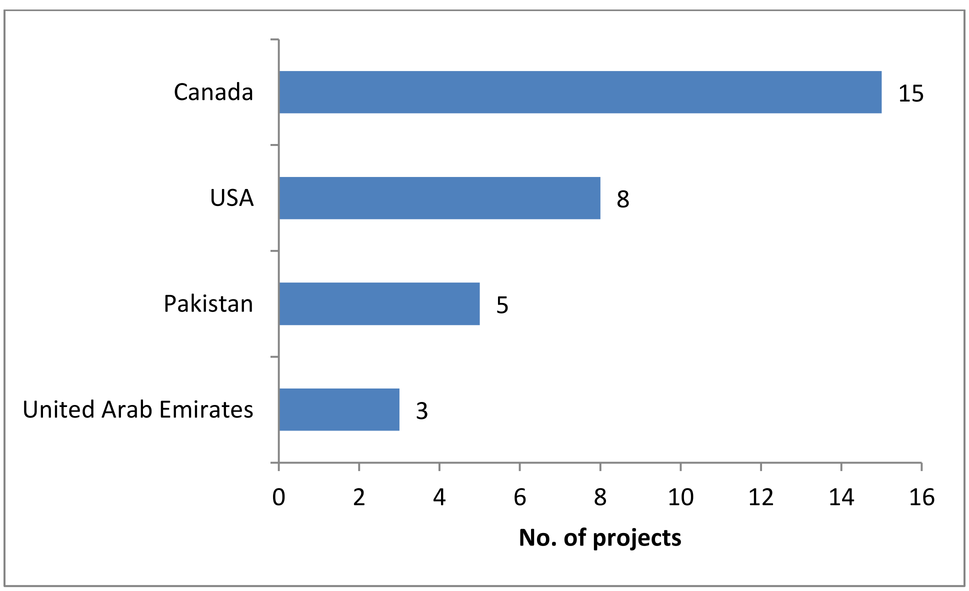


Figure 7.4: Distribution of projects by location

7.4 Descriptive Statistics

Out of the total 31 projects, some respondents did not provide complete data for productivity factor. A total of 28 projects provided data for both the productivity factor and PILs of the elements in the BPPII Infrastructure. The respondents provided data for the implementation level of practices on a scale of 1 to 5. The data collected were not based on weighted scores. Once the data were collected, then un-weighted BPPII scores were changed to the weighted scores as explained in chapter 6. Once all the projects data on the implementation level of practices were assigned relative weights, the weighted scores of the project for the BPPII were calculated. The scores of the elements in a section are summed to obtain a section score, and the scores for all sections in a category are added to obtain the category score. Finally, all the categories' weighted scores are summed to obtain the total BPPII score. The total BPPII score was then converted to a percentage score out of a total available score of 2000. The BPPII scores reported in the analyses presented in this chapter are the percentage scores of the projects. Table 7.2 shows the descriptive statistics for PF and BPPII scores for the 28 projects.

Table 7.2: Descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation
PF	28	.45	1.67	.9493	.30221
BPPII Score (%age)	28	15.49	82.39	47.7071	20.34809

The data for both the PF and BPPII were checked for normality. This was done in SPSS (V16.0) by plotting histograms and then imposing a normal curve on the graph, which makes it easier to evaluate the normality of the data. It was found that the distribution for BPPII was fairly normal. It is not precisely normal, but it is not highly skewed. The histogram fits fairly well under the normal curve superimposed on the graph. It was slightly skewed to the right. Similarly, the histogram for PF was drawn and the normal curve imposed on the graph. Although the distribution is not precisely normal, it is not highly skewed either. The histogram fits fairly well under the normal curve superimposed on the graph.

7.5 Regression Analysis between Productivity Factor and BPPII Score

The scatter plot shown in Figure 7.5 was drawn to see the relationship between the productivity factor (PF) and BPPII scores. The main idea of the BPPII Infrastructure was that the BPPII scores will be positively related to the productivity. The positive relationship is indicated by the positive slope of the line in the scatter plot.

From the figure, it can be seen that there is a positive linear relationship between the PF and BPPII scores. After plotting the scatter diagram, regression analysis was performed. Table 7.3 shows the summary of the regression model. The correlation coefficient was found to have a value of .693, which is considered a strong positive linear relationship.

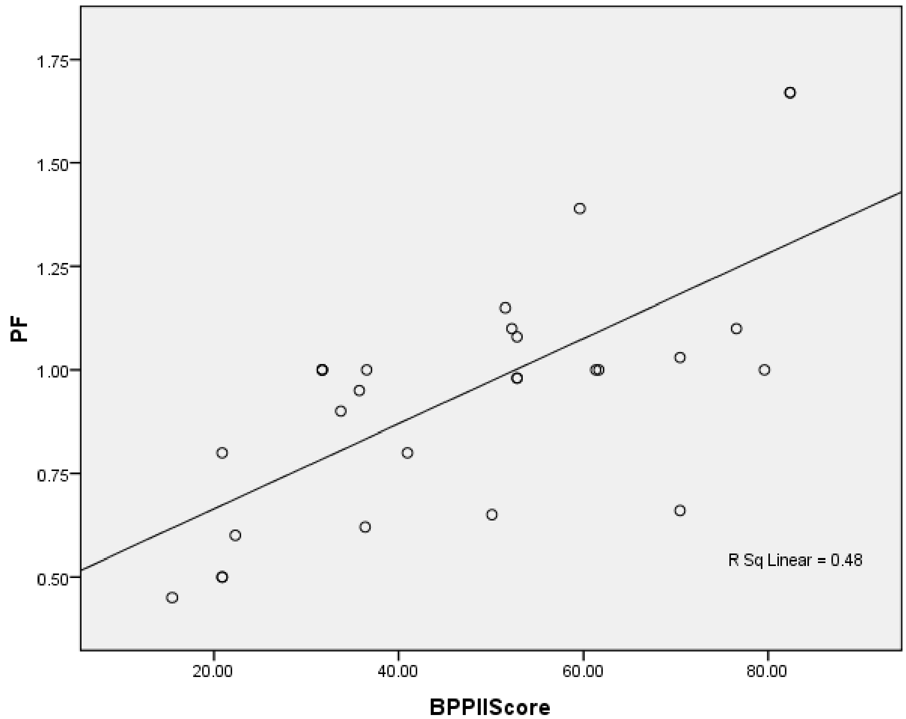


Figure 7.5: Scatter plot between BPPII Score and PF

Test of significance for the Model

The *R* Square has a value of .480, which shows the proportion of variation in PF attributable to BPPII score; that is 48% of the variation in the productivity factor is attributable to the BPPII scores. Table 7.4 shows the ANOVA table of the regression. The ANOVA table shows the *P* value for the significance test of the model. In this case, (P = .000), so we conclude that the overall model is significant.

Test of Significance for β

Table 7.5 provides the coefficients of the regression model. A test of the hypothesis H_0: $\beta = 0$ and H_1: $\beta \neq 0$ is found in the coefficients table of the regression output. The *t*-

statistic is, 4.900. The *P* value is .000 which is less than values of (α = .05 or .01), therefore, H_0 is rejected. It can be concluded that there is a nonzero and positive association between productivity factor and the BPPII scores.

Table 7.3: Summary of the regression model for BPPII score and PF

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.693[a]	.480	.460	.22205

a. Predictors: (Constant), BPPII Score, b. Dependent Variable: PF

Table 7.4: ANOVA table of regression for BPPII score and PF

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.184	1	1.184	24.012	.000[a]
	Residual	1.282	26	.049		
	Total	2.466	27			

a. Predictors: (Constant), BPPII Score b. Dependent Variable: PF

Table 7.5: Coefficients of the regression model for BPPII and PF

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.458	.109		4.219	.000	.235	.682
	BPPII Score	.010	.002	.693	4.900	.000	.006	.015

a. Dependent Variable: PF

Residual Analysis

The method of least squares regression is based on the assumptions that the regression function fits the data such that errors of prediction or residuals are normally distributed at any value of each of the independent variables, and that the variance of the residuals should have no pattern as a function of the value of each of the independent variables. Plotting the distribution of the residuals and the residuals as a function of each variable is the best way of assuring that these assumptions are being met. Figure 7.6 shows the regression residuals plot for PF. It can be seen that the residual plot has a fairly uniform distribution.

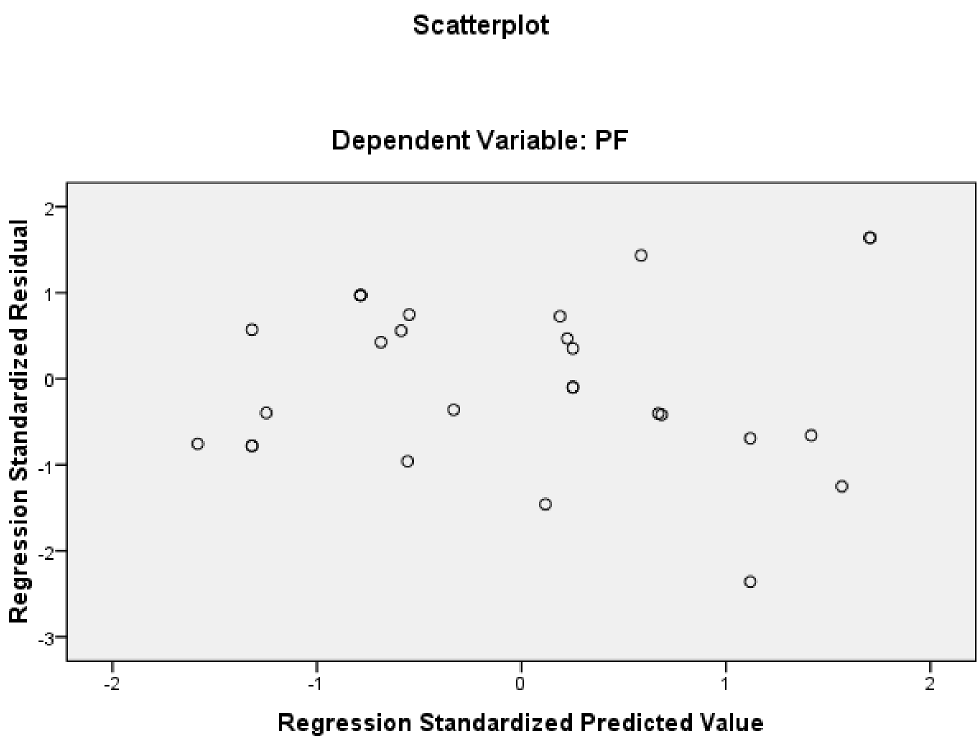


Figure 7.6: Residuals plot for PF

7.6 One-way Analysis of Variance (ANOVA)

To test the hypothesis that projects achieving a high score on the BPPII will perform better in terms of productivity than those achieving a low score, the Analysis of Variance (ANOVA) tests were done. For this purpose the projects were divided into two groups based on the scores on BPPII. For dividing the groups based on BPPII scores, several options were considered: (1) to divide based on the mean score; (2) to divide based on the median score; (3) divide based on a certain percentage below and above the mean and median score. Therefore, the two groups were divided based on both the mean and median scores. Projects scoring above the mean and median values were grouped together and called the BPPII high scores group and those scoring below the mean and median values were grouped together and called the BPPII low scores group. The ANOVA tests were conducted on these high and low scoring groups to see if their means are statistically different than each other. The results are provided below.

7.6.1 ANOVA Based on Mean score of the BPPII

The mean score of the projects on the BPPII was 47.70%. Two groups were formed, one scoring above the mean value of 47.70% and the other scoring below the mean value. SPSS 16.0 was used to conduct one-way ANOVA. The descriptive statistics of ANOVA for the two groups formed on the basis of mean score are provided in Table 7.6. The one-way ANOVA test results with the two groups are shown in Table 7.7. This test was performed with 95% confidence level, and the sample sizes of the high and low BPPII groups were 15 and 13 respectively. Means of productivity factors of the high and low BPPII groups were 1.097 and .778 respectively. The *P* value of this test is 0.003 (< 0.05), meaning that the difference between the two groups is statistically significant.

Table 7.6: Descriptive statistics of ANOVA for High BPPII score and Low BPPII score groups based on Mean score

PF	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
High BPPII Score	15	1.0973	.29234	.07548	.9354	1.2592	.65	1.67
Low BPPII Score	13	.7785	.21629	.05999	.6478	.9092	.45	1.00
Total	28	.9493	.30221	.05711	.8321	1.0665	.45	1.67

Table 7.7: ANOVA for High BPPII score and Low BPPII score groups based on Mean score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.708	1	.708	10.474	.003
Within Groups	1.758	26	.068		
Total	2.466	27			

7.6.2 ANOVA Based on Median score of the BPPII

The median score of the projects on the BPPII was 50.825%. Two groups were formed, one scoring above the median value of 50.825% and the other scoring below the median value. The descriptive statistics of ANOVA for the two groups formed on the basis of median score are provided in Table 7.8.

Table 7.8: Descriptive statistics of ANOVA for High BPPII score and Low BPPII score groups based on Median score

PF	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
High BPPII Score	14	1.1293	.27486	.07346	.9706	1.2880	.66	1.67
Low BPPII Score	14	.7693	.21062	.05629	.6477	.8909	.45	1.00
Total	28	.9493	.30221	.05711	.8321	1.0665	.45	1.67

Table 7.9 provides the results of ANOVA for the two groups. This test was performed with 95% confidence level, and the sample sizes of the high and low BPPII groups were 14 and 14 respectively. Means of productivity factors of the high and low BPPII groups were 1.129 and .769 respectively. The *P* value of this test is 0.001 (< 0.05), meaning that the difference between the two groups is statistically significant.

Table 7.9: ANOVA for High BPPII score and Low BPPII score groups based on Median score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.907	1	.907	15.132	.001
Within Groups	1.559	26	.060		
Total	2.466	27			

7.6.3 ANOVA based on +/- 5% of Mean score of the BPPII

Analyses were also performed by making two groups with one scoring above 5% of the mean score and the other scoring 5% below the mean score on the BPPII. The group scoring above 5% of the mean score was that having BPPII scores of above 50.10% and that scoring 5% below the mean score was that having BPPII scores of below 45.32%. Table 7.10 shows the descriptive statistics of these two groups. One-way ANOVA test was performed and the results are shown in Table 7.11.

Table 7.10: Descriptive statistics of ANOVA for High BPPII score and Low BPPII score groups based on +/- 5% of mean score

PF	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
High BPPII Score	14	1.1293	.27486	.07346	.9706	1.2880	.66	1.67
Low BPPII Score	13	.7785	.21629	.05999	.6478	.9092	.45	1.00
Total	27	.9604	.30211	.05814	.8409	1.0799	.45	1.67

A one-way ANOVA test with the two groups was performed with 95% confidence level, and the sample sizes of the high and low BPPII groups were 14 and 13 respectively. Means of productivity factors of the high and low BPPII groups were 1.129 and .778 respectively. The *P* value of this test is 0.001 (< 0.05), meaning that the difference between the productivity factor of the two groups is statistically significant. Figure 7.7 shows the bar chart of the productivity factor for the low and high BPPII score groups.

Table 7.11: ANOVA for High BPPII score and Low BPPII score groups based on +/- 5% of mean score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.830	1	.830	13.438	.001
Within Groups	1.543	25	.062		
Total	2.373	26			

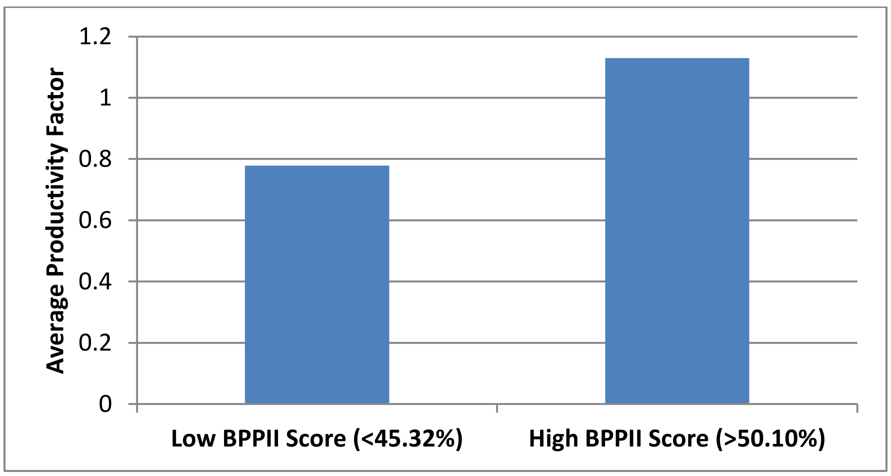


Figure 7.7: Average productivity factor for low and high BPPII score groups based on +/- 5% of mean score

Similarly, one-way ANOVA tests were performed at different scenarios based on the mean and median scores and are shown in Appendix G. All of these tests showed that there is a statistically significant difference between the productivity factor of projects having a high score on the BPPII and projects scoring low on the BPPII. These tests were conducted at

95% confidence level. Therefore, it can be concluded that projects having a high level of implementation of best practices as defined by the BPPII have better productivity than those having a low level of implementation of best practices.

7.7 Project Schedule Growth

Data for 24 projects were also collected for project performance measures of time as per part of the data collection process. The project schedule growth measures the performance of projects in terms of schedule or time required for completion of projects. The metric for calculating the project schedule growth is shown by equation:

Project schedule growth = $\frac{Actual\ total\ time\ of\ construction - Estimated\ time\ of\ construction}{Estimated\ time\ of\ construction}$

Using the above metric, a lower value is considered better. Scatter plot was drawn between the project schedule growth (% age) and BPPII scores (% age) to see if there is any visible relationship between the BPPII score and project schedule growth (Figure 7.8). The plot shows a strong negative linear relationship between the BPPII score and project schedule growth. The inverse relationship is also indicated by the negative slope of the line. In the next step, regression analysis was performed between the project schedule growth as a dependent variable and BPPII score as an independent variable. Table 7.12 shows the summary of the regression model.

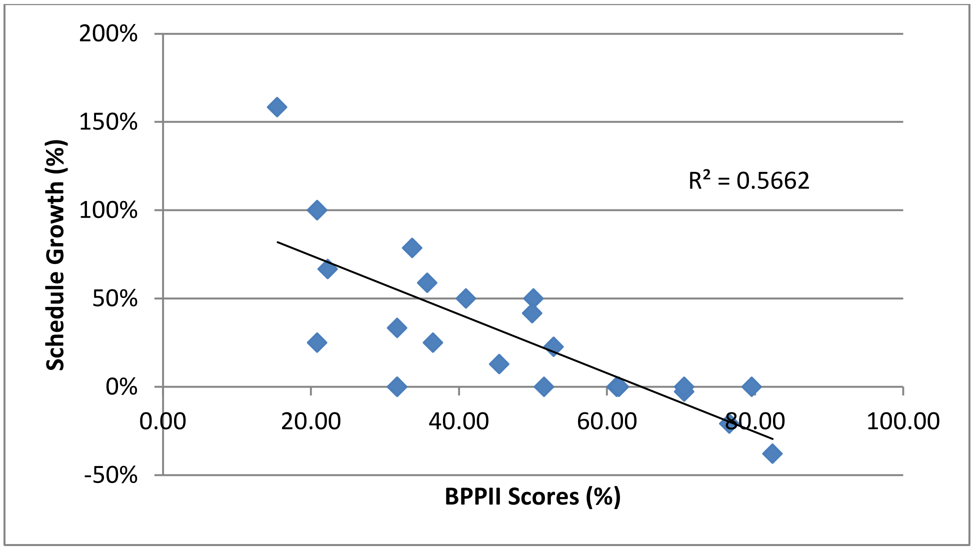


Figure 7.8: Scatter plot between BPPII score and project schedule growth

Table 7.12: Regression model summary for BPPII score and project schedule growth

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.752[a]	.566	.546	.30334

a. Predictors: (Constant), BPPII Score b. Dependent Variable: Schedule Growth

The correlation coefficient between the BPPII score and project schedule growth has a value of -.752. This is a strong, negative linear relationship between the two variables and shows that as the BPPII scores increases, the project schedule growth decreases; meaning that projects having a high BPPII score perform better in terms of schedule growth. Table

7.13 shows the ANOVA results of the regression model and Table 7.14 provides the coefficients of the regression model.

The results of the regression analysis show that overall the model is very significant; *P* value is .000 less than .05 or even .01. The *R* Square has a value of .566 which means that over 56% of the variability in the project schedule growth is explained by the BPPII scores. Therefore, it can be concluded that the BPPII scores have a statistically significant negative linear relationship with the project schedule growth.

Table 7.13: ANOVA of Regression model for BPPII score and project schedule growth

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.642	1	2.642	28.709	.000[a]
	Residual	2.024	22	.092		
	Total	4.666	23			

a. Predictors: (Constant), BPPII Score b. Dependent Variable:
Schedule Growth

Table 7.14: Coefficients of Regression model for BPPII score and project schedule growth

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1.076	.155		6.961	.000	.756	1.397
	BPPIIScore	-.017	.003	-.752	-5.358	.000	-.023	-.010

a. Dependent Variable: Schedule Growth

Figure 7.9 shows the residuals plot of the project schedule growth. The residual plot confirms that the residuals have a fairly normal distribution, and the regression results are reliable.

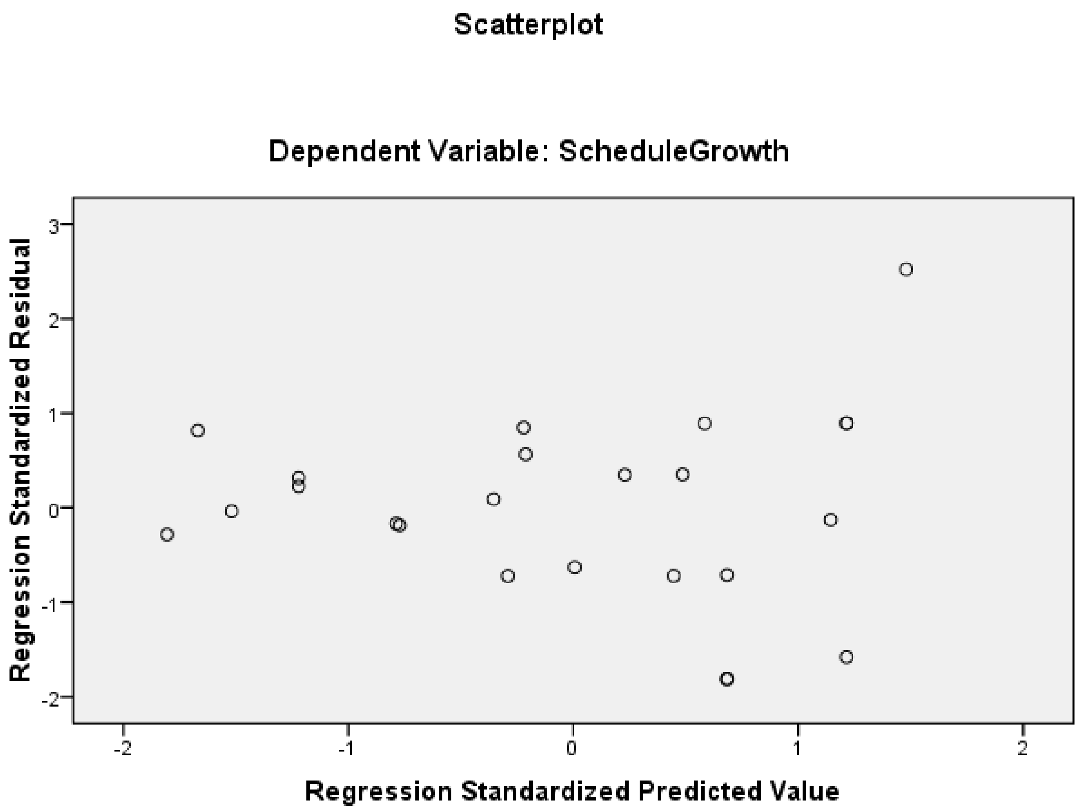


Figure 7.9: Residuals plot of project schedule growth

7.8 Summary

This chapter provided the results of data analyses. Data analyses were presented in both descriptive and inferential statistics. Regression analysis results were provided for the BPPII scores and productivity factor (PF). The results of one-way ANOVA for hypothesis testing were also discussed. Finally, regression analysis results performed for BPPII and performance measure of project schedule growth were also provided.

The relationship between a BPPII score and construction productivity was validated using productivity factor as the metric. Statistical analysis results indicated that projects with higher BPPII scores experienced better productivity performance. BPPII Infrastructure Projects scores above 50% on a certain project reflect a higher planning and implementation level of productivity related practices. Projects with high BPPII scores have the greater potential to achieve better construction productivity than was originally estimated. Also, projects with high BPPII scores have better project completion times.

Chapter 8

Using BPPII Infrastructure in Practice

This chapter explains how to use the Best Productivity Practices Implementation Index (BPPII) for Infrastructure projects in practice. It also describes an Excel based Tool developed for use by the companies that want to use the BPPII Infrastructure on their projects.

8.1 Application Stage for Using BPPII on a Project

The Best Productivity Practices Implementation Index (BPPII) Infrastructure Projects is a tool designed to assist project managers or superintendents in planning jobsite activities for making construction sites more productive. BPPII can be utilized to fit the needs of almost any individual infrastructure project. It can be used as a list of the essential practices that need to be planned and implemented in a project. It also serves as a checklist that determines the level of planning and implementation of these best productivity practices. It can also be used as a list of strategies to achieve higher implementation levels of best productivity practices.

The BPPII can be used as a complementary tool with other Construction Industry Institute (CII) indices for project assessment, such as the Project Definition Rating Index (PDRI) and the Project Health Indicator (PHI). PDRI measures the level of project scope definition during Front End Planning (FEP). PHI assesses leading indicators of project performance during the Execution phase. BPPII supplement these indices. It evaluates practice implementation levels with a focus on construction productivity. BPPII should be used at the end of the Front End Planning (FEP) phase (end of detailed scope) and the beginning of the Execution phase to support the preparation of the Project Execution Plan (PEP). It can also be used during the Execution phase for continuous assessment and improvement.

8.2 BPPII Tool

A macro-enabled spreadsheet based BPPII Tool has been developed to help the project team to assess individual projects. The tool was developed in a Microsoft Excel 2010 environment. It has five main interface components: Introduction, User Guide, Background-BPPII Descriptions, Input BPPII Rating, and Output BPPII Reporting (Figure 8.1). Important parts of this tool are the "Input BPPII Rating" and "Output BPPII Reporting" sheets. They are major input and output of this tool and are explained below.

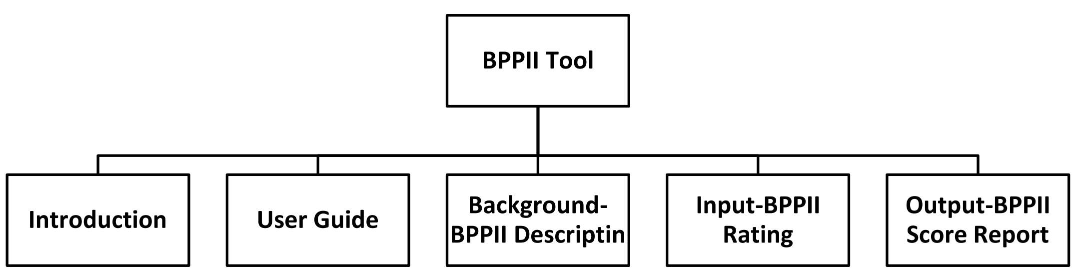


Figure 8.1: Structure of BPPII tool

8.2.1 Input BPPII Rating

The BPPII rating interface is shown in Figure 8.2. A user selects the implementation level of each element by clicking the corresponding planning and implementation level cell (0 to 5). Detailed descriptions of each element appear on the right side of rating sheet when a user clicks each element cell or a planning and implementation level cell. A user can hide these descriptions by clicking on the “hide description” button.

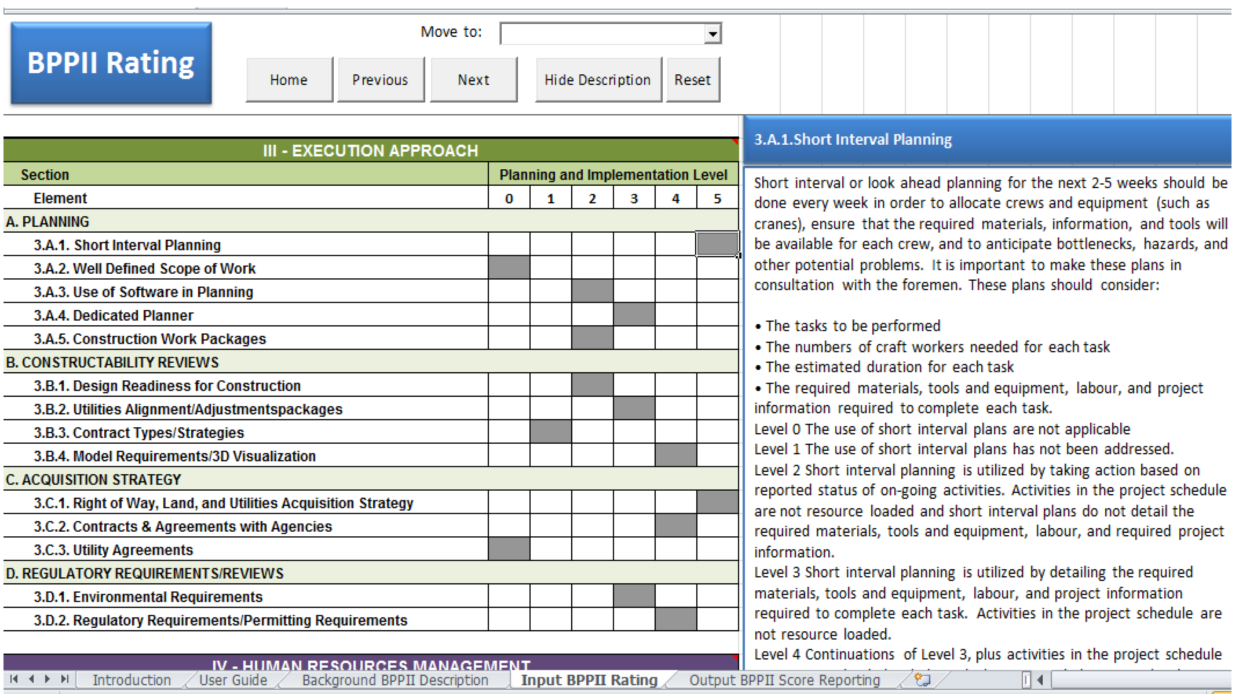


Figure 8.2: Input BPPII rating example

Also, the overall description of each category is provided by a MS Excel comment function, activated when a user moves their mouse cursor over any cell in the category. A user can initialize all existing or prior selections by clicking the “Reset” button. The results of all selections are automatically reflected in the final BPPII score calculation.

8.2.2 Output BPPII Score Report

The BPPII Score Reports sheet provides different reports for the users. It includes Cover (Project/Evaluator Information and Overall BPPII Score), Summary Charts, Project Score Sheet, and Practices with Low Implementation Level. Project/Evaluator Information is entered on the Instruction interface. BPPII score is calculated by the element ratings from the Input BPPII Rating. Figure 8.3 provides an example of project information and overall score report.

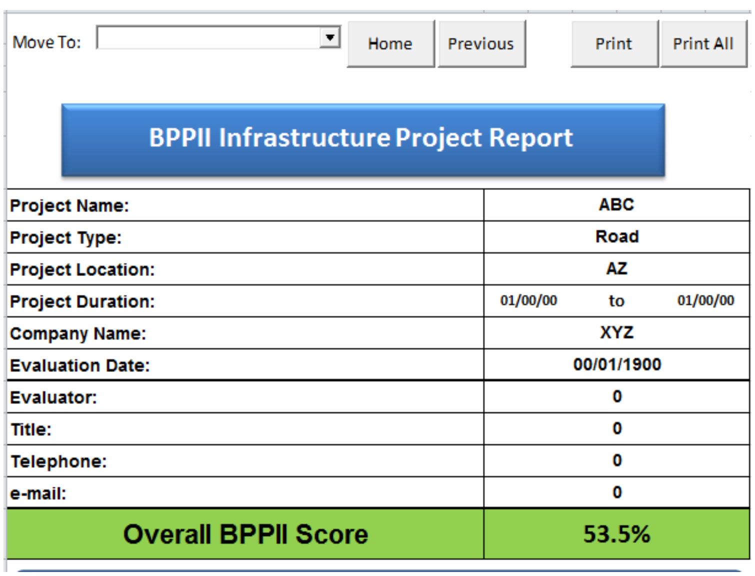


Figure 8.3: BPPII Score report, example of project information and overall score

The reports page automatically generates charts for the BPPII scores. The first summary chart compares the maximum possible BPPII score and a project's attained score. The second chart shows the same comparisons at the category level. This allows the user to determine which categories are the project's strong or weak implementation areas (Figure 8.4).

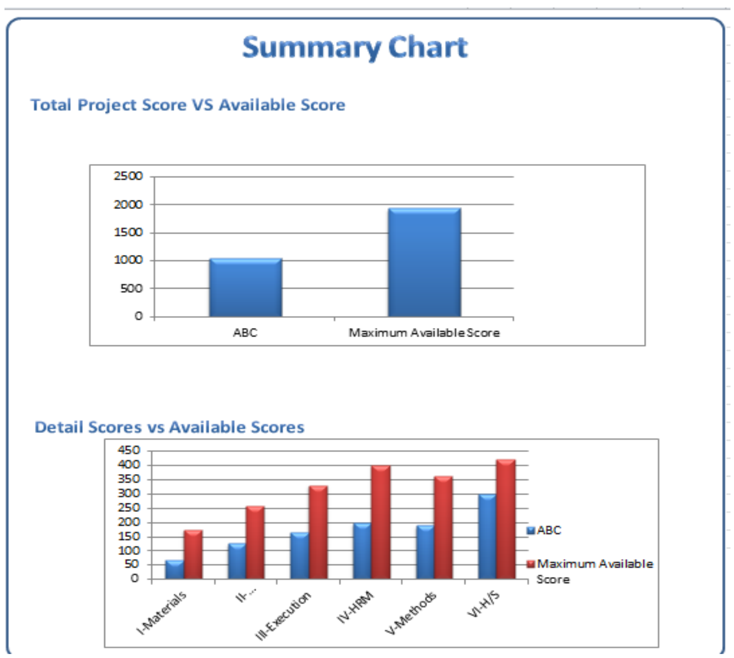


Figure 8.4: BPPII score report, example of charts

The detailed ratings of each element and the score of each category are also shown in the Project Score Sheet in this report. With this part, a user can review and confirm the details of the evaluation (Figure 8.5). The last part is Practices with Low Implementation

Level (Figure 8.6). This part shows the list of elements (practices) with low implementation level (Levels 1 or 2).

A	B	C	D	E	F	G
I - MATERIALS MANAGEMENT						
Section	**Planning and Implementation Level**					
Element	**0**	**1**	**2**	**3**	**4**	**5**
A. Procurement Strategy						
1.A.1. Procurement procedures & plans for Materials and Equipmer			X			
1.A.2. Long-Lead/Critical Equipment & Materials Identification						X
1.A.3. Procurement Team				X		
B. MATERIALS MANAGEMENT SYSTEMS						
1.B.1. Project Team Materials Status Database			X			
1.B.2. On-Site Materials Tracking Technology	X					
1.B.3. Materials Delivery Schedule					X	
C. RECEIPT AND INSPECTION OF MATERIALS						
1.C.1. Material Inspection Process				X		
1.C.2. Materials Inspection Team			X			
1.C.3. Post Receipt Preservation & Maintenance			X			
Acquired Score	**66**					
Available Score	**173**					
BPPII Sub-Total	**38.2%**					

II - CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS						
Section	**Planning and Implementation Level**					
Element	**0**	**1**	**2**	**3**	**4**	**5**
A. CONSTRUCTION MACHINERY & EQUIPMENT AVAILABILITY						
2.A.1. Procurement Procedures & Plans for Construction Machinery			X			
2.A.2. Construction Machinery Productivity Analyses			X			
2.A.3. Construction Machinery and Equipment Maintenance				X		
B. TOOLS AND EQUIPMENT MANAGEMENT BEST PRACTICES						
2.B.1. Site Tools and Equipment Management Strategy				X		
2.B.2. Tools & Equipment Tracking					X	
2.B.3. On-site Tools Maintenance						X
2.B.4. Construction Machinery& Equipment Utility Requirements				X		
Acquired Score	**124**					
Available Score	**258**					
BPPII Sub-Total	**48.1%**					

Figure 8.5: BPPII score report, example of categories scores

Practices with Low Implementation Level						
Note: High-ranked elements are more serious						
	0	1	2	3	4	5
3.B.3.Contract Types/Strategies		X				
5.A.1.Integrated Schedule		X				
4.E.2.Exit interviews		X				
6.A.1.Formal Health and Safety Policy			X			
2.A.2.Construction Machinery Productivity Analyses			X			
4.A.1.Crews Composition/Crew Formation			X			
5.B.1.Dynamic Site Layout Plan			X			
3.B.1.Design Readiness for Construction			X			
2.A.1.Procurement Procedures & Plans for Construction Machinery			X			
1.A.1.Procurement procedures & plans for Materials and Equipmen			X			
4.E.1.Retention Plan for Experienced Personnel			X			
1.B.1.Project Team Materials Status Database			X			
4.D.2.Clear Delegation of Responsibility			X			
3.A.5.Construction Work Packages			X			
5.A.2.Work Schedule Strategies			X			
3.A.3.Use of Software in Planning			X			
4.D.1.Maintain Stability of Organization Structure			X			
1.C.2.Materials Inspection Team			X			
1.C.3.Post Receipt Preservation & Maintenance			X			

Figure 8.6: BPPII score report, example of practices with low level of implementation

Though BPPII Tool is a more convenient method for the assessment of individual projects; however, the users can also manually evaluate the scores of the projects by using score sheets provided in Appendix E and Appendix F. The sheets in Appendix E are the un-weighted score sheets and do not include the weights of elements. The sheets in Appendix F are the weighted BPPII score sheets and include the same weights as in the Excel based BPPII Tool. A user can rate each element and sum the weights of the elements to calculate an overall BPPII score.

8.3 Summary

This chapter explained how to use the Best Productivity Practices Implementation Index (BPPII) for Infrastructure projects in practice. It also described an Excel based tool developed for use by the companies that want to use the BPPII Infrastructure on their projects. The major interface components of the Excel tool, the “Input BPPII Rating” and the “Output BPPII Reporting” were also explained. The next chapter provides the conclusions, contributions, and recommendation of this research.

Chapter 9

Conclusions and Recommendations

This research work has provided a tool to improve labour productivity in the infrastructure construction industry. This tool is called the “Best Productivity Practices Implementation Index (BPPII) Infrastructure. The BPPII Infrastructure is a check list of best practices that when implemented on a project should increase the productivity.

9.1 Conclusions

Based on the preceding chapters, the following conclusions can be drawn:

- A high level of implementation of best practices is positively correlated with higher productivity. This conclusion is drawn based on the statistical analysis of the productivity factor and BPPII scores. Projects that have a high score on the implementation of best practices as defined by the BPPII Infrastructure showed better productivity performance than those that have a low score on the implementation of best practices.
- The high level of implementation of best practices is negatively correlated with project schedule growth. As the score of projects on the implementation level of best practices increase, the project schedule growth decreases. This means that projects that implement best practices at the highest level have better project completion times.

9.2 Contributions

The major contribution of this research is the development of the Best Productivity Practices Implementation Index as a tool to improve labour productivity in the infrastructure domain of the construction industry. This was achieved by accomplishing the following:

- Identified and produced ontology of best practices for infrastructure construction projects. The practices and their planning and implementation levels were completely defined.
- Developed a formalized set of BPPII Infrastructure's categories, sections, and elements.
- Assigned relative weights to the elements, sections, and categories of the index based on statistical analysis.
- Used productivity factor as a metric for measuring labour productivity and demonstrated its usefulness in comparing the productivity performance of projects which have different characteristics.

9.3 Recommendations for Future Research

Following are some recommendations coming out of this research:

- A similar tool based on the planning and implementation level of best practices should be developed for the building sector of the industry to cater for its specific needs and nature.

- The BPPII Infrastructure is for use at the project level of the construction industry. A process or tool should be developed to improve the efficiency and performance at the organizational and industry level.
- A public or national database should be created by collecting labour productivity information in terms of actual and estimated productivity for different types of infrastructure projects to help in benchmarking the productivity of projects having similar characteristics to avoid unbiased conclusions.
- A whole new data set should be obtained to further validate these results.
- Produce a set of procedures by which a company can put the tool into practice and by which they can do cost/benefit analysis for levels of implementation of practices.

Appendix A

Description of BPPII Infrastructure Elements

Infrastructure BPPII Categories, Sections, and Elements

Each element in the infrastructure BPPII has its own definition and has to be scored for its planning and implementation level. The following descriptions have been developed to provide a clear understanding of the terms used in the BPPII. Some of these descriptions use checklists to clarify concepts and facilitate ideas when scoring each element. It should be noted that these checklists are not all-inclusive and the users may add/supplement these when necessary.

The descriptions are listed in the same order as they appear in the Project Score Sheet. They have been organized in a hierarchy by category, section, and element. The BPPII consists of six main categories, each of which consists of sections and the sections have been divided into individual elements. The scoring is performed by evaluating the levels of definitions of these individual elements. The categories, sections, and elements are organized as follows:

CATEGORY I: MATERIALS MANAGEMENT

This category provides information about best practices related to materials and equipment required for the project. These practices will help in ensuring the availability of the right materials at the right time when required by the project. The best practice areas include: materials procurement, management, and receipt and inspection.

Sections:

A- Procurement Strategy
B- Materials Management Systems
C- Receipt and Inspection of Materials

CATEGORY II: CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS

This category describes best practices related to the construction machinery, tools, and equipment. It includes practices related to construction machinery and equipment availability, maintenance, positioning, and productivity analysis.

Sections:

A- Construction Machinery & Equipment Availability
B- Tools and Equipment Management Best Practices

CATEGORY III: EXECUTION APPROACH

This category describes best practices regarding how the work should be planned and what are the necessary requirements to be completed before the construction begins.

Sections:

A- Planning
B- Constructability Reviews
C- Acquisition Strategy
D- Regulatory Requirements/Reviews

CATEGORY IV: HUMAN RESOURCES MANAGEMENT

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

Sections:

A- Planning
B- Training and Development
C- Behaviour
D- Organizational structure
E- Employment

CATEGORY V: CONSTRUCTION METHODS

This section lists best practices with respect to the construction methods that are determined during the planning of the project that should be used to ensure better performance and productivity.

Sections:

- A- Project Schedule Control
- B- Site Layout Plan
- C- Design/Construction Plan & Approach

CATEGORY VI: HEALTH AND SAFETY

This category describes practices that should be followed to ensure the health and safety of all persons working on the jobsite during the construction of the project and in the surrounding area.

Sections:

- A- Job Site Safety
- B- Substance Abuse Program
- C- Health and Safety Training & Orientation

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

CATEGORY I: MATERIALS MANAGEMENT

A. PROCUREMENT STRATEGY

1. Procurement procedures & plans for Materials and Equipment

Procurement procedures & plans for materials and equipment include guidelines, requirements, or systems for purchasing, expediting, and delivery of materials and equipment for the project. Issues to consider include:

- Coordinate materials procurement schedule with the construction schedule
- Facilitate a purchasing system that has the capability of allowing field purchase of consumables.
- Develop a list of authorized suppliers
- 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 integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.

2. Long-Lead/Critical Equipment & Materials Identification

Materials and equipment that require a long lead time and those that are required for critical activities of the project can affect the design and construction schedule. Therefore, it is necessary to plan, identify, and track critical and long-lead equipment and material and plan for their timely procurement at the construction site. Issues to consider include:

- Identification of items requiring a long lead time for procurement
- Adherence to the materials management plan
- Coordination of the procurement schedule of long-lead and critical equipment and materials with the construction schedule

Level 0	A separate procurement plan for long-lead & critical materials and equipment is not applicable.
Level 1	There is no documented procurement plan for long-lead and critical materials and equipment.
Level 2	A procurement plan and schedule exists for long-lead & critical materials and equipment.
Level 3	Continuation of Level 2, plus 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 integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.

3. Procurement Team

A procurement team is necessary for procurement of materials and equipment and implementing the procurement plans. Issues to consider include:

- Clear expression of and understanding of authority and responsibility for procurement of materials and equipment
- Knowledge about procurement of engineered equipment, bulk materials, fabrication/modularization
- Integration with engineering, design, and construction schedules
- Reuse of existing materials and equipment in case of renovation and rehabilitation projects

Level 0	A procurement team for materials and equipment is not applicable
Level 1	There is no procurement team for materials and equipment.
Level 2	There is a designated procurement team at the main office but none at the project site.
Level 3	There is a designated procurement team at the project level, but they can procure daily consumable materials and are not qualified and authorized to procure costly, long-lead

	critical materials and equipment.
Level 4	Continuation of Level 3, plus the procurement team is qualified and authorized to procure all materials and equipment for the project.
Level 5	Continuation of Level 4, plus the procurement team has been integrated with other project teams such as engineering, design, construction, etc., and it is integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.

B. MATERIALS MANAGEMENT SYSTEMS

1. Project Team Materials Status Database

Implementing a project team materials status database requires identifying which software system should be used in materials management. It should consider if the database will be used /accessed by different users and stakeholders (e.g. owner, designer, and subcontractors) and what this implies in terms of functional requirements. The compatibility with the existing software systems of each stakeholder organization are also important to consider.

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

2. On-Site Materials Tracking Technology

Materials locating and tracking is an important part of materials management at project job sites, particularly at projects with large laydown yards and costly materials and equipment and where lost materials represent significant project risk. Therefore, the project team should decide whether an on-site materials tracking system is required or not. The issues to consider include:

- Quantity, cost, and criticality of materials (critical path items)
- Complexity of project
- Cost of tracking and locating system

There are various technologies which can be used for on-site materials tracking. These include:

- Barcodes
- Radio Frequency Identification (RFID) tags
- Ultra Wide Band (UWB) tags
- Global Positioning Systems (GPS)

Level 0	On-site materials tracking technology is not applicable.
Level 1	No tracking is done on site beyond receivables.
Level 2	Materials are assigned a lay down and storage area and the information is recorded manually on paper.
Level 3	Continuation of level 2, plus the location information is kept updated in a software system, and well defined processes for establishing lay down area grids, developing pick lists, flagging, warehouse organization (if applicable), etc. are established and followed.
Level 4	Continuation of level 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 level 4, plus the tracking system is completely automated and integrated with other project processes.

3. Materials Delivery Schedule

A good material delivery schedule is important for effective materials management. Issues to consider in developing a materials delivery schedule include:

- Date and time of materials arrival at job site
- Date when the materials are required at site (RAS date)
- Agrees with the materials procurement plan
- Storage of materials onsite; if not, the project should consider a just-in-time delivery schedule

Level 0	Materials delivery schedule is not applicable.
Level 1	There is no documented materials delivery schedule.
Level 2	Materials 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 materials delivery planning and management is completely integrated with other automated project processes including automated materials tracking throughout the supply chain.

C. RECEIPT AND INSPECTION OF MATERIALS

1. Material Inspection Process

All materials received/delivered at site should be inspected. The materials inspection process should:

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

Level 0	A materials inspection process is not applicable.
Level 1	There is no materials inspection process.
Level 2	A materials inspection process is only utilized for large items or costly items on a project.
Level 3	A materials inspection process is utilized that includes all items delivered to the site. There is a lack of organization of the process, and materials are 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	A materials inspection process is used at the supplier and onsite, and organizes materials receipt inspections immediately upon delivery of materials, 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, standards, drawings, etc., record of the location of materials and marked materials for tracking, and prioritization quality).

2. Materials Inspection Team

A materials inspection team is required to inspect materials both onsite and offsite at the suppliers location. The team should be trained and qualified in the following areas:

- Inspection processes and procedures
- Knowledge of how to inspect materials
- Materials specifications & standards, materials test reports (MTR), etc.

Level 0	Materials inspection team is not applicable.
Level 1	There is no materials inspection team.
Level 2	There is a designated materials 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.

3. Post Receipt Preservation & Maintenance

After the materials have been received, verified, and stored at site; a plan for post receipt preservation and maintenance of the stored materials is required. It is necessary for knowing the status, location, and maintenance of the materials. An inventory of materials should be made by recording the following information of the stored materials:

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

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 for large and/or costly items only.
Level 3	Continuation of Level 2, plus plan is used for all materials delivered to 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.
Level 4	Continuation of Level 3, plus plan includes materials to be 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.

CATEGORY II: CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS

A. CONSTRUCTION MACHINERY & EQUIPMENT AVAILABILITY

1. Procurement Procedures & Plans for Construction Machinery

Procurement procedures & plans are required for construction machinery, including guidelines, requirements, or systems for purchasing/renting, expediting, and delivery of construction machinery and equipment for the project. Issues to consider include:

- Will the construction machinery be purchased, rented, or leased?
- Coordinate the construction machinery procurement schedule with the construction schedule
- Develop a list of authorized suppliers
- Coordinate with equipment logistics to determine the required at site dates for required rental machinery

Level 0	A procurement plan for construction machinery and equipment is not applicable.
Level 1	There is no documented procurement plan for construction machinery.
Level 2	A procurement plan and schedule exists for purchasing, leasing or renting construction machinery.
Level 3	Continuation of Level 2, plus 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 integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.

2. Construction Machinery Productivity Analyses

Construction machinery plays an important role in optimizing productivity, project performance, capital efficiency, and cost. It enables the tasks to be performed efficiently and much faster. However, it is necessary to understand the costs and benefits associated with the use of construction machinery. Use of and availability of a particular piece of construction equipment affects the cost/benefit ratio associated with operating it. Issues to consider include:

- Measure utilization time (uptime) of construction machinery and equipment
- Measure delays due to unavailability of construction machinery
- Machinery use is adjusted with construction schedule and contingency plans available if the schedule changes

Level 0	Use of Construction Machinery is not applicable
Level 1	Construction Machinery is utilized but requirements and usage are not planned and tracked.
Level 2	Machinery requirements are planned and scheduled on a spreadsheet or tracking device but are not tied to a schedule. Usage is tracked against a budget activity.
Level 3	Continuations of Level 2, plus needs are reviewed regularly in planning meetings. A mechanism for resolving conflicts and allocation of machinery is established.
Level 4	Continuation of Level 3, plus schedule resource curves are driver in mobilization and demobilization of equipment on site. Schedule is resource levelled with consideration of minimizing in/out cycle of equipment and maximizing use.
Level 5	Continuation of Level 4, plus usage is audited and downtime reported and tracked, equipment schedule/plan adjusted as required based on audits.

3. Construction Machinery and Equipment Maintenance

Timely maintenance of machinery is critical for keeping the machinery in good working condition and ensuring that it can perform optimally without breaking down and is available when needed. Properly managing routine/scheduled maintenance will minimize project impact due to machinery downtime/failure. For very large projects, automated machine health monitoring and notification system could also be considered. Important issues to note are:

- Will the maintenance activity be performed at site or offsite?
- Will maintenance be self-performed or outsourced?

Level 0	Equipment maintenance is not applicable.
Level 1	Equipment maintenance is not planned for on the project
Level 2	On site equipment is logged in a manual or simplified spreadsheet database. Schedule of required maintenance per type of equipment is identified but not linked to individual construction equipment items with status. Maintenance is done routinely by operator request.
Level 3	Continuation of Level 2, plus equipment is linked to individual construction equipment items with status, and maintenance is centrally scheduled and accomplished.
Level 4	Continuation of Level 3, plus a computer based program is utilized for all equipment on site including scheduled and actual on / off site dates, required and accomplished maintenance logs and usage logs.
Level 5	Continuation of Level 4, plus on site or outsourced maintenance is identified with electronic links to required purchase order information. Routine maintenance schedule is electronically updated and maintenance due notices are automatically issued via an email system to required parties. Automated machine health monitoring and notification systems are also used to some extent.

B. TOOLS AND EQUIPMENT MANAGEMENT BEST PRACTICES

1. Site Tools and Equipment Management Strategy

An effective site tools and equipment management strategy is essential to ensure improved craft productivity. Some of the factors that need to be considered follow:

- Set up a tool and equipment distribution strategy (e.g. tool box or toll & equipment storage area)
- Tool acquisition strategy that addresses both off-the-shelf (readily available) and custom (difficult to acquire) tools
- Decide whether tool management is performed in house or by a third party vendor
- All necessary tools and equipment must be properly accounted for before the beginning of the construction phase

Level 0	A site tool and equipment management strategy is not applicable.
Level 1	There is no site tool and equipment management strategy.
Level 2	The use of tool and equipment storage areas has been established.
Level 3	Continuation of Level 2, plus a decision of whether tool management will be performed in-house or by a third party vendor.
Level 4	Continuation of Level 3, plus temporary power requirements for tools have also been established and maintained during construction. Procedures are established to properly account for tools on a weekly or other regularly scheduled basis.
Level 5	Continuation of Level 4 plus includes the commitment of foremen and craft workers to be accountable for the proper care and use of the tools and equipment.

2. Tools & Equipment Tracking

It is important to have information about the exact location and responsible people for tools and equipment being used on the project. A complete list of project specific tools and equipment that needs to be installed should be made. There are some standard tools which are used for most jobs, such as hammers, screws drivers, crimpers, etc. For managing these standard tools, a simple strategy would be making lists. For some projects, the equipment needs to be manufactured and purchased specifically for construction of these projects. For these expensive and speciality equipment, more advanced technologies should be used for locating and tracking such as bar codes, RFID, etc. The tools and equipment tracking tools may include:

- Developing tools and equipment lists considering project requirements
- Using a bar coding system on all small tools and equipment
- Linking a tool to a craftsmen's ID when a tool is checked out

Level 0	Project tool and equipment tracking status database is not applicable
Level 1	There is no database and no formal paper based system to track tools.
Level 2	There is no database, but there is a formal paper based system to track tool tracking status.
Level 3	A software application is used but not integrated with your company's other information technology systems.
Level 4	A software application is used and is integrated with your company's other information technology systems. The system includes bar coding of tools.
Level 5	Continuation of Level 4, plus the system also includes RFID tracking of tools and equipment.

3. On-site Tools Maintenance

On-site tools maintenance is necessary for properly maintaining tools and ensuring that they are working properly when required. This includes:

- A mechanism for identifying tools that require routine maintenance or replacement of wearable parts
- Tools are maintained to warranty specs throughout the lifecycle of the project
- Established points (e.g. operating hours or duration of tool ownership) when a worn part should be replaced.
- Qualification of tool room personnel to repair and maintain tools

Level 0	On-site tool maintenance is not applicable.
Level 1	There is no documented on-site tool maintenance plan.
Level 2	A mechanism for identifying tools that require routine maintenance or replacement of wearable parts is established.
Level 3	Established points of tool use (e.g. operating hours or duration of tool ownership) are set when tools are inspected for required maintenance.
Level 4	Continuation of Level 3, plus a contract has been established with an outside vendor or other personnel offsite to provide required maintenance.
Level 5	Continuation of Level 4, plus qualified and dedicated personnel in the tool room exist to provide tool maintenance and repairs.

4. Construction Machinery& Equipment Utility Requirements

As infrastructure project has extensive use of construction machinery and equipment, therefore, it is necessary to have complete details of utility requirements for different machinery and equipment for determining overall utility requirements. Issues to consider include:

- Power (hard line, solar, auxiliary)
- Water
- Air and speciality gases
- Fuel
- Communications (cables, fibre-optics)
- Other user defined

Level 0	A machinery and equipment utility requirement is not applicable.
Level 1	There is no machinery and equipment utility requirement documented.

Level 2	The machinery and equipment utility requirements have been established.
Level 3	Continuation of Level 2, plus a decision of whether utility requirements will be performed in-house or by a third party vendor.
Level 4	Continuation of Level 3, plus temporary utility/power requirements for machinery and equipment have also been established and maintained during construction. Procedures are established to properly account for requirements on a weekly or other regularly scheduled basis.
Level 5	Continuation of Level 4 plus the commitment of foremen and craft workers to be accountable for the proper care and use of the machinery and equipment.

CATEGORY III: EXECUTION APPROACH

A. PLANNING

1. Short Interval Planning

Short interval or look ahead planning for the next 2-5 weeks should be done every week in order to allocate crews and equipment (such as cranes), ensure that the required materials, information, and tools will be available for each crew, and to anticipate bottlenecks, hazards, and other potential problems. It is important to make these plans in consultation with the foremen. These plans should consider:

- The tasks to be performed
- The numbers of craft workers needed for each task
- The estimated duration for each task
- The required materials, tools and equipment, labour, and project information required to complete each task.

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 status 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	Continuations of Level 3, plus activities in the project schedule are resource loaded to help with short interval planning. The short interval plan considers 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. Alternate plans are prepared such as modified equipment/machinery schedules, shortened shifts, lengthened shifts, or added shifts in case the original plans did not work.

2. Well Defined Scope of Work

For effective planning, the scope of work shall be clearly and well defined for all members of the project team. Some of the things to consider for properly defining scope of work include:

- A clear description of the project's goals
- A clear description of the owner's vision for the facility
- Basic requirements of the project
- The timeframe of all the work involved to produce the project's deliverables

Level 0	A well-defined scope of work is not applicable.
Level 1	Work is released to the field on drawings with incomplete design, and execution is controlled with a milestone schedule.
Level 2	Continuation of Level 1, plus design is complete. Work is released to the field via drawings without constructability review; execution is controlled with a master schedule.
Level 3	Continuation of Level 2, but with scope and design being complete. Also, Constructability review has been performed and execution is controlled with and integrated schedule.
Level 4	Continuation of Level 3, plus duration for scope of the work package is defined, material availability, testing and inspection requirements are defined, man-hours are charged against the work package, but budget and quantities are not reflected in scope of work.
Level 5	Continuation of Level 4, plus budget, quantities, and man-hours for the scope of work are reflected in the overall schedule. Completion percentage of the work package will be reflected in the integrated schedule.

3. Use of Software in Planning

Different software are available for use by the project team to support planning, design, and construction. Some of these software are commercially available and some are proprietary. These software can help in the following areas but not limited to, such as:

- Scheduling (weekly, monthly, etc.)
- Materials identification
- Materials delivery
- Managing life cycle data including asset information, models, and electronic documents
- Different project information
- Civil Information System (CIS)
- Geographical Information System (GIS)
- Building Information Modeling (BIM)
- Work packages

Level 0	Utilization of software in planning is not applicable.
Level 1	The project uses a software system to track the generation and closure of work packages. However it is not integrated, material status and drawing status must be entered manually. Work steps are signed off in the package when completed.
Level 2	Continuation of Level 1, plus percent complete is entered by reviewing the package. Work package status is updated to the master schedule manually.
Level 3	Continuation of Level 2, plus the project uses a software system to generate the work package and automatically includes the drawings and material delivery status. Schedule, percent complete, test and inspection status, and closure must be entered manually by review of the work package.
Level 4	Continuation of Level 3, plus which is updated regularly and automatically includes and provides current design drawing information, updated status of materials, implementation schedule with durations and quantities, test and inspection status, percent complete and closure. Work steps are signed off electronically, however work package status is updated to the master schedule manually.
Level 5	Continuation of Level 4, plus work steps are signed off electronically and work package status is updated electronically.

4. Dedicated Planner

The project needs a person that has been specifically dedicated for the planning, monitoring, reporting of the construction schedule. The planer coordinates the schedule planning with procurement, engineering, design, and others. A list of the main activities to be performed by the dedicated planner follows:

- Plan all necessary work related to project construction schedule

- Organize the timelines for all construction activities
- Initiate and communicate regarding the confirmation and inspection of all items delivered, outstanding/past due items
- Update schedule as needed
- Obtain feedback/approval of field supervisors for construction schedule

Level 0	Dedicated planner is not applicable.
Level 1	Hiring of dedicated planner has not been addressed.
Level 2	Dedication of single planner or multiple personnel with specific sectional responsibilities based upon project scope, size, and need. Initial planning needs to be coordinated with procurement, planning, and others. High level synchronization driven through utilization of project software.
Level 3	Initiate & maintain communication regarding the confirmation & inspection of all items delivered, outstanding/past due items. Update scheduling and management as appropriate. Handling of outstanding, past due items at lowest level, escalate as necessary based upon severity, impact on schedule, and past due status timeline.
Level 4	Continuation of Level 3, plus continued update of scheduling & management. Onsite inspection as necessary regarding the release, tracking, and consumption of materials. Escalated precedence on outstanding and past due items. Report progressing & audit of progressing, validate to schedule.
Level 5	Continuation of Level 4, plus continued communication of release, tracking, and consumption of materials. Initiate completion milestone, return to stores unused/not needed materials. Final validation & auditing.

5. Construction Work Packages

A Construction Work Package (CWP) is an executable construction deliverable that defines in detail a specific scope of work and should include a budget and schedule that can be compared with actual performance. The scope of work is such that it does not overlap another CWP. The CWP must include:

- Construction scope of work
- Engineering information
- Craft / Manpower
- Direct Field Equipment and Materials
- Safety
- Quality
- Special Permits / Regulatory Requirements

- Subcontractors
- Vendor Support Data
- Rigging Studies; Scaffolding
- Special Construction Equipment, Tools and Consumables
- Risk Register
- Project Controls
- Turnover Documents
- Contact List

Level 0	Completion of CWP's is not applicable
Level 1	Required CWP's have not been addressed.
Level 2	CWPs are partially complete, though there are several sections that remain incomplete. A basic budget and schedule has been completed.
Level 3	All sections of the CWP have been addressed. The sections display no in-depth consideration.
Level 4	Continuation of Level 3, plus in-depth consideration for most of the sections. A comprehensive schedule and budget has been provided.
Level 5	Continuation of Level 4, plus all sections have received in-depth consideration. The construction task can be performed easily based on the scope of work and information provided in the CWP.

B. CONSTRUCTABILITY REVIEWS

1. Design Readiness for Construction

It should be confirmed that the design for all phases of the construction is adequate and the schedule can be made and completed before actual construction begins and relevant phases are mobilized.

Level 0	Design readiness for construction is not applicable
Level 1	Design readiness for construction is not addressed
Level 2	Some scheduling and coordination of the phases of construction has been performed by the General Contractor, Construction Manager, or another agent of the Owner.
Level 3	Continuation of Level 2, plus the General Contractor, Construction Manager, or another agent of the Owner has created a detailed schedule for all phases of construction.
Level 4	Continuation of Level 3, plus the owner is more involved and all phases of the project have been determined and the schedule is complete before construction. The schedule or sequence of activities may change after construction starts.
Level 5	Continuation of Level 4, plus scheduled to be completed before construction and any relevant phases are mobilized. This scheduling utilizes critical path scheduling, reverse phase scheduling, or some other means of coordination of the project's activities.

2. Utilities Alignment/Adjustments

Some parts of the project would require working in close vicinity to the existing utilities in the area. Proper review and arrangements for working around or rerouting the utilities need to be made, so that the project schedule is not affected. In some cases the existing services have to be removed or modified and reinstated after the construction, particularly in a pipeline projects. For pipe line projects, the pipe line could run in parallel or intersect the existing utilities/services. These services include: city owned water mains, gas pipelines, optic fibre cables, underground and above ground power cables, and private irrigation systems. Issues to consider include:

- List of utilities (water, waste water, gas, electrical, etc. in the area)
- Exact location of these utilities
- Ensure that there is no disruption of service during construction around utilities
- Plan for detours if needed
- Warning signs on message boards about utilities passing in the area
- Check the city codes/laws about utilities and working around them
- Avoid disrupting the operation of any pump in construction area
- Protect valid stakes or other valid physical markings described used to mark the horizontal route of an underground facility
- Communicate and work with businesses and inform residences of utility shut offs, interruptions, if any

Level 0	Utility alignment/adjustment is not applicable.
Level 1	Utility alignment/adjustment is not addressed.
Level 2	The project has a review process for working in areas surrounding utilities. The process includes list of utilities, locations, and warning signs.
Level 3	Continuation of Level 2, plus necessary detours have been planned when necessary. City approvals have been obtained.
Level 4	Continuation of Level 3, plus communication with businesses and local community/residencies have been made. Arrangements for temporary shut offs and interruptions have been made.
Level 5	Continuation of Level 4, plus the physical markings described to mark the horizontal route of underground facilities have been protected, detours have been constructed, and the all activities related to utilities alignments have been integrated with other project schedules.

3. Contract Types/Strategies

An Infrastructure project may consist of different sub projects and it would be helpful to consider executing these sub-projects using different types of contracts. The different types of project delivery methods and contracting strategies for project design and construction delivery should be identified. The corresponding fee/payments structure and risk allocation should also be identified. Some of the options and issues to consider are:

- Self-performed
- Design/build
- Construction Management (CM)
- Design-bid-build
- Cost plus fixed fee
- Lump sum
- Cost plus negotiated
- Craft labour studies/reports
- Local conditions/requirements

Level 0	Contract types/strategies is not applicable
Level 1	Contract types/strategies is not addressed
Level 2	The project has a review process for project design and construction delivery. It considers fee structure and financing options, but risks associated with different contract types are not considered.
Level 3	Continuation of Level 2, plus risks associated with different contract types are also considered. Cost benefit analysis for different types of contracts and project delivery methods are performed
Level 4	Continuation of Level 3, plus the labour market information and reports are also studied and considered before awarding contracts.
Level 5	Continuation of Level 4, plus the local conditions in the project area are studied and monitored regularly. The company has established protocols for selecting designers, contractors, suppliers, and manufacturers.

4. Model Requirements/3D Visualization

Project models help the project team in different stages of the project, such as; pre-engineering, engineering, procurement, contracts, construction, and turnover and commissioning. These models can be 3D or 4D and they help in visualization of the project. Some of the benefits of these models include:

- Visual construction sequence (which allows integration of construction expertise into project planning and enables visual communication of construction sequence.)
- A 4D (a linked schedule – 3D model) construction simulation

Level 0	Project model requirements are not applicable
Level 1	Integration of the projects 3D and schedule information has not been addressed
Level 2	A 4D Model has been established for the project.
Level 3	Continuation of Level 2 plus includes basic updates manually made based on scheduled changes.
Level 4	Continuation of Level 3, plus the model is dynamic and includes material specifications, change order documentation, and other pertinent design and construction information related to the 4D model.
Level 5	Continuation of Level 4, plus automatically updated based work progress as measured ubiquitously by RFID, laser imagining or other technologies is also automatically updated based on scheduled changes.

C. ACQUISITION STRATEGY

1. Right of Way, Land, and Utilities Acquisition Strategy

Right-of-way and land acquisition are usually on the critical path of infrastructure projects, therefore, it is important to have a clear and well defined strategy for identification and acquisition of right-of-way, utilities adjustments, and other lands. Some important things to consider in this regard are:

- Implement a public consultation process
- Pay special attention to identification of long-lead and problematic parcels of land
- Acquisition of lands
- Relocation of existing land owners
- Identifying responsible parties for land acquisition and utility adjustments
- Appraisal issues
- Dealing with existing structures

- Review of existing right-of-way maps from previous projects
- Property records
- Control of access lines

Level 0	Right-of-way and land acquisition are not applicable
Level 1	There is no documented right-of-way and land acquisition plan.
Level 2	The project has a review process for identifying and acquiring right-of-way and utility adjustments for long-lead parcels of lands, which have historically been found problematic.
Level 3	Continuation of Level 2, plus plan identifies and acquires all right-of-way, utilities, and parcels of land in the project's scope. It has identified responsible parties for dealing with these matters.
Level 4	Continuation of Level 3, plus all information related to property descriptions from survey information have been transformed into a form of documentation that can be logged into project information systems.
Level 5	Continuation of Level 4, plus all property descriptions have been logged into project information systems and integrated with project schedules.

2. Contracts & Agreements with Agencies

Infrastructure projects require contractual agreements with local public agencies. These contracts determine and state the responsibilities regarding the acquisition of right of way, adjustment of utilities and cost sharing between the public agencies and owner/contractor. Issues to consider include:

- Compliance with local regulations and procedures
- Administration and acquisition of right of way (who will be responsible for acquisition and payments, owner or public agencies)
- Long term operations and maintenance of utilities and cost sharing

Level 0	Contracts and agreements with local public agencies are not applicable
Level 1	Contracts and agreements with local public agencies is not addressed
Level 2	The project has a review process for working with local agencies, but no formal contracts and agreements have been signed.
Level 3	Continuation of Level 2, plus formal contracts and agreements have been signed. Approvals from concerned agencies have been obtained.
Level 4	Continuation of Level 3, plus all activities related to contracts and agreements have been integrated with other project schedules.
Level 5	Continuation of Level 4, plus automatic reminders for renewal are generated in advance before a contract or agreement expires.

3. Utility Agreements

The utility agreements and contracts for joint use effectively allow the utility to share space on public or private right-of-way. It also enables completion of utility adjustments. It is important to pay attention to utility arrangements in order to ensure that the review and approval processes are coordinated in a timely and efficient manner. Some of the issues to consider include:

- Identify Public or private utilities
- Utility agreements, plans, documentation, estimate, etc.
- Crossing permits for highways, railroads, canals, etc.
- Compliance with concerned jurisdictional requirements and approvals

Level 0	Utility contracts and agreements are not applicable
Level 1	Utility agreements and joint use contracts is not addressed
Level 2	The project has a review process for utility agreements and the use of utilities, but no formal contracts and agreements have been signed.
Level 3	Continuation of Level 2, plus formal contracts and agreements have been signed for utilities use and adjustments. Approvals from concerned agencies have been obtained.
Level 4	Continuation of Level 3, plus all activities related to contracts and agreements have been integrated with other project schedules.
Level 5	Continuation of Level 4, plus automatic reminders for renewal are generated in advance before a contract or agreement expires.

D. REGULATORY REQUIREMENTS/REVIEWS

1. Environmental Requirements

Most often, infrastructure projects require environmental assessments and mitigation techniques. These environmental assessments depend on the type, size, and scope of the project. The project's environmental classification and funding sources usually determine the type and nature of environmental studies/assessments to be performed. These assessments can influence the project's design, engineering and construction. Issues to consider include:

- Environmental documentations (environmental assessments (EA), environmental impact statements (EIS), environmental impact report (EIR)
- Jurisdictional environmental policies
- Federal and Provincial environmental policies

- Mitigation techniques for;
    - Habitat
    - Water quality
    - Wetland
    - Storm water
    - Cultural resources
    - Noise

Level 0	Environmental requirements are not applicable.
Level 1	Environmental requirements and related issues have not been addressed.
Level 2	Initial investigations based upon environmental assessments and reports, jurisdictional and federal policies, mitigation techniques, timeline to attain, assignment of environmental responsibilities, pre-construction requirements has been completed.
Level 3	Continuation of level 2, plus environmental requirements tied to scheduling & milestones.
Level 4	Continuation of Level 3, plus system established for tracking & monitoring of environmental requirements, release, and closeout driven by requirements.
Level 5	Continuation of Level 4, plus system is automatically updated based on continued updates to schedule, permit closeouts, escalation of delays due to permit as deemed necessary dependent on severity of issue & assistance required.

2. **Regulatory Requirements/Permitting Requirements**

Different types of permits are required at various times during the construction of the project. A procedure should be developed that identify these permitting requirements and acquire them at appropriate times. Some of the common permits those are required but not limited to:

- Access to jobsite
- City permits
- Provincial permits
- Federal permits

Level 0	Regulatory/Permitting requirements are not applicable.
Level 1	Required permitting has not been addressed.
Level 2	Initial investigations based upon projected needs of permits, timeline to attain, how long permit is good for, are multiple permits needed, assignment of permit responsibility, sign-off authority, pre-inspection requirements, fees have been completed.
Level 3	Continuation of level 2, plus permit requirements tied to scheduling & milestones.
Level 4	Continuation of Level 3, plus system established for tracking of permit acquisition, release, and closeout driven by requirements and as designated by permit type.
Level 5	Continuation of Level 4, plus system is automatically updated based on continued updates to schedule, permit closeouts; escalation of delays due to permit as deemed necessary dependent on severity of issue & assistance required.

CATEGORY IV: HUMAN RESOURCES MANAGEMENT

A. PLANNING

1. Crews Composition/Crew Formation

Highly-skilled and highly-valued construction workers may be a challenge to find and even not available in the labour market. The workers may be required to be hired from other cities or provinces. Proper planning for crew composition for different tasks, activities, phases, locations, etc. can affect the project performance and productivity. Combination of trained and experienced, apprenticeships and journeymen should be considered and the best formation of crew be made. Some of the issues to consider are:

- Agreement with local or national labour unions
- Availability of local workers
- Nature of job
- Location of job
- Experience of workers

Level 0	Crew composition is not applicable.
Level 1	Crew composition is not addressed.
Level 2	Crew formation is addressed on the jobsite after the beginning of the project.
Level 3	Crew formation is addressed before the beginning of construction work, based on the experience and knowledge of workers, job requirements, and location.
Level 4	Continuation of Level 3, plus the performance of crew is assessed after completion of each task and adjustments made accordingly to improve performance and productivity.
Level 5	Continuation of Level 4, plus the crew formation and their performance is assessed regularly on daily, weekly, and monthly basis. Necessary changes are made and monitored and the schedules are updated automatically.

2. Skills Assessment and Evaluation

The skills level of all craft workers should be assessed before hiring them for the project or organization. This helps in planning for crew composition and management, training, and tasks assignments. Some issues to consider are:

- Trade certifications from recognized organizations
- Previous experience
- Immigration

Level 0	Skills assessment and evaluation is not applicable.
Level 1	Skills assessment and evaluation is not addressed.
Level 2	Skills assessment and evaluation is addressed on the jobsite after the beginning of the project.
Level 3	Skills assessment and evaluation is addressed before the beginning of construction work, at the time of hiring, and based on the experience and knowledge of workers, job requirements, and location.
Level 4	Continuation of Level 3, plus the assessment and evaluation is made again after completion of each task and adjustments made accordingly to improve performance and productivity.
Level 5	Continuation of Level 4, plus the assessment and evaluation is performed regularly on daily, weekly, and monthly basis. Necessary changes are made and monitored and the schedules are updated automatically.

B. TRAINING AND DEVELOPMENT

1. Employees / Trades Technical Training

Technical training is provided to the employees and trades in various disciplines such as tools usage, installation procedures, drawings reading, scheduling, etc.

Level 0	Trades technical training is not applicable.
Level 1	Trades technical training is not addressed.
Level 2	Trades technical training is addressed on the jobsite after the beginning of the project.
Level 3	Trades technical training is provided to a worker when he begins working for the company, and if needed extra training will occur on the job site.
Level 4	Continuation of Level 3, plus craft worker is certified to work in that trade. Before each project, new training in the trade will take place if necessary.
Level 5	Continuation of Level 4, plus craft worker takes part in training for new technologies that are introduced in that trade annually and bi-annually.

2. Career Development

Career development is an incentive which motivates and retains employees. Promotions is an example of career development offered to employees.

Level 0	Career development is not applicable.
Level 1	Career development is not addressed.
Level 2	The organization does not have a formal career development plan for craft workers, but management will discuss future plans with the craft workers.

Level 3	The organization has a formal career development plan for craft workers, but it only addresses short term career developments.
Level 4	Continuation of Level 3, plus it addresses long term career developments and options.
Level 5	Continuation of Level 4, plus addresses the expected performance of the worker and how the performance will affect his/her career development.

C. BEHAVIOUR

1. Non-Financial Incentive Programs

A number of non-financial incentive programs or recognition programs can be implemented based on performance in terms of productivity, quality, and safety. Some of the incentives that can be considered but not limited to include:

- Contests
- Visuals (posters and bulletin boards)
- Paid vacations

Level 0	Recognition or non-financial incentive program is not applicable.
Level 1	Recognition program is not addressed.
Level 2	The organization has an informal recognition program that will recognize craft workers occasionally, but not in a formal manner.
Level 3	The organization has a formal recognition program that provides recognition on long term basis.
Level 4	Continuation of Level 3, plus it recognizes craft workers on a regular basis for both positive safety results and good safety behaviour.
Level 5	Continuation of Level 4, plus with attending safety meetings and classes. The rewards are given on both short and long term basis, and they are recognized by the upper management of the organization. Each year the recognition program provides a report of the safety performance of the company, discusses how the organization can improve in regard to safety, and constantly looks into tweaking the program to improve it.

2. Financial Incentive Programs

Financial incentive programs are implemented based on achievements in terms of productivity, quality, and safety.

Level 0	Financial incentive program is not applicable
Level 1	Financial incentive program is not addressed.
Level 2	The organization has an informal incentive program that will recognize craft workers occasionally, but not in a formal manner.
Level 3	The organization has a formal incentive program that provides incentives on long term basis.
Level 4	Continuation of Level 3, plus it provides a monetary bonus for craft workers on a regular basis for both positive safety results and good safety behaviour.
Level 5	Continuation of Level 4, plus with attending safety meetings and classes. The rewards are given on both a short and long term basis, and they are recognized by the upper management of the organization. Each year the incentive program provides a report of the safety performance of the company, discusses how the organization can improve in regard to safety, and constantly looks into tweaking the program to improve it.

3. Social Activities

Social activities need to be planned and organized for improving relationships and creating a positive work environment.

Level 0	Social activities for the craft workers are not applicable.
Level 1	Social activities for the craft workers are not addressed.
Level 2	The organization does not formally plan social activities for the craft workers, and there is only a yearly organization wide social activity.
Level 3	The organization formally plans a social activity for the craft workers once or twice a year in which the project managers will attend, along with a yearly organization wide social activity.
Level 4	Continuation of Level 3, plus several times throughout the year which the project managers will attend, along with a yearly organization wide social activity.
Level 5	Continuation of Level 4, plus monthly which the project managers will attend and upper management including the president will attend on a quarterly basis, along with a yearly organization wide social activity.

D. ORGANIZATIONAL STRUCTURE

1. Maintain Stability of Organization Structure

It is important to keep stability of the organization structure. Too much hiring and firing can affect the productivity and performance negatively. There are some mechanisms to keep the organizational structure stable, such as:

- Avoid changes in key personnel
- Plans for incorporating any unusual or unplanned staff changes
- There is an individual on site who has the authority to act for the contractor and is in charge of the contractor's work. This person will interface with the counterpart on the owner's team
- Place clauses in the contract that prohibit the replacement of key personnel, unless there is just cause.

Level 0	Maintaining the Stability of the Organizational Structure is Not Applicable.
Level 1	No plans to manage change of key people in contract.
Level 2	Owner & Contractor name/define key individuals in contract.
Level 3	Continuation of Level 2, plus state that they cannot be changed without notice and prior approval.
Level 4	Continuation of Level 3, plus designated successors (which are pre-approved).
Level 5	Continuation of Level 4, plus contract specifies all key personnel on both Owner & Contractor teams, along with possible successors and right of approval by the other party.

2. Clear Delegation of Responsibility

There should be a clear delegation of responsibility and authority. This applies both to the owner and contractor and should be understood by both parties. Usually, the owner organization may have many levels of delegation, which may differ depending on whether it is a technical issue, construction-related, etc. A Contractor will likely have fewer levels, but not necessarily. To have a successfully executed project, the internal workings of each party must be known and understood to each other.

Level 0	Clear Delegation of Responsibility is Not Applicable.
Level 1	Simple & centralized.
Level 2	Simple & very formal.
Level 3	Stable project environment & more formal.
Level 4	Formal, but differing between technical, admin., etc.
Level 5	There is a formal delegation of authority that is clearly defined for all involved parties. The plan is reviewed periodically and evolves when necessary

E. EMPLOYMENT

1. Retention Plan for Experienced Personnel

It is a best practice to retain experienced workers in the company, because of cost effectiveness as compared to hiring and training new craft workers. Practices used to retain experienced personnel include an aggressive craft training program that includes programmed pay increases when craft workers become certified, working with craft workers to find employment opportunities on other company projects after their respective work on their current project ends, and offering retention bonuses and preferred hiring status on the next project for the same employer.

Level 0	Retention Plan for Experienced Personnel is Not Applicable.
Level 1	A retention plan is not addressed.
Level 2	Each craft foreman is responsible for retention of his craft workers.
Level 3	Craft training is available but not required. Journeymen have higher pay & preferred hiring status on the next project for the same employer.
Level 4	Continuation of Level 3, plus craft training is required for sub-journeymen: testing & certification is available on site. The employer makes available a list of opportunities for the next project.
Level 5	Continuation of Level 4, plus Craft training for sub-journeymen is required. Testing & certification on the site lead to pay increases. Employer meets with individual craft workers and offers job(s) at new project site(s) as per requirements.

2. Exit interviews

It is important to understand and address the reasons that cause people to leave the organization. Exit interviews should be conducted to know these reasons and necessary actions should then be taken.

Level 0	Exit Interview is Not Applicable.
Level 1	No exit interview.
Level 2	Exit interview for key craft only.
Level 3	Random exit interviews when there is time.
Level 4	Formal exit interview for all craft.
Level 5	Formal exit interview for all craft and feedback to management about lessons learned and how to improve retention when applicable.

CATEGORY V: CONSTRUCTION METHODS

A. PROJECT SCHEDULE CONTROL

1. Integrated Schedule

The project should have an integrated schedule using the Critical Path Method (CPM). The CPM is a scheduling technique that involves scheduling discrete activities/tasks using forward and backward pass techniques. Important things to consider for integrated scheduling include:

- Compare current schedule with the original schedule
- The combination of the two should provide a more reasonable and workable schedule
- Use the critical path method to determine those tasks where overtime will have the greatest effect on the schedule

Level 0	The use of an integrated schedule using CPM is not applicable.
Level 1	The use of an integrated schedule using CPM has not been addressed
Level 2	Developing a schedule with no resources present and managing schedule status via duration / remaining duration but no link to earned percent complete progress from associated deliverables per activity.
Level 3	Developing a schedule with resources present but no link to earned percent complete progress from associated deliverables per activity.
Level 4	Developing a schedule with resources present but no link to earned percent complete progress from associated deliverables per activity. Resources are updated to reflect current work content (quantity adjustments)
Level 5	Continuation of Level 4 and updated to include quantity adjustments. Earned progress for the activity is based on measured/assessed work complete per deliverable/s per activity. Progress measurement performed in application adapted specifically for deliverable/quantity completed status and earned value calculations, which are appropriately linked to schedule activities.

2. Work Schedule Strategies

Different work schedule strategies can be used, such as; standard straight time 40 hour per week schedule (5-8 hrs. days, 4-10 hrs. day), 2nd and 3rd shifts, overtime schedules (e.g. 5-10 hrs. days, 6-8 hrs. days, and 7-10 hrs. days), and innovative scheduling techniques (e.g.

Rolling schedules and 3-13 hrs. days). Try to avoid using overtime if possible, and when overtime is unavoidable, consider the following:

- Schedule overtime, when it is necessary, on alternate weeks rather than continuously.
- Seven 8 hrs. days are significantly less productive than six 9-hr days even though total hours are about equal. Assume each day involves two lost hours due to lunch, work starts and stoppages, and breaks.

Level 0	The development of a work schedule strategy is not applicable
Level 1	The development of a work schedule strategy has not been addressed
Level 2	Strategy is based on a single work schedule be it either a straight time 40 hour per week schedule, overtime, or other work schedule
Level 3	Strategy considers multiple work schedules considering critical and near critical activity sequences.
Level 4	Continuation of Level 3, plus strategies considers potential impact on worker fatigue, supervision, safety, and absenteeism.
Level 5	Continuation of Level 4, plus each potential strategy's impact analyzed for manpower density and congestion at an area / sub-area level.

3. Schedule Execution and Management

It is must to ensure that the project schedule is being followed and therefore, attention should be paid to practices that should ensure that the schedule is complied with. Some of the issues to consider are:

- Measure the actual progress
- Compare progress with planned schedule
- Update schedule periodically.
- Continuous communication with material suppliers to ensure that material will be onsite when needed

Level 0	The development of a schedule compliance plan is not applicable
Level 1	The development of a schedule compliance plan has not been addressed
Level 2	Consistent follow up to monitor the following; schedule updated periodically, critical path analysis, progress narrative prepared as required and effective team participation in

	schedule updates.
Level 3	Continuation of Level 2, plus Quantity reports are regularly performed but rules of completion are not formally defined. Upon request, or as project requires, may include any of the following: change management analysis, risks assessment scenarios/analysis, date variance analysis to approved baseline or previous update period, start / finish percent achieved ratio analysis, communication with material suppliers to ensure material will arrive on site when planned.
Level 4	Continuation of Level 3, plus monitor the following; schedule rigorously updated based on manual input of quantity reports, critical and near critical path analysis, progress narrative prepared and effective team participation in schedule updates. Quantity reports rigorously done by individual(s) trained on formally defined rules of completion. Material suppliers routinely contacted to track status of material delivery dates.
Level 5	Continuation of Level 4, plus will consistently include all of the following, based on project requirements and observed schedule status conditions: change management analysis, risks assessment scenarios/analysis, date variance analysis to approved baseline or previous update period, start / finish percent achieved ratio analysis; also included is automated progress tracking using 3D imaging, and UWB or RFID tags.

B. SITE LAYOUT PLAN

1. Dynamic Site Layout Plan

Dynamic site layout planning allows the project manager to organize the construction site in the most efficient and safe manner. This process should be aided by technology and software applications. This will show real time and future construction sequences visually to examine potential location of space for receipt, storage, or partial assembly of materials. It will assist in alignment and collaboration among construction supervision and materials management personnel. The dynamic site layout plan should include all of the necessary construction facilities, which will assure that the project progresses in a smooth manner and interruptions are minimized. The following facilities must be considered:

- Office trailers
- Lunch facilities
- Sanitation and Hygiene
- Field job shacks
- Welding shields
- Weather protection
- Temporary lighting
- Air handling units

- Temporary underground utilities (e.g. telecommunications and sanitary)
- Blast zones
- Heavy haul roads
- Turning radii requirements

Level 0	Site layout plan is not applicable for the project.
Level 1	A site layout plan has not been addressed.
Level 2	The project team examines the project schedule and assesses when Temporary Facilities (TF) will be brought in.
Level 3	Continuation of Level 2, plus what sizes will be needed prior to the start of the project. No consideration is given to the addition, removal and/or turnover of TFs at different stages of the project. No analysis is done in regards to the layout of the project to optimize locations of the TFs to limit travel time to and from.
Level 4	Continuation of Level 3, plus consideration is given to the addition, removal and/or turnover of TFs at different stages of the project.
Level 5	Continuation of Level 4, plus the team analyzes the layout of the project including where the different parties will be working and place their TFs in the optimum location in order to limit travel time to and from TFs.

2. Traffic Control Plan

The traffic control plans are required for projects to provide safe and efficient operations of all modes of transportation around the project site and include safety of construction workers and inspection personnel. The plan should ensure compliance with local, regional, and national jurisdictional requirements. Following are some of the issues to consider:

- Compliance with jurisdictional requirements
- Detours or by-pass plans
- Appropriate signs, markings, and barricades
- Safety equipment, such as:
  - Barrels
  - Signage
  - Flagmen
  - Vertical panels
- Clear zone protection devices, such as:
  - Concrete traffic barriers
  - Metal beam guard fencing
  - Appropriate end treatments
- Pedestrian safety

Level 0	Traffic control plans are not applicable for the project.
Level 1	Traffic control plans have not been addressed for the project.
Level 2	Project has some traffic control plans and is used on a reactive basis.
Level 3	Project has a traffic control plan, equipment, and an arrangement for day light traffic control only and has no trained traffic control persons.
Level 4	Project has a traffic control plan and equipment for all times of the day including trained persons for traffic control.
Level 5	Continuation of level 4, plus a trained traffic control supervisor. It has an approved contingency plan in place to accommodate unexpected situations, and has designed and constructed alternate arrangements for traffic such as detours, flyovers, etc.

3. Site Security Plan

Develop a plan to keep the site safe for the workers, the pedestrians or citizens that will operate close to the site, the people that will be making deliveries to the site, and will keep tools and equipment away from situations that will make vandalism and theft easy. The type of project will determine the way the security plan is set up, because a highway construction site in a rural area will have different needs than a dam or water treatment project. Some examples of precautions that need to be taken are:

- Erecting a fence surrounding the site to keep public out
- Placing signs outside of the site that warn people of the site
- Set up a security check at the site entrance to ensure that only authorized personnel are allowed on site
- Have a security system that will provide access to viewing of the site during all hours of the day
- Badging requirements
- Time keeping

Level 0	Site security plan is not applicable for the project.
Level 1	Site does not institute security in regards to entry to site, securing commodities, or tools and equipment.
Level 2	The site controls entry and exit from the site, but does not have any other formal security throughout the site.
Level 3	Site has established security procedures including visitor sign in and sign procedure and security guards at every gate. The site has implemented security measures to ensure the preservation of company assets. Protocols have been identified for searches of

	individuals and their personal property. Searches are conducted randomly.
Level 4	Continuation of Level 3, plus site has ensured that material is not leaving the jobsite by instituting "lock-ups" for items that are prone to theft.
Level 5	Continuation of Level 4, plus the use of electronic security has been implemented such as security cameras.

4. Machinery & Equipment Positioning Strategy

The construction project can run smoothly, and productivity will be improved when positioning of machinery and equipment have been planned. Some typical equipment positioning strategies may include:

- Utilization of crane animation software that examine crane interference, location and availability
- 3D Modeling/Visualization of construction sequence promotes better understanding of where to locate construction equipment for better utilization and for heavy lifts.
- A Lift Plan should be developed based on the following considerations: 1) a construction execution plan that includes sequential erection of a facility and is coordinated with machinery availability; 2) a rigging and heavy haul engineering study; 3) an evaluation of the need of lifting equipment; 4) an evaluation of the need of elevated platforms

Level 0	Equipment positioning strategy is not applicable.
Level 1	There is no strategy for positioning of equipment at the project site.
Level 2	Heavy Rigging and Lifting Studies are accomplished on all critical lifts including evaluation of equipment and rigging selection and crane location. Haul Routes for all heavy transport are evaluated for clearance and load capability.
Level 3	Continuation of Level 2, plus planning includes use of 2D layout and studies to aid in constructability for locating and utilizing equipment.
Level 4	Continuation of Level 3, plus some 3D modeling studies to aid in constructability for locating and utilizing equipment.
Level 5	Continuation of Level 4, plus planning includes use of 3D layout studies and 3D modeling/visualization to aid in constructability for locating and utilizing equipment.

C. DESIGN/CONSTRUCTION PLAN & APPROACH

1. Communications, Coordination, & Agreements

Proper communication and coordination between the contractor, owner, public and private agencies, local, provincial, and federal governments, and the public are very important in project execution for infrastructure projects. Improper communication and coordination can cause delays and negatively affect productivity. Agreements should be in place to ensure efficient project delivery. Below is a list of common entities with whom the communications and coordination should be made:

- Contractors and suppliers
- Owner/funding agencies
- Environmental protection agencies
- Law enforcement agencies
- Parks and wildlife agencies
- Local, provincial, and federal departments
- Department of transportations
- Utilities companies
- Air quality boards

Level 0	Communication, coordination, and agreements between different stakeholders are not applicable.
Level 1	There is no documented plan for communication, coordination, and agreements between different stakeholders.
Level 2	The project has a review process for communication, coordination, and agreements between different stakeholders; however, no formal written plan exists.
Level 3	The project has formal written plans and procedures for communication, coordination, and agreements between different stakeholders. It has identified responsible parties for dealing these matters.
Level 4	Continuation of Level 3, plus there are designated personnel for ensuring proper communications and coordination between different stakeholders.
Level 5	Continuation of Level 4, plus all information related to communications and coordination have been logged into project information systems and integrated with project schedules.

2. Project start-up plan

The project start-up plan is essential for the success of the project. A successful project start-up plan is possible through detailed planning. Some of the keys for successful project start-up are, but not limited to:

- Management commitment
- Defining start-up objectives
- Creating a start-up execution plan
- Time outs for analysis

Level 0	No start-up and commissioning plan exists.
Level 1	A partial start-up plan has been assembled but does not provide for buy-in by the operations group, no hazard analysis has been performed, no component/system test protocols have been developed and the plan has not been communicated to affected stakeholders.
Level 2	A basic start-up and commissioning plan has been developed and with input and buy-in of management, operations, engineering, safety and other affected employees but the plan has not been implemented.
Level 3	Continuation of Level 2, plus with considerations for interfaces with construction and operations. A commissioning plan has been developed that identifies the objectives and goals of the start-up team with the buy-in of the affected stakeholders.
Level 4	Continuation of Level 3, plus with consideration for cost analysis and detailed scheduling components. The plan is well communicated to all affected employees.
Level 5	Continuation of Level 4, plus with the plan being implemented on the project with proper review by the affected stakeholders for applicability at regular intervals as deemed necessary by the start-up and management teams.

3. Project Completion Plan

All the project completion requirements need to be documented and planned in advance to ensure a smooth transition to operations. Issues to consider include:

- Quality assurance/quality control
- Final code inspection
- Landscape requirements
- Substantial completion certificate
- Community acceptance

Level 0	The project completion requirements/turn over procedures is not applicable.
Level 1	The project completion requirements/turn over procedures has not been identified.
Level 2	The project has a turnover procedure that defines the parameters of system completion and delineates the requirements for the turnover of systems from construction to start-up.
Level 3	The project has a formal turnover process that defines the necessary documentation, system boundary identification, parameters of system completion and other parameters of system completion to assure proper turnover of project systems from construction to start-up and from start-up to operations.
Level 4	Continuation of Level 3, plus the procedure has been reviewed and approved by all stakeholders and all affected employees have been properly trained in the process.
Level 5	Continuation of Level 4 plus has the approval of project management and is reviewed for applicability during all phases of the turnover process.

4. Innovations & New Technologies

Innovations in new materials, equipment, information systems, technologies, work methods, management techniques, etc. can increase the performance and productivity of projects. It is important that new technologies are investigated to see if they can improve productivity and performance. Some elements to consider include:

- Implementation cost
- Technology materials
- Technology usage
- Technology maturity

Level 0	Innovation in new materials, equipment, information systems is not applicable.
Level 1	Innovations and new technologies investigation is not addressed.
Level 2	The project does not have a formal program for the investigation of innovations and new technologies. Implementation of innovations and new systems will only occur after the industry-wide implementation.
Level 3	The organization has an informal program for the investigation of innovations, and they will investigate the feasibility of the new technologies on a regular basis.
Level 4	Continuation of Level 3, plus the program is formal to investigate new systems and they will investigate the feasibility of the new technologies on a regular basis.
Level 5	Continuation of Level 4, plus they investigate all new technologies using a formal system of rating the new technology.

5. House Keeping

Housekeeping includes scheduling weekly times that are taken to ensure that the work face is organized and all materials, tools, and equipment are properly stored to ensure that they are not misplaced and can be easily retrieved for use. These times should be documented on the schedule, and a convenient time to schedule housekeeping sessions is on Friday afternoons or the afternoon on the final day of the work week.

Level 0	Housekeeping is not applicable to the project
Level 1	Regular housekeeping has not been addressed on the project.
Level 2	Housekeeping occurs only after incidents occur.
Level 3	Housekeeping occurs on a bi-weekly scheduled basis.
Level 4	Major travel paths are organized and clean. "Roll backs" are held weekly.
Level 5	All work areas are well organized and designated crews are regularly cleaning

CATEGORY VI: HEALTH AND SAFETY

A. JOB SITE SAFETY

1. Formal Health and Safety Policy

The organization should have a formal health and safety policy that guides their approach as it concerns the health and safety of their workers. Some of the issues to consider are:

- Adherence to the provincial construction health and safety code of practice
- Periodic adjustments to the health and safety code of practice with the changing needs of the organization and industry

Level 0	Formal health and safety policy for the organization is not applicable
Level 1	Organization does not have a formal health and safety policy.
Level 2	Organization has a formal health and safety policy. The policy is documented and publicized. Policy includes dealing with the health and safety issues of its workers.
Level 3	Continuation of Level 2, plus it is periodically updated based on the organizational and industry feedback.
Level 4	Continuations of Level 3, plus the organization screens sub-contractors for their health and safety programs and chooses those with records of good performance.
Level 5	Continuation of Level 4, plus health and safety policy is integrated with procurement processes. Money is budgeted on the construction projects to address various health and safety issues.

2. Health and Safety Plans/Zero Accident Techniques

The company needs to have health and safety plans for ensuring that its personnel are safe and the projects are executed without any accidents on the projects. Some of the important issues to consider are:

- Demonstrated management commitment
- Staffing for safety
- Planning: Pre-project and Pre-task
- Safety education: orientation and specialized training
- Worker involvement
- Evaluation and recognition award
- Subcontract management
- Accident/incident investigations

Level 0	Zero Accident Techniques are not applicable to the project.
Level 1	No Zero Accident Techniques have been examined and considered for the project.
Level 2	Some Zero Accident Techniques utilized on the project. The project has a reactive approach towards safety.
Level 3	Most but not all Zero Accident Techniques are utilized on the project.
Level 4	All Zero Accident Techniques are utilized on the project.
Level 5	Zero Accident Techniques fully utilized on the project. The project has a very proactive approach towards safety.

3. Task Safety Analysis

Task Safety analysis is essential to creating a safe job-site. The following criteria must be met:

- Perform Job Safety Analysis (JSA) on each task on a daily basis
- Determine safety hazards for the specific task
- Take protective measures
- Participation in Safety Task Analysis (e.g. toolbox talks, job safety analyses)

Level 0	Task Safety Analysis is not applicable to the project
Level 1	No Task Safety Analysis is utilized

Level 2	Limited Task Safety Analysis is utilized only on high risk areas of the project. The project has a reactive approach towards safety.
Level 3	Most but not all Zero Accident Techniques are utilized on the project.
Level 4	JSAs are utilized daily on the project.
Level 5	JSAs are utilized daily on the projects on all tasks and some crews perform additional JSA's as task changes.

4. Hazards Analysis

Hazard analysis should be performed to identify all on-site situations that could potentially lead to a hazardous or dangerous environment for the workers. Examples of potential hazards are:

- Working at heights
- Soil stability
- Toxic chemical exposure
- Hazard waste disposal
- Environmental hazards

Level 0	The process for hazard identification process is not applicable on the project.
Level 1	No hazard identification process is in place on the project.
Level 2	Hazards are identified for high risk work only.
Level 3	Hazards are identified for most work.
Level 4	Hazards are identified for the proposed scope of work.
Level 5	Hazards are identified for the proposed scope of work and incorporated into the project's task specific safety planning process.

5. Hazards Planning

Sometimes, there can be substances on job-site that if not handled correctly can be hazardous to humans and environment. Therefore, the people working on the site need to be prepared when the substance is being handled, and have measures set up to control the substance in case of an accident. Compliance with Workplace Hazardous Materials Information System (WHMIS) should be considered. The job-site needs to have criteria for the isolation of work areas due to hazards.

Level 0	No hazard evaluation has been performed
Level 1	A system hazard analysis has been performed but no plan is in place to address the hazards.
Level 2	A system hazard analysis has been performed; a plan has been developed but not communicated to affected staff.
Level 3	Continuation of Level 2, plus it is communicated to affected staff and training of affected employees has been performed and the plan is usually implemented.
Level 4	Continuation of Level 3, plus a plan has been developed with input of the safety department and training of all affected employees has been performed and the procedure is properly implemented.
Level 5	Continuation of Level 4, plus a detailed system hazard analysis has been performed, a plan has been developed with input of the safety department, Start-up group and the operations staff and management that establishes appropriate physical and administrative controls integrating the operations procedures and all start-up and operations employees have been trained and the procedure is properly implemented.

B. SUBSTANCE ABUSE PROGRAM

1. Drugs and Alcohol Testing Program

The organization should have a drug and alcohol testing policy for all employees. The policy should consider the following:

- Pre-employment testing for illegal drugs
- Testing for reasonable cause.
- Post-accident testing for illegal drugs
- Random drug tests for all employees

Level 0	Organization/Project drug testing is not applicable
Level 1	Organization/Project Drug and Alcohol Testing Policy is not written or publicized.
Level 2	Organization/Project Drug and Alcohol Testing Policy are written and publicized. Policy includes pre-employment testing and post -accident testing.
Level 3	Continuation of Level 2, plus with reasonable cause, project access requirements, and post -accident testing.
Level 4	Continuation of Level 3, plus random selection testing.
Level 5	Continuation of Level 4, plus allows for probable cause searches for drugs and alcohol. Policy also addresses management of prescription drugs used at work. Policy includes provision for confidential treatment or rehabilitation through Employee Assistance Programs either voluntary enrolment before a positive test result or mandatory as a condition of future/continued employment.

C. HEALTH AND SAFETY TRAINING & ORIENTATION

1. Health and Safety Training Programs

The organization has formal health and safety training programs. All new employees and current employees who are transferred from another project must attend a project specific, new-hire safety orientation. Issues to consider include:

- Compliance with Occupational health and safety requirements (e.g. Canadian Centre for Occupational Health and Safety (CCOHS) and Occupational Safety and Health Administration (OSHA) in Unites States).
- Management commitment

Level 0	Occupational Health and Safety compliance training is not applicable.
Level 1	The project does not have a project specific new hire safety orientation
Level 2	Project specific new hire orientation addresses personal protective equipment, housekeeping and access to site, ladders and safe access to elevated platforms, fall protection, excavations and trenching, tools and equipment, electrical hazards and fire prevention. Supervisors receive additional orientation on behaviour or people based safety, conduct of safety meetings, first aid and medical treatment processes, job hazard analysis, consequences for violation of job site work rules and violence, alcohol and drugs in the workplace.
Level 3	Continuation of Level 2, plus all personnel must pass fitness for duty testing prior to attending the project specific new hire safety orientation. Orientation addresses management commitment, general project safety rules, emergency procedures, personal protective equipment, use of ladders and safe access to elevated work areas, hazard communication, housekeeping, fire prevention and protections, barricades, injury/illness reporting, lock-out and tag-out processes, confined spaces, compressed gas cylinders, back injury prevention, excavation and trenching, and hand power tool safety.
Level 4	Continuation of Level 3, plus orientation addresses zero accidents philosophy and general project safety rules.
Level 5	Continuation of Level 4, plus craft workers trained on behavioural based training.

2. Toolbox Safety Meetings

Toolbox meeting are conducted frequently to maintain awareness, updated training, and convey important safety and health information.

Level 0	Project does not conduct safety meetings (not applicable)
Level 1	Project issues toolbox topics via handouts to employees on a periodic basis.

Level 2	The project conducts a monthly meeting at or near breaks. Meetings reiterate job site safety rules.
Level 3	The project conducts a weekly meeting at or near breaks. Meetings reiterate job site safety rules.
Level 4	The project conducts weekly meetings at a prearranged time, generally the start of the day. Meetings address current job status and hazards presented by upcoming project activities, corrective actions, review recorded injuries and near misses, or reiterate job site safety rules and expectations. Time is set aside during the meeting for interactive discussion and allows worker feedback.
Level 5	Continuation of Level 4, plus the day of the meeting vary on which they occur, or conduct them daily. Meetings address current job status and hazards presented by upcoming project activities, corrective actions, review recorded injuries and near misses, or reiterate job site safety rules and expectations.

Appendix B

Introduction to (BPPII) for Infrastructure Projects

What is Infrastructure-BPPII?

The Best Productivity Practices Implementation Index (BPPII) for Infrastructure projects is an index based on practices that are considered to have a positive influence on labour productivity at the project level for infrastructure projects. These practices have been identified through literature review and consultation with industry experts, and have statistically been proven to positively affect productivity.

It has been observed that most of the projects do not implement historically successful productivity practices. An infrastructure project needs to ensure that its productivity is being effectively managed. To meet this objective, the Infrastructure-BPPII is developed. 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, human resources management, safety, and yet they are seldom implemented completely or consistently from project to project. Improving implementation of these practices will improve labour 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 labour productivity.

Each of the practices is organized into sections that include similar practices. Each category includes between 2 to 4 sections. The sections that are included in each category are similar and related, but not the same. The Infrastructure BPPII consists of 6 categories: (1) Materials Management; (2) Construction Machinery and Equipment Logistics; (3) Execution Approach; (4) Human Resources Management; (5) Construction Methods; and (6) Health and Safety.

Scoring of the Infrastructure-BPPII

The BPPII is intended to measure the implementation levels of practices that can improve labour productivity. Each element of the BPPII is scored using a system that ranks the planning and implementation level (PIL). The PIL definitions are organized on a scale from 0 to 5. Each of the level definition is different based on the definition of each element. Therefore, each element has a planning and implementation levels definitions that are specific to that element. It is important to note that while the PIL definitions differ for each element, they are defined to be consistent throughout the tool.

Each element in the index will be assigned a weight based on the effect the element has on productivity. By using a weighted system, each element's PIL corresponds to a different score rather than a simple 0 to 5 scale. When PIL for all the elements are determined, then their weighted scores are obtained using the weighting system. The scores of the elements in a section are summed to obtain a section score, and the scores for all sections in a category are added to obtain the category score. Finally, all the categories' weighted scores are summed to obtain the total BPPII score.

How can your Organization Contribute to this Research

Your organization can contribute in this research work by completing the BPPII score sheets for each element, section, and category of the index. The detailed information for scoring the index will be provided with definitions and examples for scoring each element. Data will also be required for measuring labour productivity using productivity factor. This information can be provided for infrastructure projects currently in progress or completed.

What Benefits Will Your Organization Get?

A significant feature of the BPPII is that it can be utilized to fit the needs of almost any individual project, small or large. Following are some of the benefits, which your organization can get immediately by participating in this research:

- A listing of the essential elements that need to be planned and implemented on 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.

Once data from a reasonable number of projects is collected, a report will be provided to you. This report will compare the scores of your projects compared to the industry averages and areas of weaknesses and improvements will be identified. By using the infrastructure-BPPII, the labour productivity of your organization can be improved considerably without causing a burden on your company's budget.

Appendix C

Questionnaire for Infrastructure Best Productivity Practices Implementation Index (BPPII)

This questionnaire is designed for collecting information related to Best Productivity Practices Implementation Index for Infrastructure projects. This questionnaire is composed of four parts, which are: Project Background Information; Project Performance Information; Construction Productivity Information, and Project Score Sheet. The purpose of each section is as follows:

Items	Purpose
Project Background Information	Grouping and analyzing projects in various aspects
Project Performance Information	Analyzing project's performance for cost and time schedule
Construction Productivity Information	Analyzing relationships between BPPII Score and labour productivity
Project Score Sheet	Collect BPPII Score

Please read detail descriptions and fill out each questionnaire.

PROJECT BACKGROUND INFORMATION

General Information

Date of Completing Form (MM/DD/YYYY): ___ (________/_______/___________) ____

Company Name: ____

Project Name : ____

Contact Point:

Name: ____

Title: ____

Address:

____

____

Phone: ______________________________ Fax: __________________________________

E-mail:____

Project Description

Which of the following best describes the subcategory of this project?

- ☐ Water Pipes
- ☐ Waste Water Pipes
- ☐ Water Treatment Plants
- ☐ Waste Water Treatment Plants
- ☐ Roads/Highways
- ☐ Transmission Towers/Lines
- ☐ Dam(s)
- ☐ Railroad(s)
- ☐ Other Subcategory(Please describe):

Project Nature

Which of the following best describes the nature of this project?

- [ ] Grass Roots, Greenfield
- [ ] Modernization, Renovation, Upgrade
- [ ] Addition, Expansion
- [ ] Other Project Nature (Please describe):

Project Size

Which of the following category does your project belong?

- [ ] Less than 1 Million Dollars
- [ ] 1 - 5 Million Dollars
- [ ] 6 - 50 Million Dollars
- [ ] 51 - 100 Million Dollars
- [ ] 101 - 500 Million Dollars
- [ ] 500 - Million Dollars

Scope of Construction Contract

Which of the following best describes the scope of the construction contract?

- [ ] Construct Only
- [ ] Design and Construct
- [ ] EPCM (Engineer, Procure, Construct, and Manage)
- [ ] Construction or Project Management Only
- [ ] Other (Please specify):

Type of Construction Contract

To which of the following contract type does your project belong?

- [ ] Fixed Price
- [ ] Unit Price
- [ ] Cost Plus % Fee
- [ ] Cost Plus Lump Sum Fee
- [ ] Guaranteed Maximum Price
- [ ] PPP (Public Private Partnership)
- [ ] Other (Please specify):

PROJECT PERFORMANCE INFORMATION

A. Estimated cost of construction ($) ______________________________

(At tender award)

B. Actual cost of construction ($) ______________________________

(At completion of project)

C. Estimated time for construction (Weeks/Months ____________________________

(At tender award)

D. Actual time for construction (Weeks/Months) ______________________________

(At completion of project)

CONSTRUCTION PRODUCTIVITY METRICS

Productivity Factor

The labour productivity information should be reported for major activities such as; concrete work, earthwork, road base, and asphalt wearing course if any. They should be reported in terms of productivity factor, which is defined by the following equation.

$$\text{Productivity Factor} = \text{Performance Factor} = \frac{\text{Estimated Productivity}}{\text{Actual Productivity}}$$

Using the above equation, a productivity factor of greater than 1 is considered better; because, less labour hours would be required to complete one unit of work than planned. No need to report the actual and estimated productivity information. Just report the ratio.

Whereas,

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

And,

$$\text{Estimated Productivity} = \frac{\text{Estimated Work-Hours}}{\text{Estimated Quantity}}$$

The estimated productivity includes any revisions made in the quantities to be installed after the original estimates and would represent the current estimate.

Productivity Factor for Concrete (without any units) = ________________

Productivity Factor for Earthwork (without any units) = ________________

Productivity Factor for Road Base (without any units) = ________________

Productivity Factor for Asphalt Wearing Course (without any units) = ________________

Next, please go to the project score sheet and complete

PROJECT SCORE SHEET GUIDE

Project Rating Information:

Please complete the Project Rating Information located on the next few pages. Detailed instructions for completing this form are explained below.
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 assess an element, first refer to the Project Score Sheet.
Next, read its corresponding description in the Description section of the BPPII Elements Description document. 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 elements in the Project Score Sheet. Be sure to assess each element.

Example: How to assess "Procurement Procedures & Plans for Materials and Equipment" element?

1. Look at the project score sheet.

CATEGORY I: MATERIALS MANAGEMENT

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials and Equipment						
2. Long-Lead/Critical Equipment & Materials Identification						
3. Procurement Team						

2. Go to the corresponding page in the BPPII Element Description document and read the element definition.

1. Procurement Procedures & Plans for Materials and Equipment Procurement procedures & plans for materials and equipment include guidelines, requirements, or systems for purchasing, expediting, and delivery of materials and equipment for the project. Issues to consider include: • Coordinate materials procurement schedule with the construction schedule • Facilitate a purchasing system that has the capability of allowing field purchase of consumables. • Develop a list of authorized suppliers • 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.

2. Collect the information that you may need

3. Analyze the level of implementation of the element using the definition of the 6 levels provided below the definition of the element in the BPPII Element Description document.

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 integrated with a project information system that automatically updates the procurement schedule as the construction schedule changes.

4. Select the appropriate definition level. (For example, a procurement plan and schedule exists only for large materials and equipment and costly items. **Definition Level = 2. Check (√) the corresponding box in the BPPII score sheet.**

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials and Equipment			√			
2. Long-Lead/Critical Equipment & Materials Identification						
3. Procurement Team						

5. Move to the next element and score all elements in the score sheet.

PROJECT SCORE SHEET

Please only check (√) one box per element. Please do not leave any elements blank.
The page number next to each element refers to the element descriptions document (which contains the elements definitions).

CATEGORY I: MATERIALS MANAGEMENT

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials & Equipment *(p4)*						
2. Long-Lead/Critical Equipment & Materials Identification *(p4)*						
3. Procurement Team *(p5)*						
B. Materials Management Systems						
1. Project Team Materials Status Database *(p5)*						
2. On-Site Material Tracking Technology *(p6)*						
3. Materials Delivery Schedule *(p6)*						
C. Receipt and Inspection of Materials						
1. Materials Inspection Process *(p7)*						
2. Materials Inspection Team *(p7)*						
3. Post Receipt Preservation & Maintenance *(p8)*						

CATEGORY II: CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Construction Machinery & Equipment Availability						
1. Procurement Procedures & Plans for Construction Machinery *(p9)*						
2. Construction Machinery Productivity Analyses *(p9)*						
3. Construction Machinery and Equipment Maintenance *(p10)*						
B. Tools and Equipment Management Best Practices						
1. Site Tools and Equipment Management Strategy *(p10)*						
2. Tools & Equipment Tracking *(p11)*						
3. On-site Tools Maintenance *(p12)*						
4. Construction Machinery & Equipment Utility Requirements *(p12)*						

CATEGORY III: EXECUTION APPROACH

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Planning						
1. Short Interval Planning *(p13)*						
2. Well Defined Scope of Work *(p13)*						
3. Use of Software *(p14)*						
4. Dedicated Planner *(p15)*						
5. Construction Work Packages (CWP) *(p15)*						
B. Constructability Reviews						
1. Design Readiness for Construction *(p16)*						
2. Utility Alignment & Adjustments *(p16)*						
3. Contract Types/Strategies *(p17)*						
4. Model Requirements/3D Visualization *(p18)*						
C. Acquisition Strategy						
1. Right of Way, Land, and Utilities Acquisition Strategy *(p19)*						
2. Contracts & Agreements with Agencies *(p19)*						
3. Utility Agreements *(p20)*						
D. Regulatory Requirements/Reviews						
1. Environmental Requirements *(p20)*						
2. Regulatory Requirements/Permitting Requirements *(p21)*						

CATEGORY IV: HUMAN RESOURCES MANAGEMENT

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Planning						
1. Crews Composition/Crew Formation *(p22)*						
2. Skills Assessment and Evaluation *(p22)*						
B. Training and Development						
1. Employees / Trades Technical Training *(p23)*						
2. Career Development *(p23)*						
C. Behaviour						
1. Non-Financial Incentive Programs *(p23)*						
2. Financial Incentive Programs *(p24)*						
3. Social Activities *(p24)*						

D. Organizational structure						
1. Maintain Stability of Organization Structure *(p25)*						
2. Clear Delegation of Responsibility *(p25)*						
E. Employment						
1. Retention Plan for Experienced Personnel *(p25)*						
2. Exit interviews *(p26)*						

CATEGORY V: CONSTRUCTION METHODS

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Project Schedule Control						
1. Integrated Schedule *(p26)*						
2. Work Schedule Strategies *(p27)*						
3. Schedule Execution and Management *(p27)*						
B. Site Layout Plan						
1. Dynamic Site Layout Plan *(p28)*						
2. Traffic Control Plan *(p29)*						
3. Site Security Plan *(p30)*						
4. Machinery & Equipment Positioning Strategy *(p31)*						
C. Design/Construction Plan & Approach						
1. Communications, Coordination, & Agreements *(p31)*						
2. Project start-up plan *(p32)*						
3. Project Completion Plan *(p32)*						
4. Innovations & New Technologies *(p33)*						
5. House Keeping *(p34)*						

CATEGORY VI: HEALTH AND SAFETY

SECTION	Planning and Implementation Level (PIL)					
Element	0	1	2	3	4	5
A. Job Site Safety						
1. Formal Health and Safety Policy *(p34)*						
2. Health and Safety Plans/Zero Accident Techniques *(p34)*						
3. Task Safety Analysis *(p35)*						
4. Hazards Analysis *(p35)*						
5. Hazards Planning *(p36)*						

B. Substance Abuse Program						
1. Drugs and Alcohol Testing Program *(p36)*						
C. Health and Safety Training & Orientation						
1. Health and Safety Training Programs *(p37)*						
2. Toolbox Safety Meetings *(p38)*						

Thank you very much for your time and effort by participating in this survey.

Please send this completed form or any questions to Hassan Nasir, PhD Candidate, Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, ON, Canada, at: **hnasir@uwaterloo.ca**

Appendix D

Correlations between Productivity Factor and Each Element

The following Tables show the bivariate correlations between Productivity Factor (PF) and each individual element in a category.

CATEGORY I: MATERIALS MANAGEMENT (MM)

		PF
	PF	1
Section A	A1	0.31
	A2	0.44
	A3	0.17
Section B	B1	0.21
	B2	0.05
	B3	0.14
Section C	C1	0.03
	C2	-0.26
	C3	-0.41

CATEGORY II: CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS (CMEL)

		PF
	PF	1
Section A	A1	0.26
	A2	0.41
	A3	0.40
Section B	B1	0.31
	B2	0.40
	B3	0.00
	B4	-0.12

CATEGORY III: EXECUTION APPROACH (EA)

		PF
	PF	1
Section A	A1	0.29
	A2	0.38
	A3	0.08
	A4	0.48
	A5	0.24
Section B	B1	0.55
	B2	0.56
	B3	0.54
	B4	-0.31
Section C	C1	-0.26
	C2	0.04
	C3	0.26
Section D	D1	0.69
	D2	0.57

CATEGORY IV: HUMAN RESOURCES MANAGEMENT (HRM)

		PF
	PF	1
Section A	A1	0.73
	A2	0.69
section B	B1	0.68
	B2	0.50
Section C	C1	0.45
	C2	0.57
	C3	0.67
Section D	D1	-0.23
	D2	0.40
Section E	E1	0.43
	E2	0.44

CATEGORY V: CONSTRUCTION METHODS (CM)

	PF	*PF* 1
Section A	A1	0.55
	A2	0.02
	A3	0.01
Section B	B1	0.67
	B2	0.35
	B3	-0.34
	B4	0.23
Section C	C1	0.61
	C2	0.18
	C3	0.38
	C4	0.73
	C5	0.51

CATEGORY VI: HEALTH AND SAFETY (HS)

	PF	*PF* 1
Section A	A1	0.69
	A2	0.66
	A3	0.62
	A4	0.60
	A5	0.64
Section B	B1	0.08
Section C	C1	0.65
	C2	0.49

Appendix E

BPPII – Infrastructure Projects Score Sheet (Un-weighted)

CATEGORY I: MATERIALS MANAGEMENT

SECTION						
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials & Equipment						
2. Long-Lead/Critical Equipment & Materials Identification						
3. Procurement Team						
B. Materials Management Systems						
1. Project Team Materials Status Database						
2. On-Site Material Tracking Technology						
3. Materials Delivery Schedule						
C. Receipt and Inspection of Materials						
1. Materials Inspection Process						
2. Materials Inspection Team						
3. Post Receipt Preservation & Maintenance						

CATEGORY II: CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS

SECTION						
Element	0	1	2	3	4	5
A. Construction Machinery & Equipment Availability						
1. Procurement Procedures & Plans for Construction Machinery						
2. Construction Machinery Productivity Analyses						
3. Construction Machinery and Equipment Maintenance						
B. Tools and Equipment Management Best Practices						
1. Site Tools and Equipment Management Strategy						
2. Tools & Equipment Tracking						
3. On-site Tools Maintenance						
4. Construction Machinery & Equipment Utility Requirements						

CATEGORY III: EXECUTION APPROACH

SECTION						
Element	0	1	2	3	4	5
A. Planning						
1. Short Interval Planning						
2. Well Defined Scope of Work						
3. Use of Software						
4. Dedicated Planner						
5. Construction Work Packages (CWP)						
B. Constructability Reviews						
1. Design Readiness for Construction						
2. Utility Alignment & Adjustments						
3. Contract Types/Strategies						
4. Model Requirements/3D Visualization						
C. Acquisition Strategy						
1. Right of Way, Land, and Utilities Acquisition Strategy						
2. Contracts & Agreements with Agencies						
3. Utility Agreements						
D. Regulatory Requirements/Reviews						
1. Environmental Requirements						
2. Regulatory Requirements/Permitting Requirements						

CATEGORY IV: HUMAN RESOURCES MANAGEMENT

SECTION						
Element	0	1	2	3	4	5
A. Planning						
1. Crews Composition/Crew Formation						
2. Skills Assessment and Evaluation						
B. Training and Development						
1. Employees / Trades Technical Training						
2. Career Development						
C. Behavior						
1. Non-Financial Incentive Programs						
2. Financial Incentive Programs						
3. Social Activities						
D. Organizational structure						
1. Maintain Stability of Organization Structure						
2. Clear Delegation of Responsibility						

E. Employment						
1. Retention Plan for Experienced Personnel						
2. Exit interviews						

CATEGORY V: CONSTRUCTION METHODS

SECTION						
Element	0	1	2	3	4	5
A. Project Schedule Control						
1. Integrated Schedule						
2. Work Schedule Strategies						
3. Schedule Execution and Management						
B. Site Layout Plan						
1. Dynamic Site Layout Plan						
2. Traffic Control Plan						
3. Site Security Plan						
4. Machinery & Equipment Positioning Strategy						
C. Design/Construction Plan & Approach						
1. Communications, Coordination, & Agreements						
2. Project start-up plan						
3. Project Completion Plan						
4. Innovations & New Technologies						
5. House Keeping						

CATEGORY VI: HEALTH AND SAFETY

SECTION						
Element	0	1	2	3	4	5
A. Job Site Safety						
1. Formal Health and Safety Policy						
2. Health and Safety Plans/Zero Accident Techniques						
3. Task Safety Analysis						
4. Hazards Analysis						
5. Hazards Planning						
B. Substance Abuse Program						
1. Drugs and Alcohol Testing Program						
C. Health and Safety Training & Orientation						
1. Health and Safety Training Programs						
2. Toolbox Safety Meetings						

Appendix F

BPPII – INFRASTRUCTURE PROJECTS SCORE SHEET (WEIGHTED)

CATEGORY I: MATERIALS MANAGEMENT

SECTION						
Element	0	1	2	3	4	5
A. Procurement Strategy						
1. Procurement Procedures & Plans for Materials & Equipment	0	1	9	17	25	35
2. Long-Lead/Critical Equipment & Materials Identification	0	1	13	25	37	49
3. Procurement Team	0	1	5	9	13	19
B. Materials Management Systems						
1. Project Team Materials Status Database	0	1	8	15	22	30
2. On-Site Material Tracking Technology	0	1	3	5	7	8
3. Materials Delivery Schedule	0	1	6	11	16	20
C. Receipt and Inspection of Materials						
1. Materials Inspection Process	0	1	3	5	7	9
2. Materials Inspection Team	0	1	2	3	4	6
3. Post Receipt Preservation & Maintenance	0	1	2	3	4	5

CATEGORY II: CONSTRUCTION MACHINERY AND EQUIPMENT LOGISTICS

SECTION						
Element	0	1	2	3	4	5
A. Construction Machinery & Equipment Availability						
1. Procurement Procedures & Plans for Construction Machinery	0	1	10	19	28	37
2. Construction Machinery Productivity Analyses	0	1	15	29	43	59
3. Construction Machinery and Equipment Maintenance	0	1	15	29	43	59
B. Tools and Equipment Management Best Practices						
1. Site Tools and Equipment Management Strategy	0	1	10	19	28	36
2. Tools & Equipment Tracking	0	1	13	25	37	49
3. On-site Tools Maintenance	0	1	3	5	7	9
4. Construction Machinery & Equipment Utility Requirements	0	1	3	5	7	9

CATEGORY III: EXECUTION APPROACH

SECTION						
Element	0	1	2	3	4	5
A. Planning						
1. Short Interval Planning	0	1	6	11	16	22
2. Well Defined Scope of Work	0	1	8	15	22	30
3. Use of Software	0	1	3	5	7	9
4. Dedicated Planner	0	1	10	19	28	37
5. Construction Work Packages (CWP)	0	1	5	9	13	18
B. Constructability Reviews						
1. Design Readiness for Construction	0	1	11	21	31	41
2. Utility Alignment & Adjustments	0	1	10	19	28	39
3. Contract Types/Strategies	0	1	10	19	28	38
4. Model Requirements/3D Visualization	0	1	3	5	7	8
C. Acquisition Strategy						
1. Right of Way, Land, and Utilities Acquisition Strategy	0	1	3	5	7	9
2. Contracts & Agreements with Agencies	0	1	4	7	10	13
3. Utility Agreements	0	1	7	13	19	24
D. Regulatory Requirements/Reviews						
1. Environmental Requirements	0	1	13	25	37	51
2. Regulatory Requirements/Permitting Requirements	0	1	12	23	34	44

CATEGORY IV: HUMAN RESOURCES MANAGEMENT

SECTION						
Element	0	1	2	3	4	5
A. Planning						
1. Crews Composition/Crew Formation	0	1	14	27	40	54
2. Skills Assessment and Evaluation	0	1	13	25	37	50
B. Training and Development						
1. Employees / Trades Technical Training	0	1	13	25	37	49
2. Career Development	0	1	9	17	25	35
C. Behavior						
1. Non-Financial Incentive Programs	0	1	9	17	25	32
2. Financial Incentive Programs	0	1	11	21	31	40
3. Social Activities	0	1	13	25	37	48
D. Organizational structure						
1. Maintain Stability of Organization Structure	0	1	2	3	4	7
2. Clear Delegation of Responsibility	0	1	6	11	16	21

E. Employment						
1. Retention Plan for Experienced Personnel	0	1	8	15	22	31
2. Exit interviews	0	1	9	17	25	33

CATEGORY V: CONSTRUCTION METHODS

SECTION						
Element	0	1	2	3	4	5
A. Project Schedule Control						
1. Integrated Schedule	0	1	9	17	25	35
2. Work Schedule Strategies	0	1	3	5	7	10
3. Schedule Execution and Management	0	1	2	3	4	6
B. Site Layout Plan						
1. Dynamic Site Layout Plan	0	1	14	27	40	53
2. Traffic Control Plan	0	1	8	15	22	28
3. Site Security Plan	0	1	3	5	7	8
4. Machinery & Equipment Positioning Strategy	0	1	5	9	13	19
C. Design/Construction Plan & Approach						
1. Communications, Coordination, & Agreements	0	1	13	25	37	50
2. Project start-up plan	0	1	5	9	13	18
3. Project Completion Plan	0	1	8	15	22	30
4. Innovations & New Technologies	0	1	16	31	46	60
5. House Keeping	0	1	11	21	31	42

CATEGORY VI: HEALTH AND SAFETY

SECTION						
Element	0	1	2	3	4	5
A. Job Site Safety						
1. Formal Health and Safety Policy	0	1	17	33	49	64
2. Health and Safety Plans/Zero Accident Techniques	0	1	17	33	49	64
3. Task Safety Analysis	0	1	15	29	43	56
4. Hazards Analysis	0	1	15	29	43	57
5. Hazards Planning	0	1	16	31	46	60
B. Substance Abuse Program						
1. Drugs and Alcohol Testing Program	0	1	4	7	10	13
C. Health and Safety Training & Orientation						
1. Health and Safety Training Programs	0	1	16	31	46	60
2. Toolbox Safety Meetings	0	1	12	23	34	45

Appendix G
One-way ANOVA for Various Scenarios

+/- 5 Percent of Mean

The two groups were created; one 5 percent above the mean and one 5 percent below the mean. The mean value is 47.70. One group was has BPPII scores of above 50.10 and the other was below 45.32.

Descriptives

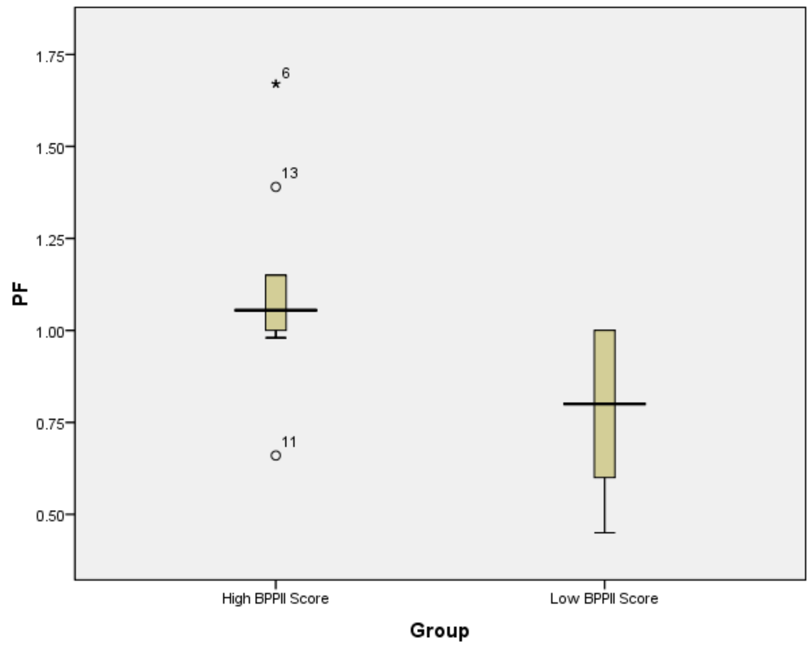
PF

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
High BPPII Score	14	1.1293	.27486	.07346	.9706	1.2880	.66	1.67
Low BPPII Score	13	.7785	.21629	.05999	.6478	.9092	.45	1.00
Total	27	.9604	.30211	.05814	.8409	1.0799	.45	1.67

ANOVA

PF

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.830	1	.830	13.438	.001
Within Groups	1.543	25	.062		
Total	2.373	26			



+/- 5 Percent of Median

Two groups plus and minus 5% above median value of 50.83 were created. One group has BPPII scores above 53.37 and other scoring below 48.29.

Descriptives

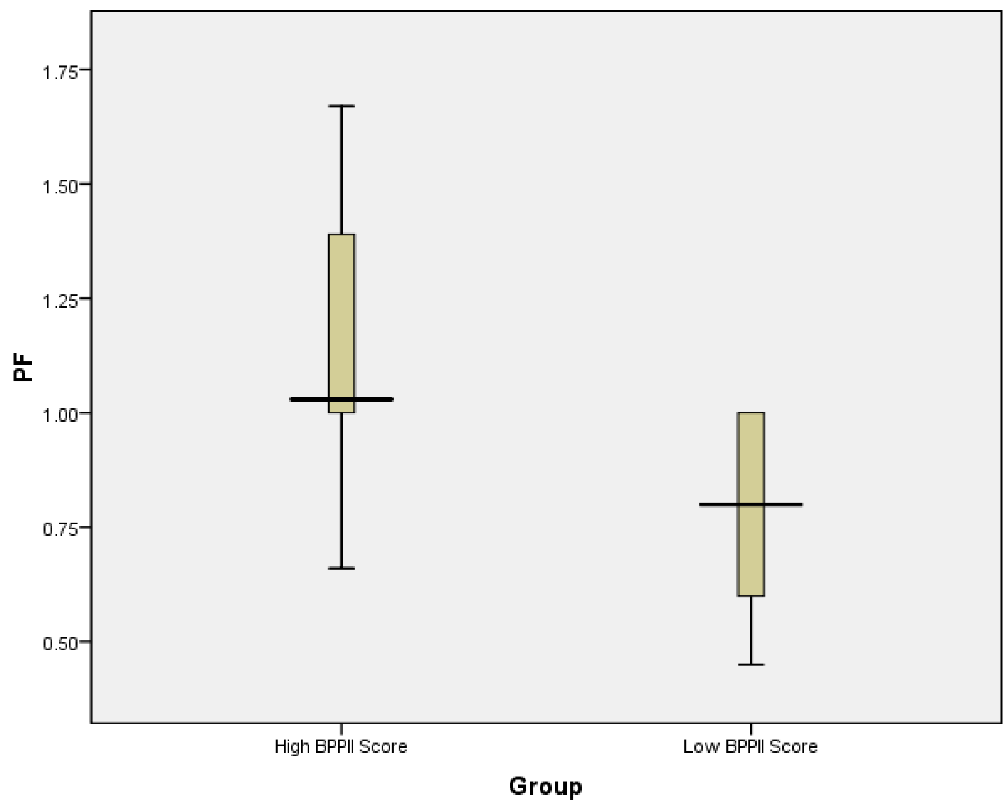
PF

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
High BPPII Score	9	1.1689	.33906	.11302	.9083	1.4295	.66	1.67
Low BPPII Score	13	.7785	.21629	.05999	.6478	.9092	.45	1.00
Total	22	.9382	.33035	.07043	.7917	1.0846	.45	1.67

ANOVA

PF

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.811	1	.811	10.947	.004
Within Groups	1.481	20	.074		
Total	2.292	21			



+/- 2.5% of Mean

Two groups plus and minus 2.5 percent of mean value of 47.70 were created. One group has BPPII scores above 48.90 and other below 46.51.

Descriptives

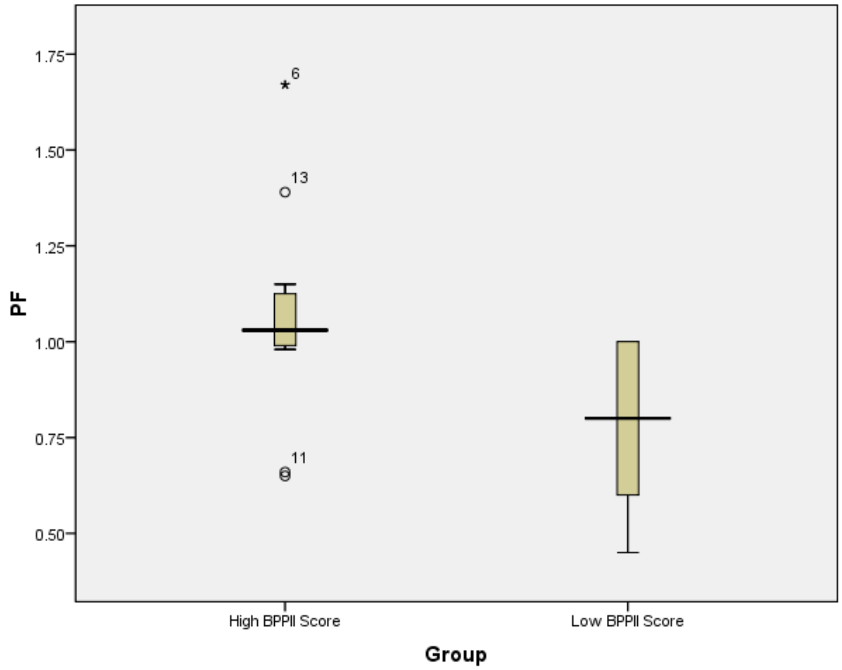
PF

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
High BPPII Score	15	1.0973	.29234	.07548	.9354	1.2592	.65	1.67
Low BPPII Score	13	.7785	.21629	.05999	.6478	.9092	.45	1.00
Total	28	.9493	.30221	.05711	.8321	1.0665	.45	1.67

ANOVA

PF

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.708	1	.708	10.474	.003
Within Groups	1.758	26	.068		
Total	2.466	27			



+/- 2.5% of Median

Two groups plus and minus 2.5 percent of median value of 50.83 were created. One group above 52.10 and other below 49.55

Descriptives

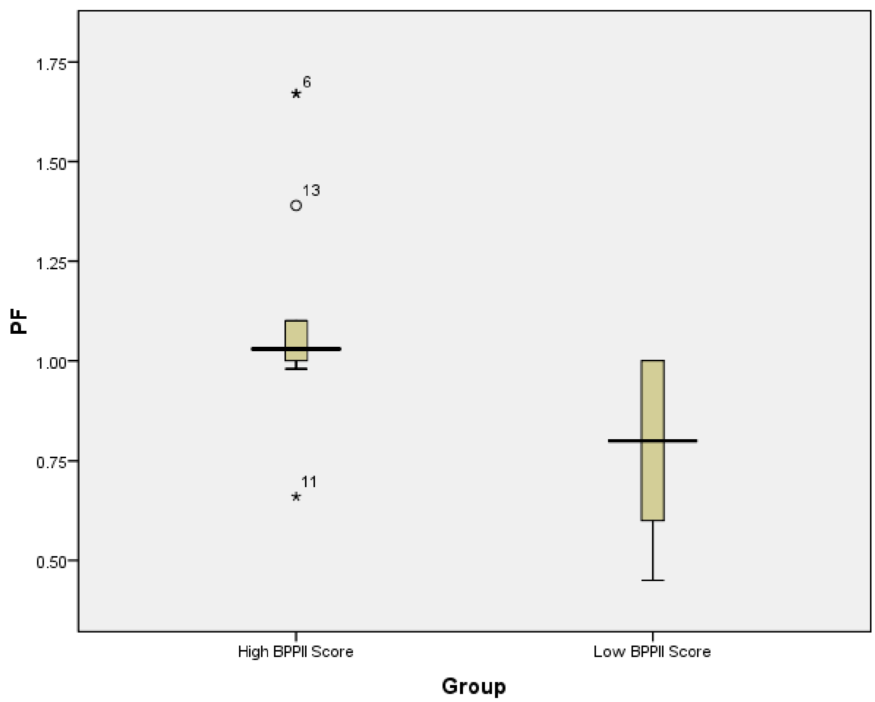
PF

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
High BPPII Score	13	1.1277	.28601	.07933	.9549	1.3005	.66	1.67
Low BPPII Score	13	.7785	.21629	.05999	.6478	.9092	.45	1.00
Total	26	.9531	.30566	.05995	.8296	1.0765	.45	1.67

ANOVA

PF

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.793	1	.793	12.331	.002
Within Groups	1.543	24	.064		
Total	2.336	25			



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